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COMPUTER-BASED ASSESSMENT OF VISUOSPATIAL ATTENTION FOLLOWING STROKE

by

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ABSTRACT

Unilateral spatial neglect is an attentional disorder and is among the most prevalent of cognitive impairments following stroke. Affected patients typically fail to attend to sensory input on the side of space opposite their brain lesion with significant implications for their function, independence and rehabilitation. Over the years there has been substantial research interest in this condition and how it is assessed. Despite the lack of a gold standard assessment, USN is traditionally evaluated using pen-and-paper tests; however multiple lines of evidence have highlighted the limitations of this approach and a growing research interest in computer-based assessment has demonstrated that this method could potentially overcome these shortcomings by providing greater sensitivity. This thesis aimed to investigate computer-based assessment for USN following stroke by examining our current knowledge, understanding the benefits and barriers of their implementation in clinical settings, and exploring ways to enhance their applicability for potential clinical use.

Results revealed a wide variety of computer-based tasks utilised in research over the last three decades, varying in type, task demands, duration, and sensitivity. The findings highlight the practical advantage of tasks with shorter durations with minimum equipment requirements, while more complex tasks exhibited greater sensitivity. Tasks with strong research foundation were identified, and adapted versions were tested with unimpaired populations, confirming their user-friendliness, acceptability, and sensitivity in detecting the presence of age-related changes in performance. These results were also corroborated with clinical populations in clinical environments demonstrating not only the feasibility of the approach but also its superiority compared with widely used pen-and-paper tasks.

Finally, following a shift in focus, the thesis explored the effect of transcranial direct current stimulation (tDCS) of the parietal lobe on spatial attention in unimpaired participants, but no effects were observed in contrast to previous studies.

Collectively, these results highlight the benefits and challenges of using computer-based assessments for visual attention. They demonstrate how computer-based assessments can be more sensitive than conventional methods and suggest their introduction into clinical practice could enhance related assessment methods, with important implications for patient care. While traditional methods are currently preferred by clinicians due to their ease of use and accessibility, computer-based tasks can be utilised not only to uncover cases overlooked by conventional methods but also to complement them by offering insights to patients' progress and response to treatment. The findings highlight the importance of refining these tools, identifying the best way to implement them for clinical use, and establishing clear clinical guidelines determining when and how to use them in conjunction with traditional methods. Finally, the results presented here support the continued development of this approach, aiming to improve it in a way that is not only valuable for research but also clinically meaningful.

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PRESENTATIONS

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LIST OF ABBREVIATIONS

ACC	Accuracy
ACE	Addenbrooke's Cognitive Exam
ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of Variance
BD	Brain Damage
BIT	Behavioural Inattention Test,
CB	Computer-Based
CBS	Catherine Bergego Scale
CoC	Centre of Cancellation,
CTI	Cue Target Interval
DAN	Dorsal Attention Network,
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
IOR	Inhibition of Return
LBD	Left Brain Damage
LCD	Liquid Crystal Display
NICE	National Institute for Health and Care Excellence
NIHSS	National Institutes of Health Stroke Scale
OCD	Obsessive Compulsive Disorder
PEST	Parameter Estimation by Sequential Testing
PIS	Patient Information Sheet

PnP	Pen-and-Paper
PPC	Posterior Parietal Cortex
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
QUADAS	Quality Assessment Tool for Diagnostic Accuracy Studies
RBD	Right Brain Damaged,
REC	Research Ethics Committee
RT	Response Time
SD	Standard Deviation
SOA	Stimulus Onset Asynchrony
TAP	Test of the Attention Testing,
tDCS	Transcranial Direct Current Stimulation
TMS	Transcranial Magnetic Stimulation
TOJ	Temporal Order Judgment,
USN	Unilateral Spatial Neglect
VAN	Ventral Attention Network
VR	Virtual Reality

CHAPTER 1

General Introduction

1.1. Thesis Overview and Key Contributions

This thesis explores the efficacy of computer-based (CB) assessments in detecting unilateral spatial neglect (USN) following stroke, providing a comprehensive evaluation of their advantages over traditional methods. Additionally, it investigates broader aspects of visuo-spatial attention in unimpaired and stroke-affected populations, as well as the effects of transcranial direct current stimulation (tDCS) on spatial attention. Each chapter contributes to a growing body of evidence supporting the clinical application of CB assessment methods.

The thesis begins with a General Introduction, which provides background on USN, its clinical significance and the limitations of conventional assessment methods. This section introduces the potential of CB tasks as more sensitive alternatives and outlines the overall structure of the thesis.

Following this, the chapter Computer-Based Assessment of Unilateral Spatial Neglect: A Systematic Review (Chapter 2), critically examines CB assessments for USN. Reviewing existing literature, it evaluates their sensitivity compared to traditional methods, identifies methodological strengths and limitations, and explores barriers to clinical implementation. The findings highlight the potential of CB assessments to enhance neglect detection while offering practical recommendations for future research and clinical adoption.

Building on this foundation, the next chapter (Chapter 3), Visuo-Spatial Attention in Younger and Older Adults: Comparing Performance on a Series of Computer-Based Tasks, investigated age-related differences in visual attention. In this study, we developed modified versions of well-established CB tasks, tailored to meet specific criteria identified after reviewing the existing literature on CB assessment (Chapter 2). These tasks were

designed to examine visual attention across age groups while maintaining consistency in task structure and administration. This study established baseline performance data for CB assessments in unimpaired populations, revealing slower RTs and a reduction in pseudoneglect in older adults. These findings provide important reference points for the later application of CB tasks in stroke populations.

The subsequent chapter (Chapter 4), Computer-Based Assessment of Visuo-Spatial Attention Following Stroke, applied these CB tasks to stroke survivors to evaluate their efficacy in detecting USN. Based in a large stroke service in the UK National Health Service, this study demonstrated that CB assessments, particularly the Conjunction Visual Search task, are more sensitive than pen-and-paper (PnP) tasks, typically used in practice and recommended by clinical guidelines. Furthermore, the CB tasks were well tolerated by patients, supporting their acceptability and feasibility for clinical use.

Shifting focus to neuromodulation, Chapter 5 (Does Transcranial Direct Current Stimulation (tDCS) of the Right Parietal Lobe Affect Spatial Attention?) explores the potential of tDCS to modulate spatial attention in healthy adults. While previous research suggests that tDCS influences attentional processing, this study found no significant stimulation effects, raising important questions about the reliability of tDCS in altering related performance.

Finally, the General Discussion (Chapter 6) synthesizes the key findings across all studies, reflecting on their implications for both theoretical understanding and clinical application. This concluding chapter evaluates the advantages of CB assessments, considers their potential integration into clinical settings, and discusses future research directions, including the refinement of assessment tools and further exploration of neuromodulation techniques.

Together, these chapters provide a comprehensive investigation into the use of CB tasks for assessing spatial attention, bridging the gap between experimental research and clinical application.

1.2. A Historical Perspective on Unilateral Spatial Neglect

USN emerged as a significant area of neurological research in the late 19th and early 20th centuries. Historically, USN has been referred to by various terms, including hemi-inattention, visual neglect, hemi-spatial neglect and hemi-neglect reflecting its broad impact across sensory and cognitive domains (Heilman et al., 2000; Robertson & Walker, 1993). One of the earliest systematic descriptions came from Brain (1941), who documented cases of stroke patients exhibiting profound inattention to one side of space. USN was formally defined by Heilman and Valenstein (1979) as “a failure to report, respond, or orient to stimuli that are presented contralateral to a brain lesion, provided that this failure is not due to elementary sensory or motor disorders”. Since then, research has demonstrated that USN is a complex, multifaceted disorder affecting not only perception but also attention, motor control, and even the mental representation of space. Attentional impairments in neglect have been extensively studied, demonstrating the role of attention in spatial awareness (Corbetta et al., 2005; Posner et al., 1984; Takamura et al., 2021). Additionally, deficits affecting the mental imagery domain have been highlighted in cases of representational neglect, where patients may fail to acknowledge objects or landmarks on one side of a mental image (Bisiach & Luzzatti, 1978). Motor-related neglect, characterized by underuse of the contralesional side in the absence of sensorimotor deficits, has been explored in studies demonstrating impaired movement initiation and execution on that side (Bartolomeo, 2021; Coulthard et al., 2008; Mattingley et al., 1992).

In the following years, interest in USN grew due to its implications for cognitive processes like spatial attention and pre-motor planning (Bisiach & Vallar, 1988; Jeannerod, 1987). USN emerged as a significant disability for stroke survivors, complicating rehabilitation efforts (Denes et al., 1982). Researchers found that USN affects multiple spatial domains, such as personal and extrapersonal spaces, and is not just limited to left-sided neglect but can involve a gradient of attentional bias (Bisiach & Luzzatti, 1978; Kinsbourne, 1977). This shift in understanding led to the exploration of different forms of neglect, such as word- and object-centered neglect, and how visual configurations impact attention (Caramazza & Hillis, 1990; Halligan & Marshall, 1991).

Over the past 35 years, advances in neuroimaging techniques (e.g., functional MRI (fMRI), PET scans etc.) have provided deeper insights into the neural mechanisms underlying USN, confirming the involvement of large-scale attentional networks rather than isolated lesion sites (Bartolomeo et al., 2012; Buxbaum et al., 2004; Vallar & Perani, 1986). In parallel, research efforts have increasingly focused on rehabilitation strategies aimed at ameliorating neglect, including prism adaptation (Chen et al., 2022), visual scanning training (Pizzamiglio et al., 1992), and non-invasive brain stimulation (e.g., tDCS, transcranial magnetic stimulation (TMS)) (Cha & Kim, 2015; Müri et al., 2013; Yi et al., 2016). These developments have shaped a more comprehensive approach to studying neglect, not only in understanding its neural basis but also in guiding targeted interventions to improve recovery outcomes for stroke survivors.

1.3. Conceptual Distinctions: Neglect, Inattention, and Extinction

In the literature, the terms inattention and spatial neglect have distinct definitions, however there is a debate to the extent they may overlap. Inattention describes a reduced ability to sustain or allocate attention to stimuli, while USN, also referred to as hemi-inattention, is associated with a lateralised rather than general difficulty to detect, respond, or orient to stimuli presented on the contralesional side of space (Heilman et al., 1987). A more recent definition by Cubelli (2017) describes spatial neglect as "a consistent, exaggerated spatial asymmetry in processing information in bodily and/or extrabodily space due to an acquired cerebral lesion". Some researchers have highlighted the presence of non-spatial attentional deficits in USN patients (Corbetta & Shulman, 2011; Husain & Rorden, 2003; Takamura et al., 2021), which highlights theories suggesting that USN also includes elements of non-lateralised inattention.

The Theory of Visual Attention (Bundesen, 1990) is a mathematical formulisation where visual selection is processed as a competitive process in which stimuli are assigned attentional weights based on relevance and spatial location. In this framework, USN is presented as an extreme imbalance in attentional weighting, with near-zero weight for contralesional stimuli. In contrast, general inattention may involve moderately reduced weights across all stimuli (Duncan et al., 1999). These align with the model of competitive brain activity, describing attention as emerging from dynamic competition between multiple brain systems, with impairments like USN reflecting disruptions in how this competition is addressed (Duncan et al., 1997). This may suggest that visuospatial neglect and inattention are not completely separate conditions but are part of a spectrum of attention problems.

Additionally, there has been debate over whether extinction represents a milder form of USN or whether the two are distinct conditions (Christopoulos et al., 2018; Mattingley, 1999). Extinction is defined by Kerkhoff (2001) “as the inability to process or attend to the more contralesionally located stimulus when two stimuli are simultaneously presented, or when two actions have to be performed with both hands simultaneously” (p.11). This debate could be further enriched by the theory proposed by Kinsbourne (1977) on the rival work of the two hemispheres in inhibitory control over attention spatial allocation. Extinction can be considered as a milder presentation of this imbalance, where contralesional stimuli are detected alone but missed when presented simultaneously with ipsilesional stimuli, due to competition between hemispheres. However, many studies suggest that USN and extinction are distinct conditions and can coexist, with evidence from neuroimaging and lesion studies suggesting that they involve different brain regions (Beume et al., 2020; Vossel et al., 2011).

For the purposes of this thesis, USN is considered as defined by Heilman et al (1987). While is acknowledged the theoretical debate as to whether neglect is qualitatively different from, or simply a term typically used to describe more severe forms of lateralised inattention or extinction, this thesis considers USN as a lateralised attentional deficit observed as abnormal asymmetric performance differences on CB tasks. It is likely that some of the tasks included in our battery are sensitive to detecting milder forms of spatial inattention or extinction-like effects, particularly in patients who do not meet formal criteria for USN based on traditional PnP tests. This possibility is explored further in the general discussion, where it is considered how our battery contributes to the broader understanding of spatial attention deficits following stroke.

1.4. USN Clinical Presentation

USN presents in several forms, with each affecting how patients perceive and respond to stimuli in their environment. Types of neglect may be categorized based on the reference frame used by the individual and the spatial domain involved (Spaccavento et al., 2017).

Egocentric neglect is a body-centered form of neglect, where patients fail to attend to stimuli on one side of space relative to their own body. This type of neglect occurs based on the individual's physical position. For example, a patient may ignore objects to their left, regardless of their location in the environment, which can affect tasks like reading or eating (Demeyere & Gillebert, 2019). In contrast, allocentric neglect occurs when patients fail to attend to objects in the environment, regardless of their body position. This object-centered neglect means patients may ignore one side of an object, even if it's directly in front of them (Leyland et al., 2017).

Personal neglect involves a lack of awareness of one side of the body, such as ignoring one side of the face or failing to notice a limb (Caggiano & Jehkonen, 2018). An example of a daily activity affected would be grooming (e.g., a person may fail to shave one side of their face). Peripersonal neglect refers to neglect of the space within arm's reach. This can affect actions like reaching for objects or interacting with items in the immediate environment. Patients may ignore objects placed close to them on the neglected side, even though these objects are within reach (Ten Brink et al., 2019). An everyday activity impacted could be eating, where the patient fails to reach for food placed on one side of their plate. Extrapersonal neglect refers to failing to attend to stimuli beyond arm's reach. This can impact navigating larger spaces or interacting with objects in the distance, such as crossing a room or using a map (Guariglia & Antonucci, 1992). As we can see, USN is a highly heterogeneous syndrome and types of neglect may occur in isolation or co-occur,

and their severity vary depending on the underlying brain injury and the specific spatial domain affected (Kleinman et al., 2007). It is important to recognize that while patients may show specific behaviours indicative of these types of neglect, the manifestations are typically a matter of degree. Computer-based tasks, like those tested in this study, may be limited in capturing the full spectrum of neglect, but they still provide valuable insights into attentional deficits in USN, even if they cannot reflect all aspects of neglect seen in real-world settings.

1.5. USN Recovery Trajectories

USN often shows a degree of natural and spontaneous recovery following stroke, particularly in the early months (Winters et al., 2017). Most studies indicate that the majority of recovery occurs within the first six months. Nijboer et al. (2013) reported that 54% of patients recovered by 12 weeks and approximately 60% within the first year, with recovery defined by improvements on two widely used PnP tests, the letter cancellation and line bisection tests. More recently, Moore et al. (2021) found that 69% recovered within the first six months, using the Oxford Cognitive Screen and Birmingham Cognitive Screen cancellation tasks, alongside improved self-reported functional outcomes on the Stroke Impact Scale to define USN recovery. A systematic review by Overman et al. (2024) found that 53% of patients recovered within the first six months, with most recovery occurring in the first three, suggesting that around 40% of USN patients will show chronic symptoms. This review based recovery rates on validated neglect screening tools, with most studies using the Behavioural Inattention Test (BIT).

Previous studies have linked recovery to stroke and neglect severity, but hemisphere and reference frame might have a more significant impact. Moore et al. (2021) demonstrated that egocentric neglect recovers proportionally to initial severity, while allocentric neglect often persists or worsens, with only acute allocentric severity serving as a predictor of poorer long-term outcomes. In this study, USN severity was measured with PnP cancellation tasks from the Oxford Cognitive Screen and Birmingham Cognitive Screen, using asymmetry scores and the centre of cancellation for egocentric neglect, and false positive differences for allocentric neglect. Additionally, USN following LBD tends to improve faster than after RBD, which shows slower recovery (Durfee & Hillis, 2023). These findings align with Esposito et al. (2020), who reported a 30% prevalence of chronic USN, showing greater persistence after right hemisphere strokes but still occurring in about 20% of left brain damage cases.

Additional factors that determine long-term neglect, beyond the severity of acute USN and overall stroke, include lesion type and patient age. More research is needed to fully understand these factors; however, some studies have shown that older patients tend to exhibit more severe neglect and experience slower recovery (Gottesman et al., 2008). Other predictors include early interhemispheric functional connectivity and contralesional recruitment (Umarova et al., 2016), and the presence or absence of anosognosia also plays a critical role (Durfee & Hillis, 2023).

1.6. Conventional Methods for Assessing USN

Diagnosing USN remains challenging not only due to the high heterogeneity of the syndrome, but also due to the absence of a universally accepted gold standard and the

wide range of assessment tools available (Escalante et al., 2020; Rode et al., 2017). Menon and Korner-Bitensky (2004) identified over 60 behavioural and functional assessments, both standardized and non-standardized, each varying in methodology, task design, and diagnostic accuracy.

The Line Bisection task was one of the most common and earliest assessments for USN and has been linked to neglect for more than a century published by Dr. D. Axenfeld, a german physician (Kerkhoff & Bucher, 2008). Over time, numerous cancellation tests have been developed, including the Albert's Test (Albert, 1973), the Bells test (Gauthier et al., 1989), Symbols Cancelation Test designed by Mesulam in 1985 (Lowery et al., 2004), and more recently, the Apples test (Bickerton et al., 2011).

Among the most commonly used assessment methods for USN are the BIT Conventional subtests (Wilson et al., 1987), a comprehensive battery of PnP tasks. It evaluates neglect across multiple modalities through tasks such as line bisection, copying and representational drawing, as well as line, letter, and star cancellation.

Functional assessment can be carried out using tools such as the BIT Behavioural subtests (Wilson et al., 1987), which includes tasks related to daily activities. Similarly, the Catherine Bergego Scale (CBS) (Azouvi et al., 1996) is another widely used tool that provides a structured approach to assessing the functional impact of neglect in everyday life. Test batteries, offering a more detailed perspective on neglect by focusing on real-world behaviour and have demonstrated greater sensitivity than single tests (Azouvi et al., 2002).

More recently, a multidisciplinary international survey by Checketts et al. (2021) revealed that, despite the variety of available assessments, the BIT and CBS remain the most

widely used diagnostic tools for USN in clinical practice. Additionally, recommendations from the European Academy of Neurology Scientific Panel on Higher Cortical Functions emphasize the use of multiple tests, including a cancellation test as the primary rapid screening tool, along with secondary tests like line bisection and figure copying, and functional assessments like the CBS if feasible (Moore et al., 2022a).

1.7. Technological Advancements in USN Assessment

Clinical guidelines, such as those from the National Institute for Health and Care Excellence (NICE, 2023), emphasize the importance of evaluating spatial attention deficits in stroke survivors and recommend the use of standardized test batteries over a single test. However, conventional methods, such as the BIT, primarily rely on PnP tasks, including line bisection and cancellation tests. While these tools are widely used and have many benefits associated with their ease of use and cost-effectiveness, they are associated with several challenges that may limit their effectiveness in clinical settings (Azouvi et al., 2006).

Even though these tests, especially cancellation tests (Marsh & Kersel, 1993), have been demonstrated to be effective in detecting USN, one of the main limitations of PnP tasks is their limited sensitivity in detecting subtle forms or differentiate between USN subtypes (Williams et al., 2021). These assessments may fail to identify mild neglect symptoms, leading to underdiagnosis or an underestimation of its severity (Bonato et al., 2011). Additionally, the ecological validity of such tasks is often questioned, as they do not accurately reflect the complexities of real-world environments (Azouvi, 2017). For

example, stroke survivors may perform well in a copy-and-drawing task yet struggle with navigation and object interaction in daily life.

Further challenges include ceiling and floor effects, where some patients excel or perform poorly, making it difficult to determine the true extent of their spatial attention deficits (Hougaard et al., 2021). Moreover, these tasks' repetitive and monotonous nature can result in low patient engagement, potentially influencing assessment outcomes due to decreased motivation and effort.

There is a growing need for assessment methods that provide greater sensitivity, ecological validity, and engagement, as spatial neglect remains significantly underreported and underdiagnosed in clinical practice (Carter & Barrett, 2023; Chen et al., 2013; Morrow et al., 2024). Standard screening tools like the NIHSS have been criticised for poor sensitivity to USN symptoms, leading to missed cases or misdiagnosis with visual field deficits (e.g., hemianopia), especially when both conditions co-occur (Moore et al., 2019; Puig-Pijoan et al., 2018).

Over the last three decades, a growing body of evidence has demonstrated that CB assessments offer a promising alternative/addition to traditional methods by addressing these limitations (Borsotti et al., 2020; Chiba et al., 2010; Guest et al., 2002; Halligan & Marshall, 1989). One of the key advantages is their enhanced sensitivity, as they can capture more detailed data on response times (RT) and accuracy, allowing for the detection of subtle neglect presentations (Rengachary et al., 2011). Furthermore, dynamic and interactive environments in CB tasks can simulate real-life scenarios, improving ecological validity and providing a more accurate representation of how USN affects daily functioning (Bonato & Deouell, 2013).

Another advantage is that these tasks can offer increased engagement. Interactive elements and gamified features can enhance patient motivation, leading to more reliable results. Finally, these tools are highly adaptable, allowing for personalized adjustments in task difficulty and stimuli presentation to suit individual patient needs (List et al., 2008).

Incorporating CB assessments into clinical practice could provide a more effective and accurate method for diagnosing USN. By overcoming the limitations of traditional PnP tasks, these tools may lead to improved detection, better intervention strategies, and ultimately enhanced rehabilitation outcomes for stroke survivors. However, they have not yet been widely incorporated into clinical settings.

1.8. Insights from the Systematic Review of Computer-Based Tasks

The systematic review (Chapter 2) highlighted several key findings that informed the development of our task battery. Advanced task designs, such as visual search tasks (e.g., feature and conjunction search), were found to be more effective in detecting neglect symptoms, particularly in cases that are mild, chronic, or subclinical. These tasks, which present greater complexity, were able to capture a wider array of neglect-related deficits compared to simpler versions (e.g., computerized versions of conventional tests).

Among the most sensitive outcome measures identified were RT and accuracy in visual search tasks, which align with previous studies demonstrating the advantages of these measures in detecting spatial bias and visual search deficits. Despite these advancements, there were important gaps in the literature. Notably, there is limited understanding of how task parameters such as duration, screen size, and apparatus affect

the effectiveness of CB tasks. Furthermore, while CB tasks were shown to be more sensitive than conventional methods, their specificity and reliability remain largely underexplored.

These gaps directly informed the design of our task battery, which aimed to address these issues. The review was crucial in identifying key factors, such as optimal combinations of task types, and well-established tasks with demonstrated sensitivity and diagnostic accuracy. It also helped refine our understanding of how different task demands could capture different aspects of USN. Additionally, the review highlighted important practical considerations, such as hardware specifications and task duration, ensuring the battery's clinically feasibility.

1.9. Designing a Computer-Based Battery for USN

The primary objective of this work was to develop a battery of CB tasks capable of identifying cases of USN that may be missed by conventional PnP assessments, particularly in the chronic phase of stroke recovery. Additionally, the tasks were designed to be practical and feasible for use in real-world clinical settings. In the acute stage, USN symptoms tend to be more severe and are typically detectable with standard tools (Azouvi, 2017). However, because USN often shows spontaneous recovery within the first six months post-stroke, symptoms may be more subtle at the more chronic stage (Moore et al., 2021; Overman et al., 2024). Accurate detection of lateralised deficits in attention is important both during the acute and chronic phase, however traditional assessments often fail to detect these mild impairments (Bonato et al., 2013; Cavedoni et al., 2022). Our CB battery is designed to capture these subtle and mild impairments, informing personalised

rehabilitation strategies. Therefore, while early detection in the acute phase is crucial, and usually achievable with conventional tools, our focus is on improving sensitivity to mild and persistent deficits in later stages of recovery, which are often missed but still might have an impact on daily activities and rehabilitation planning (Bonato & Deouell, 2013; Ogourtsova et al., 2017).

Building on insights from the systematic review, we carefully selected established tasks and incorporated practical considerations such as task duration and hardware requirements to ensure clinical feasibility. Our goal was to combine different task types to maximize sensitivity, allowing for broader data collection that captures the multifaceted nature of USN. To achieve this, we included a mix of components and varying task difficulties, such as cueing tasks, visual search, and dynamic tasks. We also carefully considered key task parameters, including the optimal stimulus onset asynchrony (SOA) for the cueing task, the number of distractors for the visual search task, and the number of trials and catch trials. These design choices were informed by prior research to enhance the sensitivity and reliability of the battery, ensuring it effectively detects subtle deficits while maintaining participant engagement. Our task battery was designed to be flexible and user-friendly, making it a clinically applicable tool for USN assessment. To our knowledge, this is the first CB battery to integrate established tasks in a structured and comprehensive manner, distinguishing it from existing CB task batteries.

Normative data (presented in Chapter 3) play a crucial role in interpreting task performance by establishing expected response patterns in unimpaired individuals. In this study, data were collected from both younger adults and age-matched older adults, to differentiate between typical aging effects, stroke survivors and USN-related deficits. By defining performance thresholds, normative data enhance diagnostic accuracy, improving

sensitivity in detecting subtle impairments. These benchmarks also support individualized assessments, aiding in both initial diagnosis and longitudinal monitoring. Establishing robust normative data ensures the battery's clinical applicability across diverse patient populations, making it a valuable tool for both research and clinical practice.

1.10. Testing the Battery with Stroke Patients – Integrating Normative and Clinical Data

The next chapter (Chapter 4) details the testing of stroke survivors, which we conducted in both hospital settings with inpatients and other clinical environments with outpatients. While our goal was to recruit a large number of participants, the process proved challenging due to various logistical and clinical constraints. Despite these difficulties, the application of our CB battery to stroke patients demonstrated its potential for improving diagnostic accuracy and early detection of USN. By assessing stroke patients alongside normative data from unimpaired individuals, we established a clearer baseline for comparison, enhancing the ability to distinguish between typical and impaired performance.

The battery's design, incorporating well-researched tasks with optimized parameters, allowed for the identification of mild spatial attention deficits that traditional assessments often missed. Integrating normative and clinical data provided a more comprehensive understanding of USN, improving diagnostic precision. This approach ensures that clinicians have a reliable and sensitive tool for detecting USN, tracking recovery, and guiding rehabilitation efforts more effectively.

1.11. Rehabilitation approaches for USN and Guidelines

The rehabilitation of USN involves various strategies aimed at enhancing recovery by encouraging attention to neglected space, including visual scanning training (traditional and computerised) (Antonucci et al., 1995; van Kessel, Geurts, et al., 2013), prism adaptation (PA) using prisms to shift visual input (Mizuno et al., 2021) and sensory integration with auditory and tactile stimulation (Guilbert et al., 2014). Virtual reality (VR) and CB techniques have emerged as adaptable tools for both assessment and rehabilitation (Cavedoni et al., 2022; Pedroli et al., 2015). Non-invasive brain stimulation (NIBS) techniques (tDCS, repetitive transcranial magnetic stimulation (rTMS), modulate cortical excitability and promote neuroplasticity by targeting brain regions involved in spatial attention (Kashiwagi et al., 2018).

The rehabilitation of stroke survivors with USN is outlined in various clinical guidelines. The National Clinical Guidelines for Stroke (2023) recommends several interventions for USN, including mirror therapy, limb activation, visual scanning and prism adaptation training, eye patching, galvanic vestibular stimulation and TMS for patients with USN, but note that these should ideally be delivered within clinical trials, highlighting the ongoing uncertainty around their effectiveness. The American Heart Association (2016) suggests interventions such as PA, visual scanning, optokinetic stimulation, VR, and neck vibration to improve neglect symptoms, with rTMS considered for ameliorating symptoms. The Department of Veterans Affairs/ Department of Defence (2024) guidelines suggest mirror therapy for managing USN, while remaining neutral for interventions such as eye patching and prism adaptation. The Canadian Stroke Best Practice Recommendations (2019) emphasize the use of visual scanning techniques and consider VR or CB interventions and mirror therapy for improving visual perception and neglect symptoms. There is conflicting

evidence on the effectiveness of prism glasses and eye patches for improving neglect. NICE (2023) advocates for functional interventions, such as scanning techniques, sound alerts, and prism glasses, to address visual inattention in stroke patients.

1.12. Investigating the Potential of tDCS in USN

For the final study (Chapter 5), we explored the potential of tDCS as a rehabilitation tool for individuals with USN. Our goal was to replicate the findings of a previous study, by Filmer et al. (2015), that demonstrated the ability of tDCS applied to the right PPC to modulate performance in tasks involving both competing and single contralateral stimuli detection.

The rationale for investigating tDCS in the context of USN stems from its potential to modulate brain activity in regions responsible for spatial attention, particularly in stroke survivors, offering a non-invasive approach to target critical brain areas associated with USN (Zhao et al., 2017). As mentioned earlier, a theory suggests that neglect is caused by an interhemispheric imbalance of attention networks, and tDCS can enhance or restore neural activity to rebalance spatial attention (da Silva et al., 2022)

The theoretical relevance of tDCS lies in its capacity to selectively modulate neural activity in targeted brain regions, potentially improving spatial attention allocation. By applying anodal stimulation to the intact hemisphere or cathodal stimulation to the damaged hemisphere, tDCS may help rebalance attentional networks involved in detecting stimuli in neglected space (Sunwoo et al., 2013). This lateralized modulation of spatial attention could prove valuable in rehabilitation, aiding the restoration of functional attention mechanisms and enhancing patients' ability to engage with their environment (Yi et al.,

2016). However, many studies suffer from methodological limitations, and results are inconsistent, leaving the precise effects of tDCS on USN uncertain (Kashiwagi et al., 2018). While this approach offers a promising complementary intervention to traditional rehabilitation techniques, further research is needed to fully determine its efficacy.

1.13. Concluding Remarks: Impact and Future Directions

This thesis contributes to the understanding of USN by exploring the use of CB tasks as more sensitive diagnostic tools. The findings emphasize the potential of this method to provide detailed, performance monitoring, offering significant advantages over traditional PnP assessments. Furthermore, the exploration of tDCS as a non-invasive intervention for addressing USN symptoms adds valuable insight into its role in stroke rehabilitation and USN. Incorporating these tasks into clinical settings represents an important next step for improving diagnosis and treatment.

Future research should prioritize the advancement of both assessment and intervention methods. Further innovation in CB diagnostic tools is essential to enhance their sensitivity, scalability, and accessibility in clinical practice. These tasks can provide a more nuanced understanding of USN symptoms and making them valuable for both diagnosis and monitoring recovery. Exploring ways to integrate them seamlessly into clinical settings and assessing their effectiveness in diverse patient populations will be key next steps.

Additionally, further research is needed to optimize tDCS stimulation protocols and re-evaluate both its short- and long-term efficacy. Finally, collaborative research between neuroscience and clinical practice is key to bridging the gap between theoretical advancements and their real-world applications.

CHAPTER 2

Computer-based assessment of unilateral spatial neglect: a systematic review

Abstract

Background: To date, no gold standard exists for the assessment of USN, a common post-stroke cognitive impairment, with limited sensitivity provided by currently used clinical assessments. Extensive research has shown that CB assessment can be more sensitive, but these have not been adopted by stroke services yet.

Objective: We conducted a systematic review to evaluate whether CB tasks enhance the ability to detect USN in stroke survivors compared with conventional tests. The review examined the diagnostic accuracy, sensitivity, and clinical utility of CB assessments, and identified methodological gaps and implementation challenges to inform future research and practice.

Methodology: We included studies that investigated the efficacy of CB neglect assessment tasks compared to conventional methods in detecting USN for adults with brain damage. Study identification was conducted through electronic database searches (e.g., Scopus), using keywords and standardized terms combinations, without date limitation (last search: 08/06/2022). Literature review and study selection were based on prespecified inclusion criteria. The quality of studies was assessed with the quality assessment of diagnostic accuracy studies tool (Quadas-2). Data synthesis included a narrative synthesis, a table summarizing the evidence, and vote counting analysis based on a direction of effect plot.

Results: A total of 28 studies met the eligibility criteria and were included in the review. According to our results, 13/28 studies explored CB versions of conventional tasks, 11/28 involved visual search tasks, and 5/28 other types of tasks. The vote counting analysis revealed that 17/28 studies found CB tasks had either equal or higher sensitivity than conventional methods and positive correlation with conventional methods (15/28 studies).

Finally, 20/28 studies showed CB tasks effectively detected patients with USN within different patient groups and control groups (17/28).

Conclusion: The findings of this review provide practical implications for the implementation of CB assessment in the future, offering important information to enhance a variety of methodological issues. The study adds to our understanding of using CB tasks for USN assessment, exploring their efficacy and benefits compared to conventional methods, and considers their adoption in clinical environments.

2.1. Introduction

USN is one of the most common post-stroke cognitive impairments with a prevalence of up to 80% early after stroke (Hammerbeck et al., 2019; Stone et al., 1993) and around 30% in the chronic phase of stroke (Esposito et al., 2020). USN as defined by Heilman et al. (1987) is an inability to explore or respond to a stimulus on the contralesional side of space, provided that this failure is not caused by lower-level sensory, motor, or visual impairment. USN can be observed either on the left or right side of space with higher frequency and more severe lateralized attention deficits on the left side (Ten Brink et al., 2017). In the early stages of stroke, the severity of USN can be a prognostic factor of increased hospital length of stay, worse rehabilitation outcome, family burden, and long-lasting impairments (Buxbaum et al., 2004; Hammerbeck et al., 2019; Luvizutto et al., 2018). The severity of neglect has also been associated with a higher risk of falls, reduced quality of life, reduced functional outcome, and reduced independence in the chronic stages (Chen et al., 2015; Jehkonen et al., 2006). The underlying mechanisms of USN have been intensively investigated by researchers, with proposed theories mainly focused on representational (Bisiach & Luzzatti, 1978; Milner et al., 1993) and attentional factors (Heilman & Van Den Abell, 1980; Kinsbourne, 1993; Posner et al., 1982). However, some aspects of the theoretical underpinnings of USN remain controversial in the literature (Baldassarre et al., 2014; Karnath & Rorden, 2012; Montedoro et al., 2018), possibly as a result of the complex and heterogeneous nature of the neglect syndrome; and diverse subtypes might be associated with varied brain areas and forms of the disorder (Gammeri et al., 2020; Rode et al., 2017). For example, USN can subdivide based on spatial domains and frames of reference (Buxbaum et al., 2004; Caggiano & Jehkonen, 2018). And in the last twenty years, neuroanatomical studies have highlighted associations with

parietal, temporal, and frontal lobe brain lesions in affected patients (Corbetta & Shulman, 2011; Lunven & Bartolomeo, 2017; Zebhauser et al., 2019).

An additional challenge in our understanding of USN is diagnosis, associated with both the lack of gold standard assessment and the use of numerous and varied diagnostic tools (Azouvi et al., 2016). Menon and Korner-Bitensky (2004) detected more than 60 behavioural tests and functional assessment tools with a large variety of apparatus use, task requirements/design, and diagnostic accuracy, also highlighting different neglect subtypes or syndrome components (Grattan & Woodbury, 2017; Verdon et al., 2010). National clinical guidelines for stroke suggest using standardized assessments to assess USN, including PnP tests (Canadian Stroke Best Practice Recommendations, 2019; Royal College of Physicians, 2016). A multidisciplinary international survey (Checketts et al., 2021) reported that currently the most widely used USN assessments include those such as the BIT, developed by Wilson et al. (1987), and the CBS, developed by Azouvi et al. (1996). Even though these tests are used on a daily basis in clinical practice, there remains criticism regarding how optimal they are, and studies have demonstrated that they still suffer from many limitations related to lack of precision, ecological validity, reduced sensitivity, and high false-negative results (Bonato & Deouell, 2013; Kaufmann et al., 2020; Rengachary et al., 2009).

There remains a need for higher quality assessment methods to be introduced to clinical practice and in the last two decades, a variety of studies have demonstrated that CB tasks may be able to make a significant contribution. These tasks can provide higher sensitivity and diagnostic accuracy (also detecting mild and chronic cases) and better psychometric properties (especially diagnostic validity) with low cost and short administration time (Bonato, 2012; Deouell et al., 2005; Erez et al., 2009; Rengachary et al., 2009; Schendel &

Robertson, 2002; Villarreal et al., 2020). These CB tasks appear to be well-accepted by patients, and offer design flexibility, stimulus modification, adjustment of difficulty, and may also limit the use of compensatory strategies by patients. They may also be less likely to include floor and ceiling effects (Bonato, 2012; Bonato et al., 2010; Bonato et al., 2013). These tasks can also provide important patient information regarding subtype and severity of neglect providing data to inform a more specific individually tailored rehabilitation program (Dalmaijer et al., 2015; Ulm et al., 2013). CB tasks may therefore provide an opportunity to augment USN assessment in clinical practice; PnP are likely to remain important, due to some practical limitations for some CB tests such as the need for specified hardware or software, and the current requirement for basic programming/statistical skills to implement them (Bonato & Deouell, 2013). However, the practical limitations of CB assessment have been gradually minimised, and the past decade has seen the rapid increase of the accessibility of computers and their role in everyday life (e.g., education, entertainment etc.) providing a more supportive environment for their implementation in clinical practice.

This review draws a distinction between CB assessment and assessment using VR. Previous reviews have focused on VR tasks (immersive and non-immersive) used in the assessment and rehabilitation of USN, demonstrating that VR assessment can effectively detect USN (Ogourtsova et al., 2017; Pedroli et al., 2015; Tsirlin et al., 2009). In contrast, this is the first study to provide an evaluation and overview of existing CB assessment tools for USN, not involving VR. The reviewers were not able to find existing operational definitions in the related literature for CB assessment and how this differs from non-immersive VR tasks; however, there is a clear distinction, since there was only very minimal overlap in this review (1 out of 28 studies) with a VR-focused systematic review

(Ogourtsova et al., 2017). For the purpose of this systematic review, CB tasks were defined as screen-based tasks, where the authors of included studies defined these as CB tasks (even if they could potentially be taxonomized in the grey area of CB tasks and non-immersive VR tasks), using a variety of different displays (e.g., monitor, projector, tablet).

To our knowledge, no previous study has conducted a systematic review on CB assessment for USN. This systematic review addresses a clear research question, defined using a PICO (population, intervention, comparison, and outcome) framework was adopted (Higgins, 2022):

"Do CB tasks enhance the ability to detect USN in stroke survivors compared with conventional tests?"

PICO:

Participants: Studies including adult (aged over 18 years) stroke survivors or patients with other types of brain damage (BD) with or without USN.

Intervention: CB tasks (screen-based tasks that are categorized by the authors of the included studies as CB assessment/testing or computerised tasks etc., using displays such as monitor, projector, tablet etc.)

Comparison: Conventional tests (e.g., PnP, or functional assessment) or CB design based on PnP.

Outcomes: A variety of outcomes were accepted such as [diagnostic accuracy measures (e.g., sensitivity, specificity), psychometric properties (e.g., validity, reliability), correlation coefficient, subjects' performance data, narrative reports].

2.2. Methodology

The review was conducted based on the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines (Moher et al., 2009).

2.2.1. Search Strategy

This review considered studies focusing on evaluating the diagnostic accuracy and performance of CB tasks in identifying USN in stroke survivors and patients with other types of BD.

A comprehensive search strategy of electronic databases (PsycINFO, EMBASE, MEDLINE (OVID), AMED, CINAHL (EBSCO), WEB of Science, PubMed, Scopus) using keywords and a combination of standardized terms was conducted.

The last search was conducted on 08/06/2022 with the following search strategy keywords:

- ("brain damage" OR "brain lesion" OR aneurysm OR “transient ischaemic attack” OR "ischemic attack" OR TIA OR "cerebrovascular accident" OR "cerebral vascular accident" OR CVA OR "traumatic brain injury" OR TBI OR stroke OR "brain tumour") AND
- (neglect OR “visuospatial neglect” OR inattention OR "unilateral neglect" OR "unilateral inattention" OR hemineglect OR "unilateral spatial neglect" OR "hemispatial neglect" OR "visual neglect" OR "hemi-inattention" OR "perceptual disorder*”) AND

- (assess* OR measur* OR evaluat* OR test* OR screen* OR diagnos* OR assessment OR measurement OR evaluation OR diagnosis OR screening) AND
- (computer* OR computer OR computerized OR computer-based OR phone OR smartphone OR tablet)

In order to retrieve further published, unpublished and ongoing studies, manual searches were utilized through the references of included articles, grey literature was identified through Google Scholar and registered ongoing trials were searched (ClinicalTrials.gov (http://clinicaltrials.gov/)).

No restriction was considered regarding the publication date or status. Studies were not limited to those written in English, but all eligible studies were written in English.

2.2.2. Eligibility Criteria

• Inclusion criteria

- Context: Studies that present or evaluate the diagnostic accuracy and performance of CB tests for USN in stroke survivors and patients with other types of BD (e.g., brain lesion, aneurysm, traumatic brain injury, or brain tumour etc.).
- Studies that fulfil the criteria established by the PICO framework.
- The term ‘CB tasks’ was not consistent in the literature, so the reviewers decided to include studies exploring screen-based tasks presented by the authors of the included studies as CB assessment/testing (or using related synonyms such as computerised or digitised/computer version of PnP etc.). We included CB tasks that followed these criteria even if they could be potentially classified in the grey area of CB tasks and non-immersive VR tasks, using a variety of different apparatus (e.g., computer-monitor, projectors, tablet).

• Exclusion criteria

- Studies not including stroke survivors or patients with other types of BD.
- Studies that did not focus on USN assessment.
- Studies where CB task is not the index test.
- Studies where the design of the CB task and apparatus are not substantially defined so that the reviewers can decide whether it can be included in the review. Studies that did not clarify the type of apparatus (e.g., response box, computer-monitor, projector) or specific design details (e.g., task demands and outcome measures) were excluded.
- Studies that did not clarify the use of a comparison tool.
- Studies that did not report or evaluate any form of diagnostic accuracy or performance of the CB test.
- Studies exploring VR based tasks (as defined by the authors and/or as interpreted by the reviewers).

2.2.3. Data extraction and selection

Duplicates were removed and the title and abstract of all identified studies were screened, excluding irrelevant studies. The remaining studies were screened by full-text and excluded based on the eligibility criteria. This was verified by two authors (IG and DL) and in the case of conflict, it was resolved by discussion and if the discrepancy was not resolved, a third author would be included (but it was not needed).

Data extraction was performed using a data extraction sheet (Table 2.1.), that was developed to accurately collect study characteristics and data. Data collection was verified, and disagreements resolved by discussion and consensus.

Extracted data included:

- Study Characteristics: Study type, population, sample size, year, number of participants with USN (+) and without USN (-), patients with right brain damage (RBD) or left-brain damage (LBD), follow-up, inclusion/exclusion criteria, etc.
- CB task information (e.g., apparatus, outcome measures, administration time) and reference standards comparison for diagnosing USN.
- Study data: Diagnostic accuracy measures, psychometric properties, outcome measures efficacy, patient history data, and test performance data, etc.
- Information for risk of bias assessment.

STUDY DETAILS	
AUTHOR/YEAR	
OBJECTIVES	
PARTICIPANTS (CHARACTERISTICS/TOTAL NUMBER)	
PATIENTS EXCLUDED	
PATIENT DEMOGRAPHICS	
SETTING	
INDEX TEST	
INDEX TEST TYPE	
APPARATUS	
TASK DETAILS	
SESSIONS/DURATION	
OUTCOME MEASURE	
COMPARISON TESTS	
DIAGNOSTIC ACCURACY MEASURES	
PSYCHOMETRIC PROPERTIES	
RESULTS	
CONCLUSION	
RISK OF BIAS	
LIMITATION	
NOTES	

Table 2.1 Data extraction sheet

2.2.4. Risk of bias(quality) assessment

IG and DL independently used the quality assessment tool for diagnostic accuracy studies (QUADAS-2) for systematic reviews to evaluate the quality of evidence for the identified studies (Whiting et al., 2011).

2.2.5. Data Synthesis

This review includes a narrative synthesis and analysis of the results of the included studies (McKenzie & Brennan, 2019). Studies were tabulated and compared in groups based on the index test type (e.g., CB version of PnP, visual search tasks, and other types) and heterogeneity was explored according to the type of analysis, data, and index

test (Campbell et al., 2020). Study characteristics were synthesized and presented in a table (Table 2.2) containing summaries of the outcome measures, patient history data, study details, and risk of bias. The main results were tabulated (Table 2.3) and data were analysed and presented as an effect direction plot (Figure 2.1.) for 6 domains (sensitivity, correlation coefficient with conventional task or neglect symptoms, ability to distinguish among patient groups, ability to distinguish patients from control groups, specificity, reliability) (Boon & Thomson, 2021). In order to gain a better understanding and deeper analysis of the data, a vote counting technique of effect direction was conducted (McKenzie & Brennan, 2019).

Ideally, we would have performed a meta-analysis of our dataset from the included studies to compare outcomes of the CB assessment tools including properties (e.g., sensitivity, specificity) and outcome measures (e.g., RT and accuracy). However, there was not sufficient data with acceptable homogeneity to undertake a meta-analysis (Deeks et al., 2019).

STUDY/TASK TYPE	RISK OF BIAS	POPULATION	CONVENTIONAL METHOD	COMPUTER-BASED METHOD	RESULTS	CONCLUSION
1.COMPUTERISED VERSIONS OF PnP TASKS						
Rabuffetti et al. (2002) *Touchscreen Cancellation*	D1: Low D2: Unclear D3: Low D4: Low	10 controls 15 stroke pt (5 LBD- 5 RBD- 5RBD+)	Line & letter cancellation Line bisection Sentence reading	Four visuospatial exploratory tasks, cancelation tests ('sparse letter', 'row shape', 'row letter' and 'sparse shape' test) presented on a PC with a touch-screen monitor. Measuring the percentage of omitted targets, touched distractors/target perseveration, crossing etc.	RBD+ pt had significantly ($p < 0.05$) higher positive measures for neglect than other groups (especially controls) in four CB tasks with different modalities *Kruskall–Walls* one way analysis revealed ($p = 0.007$, $p = 0.019$, $p = 0.020$) and a close relationship was found between CB & PnP, *Spearman R coefficient* (0.862).	This tool was proved to be a useful, easy to administer and possibly more sensitive tool than PnP for assessing USN.
Liang et al. (2007) *Graphic Tablet Battery*	D1: Low D2: Low D3: Low D4: Unclear	Stroke pt: 33 USN+ 110 USN-	BIT	14 overlays (A4 oversized) on a Wacom graphic tablet. Tasks were performed with a cordless pen, divided in 4 sub-groups (2 cancellation, 4 figure copying, 3 figure completion L/R and 2 drawing from memory tasks).	Low error rate (varying 3.3%, 6.8%, 0%) can be achieved in distinguishing between USN+ and USN- in more than half time than the BIT. Features were found to be sensitive and significantly correlated ($p < 0.05$) to the detection of USN symptoms, revealing more aspects than the BIT.	This approach can provide a quick, objective, and sensitive assessment tool. This method can reveal more aspects of neglect than BIT and offer a reduction of the overall assessment time.
Chiba et al. (2010) *CB Line Bisection*	D1: Unclear D2: Low D3: Low D4: Unclear	10 USN+ pt	Line bisection Line cancellation Drawing task	Verbal line bisection (VLB) and VLB & pointing task was performed on a 15.4-inch laptop computer (45cm distance). Participants were asked to define their subjective midpoint of a line, or a phrase and mean deviation was measured.	A *paired Student's t-test* comparison revealed no significant difference in mean deviation in the two tasks as a group. Four pt had significantly ($p < 0.05$) greater rightward deviation in the VLB task plus pointing than the VLB and 2 in the opposite.	These tasks successfully assessed visual and proprioceptive bias, identifying perceptual-attentional bias of neglect.
Rabuffetti et al. (2012) *Touchscreen Cancellation*	D1: Low D2: Low D3L Low D4: Low	119 controls 193pt (72 LBD- 66 RBD- 55 RBD+)	Line & letter cancellation Sentence reading Line bisection	A computerized cancellation test on a pc with 19" touchscreen interface. Each participant performed randomly, two tests letter and shapes distribution. Number of touched targets/distractors, revisits and omissions were measured among other parameters.	An across-group *Kruskall-Walls* ANOVA was found significant ($p < 0.01$) for all indexes except one. RBD+ compared to control and RBD- pt showed significantly more abnormal scores. Analysis revealed not significantly ($p = 0.22$; x2 test), but higher sensitivity of the CB than PnP.	The task can detect spatial exploration deficits with higher sensitivity than PnP, even in patients without USN in clinical testing.
Ulm et al. (2013) *CB Battery*	D1: Low D2: Low D3: Low D4: Unclear	10 USN+ Stroke pt 10 controls	NET (german BIT): Star cancellation Line bisection Figure copying Clock drawing	Circle monitor was a 10–15 minutes assessment performed in 8 touchscreens in a circle. It included 4 different tests in the star cancellation test, line bisection, dice task (similar to baking tray), puzzle test (based on the hooper visual organization test). Each task captured among other measures omissions, average bisection position, deviation scores and correct selection respectively.	Both standard and CB version of the star cancellation test and line bisection differed reliably between patients and healthy controls ($p = 0.025$, $p = 0.001$), the dice task did not. Significant discriminant function was revealed for the CB (66.1% $p = 0.003$) and not significant (43,9% $p > 0.05$) for the NET (PnP). Most patients and controls rated the test as user-friendlier than PnP.	The test was proved to be a sensitive, well-accepted tool capturing quickly and accurately visual neglect symptoms with greater diagnostic validity than PnP.
Jee et al. (2015) *CB Line Bisection*	D1: Unclear D2: Low D3: High D4: Unclear	30 controls 11 RBD+	Line bisection	Line bisection test in a semi-computerized e-system performed though a pc, an electronic pen and micro pattern printed paper. Capturing the percent of deviation (%) and assessment duration.	High levels of reliability were found. Inter-rater (nearly perfect) observer agreement between the e-system and raters for all tests, varied from 0. 84 to 0.98 ($p < 0.001$) and the intra-rater (test-retest) reliability from 0.84 to 0.91 ($p < 0.001$) for the patient group.	It was found to be a valid and reliable assessment method that can feasibly replace traditional PnP.
Pallavicini et al. (2015) *Touchscreen App Battery*	D1: Low D2: Unclear D3: Low D4: Unclear	8 RBD+ 8 RBD-	Line & star cancellation Conventional card dealing task	'Neglect App' task performed on an iPad2 touchscreen with stylus. Including a simple line cancellation and cancellation with distractors test (similar to star cancellation) and a CB card dealing task. Measuring omissions and number of correctly given cards respectively.	*Mann-Whitney U* test revealed that: The app versions of cancellation tests were similarly effective as PnP in neglect diagnosis both distinguishing significantly ($p = 0.008$) and ($p = 0.001$) respectively between groups. Similarly, the CB Card Dealing task ($p < 0.05$), but not the conventional ($p = 0.755$).	This app was found to be a sensitive and user-friendly tool for the detection of neglect symptoms.

Vaes et al. (2015) *CB Battery*	D1: Unclear D2: Low D3: Low D4 Unclear	20 controls 20 stroke pt	Star cancellation Line bisection	A digital USN test battery with prism measurements using a variety of equipment such as PC/laptop, response box and graphic tablet. It includes 9 tasks approximately 5min each (2 cancellation, 2 bisection tests, drawing, extinction, spatial memory, and a visuospatial navigation tests). Each captures a variety of measures such as CoC, deviation, correct responses, and RT.	Mann-Whitney U test revealed that 21 of the 26 test indexes/variables could significantly ($p < 0.05$) differentiate between neglect and control group, most of which could not be implemented in PnP tests.	This test offers user-friendly, flexible, standardized online measurements and performance monitoring of USN. Providing a wider collection of quantitative and qualitative data than PnP.
Chung et al. (2016) *Touchscreen App*	D1: Low D2: Low D3: Low D4: Unclear	40 stroke pt (20 RBD+ 10 RBD- 10 LBD-) 10 controls	Line bisection Star cancellation	The computerized table setting test (CTST) is performed in an iPad touchscreen. Subjects are required to set a table by dragging 12 dishes located below the table on the tablet screen (similar to the Baking Tray task). It captures measures like midline deviation, time, selection tendency.	Horizontal deviation was significantly higher for RBD+ compared to others. All 3 indexes of the CTST were significantly correlated with the total neglect score of conventional tasks ($p < 0.01$). Overall sensitivity of the CTST was 95% of Line Bisection test was 75% and of Star Cancellation test was 94.4%.	The test can be feasibly administered and is comparable with traditional test with higher sensitivity providing useful information for the diagnosis of neglect.
Ten Brink et al. (2016) *CB Battery (Line Bisection & Cancellation)*	D1: Low D2: Low D3: Low D4: Low	37 controls 280 stroke pt (115 LBD- 108 RBD– 18 LBD+ 39 RBD+)	Digital: Shape cancellation Line bisection	Computerized shape cancellation test and line bisection test. Capturing omissions score, revisits, intersections, search direction, best r and average deviation.	Performance comparison revealed higher numbers of intersections for RBD+ than LBD+ ($p = 0.009$) and RBD- ($p = 0.001$) pt. Significantly higher numbers of intersections ($p < 0.003$) and omissions ($p < 0.001$) for RBD+ and LBD+ pt compared to controls.	Disorganized search was strongly related to USN, and the number of intersections was found to be the most sensitive measure for visual search deficits in stroke survivors.
Quinn et al. (2018) *Touchscreen App (Line Bisection & Cancellation)*	D1: Low D2: Low D3: Low D4: Unclear	48 stroke pt	A bert's test Star cancelation Line Bisection	The stroke vision app (Tarbert et al., 2014) is including tests for visual acuity, visual field and digital tests of visual inattention (line bisection and face cancelation) performed at a Google Nexus 10 tablet device (33cm distance).	Comparison of app-based method with PnP revealed: Similar acceptability scores. Moderate to good accuracy measures. Overall, 79% sensitivity and 88% specificity for detecting stroke visual field deficits.	The app was similarly good as the conventional methods and can be used as post-stroke visual impairment screening tool providing more information than PnP.
Morando et al. (2019) Touchscreen App (Line Bisection & Cancellation)	D1: Unclear D2: High D3: Low D4: Unclear	10 pt	Line bisection A bert's test	Digital line bisection and an a bert (Cancellation) Test through the remote monitoring validation engineering system (ReMoVES) platform on a touchscreen smartphone/tablet display.	Statistical analysis reported high test-retest reliability (higher than 0.75) for conventional PnP versions and similarly high Pearson Correlation Coefficient for digital versions line bisection (offset: = 0.83, Rate: $p = 0.94$), Albert's test (uncrossed L/R: $p = 0.98$ / $p = 0.80$).	The severity of USN can be effectively monitored remotely for de-hospitalized patients by the novel tool.
				2.VISUAL SEARCH TASKS		
				2A. DUAL & DYNAMIC TASKS		
Marshall et al. (1997) *Dual Dynamic Visual Search Task*	D1: Low D2: Unclear D3: Low D4: Unclear	36 stroke pt (20 RBD 16 LBD) 20 controls	Clock drawing Letter cancellation	*A 3 min* visual tracking task (keeping a blue cross in the centre of a white square, capturing accuracy), a 6min target detection task (identifying all yellow circles, measuring detected targets), a 6min dual task (both tasks), displayed on a computer monitor (21'', 50-60 cm distance) with mouse.	RBD pt had worse performance ($p = 0.03$) than the other two groups in visual tracking task. The control group had significantly better performance than the pt groups on the single CB task ($p < 0.004$) and on the dual task ($p < 0.02$).	Conventional methods were found insensitive for detecting inattention. The dynamic task could identify impaired attention in a more sensitive way.
Deouell et al. (2005)	D1: Low D2: Low D3: Low D4: Unclear	9 controls 32 RBD 16 LBD	BIT	The "Starry Night Test" (SNT) was performed in a 15" monitor (100cm distance, around 30min duration), through a response	70% of the RBD pt had significantly prolonged left RT ($p < 0.05$) and as a group performed significantly worse than the LBD pt and control group ($p <$	The test was proved to be feasible for hospitalized patients and more sensitive than

RT Dynamic Visual Search Task				box. Patients had to detect dynamically appearing targets between blinking distractors and RT was captured.	0.001). In 50% of the cases SNT showed significant side differences and the BIT did not.	conventional tests, providing quantitative data of neglect severity and recovery.
Bonato et al. (2013) *Dual Task*	D1: Unclear D2: Low D3: Low D4: Low	10 stroke RBD	BIT (3 cancellation subtests)	The CB paradigm captured the percentage of correct detections for: single task (verbal report of the target position). Visual dual task (letter identification before reporting target position). Auditory dual task (count an announced number by 2 twice before reporting target position).	A significant L/R difference between target detection is reported ($p < 0.001$). Percentage of correct left target was significantly decreased in dual tasks ($p < 0.05$). Cancellation tasks revealed fewer overall omissions to the left (6.9%) than the CB task (60.2%).	CB attention-demanding tasks can avoid compensatory strategies implemented by stroke survivors and have higher sensitivity than conventional cancellation tasks.
Van Kessel, Van Nes, et al. (2013) *RT Dual & Driving Simulator Task*	D1: Unclear D2: Low D3: Low D4: Low	43 stroke pt (22 LBD 21 RBD) 20 Controls	BIT	Computerized visual RT single (CVRT) and dual (CVRT-D) task (van Kessel et al., 2010) was performed with the use of a steering wheel, projector, a screen, and a pc. It was a 5 min dynamic lane tracking (CVRT) and a continuous RT task where patients had to detect a rectangle (by pressing a button) while performing a driving simulator test (CVRT-D). Number of omissions and RT asymmetries, ipsilesional RT were measured.	Significant Pearson Correlation between BIT and contralesional omissions were revealed CVRT ($p < 0.05$) and CVRT-D ($p < 0.005$). Significant Pearson Correlation in pt groups and RT asymmetries were detected in the single ($p < 0.01$) and dual task ($p < 0.05$). The CVRT-D task was able to detect cases with no symptoms on the BIT and CVRT.	CVRT test was sensitive in discriminating RBD pt group and was able to overcome the compensational strategies. CVRT-D can detect also mild cases of neglect without clinical signs. The RT asymmetry scores were found to be sensitive for spatial bias detection.
Andres et al. (2019) *Dual Task*	D1: High D2: Unclear D3: Low D4: Low	2 RBD-pt 6 Controls	Bells test, TAP (visual neglect) Apple test Line bisection	Dual task (Bonato et al., 2010; Bonato et al., 2013) performed in a Dell laptop (17' screen, 60 cm distance) with Psychopy software.	Normal range patient performance was found at PnP and simple CB task (TAP). Although single task omissions were not significant ($p = 0.15$), the dual task revealed significantly ($p < 0.001$) the neglect/extinction symptoms for 2 cases.	Dual tasks have higher sensitivity than PnP and simple CB tasks, capturing more quantitative and qualitative data of spatial attention deficits especially in chronic stages.
Villarreal et al. (2020) *Dual Dynamic Task*	D1: Low D2: Low D3: Low D4: Low	40 USN+ pt (20 LBD 20 RBD) 20 controls	Bells test	The 2 min detection task (reacting to a red sphere flashing among others appearing and to a number) and 4 min crash task (reacting to a collision of two moving grey spheres resulting in a white flash and to number sequence). The tasks were presented on a video projector capturing HR, correct reactions, RT and omissions.	No significant group differences in bells test performance were found. RBD pt had significantly increased left hemispace HR than controls in both crash ($p = 0.12$) and detection ($p = 0.033$) tasks. All groups had significantly ($p < 0.001$) slower RT in complex tasks.	Dual tasks were found to have higher sensitivity than conventional tasks, revealing subclinical neglect in stroke.
				2B. FEATURE & CONJUCTION TASKS		
List et al. (2008) *Feature & Conjunction, RT, Visual Search Task*	D1: Low D2: Low D3: Low D4: Unclear	12 controls 23 unilateral BD pt	Line cancellation Letter search Symbol search	A 5-20 min feature search (detecting a blue circle among red distractors), a scattered feature search (detecting a red square among blue) and a conjunction search task (detecting a red square among red triangles and blue squares) on a laptop widescreen (60-70 cm distance). L/R Accuracy and RT were measured.	Healthy individuals demonstrated symmetricity of the test and normative data were collected. Feature search task ($p = 0.07$) was not significant in detecting contralesional deficits in patients, but in the Conjunction task RBD pt performed significantly worse than the LBD pt ($p < 0.05$) and controls. A variety of test performance was detected across sessions.	The adaptive procedure successfully detected lateralized visual deficits (even subtle) and had relatively quick administration time. The Conjunction task was found to be more sensitive in detecting lateralized deficits than the feature task.
Erez et al. (2009) *Feature & Conjunction RT, Visual*	D1: Low D2: Low D3: Low D4: Unclear	72 Stroke pt (25 RBD+ 27 RBD-	BIT CBS	Visual spatial search task (VISSTA) includes a feature (detecting a red circle among blue) and a conjunction task (detecting a red circle among blue circles and red squares). The apparatus included a	RBD+ pt showed a significant ($p < 0.001$) contralesional disadvantage in feature and conjunction HR and RT than the other groups. All groups had worse mean RT in the conjunction than the feature task ($p < 0.001$) Pearson Correlation coefficients of HR and cancellation task were significant for	Combining CB assessment with PnP can increase sensitivity and provide useful information for visual-spatial inattention.

Search Task		20 LBD-) 39 controls		computer screen and a response button, capturing HR and RT.	feature task in RBD pt and for conjunction in all groups and similarly only in RBD+ pt for CBS.	
				2C. STATIC VISUAL SEARCH		
Mizuno et al. (2016) *CB Cancellation and RT Visual Search*	D1: Low D2: Unclear D3: Low D4: Unclear	2 USN+ 1 USN- 16 Controls	BIT	Four tasks of visual exploration (2 cancellation, a visuomotor & visual search task). Participants were asked to detect targets on a 32-inch touchscreen display (45 cm distance) or by pressing a response button. Capturing measures such as RT, order of cancellation, omission, total cancellation time and CoC.	The CB test detected one viewer and one stimulus centred USN+ pt. Spatial and temporal patterns of cancellation between the two subtypes were compared revealing that the first had not significant rightward attention bias (longer left RT) ($p > 0.05$) while the second did ($p < 0.01$) in both visuomotor and visual search tests.	The CB test can provide information about USN patients' temporal and spatial dynamics of visual search strategy, and can be more sensitive than PnP, detecting also mild USN cases.
Machner et al. (2018) *Static Visual Search & Posner task*	D1: Low D2: Low D3: Low D4: Low	34 RBD pt (10 USN- 12 moderate 12 severe neglect) 11 controls	French CBS Line bisection Text reading Star & bell cancellation Figure copying	The desk task is a naturalistic visual search task performed in 24-inch widescreen monitor. Participants are asked to detect a paperclip among 30 objects in a desk picture and respond by pressing a button (max 12s /100 desk images) measuring false alarms, detection rate etc. Subjects also performed a variant of RT Posner task.	The severe and the moderate neglect group showed significantly ($p < 0.01$) increasing durations and decreasing detection rate ($p < 0.001$, $p < 0.05$) from outmost right to outmost left. High correlations were found between Posner task, CBS and desk task, with mean search time for desk task ($p < 0.001$), latency index of Posner task ($p < 0.001$) and CoC of bell's task ($p < 0.001$).	The desk task was found to be more sensitive than PnP by detecting also neglect patients without clinical signs.
Ten Brink et al. (2020) *CB Static Visual Search Task*	D1: Low D2: Low D3: Low D4: Low	23 RBD + 55 RBD - 49 LBD -	Shape cancellation Line bisection CBS	In the visual search task participants had to find targets among distractors (performed on a 13.3-inch touchscreen laptop). Each trial varied in number of distractors and target location. The effect of these variants was evaluated through HR.	Increasing target number revealed significantly lower HR for RBD+ pt ($p = 0.006$). No effect of number of targets on HR was seen in patients with LBD pt ($p = 0.063$) and RBD- pt ($p = 0.015$). Moderate positive relation was found between the CB task and PnP task ($p < 0.001$) and CBS ($p < 0.001$).	Additional targets reduce HR and can increase the sensitivity of USN visual search tasks.
				3.DIFFERENT TYPES OF TASKS		
Rengachary et al. (2009) *Posner Cue Paradigm*	D1: Low D2: Low` D3: Low D4: Low	59 LUSN+ stroke pt 30 controls	Line & shape cancellation Mesulam test Clock drawing Baking tray Fluff test	Posner cueing paradigm (40 trials around 15 min) was performed in a computer with a 17-inch monitor through a response button box. Patients had to detect a target (left or right) in two square frames as quickly as possible. Accuracy and RT was measured.	The Posner task (L/R RT) was significantly ($p < 0.05$) more sensitive than most of the conventional methods in the acute stage and chronic stage, except Mesulam cancellation tasks which revealed similar sensitivity scores.	CB RT tasks can accurately detect and assess the severity of neglect even on mild and chronic cases that PnP could not.
Vossel et al. (2010) *Extinction / Neglect Task*	D1: Low D2: Low D3: Low D4: Unclear	56 RBD Stroke pt 18 controls	BIT Confrontation technique	The neglect and extinction CB test was performed through a PC, a monitor, and a response button. Subjects had to respond whenever they detected a target (square) appearing unilaterally or bilaterally with a distractor (circle). The task duration was around 11,3 min and measured detection probabilities.	Controls had almost no errors. It was revealed that 23,2% of the pt had extinction, 17,86% moderate and 14,28% severe neglect. Low correlation between CB and confrontation technique, but high Pearson correlation between line bisection and cancellation tasks ($p < 0.001$) was detected.	The computerized test can be easily applied in a clinical setting and repeated reliably on separate occasions, identifying visual neglect and extinction.
Stigchel and Nijboer (2017) *Temporal Order Judgment Task*	D1: Unclear D2: Low D3: Low D4: Low	73 stroke pt	Digital shape cancellation Line bisection	In the temporal order judgment (TOJ) subjects had to detect which colour of a square (red or green) appeared first in a monitor display (90cm distance) by pressing two different response buttons.	Performance on TOJ revealed strong correlation ($p < 0.01$) with the shape cancellation (both can sensitively capture spatial bias), but not with the line bisection test ($p = 0.08$), which captures object-based deficits. TOJ minimized chances of ceiling flour increasing sensitivity.	The TOJ test can be used supplementary with the line bisection and shape cancellation test and capture spatial and non-spatial components of neglect in a more sensitive manner than PnP.

Spreij et al. (2020) *Driving Simulator Task*	D1: Low D2: Unclear D3: Low D4: Low	33 LUSN+ 7 RUSN+ 7 LRUSN +(Recovered) 53 USN- 21 controls	Shape cancellation CBS	The 2min steering wheel simulated driving task (van Kessel et al., 2010) was projected on a large screen. Measures such as average road position and deviation were captured. Also, omissions and asymmetry score between sides were captured by a digitised shape cancellation task of 54 targets and 75 distractors in different sizes and shapes.	The sensitivity was 51.5% for LUSN+ pt, but only 28.6 for RUSN+ pt. Specificity: 94.3% of USN- had normal performance, Positive predictive values for LUSN+ and RUSN+ pt were 85% and 40% respectively and negative were 75.8% and 90.9% respectively. Correlation between average position and neglect severity according to CBS was analysed (p = 0.05).	It is proposed to include several types of tasks rather in isolation. Dynamic tasks can effectively assess mild and chronic USN cases.
Pierce et al. (2021) *Manual Exploration Touchscreen App*	D1: Low D2: Low D3: Low D4: Low	39 pt (12 RBD+ 17 LBD- 10 RBD-) 14 Controls	Bells & apple cancellation Line bisection	The manual exploration task was performed on a touchscreen tablet. Participants had to tap on the screen using their index finger with their eyes closed until they found the target (a rectangular area) appearing in a random location (3 min). Measures such as percentage of time spent L/R, percentage of taps within five columns, and mean horizontal position.	No significant correlation was revealed between the manual exploration task and the line Bisection, bells, or apples cancellation. RBD+ pt (3/4) showed a significant rightward bias in CB task as compared to the other groups. USN+ pt (4/12) showed neglect signs in the CB tasks. Patients with severest neglect had poor performance on multiple tasks.	This is an easy and quick task to administer without visual input and can be used supplementary to conventional methods to assess the severity of neglect.

Table Notes: BIT: Behavioural Inattention Test, BD: Brain damage, CB: Computer-based, CBS: Catherine Bergego Scale, CoC: Centre of cancellation, D(1,2,3,4): Domain (1,2,3,4), L: Left, R:Right., USN: Unilateral spatial neglect,), HR: Hit rate, NET: Neglect test, PnP: Pen-and-Paper tasks, Pt: Patient/patients, RT: Response time, TAP: Test of Attentional Performance, -: without USN, +: with USN.

Table 2.2 Summary of Included Studies

EFFECT DIRECTION PLOT						
Domain (D) :	D1	D2	D3	D4	D5	D6
Marshall et al. (1997)	-	-	▲1	▲1	-	-
Rabuffetti et al. (2002)	-	▲1	▲3	▲3	-	-
Deouell et al. (2005)	▲	-	▲1	▲1	-	-
Liang et al. (2007)	-	▲8	◄►	◄►8	-	-
List et al. (2008)	◄►	◄►1	▲2	▲2	-	-
Erez et al. (2009)	Λ	▲2	▲2	▲2	-	-
Rengachary et al. (2009)	▲	-	▲2	▲2	▲	-
Chiba et al. (2010)	-	-	◄►1	-	-	-
Vossel et al. (2010)	Λ	◄►1	Λ1	Λ1	-	-
Rabuffetti et al. (2012)	▲	▲2	▲13	▲13	-	-
Bonato et al. (2013)	▲	-	▲2	-	-	-
Ulm et al. (2013)	Λ	-	-	▲2	-	-
Van Kessel et al. (2013)	Λ	▲1	▲1	▲1	-	-
Jee et al. (2015)	-	-	-	-	-	▲
Pallavicini et al. (2015)	◄►	-	▲1	-	-	-
Vaes et al. (2015)	-	-	-	▲21	-	-
Chung et al. (2016)	▲	▲3	▲3	▲3	-	-
Mizuno et al. (2016)	◄►	-	▲1	▲1	-	-
Ten Brink et al. (2016)	-	▲1	▲2	▲2	-	-
Stigchel and Nijboer (2017)	Λ	◄►1	▲1	-	-	-
Machner et al. (2018)	Λ	▲2	▲2	▲2	-	-
Quinn et al. (2018)	▲	-	-	-	▲	-
Andres et al. (2019)	▲	-	▲1	-	-	-
Morando et al. (2019)	▲	▲2	-	-	-	▲
Spreij et al. (2020)	▲	▲1	▲2	▲2	▲	-
Ten Brink et al. (2020)	Λ	▲1	▲1	-	-	-
Villarreal et al. (2020)	Λ	-	▲1	▲1	-	-
Pierce et al. (2021)	-	▲	▲2	-	-	-

Figure 2.1 Effect direction plot. Direction of arrow indicates a positive / negative result. Size of arrow indicates sample size. Number indicates number of outcome measures reported in that domain. D1: Sensitivity, D2: Correlation coefficient with comparison tool, D3: Ability to distinguish among patient groups, D4: Ability to distinguish patients from controls, D5: Specificity, D6: Reliability. ▲: Statistically significant difference., ▲: Not statistically significant difference, Λ: no data presented (narrative report only), -: No reports or data, ◄►: No change/mixed effects conflicting finding.

2.3. Results

In the current systematic review, we aimed to provide a review of studies evaluating CB assessment of USN. The screening process is. summarised within a PRISMA flow diagram (Figure 2.2) (Page et al., 2021). In total, 28 articles met the inclusion criteria and were critically appraised. However, we full screened 136 studies. The excluded citations and the reasons for exclusion were tabulated (Appendix 1). There were three main reasons for the exclusion of studies that were not out of scope. The first case was where there was either an absence or not clear use of a comparison tool. Secondly, studies were excluded where authors did not clarify whether USN was assessed. Lastly, studies were excluded when the specific details regarding the design of the CB tasks were not explained thoroughly enough to allow the reviewers to decide whether the study was eligible for inclusion. This process led to excluding some important studies that explored CB assessment methods by using overlays of PnP on graphic tablets (Donnelly et al., 1999; Guest et al., 2002), CB versions of PnP tests (Chiba et al., 2006; Halligan & Marshall, 1989; Hopfner et al., 2015; Kerkhoff & Marquardt, 1995; Smit et al., 2013; Van der Stoep et al., 2013) and software for analysis (Dalmaijer et al., 2015; Rorden & Karnath, 2010). Moreover, the reviewers had to exclude a large body of work that investigated target/stimulus detection tasks (Baylis et al., 2004; Beis et al., 1994; Tipper & Behrmann, 1996), RT tasks (Anderson et al., 2000; Sacher et al., 2004; Schendel & Robertson, 2002), visual search task (Borsotti et al., 2020; Laeng et al., 2002; Toba et al., 2018), visual attention theory focused tasks (Bublak et al., 2005; Habekost & Bundesen, 2003) and the test battery of attentional performance (TAP) (Zimmermann & Fimm, 2002). Table 2.2 illustrates some of the main characteristics of the included studies (risk of bias, subjects, conventional tool comparison, task details, results, and conclusions). The studies were

grouped based on the CB assessment type in 3 groups (1. CB versions of conventional tasks, 2. Visual search tasks (2a. Dynamic & dual tasks, 2b. Feature & Conjunction tasks, 2c. Static tasks) 3. Different types of tasks). In our synthesis, we explored the apparatus, response method, outcome measure, comparison, and properties of the CB tools. Table 2.3 represents a summary of the main results of the studies and Figure 2.1 is an effect direction plot based on the vote counting analysis conducted.

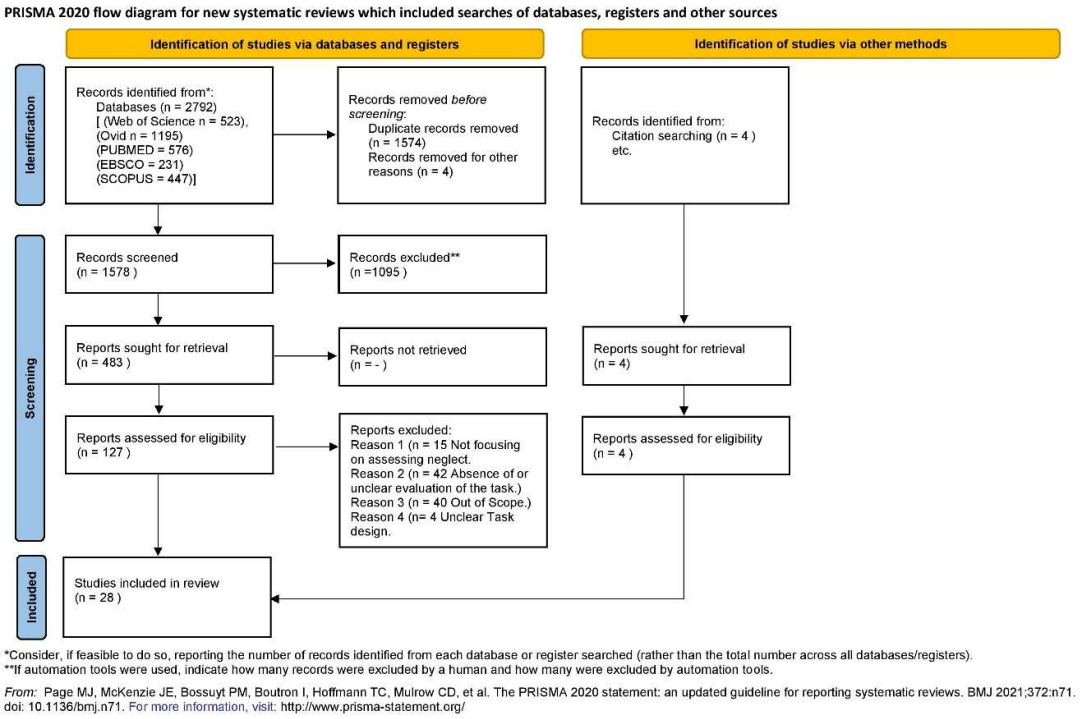

Figure 2.2 Prisma Flow Diagram

2.3.1. Computer-based Task Type

The authors identified 13 studies, that investigated test batteries of CB versions of conventional tasks, including tasks similar to line bisection (Chiba et al., 2010; Jee et al., 2015), cancellation (Rabuffetti et al., 2012; Rabuffetti et al., 2002), baking tray (Chung et al., 2016) or combinations of different types of tasks (Liang et al., 2007; Mizuno et al.,

2016; Morando et al., 2019; Pallavicini et al., 2015; Quinn et al., 2018; Ten Brink et al., 2016; Ulm et al., 2013; Vaes et al., 2015). Our synthesis included 11 studies exploring visual search tasks such as static (Machner et al., 2018; Mizuno et al., 2016; Ten Brink et al., 2020), feature and conjunction (Erez et al., 2009; List et al., 2008), dynamic and dual tasks (Andres et al., 2019; Bonato et al., 2013; Deouell et al., 2005; Marshall et al., 1997; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020). We detected 5 studies that observed different types of tasks such as the widely investigated Posner cueing paradigm (Rengachary et al., 2009), a neglect/extinction task (Vossel et al., 2010), a temporal order judgment (TOJ) task (Stigchel & Nijboer, 2017), a driving simulator task (Spreij et al., 2020) and a manual spatial exploration task (Pierce et al., 2021).

By carefully examining the data, it was found that CB functional (Pallavicini et al., 2015) and visual search tasks were shown to be more sensitive than CB versions of PnP tasks (Ten Brink et al., 2020). Moreover, combining different types of tasks can capture a wider aspect of neglect symptoms (Erez et al., 2009; Mizuno et al., 2016; Spreij et al., 2020). An interesting finding was that different types of tasks were associated with different types of errors, for example, cancellation tasks were more sensitive to viewer-centred (egocentric) errors, with visual search and line bisection tasks more sensitive to stimulus-centred (allocentric) errors; Similarly RT and TOJ tasks also detected spatial bias deficits (Mizuno et al., 2016; Stigchel & Nijboer, 2017; Van Kessel, Van Nes, et al., 2013).

Some studies compared diagnostic accuracy between CB tests, and as expected the more complex CB tasks (e.g., higher demands, dual tasks, increased number of targets, conjunction tasks) were more sensitive and could detect more cases (chronic/subclinical) than more simple versions (e.g., feature tasks) (Andres et al., 2019; Bonato et al., 2013;

Erez et al., 2009; List et al., 2008; Marshall et al., 1997; Ten Brink et al., 2020; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020).

2.3.2. Outcome Measures

Most cancellation tasks obtained measures including the number of touched (cancelled) targets, revisits, intersections, omissions, centre of cancellation (CoC) (Pallavicini et al., 2015; Rabuffetti et al., 2012; Rabuffetti et al., 2002; Ten Brink et al., 2016; Ulm et al., 2013). Line bisection tasks usually captured the mean deviation (Chiba et al., 2010; Jee et al., 2015; Ulm et al., 2013).

Visual search and exploration tasks included measures based on false alarms/catch trials responses, target detection (capturing accuracy, detection rate/probability) and time (such as RT, search time and task duration); data analysis in these tasks was performed based on target position (e.g., left/right (L/R)) and task demands (e.g., level of difficulty, number of distractors) (Andres et al., 2019; Bonato et al., 2013; Deouell et al., 2005; Erez et al., 2009; List et al., 2008; Machner et al., 2018; Marshall et al., 1997; Mizuno et al., 2016; Rengachary et al., 2011; Ten Brink et al., 2020; Vaes et al., 2015; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010).

In the course of this work, we discovered that (L/R) target detection (Andres et al., 2019; Bonato et al., 2013; Machner et al., 2018; Pallavicini et al., 2015; Van Kessel, Van Nes, et al., 2013), hit rate (response rate) (Erez et al., 2009; Ten Brink et al., 2020), RT asymmetry scores (Deouell et al., 2005; Machner et al., 2018; Rengachary et al., 2009; Van Kessel, Van Nes, et al., 2013) and the number of intersection (disorganized search) (Ten Brink et al., 2016) were all shown to be among the most sensitive measures for spatial bias and visual search deficits detection in patients with BD.

2.3.3. Apparatus and Response Type

A number of studies have used manual response displays such as touchscreen monitors (Rabuffetti et al., 2012; Rabuffetti et al., 2002; Ten Brink et al., 2020; Ten Brink et al., 2016; Ulm et al., 2013), smartphone/tablet devices (Chung et al., 2016; Morando et al., 2019; Pallavicini et al., 2015; Pierce et al., 2021; Quinn et al., 2018) or graphic tablets (Liang et al., 2007; Vaes et al., 2015). Several authors have explored the efficacy of using projectors/large screens (Machner et al., 2018; Spreij et al., 2020; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020), PC/laptop with a mouse (Marshall et al., 1997) or with a response box (Chiba et al., 2010; Deouell et al., 2005; Erez et al., 2009; Rengachary et al., 2009; Stigchel & Nijboer, 2017; Vossel et al., 2010). Some tests are designed requiring verbal (Andres et al., 2019; Bonato et al., 2013; List et al., 2008) or both verbal and manual responses (Chiba et al., 2010). Various tasks captured performance with more than one type of response or apparatus (Jee et al., 2015; Vaes et al., 2015; Van Kessel, Van Nes, et al., 2013).

Some methods may be more accurate than others, however, the literature was reviewed, and no apparatus or response type was proved to be superior to any other.

2.3.4. Specific Details

Tasks could take from either five to ten minutes to complete (Marshall et al., 1997; Van Kessel, Van Nes, et al., 2013) or 10-20 minutes (List et al., 2008; Rengachary et al., 2009; Ulm et al., 2013; Vossel et al., 2010) and test batteries could last more than 20 minutes (Vaes et al., 2015). The CB tasks were considered to provide accurate results within short administration time (Pierce et al., 2021; Ulm et al., 2013). Authors suggest they also offer reduced overall assessment time compared to conventional methods (e.g., batteries of

PnP tasks), which is important as long administration time can cause fatigue to the patients and modulate the results (Liang et al., 2007; List et al., 2008).

The diameter of the screen/display varied from 13- 15inch (Chiba et al., 2010; Deouell et al., 2005; Ten Brink et al., 2020) to 17 -19 inches (Andres et al., 2019; Rabuffetti et al., 2012; Rengachary et al., 2009) to 24-33 inches (Machner et al., 2018; Mizuno et al., 2016). The distance from the subject could be around 30-46cm (Chiba et al., 2010; Mizuno et al., 2016; Quinn et al., 2018), 60-70cm (Andres et al., 2019; List et al., 2008) or 90-100cm (Deouell et al., 2005; Stigchel & Nijboer, 2017). These two factors were not found to affect the tasks' accuracy or the participants' performance.

2.3.5. Sensitivity

Sensitivity was reported in 20/28 studies with four reporting in the form of a percentage (Bonato et al., 2013; Chung et al., 2016; Quinn et al., 2018; Spreij et al., 2020), four with statistical significance values (Andres et al., 2019; Deouell et al., 2005; Rabuffetti et al., 2012; Rengachary et al., 2009) and 11 in a narrative manner (Erez et al., 2009; List et al., 2008; Machner et al., 2018; Mizuno et al., 2016; Pallavicini et al., 2015; Stigchel & Nijboer, 2017; Ten Brink et al., 2020; Ulm et al., 2013; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010). Some CB tools had varied results, reporting both positive and negative or neutral outcomes (List et al., 2008; Mizuno et al., 2016; Pallavicini et al., 2015). Overall 17/28 CB tasks report superior or equal sensitivity in detecting USN symptoms when compared to a variety of conventional tasks (Chung et al., 2016; Deouell et al., 2005; Erez et al., 2009; Morando et al., 2019; Quinn et al., 2018; Rabuffetti et al., 2012; Spreij et al., 2020; Stigchel & Nijboer, 2017; Ten Brink et al., 2020; Ulm et al., 2013; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010). The CB

methods were able to detect USN cases that the PnP did not, either due to compensatory strategies implemented by the patients or due to ceiling effects (Bonato et al., 2013; Deouell et al., 2005; Marshall et al., 1997; Rabuffetti et al., 2012; Rengachary et al., 2009; Van Kessel, Van Nes, et al., 2013); especially in chronic (Andres et al., 2019) mild (Mizuno et al., 2016; Rengachary et al., 2009) and subclinical cases (Machner et al., 2018; Van Kessel, Van Nes, et al., 2013).

2.3.6. Specificity / Reliability

Specificity was reported in 3/28 studies; however, only two studies included specificity percentage reports (high) (Quinn et al., 2018; Spreij et al., 2020) and only the latter included predictive values. Similarly, 2/28 studies reported high test-retest reliability (Jee et al., 2015; Morando et al., 2019). More specifically, Jee et al. (2015) reported test-retest reliability in combination with intra-rater reliability and also provided a high inter-rater reliability score.

2.3.7. Group Differences

The ability of the CB task indices/variables to distinguish among patient groups (LBD+, LBD-, RBD+, RBD-) was explored by 22/28 studies, with 2/28 reporting limited (Chiba et al., 2010; Liang et al., 2007) and 20/28 stronger ability (Andres et al., 2019; Bonato et al., 2013; Chung et al., 2016; Deouell et al., 2005; Erez et al., 2009; List et al., 2008; Machner et al., 2018; Marshall et al., 1997; Mizuno et al., 2016; Pallavicini et al., 2015; Pierce et al., 2021; Rabuffetti et al., 2012; Rabuffetti et al., 2002; Rengachary et al., 2009; Spreij et al., 2020; Stigchel & Nijboer, 2017; Ten Brink et al., 2020; Ten Brink et al., 2016; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010). In a similar way, 18/28 studies discussed the ability of CB tasks to detect USN patients among control groups with

the majority of the studies reporting positive results (Chung et al., 2016; Deouell et al., 2005; Erez et al., 2009; List et al., 2008; Machner et al., 2018; Marshall et al., 1997; Mizuno et al., 2016; Rabuffetti et al., 2012; Rabuffetti et al., 2002; Rengachary et al., 2009; Spreij et al., 2020; Ten Brink et al., 2016; Ulm et al., 2013; Vaes et al., 2015; Van Kessel, Van Nes, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010).

2.3.8. Conventional or PnP Comparison

Many studies compared CB tasks with the BIT (Deouell et al., 2005; Liang et al., 2007; Mizuno et al., 2016; Van Kessel, Van Nes, et al., 2013; Vossel et al., 2010), with a combination of two or more original or similar subtests such as letter/star/line cancellation, line bisection, drawing and reading tasks (Chiba et al., 2010; Marshall et al., 1997; Morando et al., 2019; Pallavicini et al., 2015; Rabuffetti et al., 2012; Rabuffetti et al., 2002; Ulm et al., 2013). Some studies used only cancellation tasks (Bonato et al., 2013; List et al., 2008) or cancellation task(s) and line bisection (Morando et al., 2019; Pierce et al., 2021; Quinn et al., 2018). Other important tasks used as comparisons would be the baking tray and clock drawing task (Rengachary et al., 2009). Some studies compared CB tasks with both functional (e.g., CBS) (Erez et al., 2009; Machner et al., 2018; Spreij et al., 2020; Ten Brink et al., 2016) and PnP assessment (e.g., BIT) or with other widely used CB tools (e.g., TAP, CB, cancellation and line bisection) (Andres et al., 2019; Stigchel & Nijboer, 2017).

2.3.9. Correlation Coefficient

Correlation coefficients were reported by 15/28 studies using data from the CB tasks comparing them to conventional methods. Most of these report positive correlations (Chung et al., 2016; Erez et al., 2009; Liang et al., 2007; Machner et al., 2018; Morando et

al., 2019; Pierce et al., 2021; Rabuffetti et al., 2002; Spreij et al., 2020; Ten Brink et al., 2020; Ten Brink et al., 2016; Van Kessel, Van Nes, et al., 2013), whereas in some cases there were more mixed results (List et al., 2008; Stigchel & Nijboer, 2017; Vossel et al., 2010). A variety of CB tasks (e.g., TOJ, conjunction/feature, Posner, etc.) were found to be highly correlated with cancellation tasks (Erez et al., 2009; Machner et al., 2018; Stigchel & Nijboer, 2017; Ten Brink et al., 2020; Vossel et al., 2010) and similarly with the CBS test (Erez et al., 2009; Machner et al., 2018; Spreij et al., 2020; Ten Brink et al., 2020).

2.3.10. General Benefits of CB Assessment

The results of this investigation show that CB methods have been shown in many cases to be feasible (Chung et al., 2016; Deouell et al., 2005; Jee et al., 2015; Morando et al., 2019; Rabuffetti et al., 2002; Vossel et al., 2010), flexible (List et al., 2008; Vaes et al., 2015), valid (Erez et al., 2009; Jee et al., 2015; Morando et al., 2019; Ulm et al., 2013; Villarreal et al., 2020), reliable (Jee et al., 2015; Morando et al., 2019; Vossel et al., 2010) and user-friendly tools (List et al., 2008; Pallavicini et al., 2015; Rabuffetti et al., 2012; Ulm et al., 2013; Vaes et al., 2015).

This review confirms that CB assessment can provide important patient information and reveal more aspects of neglect symptoms than PnP assessment (Chung et al., 2016; Erez et al., 2009; Liang et al., 2007; Quinn et al., 2018), such as severity (Pierce et al., 2021; Rengachary et al., 2009), quantitative and qualitative data regarding patient behaviour (Andres et al., 2019). Moreover, CB tasks can identify temporal, spatial, and non-spatial search strategy dynamics, helping to differentiate between different subtypes (Mizuno et al., 2016; Stigchel & Nijboer, 2017) with a relatively short administration time (Liang et al., 2007; List et al., 2008; Pierce et al., 2021; Ulm et al., 2013; Vossel et al., 2010).

2.3.11. Limitations of the studies

The majority of the studies reviewed had a relatively small sample size (e.g., less than 50 participants) for demonstrating the clinical validity of the CB tests and control demographics among patients (Jee et al., 2015; List et al., 2008; Machner et al., 2018; Quinn et al., 2018; Ulm et al., 2013; Vaes et al., 2015). However some studies had smaller sample sizes (Andres et al., 2019; Bonato et al., 2013; Chiba et al., 2010; Deouell et al., 2005; Mizuno et al., 2016; Morando et al., 2019; Pallavicini et al., 2015; Pierce et al., 2021; Rabuffetti et al., 2002) and a number of authors did not include an unimpaired control group (Andres et al., 2019; Bonato et al., 2013; Chiba et al., 2010; List et al., 2008; Marshall et al., 1997; Morando et al., 2019; Pallavicini et al., 2015; Quinn et al., 2018; Stigchel & Nijboer, 2017; Ten Brink et al., 2020). In specific studies, no clear attempt was made to compare with a PnP task (Ten Brink et al., 2016; Vaes et al., 2015) or only one or two comparison tasks were conducted (Chung et al., 2016; Jee et al., 2015; Marshall et al., 1997; Morando et al., 2019; Vaes et al., 2015). The reliance on unclear or limited conventional tasks may have contributed to inflated sensitivity results. Another key limitation is that most studies, except for three (Quinn et al., 2018; Rengachary et al., 2009; Spreij et al., 2020), reported sensitivity without accompanying specificity, limiting the ability to fully assess diagnostic accuracy. Additionally, several studies relied solely on narrative descriptions to report sensitivity rather than formal analyses (Erez et al., 2009; Machner et al., 2018; Stigchel & Nijboer, 2017; Ten Brink et al., 2020; Ulm et al., 2013; van Kessel, Geurts, et al., 2013; Villarreal et al., 2020; Vossel et al., 2010). Practical issues are among the most important drawbacks for example, CB tasks can be impractical to perform in a clinical setting, especially where these require large/expensive equipment rather than a typical computer and monitor (Jee et al., 2015; Spreij et al., 2020; Ulm et al., 2013; Vaes

et al., 2015; Van Kessel, Van Nes, et al., 2013). Selection bias is another potential concern in cases where samples do not represent the entire stroke population (e.g., acute/subacute/chronic or RBD/LBD) (Chung et al., 2016; Deouell et al., 2005; Erez et al., 2009; List et al., 2008; Quinn et al., 2018; Vossel et al., 2010). Other limitations include follow-up absence, covering only specific neglect component (Jee et al., 2015; Pallavicini et al., 2015; Vaes et al., 2015), not controlling demographics (Jee et al., 2015; Mizuno et al., 2016; Van Kessel, Van Nes, et al., 2013) and factors such as hemianopia (Spreij et al., 2020; Stigchel & Nijboer, 2017; Vossel et al., 2010). Only 7/28 studies had a low risk of bias (Machner et al., 2018; Pierce et al., 2021; Rabuffetti et al., 2012; Rengachary et al., 2009; Ten Brink et al., 2020; Ten Brink et al., 2016; Villarreal et al., 2020) the rest of them had moderate (Bonato et al., 2013; Chung et al., 2016; Deouell et al., 2005; Erez et al., 2009; Liang et al., 2007; List et al., 2008; Quinn et al., 2018; Rabuffetti et al., 2002; Spreij et al., 2020; Stigchel & Nijboer, 2017; Ulm et al., 2013; Van Kessel, Van Nes, et al., 2013; Vossel et al., 2010) and unclear (Andres et al., 2019; Chiba et al., 2010; Jee et al., 2015; Marshall et al., 1997; Mizuno et al., 2016; Morando et al., 2019; Pallavicini et al., 2015; Vaes et al., 2015). Another key

Authors/Year	Sensitivity	Specificity	Reliability	Correlation Coefficients	Between groups differences. Sensitive Variables/ Features	Other reports:
Marshall et al. (1997)					The visual tracking task can distinguish between RBD pt and other groups ($p = 0.03$), between pt and the control group ($p < 0.02$) It demonstrated significantly better control performance on the target detection single task ($p < 0.004$) and dual task ($p < 0.02$).	
Rabuffetti et al. (2002)				Close relationship (Spearman R: 0.862) between PnP Cancellation tests.	RBD+ pt had significantly higher neglect indexes (Crossing indexes, Latency indexes, Latency gradients significant group differences) than other groups (especially control) ($p < 0.05$).	Feasible
Deouell et al. (2005)	More sensitive than BIT (6/12 pt showed normal scores in the BIT and significant ($p < 0.05$) side difference).				RT can distinguish between RBD and LBD pt and the control group ($p < 0.001$). Significantly longer L RT for the RBD pt ($p < 0.05$). Only the RBD pt group had L/R RT side difference ($p < 0.001$).	
Liang et al. (2007)				More than 8 features were significantly correlated ($p < 0.05$) with neglect symptoms.	Error rate: Varying from (3.3%, 6.8% and 0%)	
List et al. (2008)	The conjunction task was more sensitive than the feature task.			Correlation between PnP and conjunction search score was significant ($p < 0.05$) but not with the feature task.	Conjunction tasks can distinguish RBD from LBD pt ($p < 0.05$) and control group ($p < 0.005$) in contralesional deficits and search score.	Flex ble, user-friendly, and quick.
Erez et al. (2009)	Conjunction tasks can be more sensitive than feature and conventional methods.			Pearson correlation coefficients were significant between feature/conjunction tasks (HR) and cancellation task performance, in RBD+	CB tasks can significantly distinguish RBD+ from RBD- pt, LBD pt and the control group in	Valid for spatial attention post-stroke.

				($p < 0.001$) / $p < 0.005$) and RBD- pt ($p < 0.001$) / ($p < 0.001$). Similarly, between the CBS and feature/conjunction tasks (HR) ($p < 0.005$/ $p < 0.001$).	left RT and HR ($p < 0.001$)	
Rengachary et al. (2009)	High accuracy (sensitivity/specificity). The Posner task was significantly more sensitive ($p < 0.05$) than most PnP in detecting chronic and acute neglect cases.	High specificity.			Posner L/R RT differences and average RT can significantly ($p < 0.05$) distinguish acute pt (AUC: 0.97/0.99) and chronic pt (AUC (0.89/0.91) from the control group.	
Chiba et al. (2010)				Significant correlation between the two CB tasks ($p < 0.05$).	4 pt had significantly greater rightward deviation in the more complex task ($p < 0.05$).	
Vossel et al. (2010)	Sensitive.			Correlation with CB latency quotient and confrontation technique was low, but significant with CoC of line and star cancellation tasks and deviation of line bisection ($p < 0.001$).	Distinguish between the control group, extinction pt, moderate and severe neglect.	Easily applied, reliable, quick
Rabuffetti et al. (2012)	Not significant ($p = 0.22$) but higher than PnP.			No strong correlation, never exceeded 0.30 in the module (the largest coefficient being 0.27 for correlation between mini mental state examination and number of touched distracters).	Significant differences among RUSN+ pt vs the control group and RUSN- pt ($p < 0.05$), significant group differences were found ($p < 0.01$) in 13/14 indexes.	User-friendly.
Bonato et al. (2013)	CB was more sensitive (detected overall left omissions (60.2%) and the PnP (6.9%).				Can detect neglect symptoms: Difference L/R target detection was significant ($p < 0.001$). Detection of left targets was decreasing in more complex tasks ($p < 0.005$).	
Ulm et al. (2013)	More sensitive than NET (German BIT).				CB versions distinguish significantly (star cancellation $p = 0.025$) and line bisection ($p = 0.001$) between USN+ pt and the control group. Significant discriminant function was shown with (2/4) CB variables ($p = 0.003$).	Valid.

Van Kessel, Van Nes, et al. 2013)	The computerized dual task (CVRT-D) was able to detect cases with normal BIT and computerized single-detection task (CVRT) scores.			Significant correlation coefficient for contralesional omissions for RBD pt group between BIT and CVRT ($p < 0.05$) and CVRT-D ($p < 0.005$).	Number of contralesional omission can distinguish RBD pt from the control group and LBD pt. RBD pt had higher RT asymmetries ($p < 0.001$) compared to other groups.	
Jee et al. (2015)			Inter-rater: 0.84 -0.98 ($p < 0.001$). Test-retest and Intra-rater 0.84-0.91 ($p < 0.001$).			Feasible, valid and reliable.
Pallavicini et al. (2015)	The CB card dealing task was more sensitive than the conventional method. CB cancellation tasks were equally sensitive to PnP.				L side number of omissions can significantly distinguish between USN+ and USN- groups in CB cancellation tasks ($p < 0.01$) and card dealing task ($p < 0.05$).	User-friendly with high usability.
Vaes et al. (2015)					The (21/26) CB variables can significantly ($p < 0.05$) distinguish between USN+ pt and the control group.	User-friendly.
Chung et al. (2016)	95% sensitivity (higher than PnP line bisection with 75%, and star cancellation with 94.4%).			The computerized table setting test (CTST) parameters significantly correlated with total neglect score (horizontal deviation, $p < 0.001$, selection tendency, $p < 0.001$, and elapsed time $p = 0.007$).	CTST 3/3 parameters significantly distinguished between RBD+ and LBD pt and the control group (horizontal deviation, $p < 0.001$; selection tendency, $p < 0.001$; and elapsed time, $p = 0.006$).	Feasible.
Mizuno et al. (2016)	CB may be more sensitive than BIT.				Circle test (average cancellation time) can distinguish between pt and controls. Visual and visuomotor test detected significant difference in average RT ($p < 0.01$) between stimulus-centered pt and other pt groups and control.	

Ten Brink et al. (2016)				CB shape cancellation (number of intersections) showed a moderate correlation with neglect severity ($p = 0.009$).	The CB task can significantly distinguish between RBD+ and LUSN+ pt from the control group with significantly higher numbers of intersections ($p < 0.003$) and omissions ($p < 0.001$), similarly the number of intersections can significantly differentiate RUSN+ from LUSN+ pt ($p = 0.09$) and RUSN- pt ($p = 0.001$).	
Stigchel and Nijboer (2017)	Sensitive for spatial bias deficits.			Strong correlation between Temporal order judgment (PSS) and with shape cancellation (omission difference) ($p < 0.001$), but not with line bisection (deviation score) ($p = 0.08$).	Temporal order judgment task (PSS) significantly detected patients with spatial deficits ($p = 0.0002$).	
Machner et al. (2018)	The desk task was more sensitive than PnP and as sensitive as the Posner Task in detecting spatial attention bias.			The desk task (mean search duration) and the Posner task (mean RT) were highly correlated with the CBS score ($p < 0.001$). Latency index of the desk task was correlated with the Posner task and with the bell's task CoC ($p < 0.001$). .	Desk task: USN+ groups had longer left search duration and left target detection than the control group and USN- pt ($p < 0.01$). Posner: Severe USN+ pt had lower left detection rate than other groups ($p < 0.001$). The Posner (RT) can distinguish between the control group and all pt groups ($p < 0.003$).	
Quinn et al. (2018)	79% sensitivity (for stroke related visual field deficits).	Specificity: 88% (For stroke related visual field deficits).			.	Similar acceptability scores with PnP.
Andres et al. (2019)	CB tasks significantly revealed ($p < 0.001$) neglect/extinction symptoms for more cases than conventional tasks.				L/R omission in single and dual task can significantly reveal neglect ($p < 0.001$).	
Morando et al. (2019)			High test-retest reliability over 0.75 for both tasks.	High Pearson correlation coefficient for repeated CB test and line bisection and Albert's test respectively (offset: = 0.083, Rate: $p = 0.094$) and (uncrossed		Feasible and valid.

				L/R: p = 0.098 / p = 0.080).		
Spreij et al. (2020)	Sensitivity: 51.5% (for LUSN+ pt) and 28.6% (for RUSN+ pt).	Specificity: 94.3% (for USN- and LUSN+ pt). LUSN+: (85% Positive Predictive Value (PPV), 75.8% Negative Predictive Value (NPV) pt). RUSN+: (40% PPV, 90.9% NPV).		Spearman correlation between the CB (average position of the road) and CBS (neglect severity) was significant (p = 0.05).	CB average position deviation and magnitude of sway distinguished USN+ pt from LUSN- pt (p < 0.001) and controls, but not RUSN+ vs USN- pt.	
Ten Brink et al. (2020)	Adding targets can increase sensitivity.			Correlation between CB percentage of hits and shape cancellation omissions (p < 0.001) of deviation and line bisection (p < 0.001) and total CBS score (p < 0.001).	Increased number of target task can significantly affect HR performance (p = 0.008) and distinguish RBD+ from LBD and RBD- pt.	
Villarreal et al. (2020)	Higher sensitivity than PnP. The CB detected more cases and could distinguish between groups.				RBD pt had significantly increased missed left target than the control group (p < 0.05) and LBD pt in both tasks.	High ecological validity.
Pierce et al. (2021)				No significant correlation was detected between manual exploration task mean horizontal position and deviation of line bisection or CoC of bells or apples cancellation.	Percentage of taps showed significant groups differences (p < 0.05), USN+ pt vs other groups had significantly different left percentage of taps (p = 0.037).	Quick.
Table Notes: BIT: Behavioural inattention test, BD: Brain damage, CB: Computer-based, CBS: Catherine Bergego scale, CoC: Centre of cancellation, L: Left, R: Right, USN: Unilateral spatial neglect, HR: Hit rate, PnP: Pen-and-Paper tasks, PSS: Point of subjective simultaneity, Pt: Patient/patients, RT: Response time, -: without USN, +: with USN.						

Table 2.3 Summary of main results

2.4. Discussion

In this review, the main objective was to provide a summary and critical analysis of the existing evidence around CB assessment of USN, by investigating the shortcomings and strengths of the approaches followed by previous studies. Another purpose of our review was to generate fresh insight into our understanding of CB tasks and enhance future designs by demonstrating essential indications regarding clinical applicability and utility of CB assessment of USN.

One of our most important findings relates to the task type; most of the studies preferred to use CB versions of conventional tasks, however, it is revealed that CB tasks with more advanced designs such as RT and visual search tasks (e.g., feature and conjunction) can be more effective in detecting neglect symptoms. It was revealed that these types of tasks can capture more mild/chronic/subclinical cases than simple versions. Similarly, more complex designs, combining a variety of task types with different task demands, can maximize sensitivity by providing a wider data collection. These results are in line with existing evidence that presenting greater task difficulty can enhance sensitivity (Bonato, 2012; Buxbaum et al., 2012). These findings also support the work of other studies in the area demonstrating that divergent tasks can capture distinct components of this multifactorial syndrome (Sacher et al., 2004) and diversity of task demands can highlight disparate deficits associated with USN (Dukewich et al., 2012).

The results of this study explore the potential superiority of some outcome measures' sensitivity for detecting spatial bias and visual search deficit, such as RT and accuracy for visual search and comparable target detection tasks. This has previously been observed in a variety of other studies exploring the advantages of these measures (Anderson et al.,

2000; Bartolomeo et al., 1998; Schendel & Robertson, 2002). Similarly, it was revealed in our review that in cancellation tasks and other CB versions of PnP, the CoC was among the most sensitive. These results are also in accordance with a wide background of evidence highlighting the benefits of capturing CoC in cancellation tasks (Dalmaijer et al., 2015; Rorden & Karnath, 2010; Suchan et al., 2012).

One of our objectives was to investigate features that optimize CB task design, but we were unable to demonstrate how some factors such as task duration, size of the display, and apparatus affect the effectiveness of these tasks. However, we concluded that most of the tasks last between 10-20 minutes, use a display with a 13-19 inches diagonal screen size, at a distance of 40-70 from the subject depending on the task design. Previous studies have reported that a short administration time can be more practical for a clinical environment and can avoid fatigue effect which can affect the patients' outcomes (Grattan & Woodbury, 2017; Pedroli et al., 2015). It was also observed that there are three main types of apparatus with the most used being a classic PC/laptop-monitor combination, the second most explored was the graphic tablet, and finally, the last decade has seen the introduction of touchscreen smartphone/tablet app tasks. It is important to consider various factors regarding hardware selection to enhance cost-effectiveness, feasibility and minimize practical issues affecting the clinician and patient (Bonato & Deouell, 2013; Tsirlin et al., 2009). The importance of minimizing motor and visuomotor task demands in order to avoid any contributing factors related to movement limitations is highlighted by the majority of the tests requiring a simple manual response either through a touchscreen, mouse, or response box/button. Previous research has established that increased motor demands can affect performance or cause motor bias to neglect patients with coexisting conditions such as directional hypokinesia (Mattingley et al., 1998; Sapir et al., 2007). One challenge

influencing the optimization of CB tasks design is finding the right balance between the quantity and quality of data. For instance, a wider data collection would provide more information about the patient but could also increase the task duration, which could cause fatigue and affect the quality of the data.

As mentioned in the review most of the studies chose the CBS, cancellation, and line bisection tasks as a conventional comparison tool, these tests being among the most widely investigated existing neglect assessment tools with relatively high sensitivity scores (Azouvi, 2017; Bailey et al., 2000; Chen et al., 2012; Sarri et al., 2009). Several CB tasks were highly correlated with the CBS and cancellation tasks, and some studies reported varied results, which can be explained considering the lack of gold standard and the comparison with tasks requiring different demands and performance components. However, in order to accurately evaluate the diagnostic accuracy of a task, it is recommended to follow methodologies such as the ones summarized by Umemneku Chikere et al. (2019) in the absence of a golden standard. The CB tasks were overall more sensitive than conventional tools and could distinguish different patients groups (LBD, RBD+, RBD- etc.) from each other and from unimpaired control subjects, which corroborate the findings of a great deal of previous work (Bonato, 2012; Bonato & Deouell, 2013; Dawson et al., 2008; Schendel & Robertson, 2002). In the course of this review, we also discovered that CB tasks can collect a broad spectrum of data and provide more information about the patient's profile and behaviour than PnP tasks. However, very little data were found in the literature around the specificity and reliability of CB tasks, and it was not possible to draw a conclusion regarding this. As presented in the review, CB tasks can provide greater flexibility than PnP (e.g., by projecting stimuli and testing neglect in near vs far space). However, they operate in extra-personal space, in a similar way to PnP

tasks, and cannot address all spatial representations relevant to the neglect syndrome (e.g., personal neglect).

The results suggest that CB tasks show promise in several domains of USN assessment compared to conventional methods, particularly in their sensitivity to detect subtle deficits; however, conclusions about diagnostic superiority remain limited by the lack of comprehensive accuracy metrics. This outcome is not unexpected considering most conventional tasks were designed and revised many years ago (e.g., the widely used BIT created by Wilson et al. in 1987). In recent years, the global technological expansion and digitalization of everyday life have minimized the practical constraints of CB assessment concerning requirements for hardware access. Additionally, technological advances have allowed the creation of more accessible designs, with some authors reducing further the practical boundaries by providing access to online/offline software for analysis and assessment (Dalmaijer et al., 2015; Rorden & Karnath, 2010). While the reduction in barriers to implementing CB tasks and emerging evidence supporting their advantages, particularly in detecting mild and chronic neglect, highlight their potential, the current evidence is not yet sufficient to support widespread clinical adoption. Further rigorous validation studies are needed to establish diagnostic accuracy, clinical utility, and feasibility across diverse settings. Therefore, before CB tasks can be routinely introduced into clinical practice, more research is essential to confirm their benefits and address practical considerations related to implementation. We also do not suggest the total removal of conventional methods, since they can overcome practical restrictions (e.g., need for hardware) when CB methods are not necessary, such as in severe and acute cases. It can therefore be assumed that an optimized future model will include a combination of both conventional and CB assessment tools.

The evidence presented in this review suggest that CB neglect assessment methods show promise as feasible, valid, flexible, reliable, and user-friendly tools; however, more rigorous usability research is needed to confirm this. Our results are in accordance with the findings of multiple studies exploring the advantages of these methods (Donnelly et al., 1999; Guest et al., 2000; Halligan & Marshall, 1989; Hopfner et al., 2015; Kerkhoff & Marquardt, 1995; Smit et al., 2013; Van der Stoep et al., 2013).

Limitations

Most of the included studies suffer similar limitations. In order to overcome these issues and minimize bias, it is recommended that future studies avoid selection bias by including a consecutive or random large sample of control subjects and patients from a wide stroke population with equivalent demographics (Chassé & Fergusson, 2019). A notable limitation across several studies is the frequent reporting of sensitivity without corresponding specificity, which restricts a full evaluation of diagnostic accuracy (Cohen et al., 2016; Shreffler & Huecker, 2025). Only 3/28 studies reported both measures, limiting the ability to make a balanced judgment on diagnostic utility and to determine whether results reflect accurate detection or potential overdiagnosis. Many studies used unclear or limited reference standards for comparison, which may partly arise from the lack of a well-defined gold standard for USN assessment (Demeyere et al., 2015; Ogourtsova et al., 2017); however, inconsistencies and variations in the choice or definition of reference standards likely contribute to inflated sensitivity values. Such variability suggests that some high sensitivity results may reflect limitations in the comparison criteria rather than true test accuracy. Future research should aim to include both sensitivity and specificity and emphasize using multiple sensitive conventional assessment tools as comparison measures, since there is no universally accepted gold standard for USN (Rutjes et al.,

2007; Umemneku Chikere et al., 2019). Follow-up testing in order to explore effectively clinical validity, psychometric properties, and accuracy of the tasks would also be welcome (Umemneku Chikere et al., 2019). The main weakness of our study is that we could not perform a meta-analysis due to the high heterogeneity among index/comparison tests, study data types, and methodologies of analysis. However, we performed a vote counting analysis based on a direction of effect plot, which can be used to synthesize evidence when there is a lack of data consistency across the selected studies; this method is considered appropriate though less powerful than methods that include p values (McKenzie & Brennan, 2019). Even though the QUADAS-2 tool seemed like the optimal tool it was designed for diagnostic accuracy studies and the heterogeneity of the studies affected the risk of bias decision, since the authors could not answer the questions confidently. The reviewers did not expand the inclusion criteria to include VR assessment studies, which would have increased the quantity of data. However, this allowed a more distinctive focus to be applied to the review on CB assessment. VR-based assessment of USN has already been the focus of similar previous work (Tsirlin et al., 2009).

Conclusion

Our review of major studies indicates that CB assessment of USN may offer advantages in acceptability, flexibility, and feasibility compared to conventional methods. CB methods have been proved to provide a wider variety of data than PnP tasks which can be crucial in understanding patients' profile and severity, as well as monitor progress and the effect of rehabilitation. There is a strong body of evidence demonstrating that CB assessment may be more sensitive and overcome conventional methods' practical issues such as compensatory strategies and ceiling effects, especially with more complex designs and combinations of different task types. The results obtained here may have implications for

understanding essential features affecting the efficacy of CB tasks and indications can be implemented as a guide to improving future designs. The findings of this review complement those of earlier studies and suggest that CB tasks for USN assessment should be implemented in clinical settings.

CHAPTER 3

Visuo-spatial attention in younger and older adults: comparing performance on a series of computer-based tasks.

Abstract

Background: The aim of the study was to investigate age-related effects on visual attention and provide a normative data for a set of four computer-based tasks, as a basis for future clinical studies.

Methods: A cross-sectional observational approach was utilised in this study. A battery of four CB tasks, with previously demonstrated sensitivity, were employed to assess visual attention between young and older adults. The duration of each task was approximately 5 minutes, gathering RT (ms) and accuracy (%) data. A feedback questionnaire was used to gather insights on participants' qualitative experience of the tasks.

Results: 125 participants, 51 younger (aged between 18-30) and 74 older adults (aged between 65-90) took part. Older adults had significantly slower response times compared to younger adults, across all tasks, but accuracy results were comparable for most tasks. However, in the feature task, older adults demonstrated greater accuracy, especially on the right side. Although this pattern was evident in both groups across tasks, this result highlights the presence of a more pronounced leftward bias in the younger group, indicative of pseudoneglect. Increasing task demands, for example, by adding a dynamic component or introducing more complex or a larger number of distractors, had a greater impact on older adults' performance. Both age groups displayed adaptability in search strategies based on task demands and reported the tasks as user-friendly, easy to understand, and with an appropriate duration.

Conclusion: The study provides valuable insights regarding the effect of age on visual attention and demonstrates the high sensitivity and feasibility of using computer-based

assessment in unimpaired populations. Data presented here provide a basis for future studies using the same task battery with clinical populations.

3.1 Introduction

One key to healthy aging is the maintenance of cognitive function, a loss of which can have a significant negative impact on the quality of life and everyday activities for older adults (Gray et al., 2021; Lee et al., 2019; Stites et al., 2018). Visual attention, the ability to focus or selectively attend to elements of a visual scene, declines with age, affecting wider cognitive performance by diminishing a wide array of functions, including visual search, visuo-spatial attention and spatial working memory capacities (Madden & Monge, 2019; Müller-Oehring et al., 2013). Hence, age-related impairments of visual attention impact everyday activities including reading, locating objects, navigating and driving safely. The effects of aging on visuo-spatial attention have been investigated in multiple studies demonstrating that older adults interpret stimuli in their environment more slowly and in some cases less accurately compared to younger adults (Ebaid & Crewther, 2019; Pesce et al., 2005; Vallesi et al., 2021).

Several lines of evidence on hemispheric lateralization have established a right hemisphere dominance for visuo-spatial attention networks (Corbetta et al., 2000; Heilman & Van Den Abell, 1980). Brain lesions in the right hemisphere, particularly in the attention network regions (e.g., fronto-parietal pathways, temporoparietal junction), can lead to severe attention impairments, such as USN (Corbetta & Shulman, 2011; Ptak & Schnider, 2011). USN is a common post-stroke cognitive syndrome; patients with USN experience an ipsilesional attention bias with a concomitant difficulty in orienting and responding to stimuli displayed in space opposite to the BD (Heilman et al., 1997). Additionally, the right hemisphere is often associated with the pseudoneglect phenomenon, a leftward attention bias observed in healthy individuals. This bias is commonly attributed to the right hemisphere's dominance in visuospatial attention, although this theory remains debated

(Bartolomeo & Seidel Malkinson, 2019; Gerrits et al., 2020). The age-effect on pseudoneglect is not yet fully understood; however some evidence suggest an increasing rightward perceptual shift in older adults, diminishing pseudoneglect characteristics (Benwell et al., 2014; Friedrich et al., 2018). This transition aligns with the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) model (Cabeza, 2002), which suggests that older adults recruit bilateral brain regions to counteract age-related neural decline. Such compensatory mechanisms may account for the diminished leftward bias in older adults compared to younger adults. This pattern of leftward bias observed in healthy adults contrasts with the rightward bias detected in stroke patients with USN, signifying a distinct differentiation between these two lateralized attention mechanisms.

Visuospatial attention is commonly assessed in clinical and research settings by using PnP tasks such as line bisection and star cancellation for both patient and unimpaired populations (Checketts et al., 2021; Learmonth & Papadatou-Pastou, 2022). The PnP subtests of the BIT and the functional assessment CBS are among the most common and sensitive standardized test batteries for USN assessment (Luukkainen-Markkula et al., 2011; Marques et al., 2019). These conventional methods are effective at identifying major lateralised bias; however, they fail to detect mild cases, unlike more sensitive CB tasks (Bonato & Deouell, 2013; Bonato et al., 2013; Machner et al., 2018). CB tasks have a number of advantages over traditional USN assessment methods, including higher sensitivity and diagnostic accuracy (List et al., 2008; Rengachary et al., 2009; Vaes et al., 2015; Villarreal et al., 2020), however they haven’t been adopted in clinical settings yet, possibly due to equipment requirements, familiarity or the wide variety of existing CB tools lacking a ‘gold-standard’ (Evald et al., 2021; National Clinical Guidelines for Stroke, 2023).

While the development of CB assessment tools is primarily driven by stroke-related neglect syndromes, establishing a standardized CB assessment tool that can accurately detect perceptual bias would not only be advantageous to the patient population but also essential for exploring age-related visuospatial attention changes. To address the challenge presented by the heterogeneity and diversity of the many CB tasks across the literature, we conducted a systematic review (Chapter 2). The review provides an overview and evaluation of the different task designs, and identified tasks with wider evidence for their efficacy (Giannakou et al., 2022). Following the review, the selected tasks were the Posner Cueing Task (Posner, 1980; Rengachary et al., 2009), the Starry Night task (Deouell et al., 2005) and the visual search Feature and Conjunction Tasks (Erez et al., 2009). These tasks were also chosen because they explore different facets of visual attention. For instance, the Posner task utilizes cues to assess covert attention, where overt attention involves prior target fixation and eye movement, and covert attention does not (Van der Stigchel & Theeuwes, 2007). The Feature and Conjunction visual search tasks employ distractors to evaluate respectively bottom-up, stimulus-driven mechanisms, and top-down, goal-directed processes (McMains & Kastner, 2011). Collectively, these tasks, with the dynamic environmental features of the Starry Night task, address diverse aspects of visual attention. The four tasks were re-created in this study to form a battery of CB tasks, designed to provide a comprehensive assessment of perceptual bias by addressing a broad spectrum of attentional components.

The primary aim of this chapter was to establish normative data to inform the development of impairment cut-offs for the computer-based tasks. While previous research has shown that age can influence visual attention, here we examined whether such differences emerge within the specific parameters of our tasks. Additionally, we explored possible age-

related differences and aimed to identify any emerging patterns within the normative data, such as the presence of pseudoneglect. Exploring lateralized bias and understanding how healthy older populations respond to different task elements are crucial for developing effective tasks for patients. Therefore, this research has substantial clinical relevance, aligning with our ultimate goal of gaining valuable insights to enhance the application of CB tasks for visual attention assessment in stroke survivors.

3.2 Methodology

3.2.1 Study Design

A cross-sectional observational approach was employed in this study. The major benefit of this approach is its efficiency in generating robust normative data from different age groups within one session, allowing one-point explorations of multiple variables related to age-related variations in visual attention, offering valuable insights for designing future research involving patient data (Wang & Cheng, 2020). We determined that a minimum of 50 participants in each group would provide a balanced sample size, consistent with similar studies exploring visual attention in younger and older adults (Erel et al., 2019; Langley et al., 2011; Olk & Kingstone, 2015).

3.2.2 Participants

The sample included unimpaired young and older adults. We recruited 125 participants, 51 younger (aged between 18-30 years; M = 24.0 years; SD = 2.22; 31 female) and 74 older adults ((aged between 65-90); M = 76.5; SD = 6.38; 47 female). The demographic data are summarised in Table 3.1. Exclusion criteria included the presence of any impairments that

may knowingly affect their performance on the CB tasks. All participants were considered eligible if they were able to follow simple verbal instructions, reported having normal or corrected to normal vision, could use one hand to push a button and observe a computer screen for approximately five minutes at a time, and were able and willing to give written informed consent. The research protocol was approved by the University of Birmingham's Science, Technology, Engineering and Mathematics Ethical Review Committee.

	Younger Adults (N = 51)		**Older Adults (N = 74)**		**Total (N = 125)**	
	Mean	+/- SD	Mean	+/- SD	Mean	+/- SD
Age (Years)	24	2.22	76.5	6.38	55.1	26.4
Gender						
Female	31	60.8	47	63.5	78	62.4
Male	20	39.2	27	36.5	47	37.6
Handedness						
Right	47	92.2	60	81.1	107	85.6
Left	4	7.8	14	18.9	18	14.4
Level Of Computer Knowledge						
Beginner	7	13.7	52	70.3	59	47.2
Intermediate	36	70.6	21	28.4	57	45.6
Advanced	8	15.7	1	1.4	9	7.2

Table 0.1 Demographic Data for Younger and Older Unimpaired Adults

3.2.3 Material And Procedure

Written informed consent was obtained from all the participants before taking part in the study. During a session of approximately 60-minute in a quiet room with dim lighting, participants were seated on an adjustable-height chair to ensure comfort, maintaining a consistent 60 cm distance from the screen. The study session consisted of a demographic questionnaire form, four CB and a feedback questionnaire.

Demographic Questionnaire Form

The questionnaire took 2-5 minutes to administer, requiring participants to provide basic demographic information (e.g., age, gender, handedness, level of computer experience).

CB Tasks

CB Task Selection:

To address the challenge presented by the heterogeneity and diversity of the many computer-based tasks across the literature, a systematic review was conducted (see Chapter 2, also Giannakou et al., 2022). The review provides an overview and evaluation of the different task designs and identified tasks with wider evidence for their efficacy. Following the review, four well-established tasks with extensive use in the literature and demonstrated sensitivity to lateralised attentional deficits were selected. These were the Posner Cueing Task (Posner, 1980; Rengachary et al., 2009), the Starry Night Task (Deouell et al., 2005) and the Feature and Conjunction Visual Search Tasks (Erez et al., 2009). These tasks were also chosen because they explore different facets of visual attention. For instance, the Posner task utilizes cues to assess covert attention, while also examining how spatial cues influence attention allocation and response speed (Van der Stigchel & Theeuwes, 2007). The Feature and Conjunction visual search tasks use distractors to assess selective attention, with the Feature task focusing on bottom-up, stimulus-driven mechanisms, and the Conjunction task examining top-down, goal-directed processes (McMains & Kastner, 2011). The Starry Night Task evaluates selective and sustained attention in a dynamic, cluttered setting, offering a sensitive measure of lateralized perception (Deouell et al., 2005; Erel et al., 2019). Collectively, these tasks assess spatial bias and address diverse aspects of visual attention.

Participants completed four versions of these tasks; (i) a Starry Night Task *(Deouell et al., 2005)*, (ii) a Feature Visual Search Task, (iii) a Conjunction Visual Search Task *(Erez et al., 2009)* and (iv) a Posner Cueing Task *(Hayward & Ristic, 2013; Posner, 1980)*. The four tasks employed are adapted versions of those previously developed to examine visuo-spatial attention following stroke. The tasks required between 15 and 20 minutes to complete in total, with each task lasting no longer than five minutes each. The task order was pseudorandomized for each participant. The subsequent sections will delve into a comprehensive overview of the design and objectives of each task.

Starry Night Task (Deouell et al., 2005):

The dynamic Starry Night task (Figure 3.1) required participants to make a speeded button press when detecting targets (red stars) within a changing environment of distractors. During the pre-target period (see Figure 3.1 for timings) participants were exposed to a dynamic background with distractors varying in size (small or big) and state (visible or invisible). Our version of the task comprised a total of 100 trials, with 92 being target trials and 8 being catch trials (no target was presented in order to assess participants' ability to withhold a response, capturing attentiveness and response accuracy). Overall, the Starry Night task aimed to assess target detection in a dynamic environment of varying distractor conditions and locations, evaluating the ability to explore visual stimuli while managing multiple distractors and focusing on target detection.

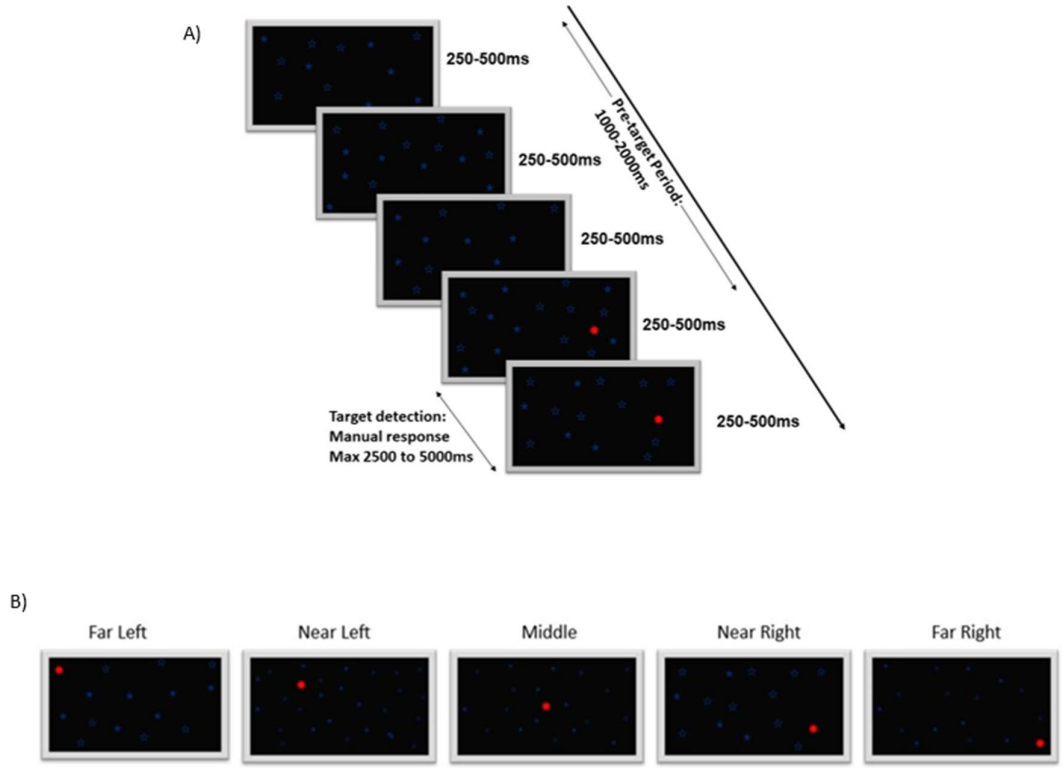

Figure 0.1 Starry Night Task. A) The figure shows frames from a sample trial of the task. During the pre-target interval (1000-2000ms) distractors changed size (small and big blue stars, approximately 0.94° and 1.25° degrees of visual angle, respectively) and state (visible/invisible) every 250-500ms. B) The figure shows examples of target appearances in each spatial location: Far Left, Near Left, Middle, Near Right, and Far Right. The display had 28 potential locations for distractors and target placement, grouped into five screen sections: 8 Left (5%–25%), 4 Near Left (30%–40%), 4 Middle (45%–55%), 4 Near Right (60%–70%), and 8 Right (75%–95%) with 50% being the centre of the screen. Following the pre-target interval, a target (a red star, approximately 1.57° visual angle) was presented against the changing background. The trial ended when a participant responded or after 2500-5000ms.

Feature Visual Search Task (Erez et al., 2009):

In Feature Visual Search Tasks, participants are required to identify a pop-out target characterised by a single feature (e.g., colour, shape) across 100 trials, including 75 target trials and 25 catch trials. In this version, participants were presented with a display consisting of static distractors (blue circles), with the number of distractors being either 5,

10, 15, or 20. Their goal was to detect the target (a red circle). The number of distractors and the target's location varied in each trial. The response requirements were two-fold: participants responded using the Chronos response box, pressing one designated button when they spotted the red circle among the distractors and another designated button when the target was absent (see Figure 3.2 for timings).

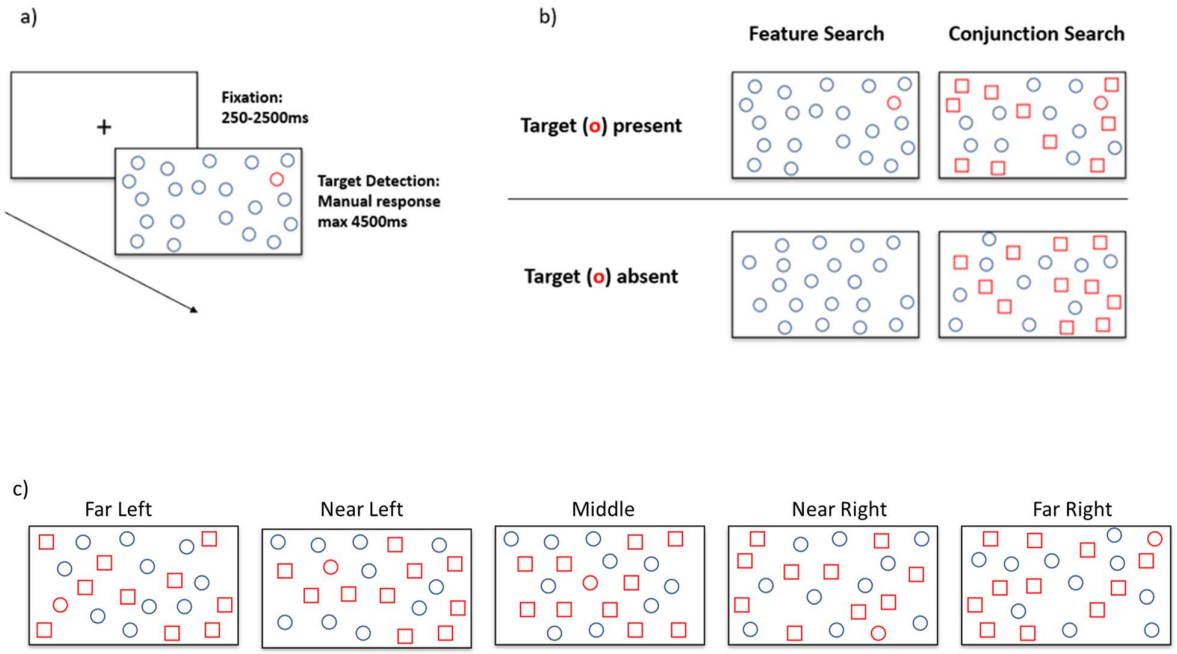

Figure 0.2 Feature and Conjunction Visual Search Tasks. PowerPoint slides were created and saved as BMP (bitmap) images, which were then integrated into E-Prime for presentation in full screen on a 24-inch monitor. Stimuli in each section were spaced similarly along the horizontal axis and were 2.23 cm to 2.25 cm in size (approximately 81.25 pixels to 81.75 pixels. A) Representation of an example target trial for the Feature Visual Search task. At the beginning of each trial, a fixation point (a small black cross) appeared at the display centre for 250 to 2500ms. Following the fixation period, the target (a red circle) could appear at any of the 25 potential positions (grouped as far left, near left, middle, near right and far right). Distractors (blue circles) were randomly scattered, with the number of distractors ranging from 5 to 20 in each trial. In the example shown, the target is presented among 20 distractors B) Representation of Target and Catch Trials of the Feature and Conjunction Visual Search tasks. For the Conjunction Visual Search Task, the target remained a red circle, while the distractors consisted of both red squares and blue circles. This figure illustrates a trial example with 20 distractors. The stimulus display terminated by a response or after 4500ms if no response was detected. Both tasks consisted of 100 trials: 75 target and 25 catch trials. C) The figure illustrates example target appearances at each of the five spatial locations in the Conjunction Task. Both the Feature and Conjunction tasks included 25 potential

target/distractor positions distributed across five screen sections: Left (5%–25%), Middle Left (25%–40%), Middle (40%–60%), Middle Right (60%–75%), and Right (75%–95%), with the screen centre at 50%.

Conjunction Visual Search Task (Erez et al., 2009):

Conjunction search involves identifying a target by the combination of two or more elements, prompting participants to perform serial search strategies, in contrast to the pop-out nature of feature search where the target is typically more easily detected. The Conjunction task employed here shared a similar display with the Feature task and included 100 trials (75 target and 25 catch trials). Participants were required to respond to the presence or absence of the target (red circle) among two types of static distractors (blue circles and red squares). Both tasks involved varying number of distractors (5, 10, 15 or 20), providing the ability to investigate how participants perform under different levels of complexity.

Posner Cueing Task (Posner, 1980):

Participants completed 100 trials, including 70 valid target trials, 20 invalid trials, and 10 catch trials, in a display featuring two boxes (left/right) and a fixation cross. They were instructed to respond by pressing a button whenever they detected the target (a white star) appearing in one of the two boxes. Before the target appeared, a cue was presented. The cue-target interval (CTI), the time interval between the cue and the appearance of the target varied for each trial. The CTI is important because it allows for the examination of how cue timing influences the speed and accuracy of attentional shifts, providing insights into the dynamics of attentional control over time, and helps assess Inhibition of Return (IOR), a phenomenon where attention is inhibited from returning to a previously attended

location after a delay (Klein, 2000). The Posner Cueing Task aimed to investigate participants' ability to detect the target under different CTI conditions and assess the influence of the cue on their RT and accuracy. The Posner task is widely employed in diverse research settings to investigate visuospatial attention, by primarily measuring the capacity to focus, shift and disengage attention at specific spatial locations (Rengachary et al., 2009). (see Figure 3.3 for timings).

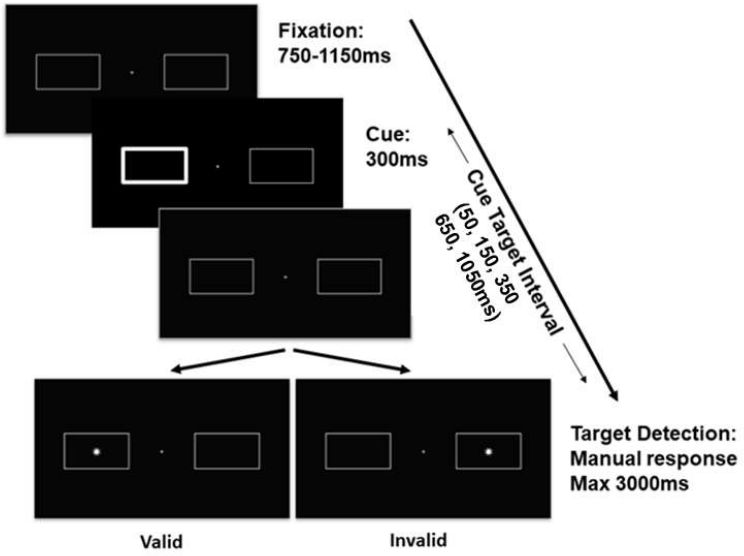

Figure 0.3 Posner Cueing Task. The visual representation illustrates the Posner Cueing Task, featuring both trials with valid cues (target presented at the same side as the cue) and invalid cues (target appeared on the opposite side of the cue). This task is an exogenous version, where attention is automatically drawn to the cued location by an external stimulus, the cue (a bright white square), enabling the study of reflexive attentional shifts that occur and whether IOR is present. Two rectangles were presented on the screen, each occupying 25% of the display's width (480 pixels) and 25% of its height (270 pixels), based on a 24" monitor with a resolution of 1920 × 1080 pixels. The rectangles were horizontally centered at 25% (left: 480 pixels) and 75% (right: 1440 pixels) of the screen width, both aligned vertically to the centre of the screen. Each rectangle was outlined with a 5-pixel border. On cue trials, the border of the cued rectangle was increased to 9 pixels to draw attention. A central fixation cross (Consolas font, 40 pt; ~53 pixels) appeared at the centre of the screen ([960, 540]). The target symbol (✷) was presented in Consolas font at 80 pt (~106 pixels) and was centrally located within the rectangle. The stimuli were white on a black background, with white having a luminance of 255 and the black background having a luminance of 0. The task includes random fixation durations (750 - 1150ms), followed by a 300ms display of the cue. The cue-target interval varied in each trial and with five different conditions (50ms, 150ms,

350ms, 650ms, and 1050ms). These varying CTIs are crucial for probing the time course of attentional shifts, allowing for the investigation of when attentional shifts occur and whether IOR is present. The trial ended after 3000ms of the target (a 3.14° white star) presentation or immediately following a response. This task consisted of 100 trials; 70 trials involved a valid target presentation 20 invalid trials and 10 catch trials. This ratio closely aligns with the original 80-20 ratio by Posner et al. 1980, which facilitates a covert shift to the cue, with the addition of catch trials to assess attentiveness.

Tasks Summary:

Each task was chosen to target distinct components of visual attention and cognitive processing. The Feature Search Task examines feature-based attention, focusing on participants' ability to detect a target defined by a single visual feature (e.g., colour or shape), highlighting how attention is allocated to specific attributes in isolation. The Conjunction Search Task investigates conjunction-based attention, where participants are required to detect a target defined by a combination of two or more features, testing how attention integrates multiple features to identify a target in a more complex search. The Posner Cueing Task assesses spatial attention and the ability to shift attention, evaluating how participants' attention is directed towards a location based on an external cue, and how effectively they can adjust their focus in response to cue validity and different CTIs. Finally, the Starry Night Task probes dynamic attention, measuring participants' ability to detect targets in a constantly changing environment with shifting distractors, testing how attention adapts to new visual information.

Feedback Questionnaire

As a final step, participants were asked to complete a feedback questionnaire that typically required 5-10 minutes to complete. The questionnaire encompassed a combination of closed ended (quantitative) and open-ended questions for qualitative insights. The questionnaire was designed to capture how participants perceived the tasks in terms of

user-friendliness, comprehensibility and duration. Participants were also asked about their task preferences and which tasks they found most challenging, if any. Additionally, we investigated whether participants perceived specific search strategies and gathered their insights regarding practicalities to potentially improve the tasks. Capturing participants' experiences and preferences provided valuable input for designing future research utilising CB tasks for visual attention assessment.

3.2.4 Equipment

E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and gather data for all CB tasks. Stimuli was displayed on a 24" monitor, with 1920 x 1080 resolution and 60 Hz refresh rate. Chronos USB-based response box (Psychology Software Tools, Pittsburgh, PA) was used to collect data, i.e. response choice and latency of responses.

3.3 Results

GROUP	Variable	Measure	Starry-Night	Feature	Conjunction	Posner	Total
OA	**RT (ms)**	Mean	487	678	1076	442	654
		Median	422	615	968	401	520
		Std Deviation	252	259	460	186	388
	ACC (%)	Mean	100	99	97	100	100
		Median	100	100	100	1.00	100
		Std Deviation	4	10	19	3	11
YA	**RT (ms)**	Mean	341	436	682	311	434
		Median	330	408	607	294	361
		Std Deviation	80	138	266	101	214
	ACC (%)	Mean	99	98	98	100	100
		Median	100	100	100	100	100
		Std Deviation	0	12	15	0	10

Table 0.2 Descriptive Statistics for Response Times and Accuracy Across Tasks

3.3.1 Starry Night Task

Mean accuracy data for each participant as a function of Target Location (far left vs. near left vs. middle vs. near right vs. far right) and group (younger vs. older) were entered for analysis. Accuracy across groups was comparable (F (1, 123) = 3.37, p = 0.073, ηp^2= 0.026), suggesting that both groups performed similarly, with accuracy levels approaching the ceiling effect. Additionally, accuracy across target positions was comparable (F (4,492) = 1.04, p = 0.388, ηp^2= 0.008). There was also no Group x Target Location interaction (F (4, 492) = 1.04, p = 0.388, ηp^2= 0.008).

In the analysis of RT, inaccurate responses and responses that were considered anticipatory (i.e. faster than 100ms) were excluded (0.19%). Median RT data for each participant categorized by Target Location and group, were subjected to analysis. As can be seen in Figure 3.4, RTs were slower for older adults with a resulting significant main effect of Group (F (1, 123) = 53.8, p < 0.001, ηp^2= 0.304). Targets distant from the center of the screen were also slower with a resulting significant main effect of Target Location (F (3.03, 372.68) = 49.8, p<0.001, $\eta p^2 = 0.289$). The ANOVA also revealed a Group x Target Location interaction, F (3.03, 372.68) = 10.9, p <0.001, $\eta p^2 = 0.082$. To explore the interaction, planned pairwise comparisons were conducted for the two groups individually, revealing similar patterns across screen locations in the two groups.

Specifically, RTs to far left and far right targets were significantly slower (p<0.001) than those to the three central Target Locations (i.e. near left, middle, near right) for both groups. For older adults, these three central Target Locations elicited comparable RTs. However, for younger adults, while RTs to near left and center targets were comparable,

responses to near right targets were significantly slower (p = 0.011) than those to center targets consistent with the phenomenon of pseudoneglect in this age group.

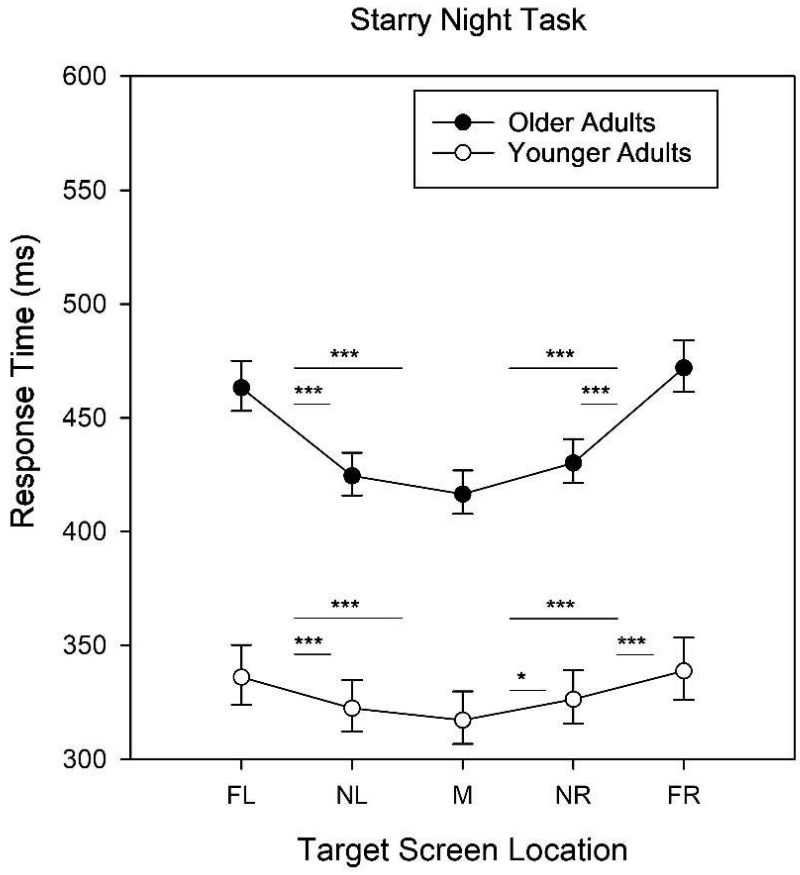

*Figure 0.4 Mean response times (ms) for older and younger adults as a function of Target Location (FL: Far Left, NL: Near Left, M: Midde, NR: Near Right and FR: Far Right) for the Starry Night Task. Error bars denote standard error. Significance markers represent the comparison between Target Locations: *p < 0.05, **p < 0.01, ***p < 0.001.*

3.3.2 Feature Visual Search Task

Feature Visual Search Task and Target Location

Mean accuracy data for each participant, grouped by Target Location and age group, were analysed. Responses deemed anticipatory (i.e., faster than 100ms) were excluded from the analysis (0.01%). Accuracy across groups was significantly different (F (1, 123) = 3.94,

p = 0.049, ηp^2= 0.031) with young adults being less accurate, despite both groups achieving high levels of accuracy, with younger adults averaging 98% and older adults averaging 99%. Additionally, targets distant from the centre had lower accuracy scores resulting in a significant main effect of Target Location (F (1.90, 233.32) = 35.44, p = <0.001, ηp^2= 0.224). A Group x Target Location interaction (F (1.90, 233.32) = 3.38, p = 0.038, ηp^2= 0.027) was explored with individual pairwise comparisons. Both groups exhibited comparable accuracy scores for the three central targets: however, older adults demonstrated significantly lower accuracy scores (p<0.001) for the far left and far right targets compared to central targets. For young adults, all Target Locations elicited comparable scores except for response for far right targets that were significantly less accurate (p<0.001), consistent with pseudoneglect in this age group.

In the analysis of RT, inaccurate responses (1.26%) were excluded and median RT data for each participant categorized by Target Location and group, were subjected to analysis. As can be observed in Figure 3.5c, RTs were slower for older adults with a resulting significant Group main effect (F (1, 123) = 72.4, p < 0.001, ηp^2= 0.370). Responses to peripheral targets were also slower with a resulting significant main effect of Target Location (F (2.87, 353.20) = 167.7, p<0.001, ηp^2= 0.577). Individual group pairwise comparisons were conducted to explore the Group x Target Location interaction, F (2.87, 353.20) = 18.1, p <0.001, ηp^2=0.129). Both groups exhibited significantly slower RTs for far targets and near right (p<0.001) compared to near left and middle targets, indicating a peripheral and pseudoneglect effect. Additionally, far right targets had significantly slower RTs compared to far left (p<0.001) in both groups. However, in younger adults, this pseudoneglect effect appeared more pronounced, with near right performance comparable with that for far-left targets.

Feature Visual Search Task and Number of Distractors

Mean accuracy data for each participant, grouped by number of distractors (5, 10, 15 and 20) and age group, were analysed. Again, older adults were shown to be significantly more accurate than the younger adults as indicated by a significant Group effect (F (1, 123) = 8.59, p = 0.004, ηp^2= 0.065). A significant main effect of Distractors (F (2.82, 347.06) = 5.34, p = 0.002, ηp^2= 0.042) was also observed. Additionally, the ANOVA revealed a Group x Distractors interaction, F (2.82, 347.06) = 2.77, p = 0.045, ηp^2=0.022). However, pairwise comparisons for distractor number conducted for each group indicated comparable accuracy.

RTs were slower for older adults with a resulting significant main effect of Group (F (1, 123) = 76.2, p < 0.001, ηp^2= 0.383). Additionally, despite the absence of a clear pattern, RTs varied based on the number of distractors, as shown in Figure 3.5c, indicating a main effect of Distractors (F (2.66, 326.78) = 9.63, p = <0.001, ηp^2= 0.073). There was no Group x Distractors interaction (F (2.66, 326.78) = 1, p = 0.386, ηp^2= 0.008), suggesting that the influence of distractors on RT did not vary across the two age groups. In both groups, pairwise comparisons showed that RTs were significantly faster with 10 distractors compared to 5, 15, and 20.

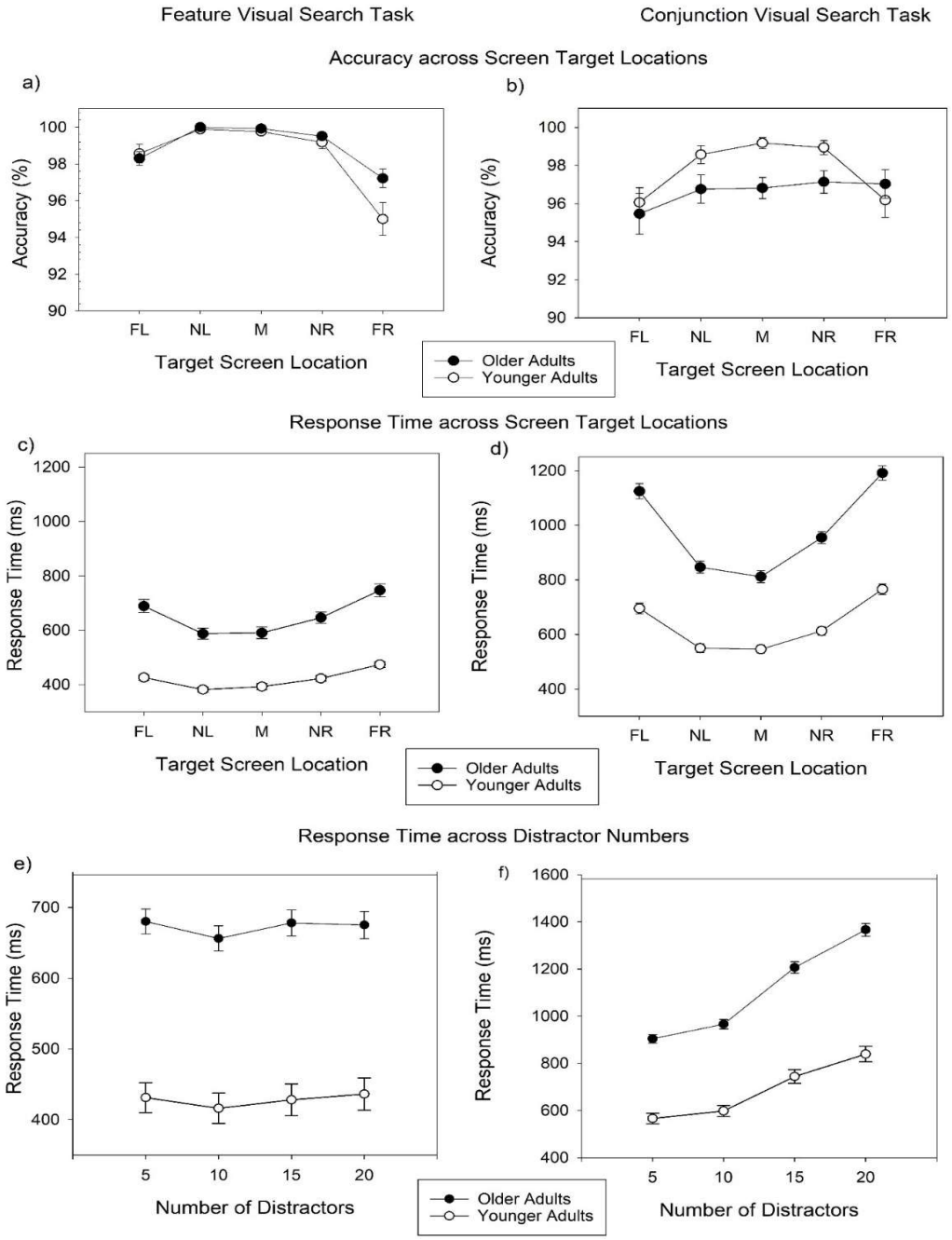

Figure 0.5 Mean accuracy scores (%) for older and younger adults as a function of Target Location.(FL: Far Left, NL: Near Left, M: Midde, NR: Near Right and FR: Far Right) for Feature (a) and Conjunction (b) tasks. Mean RT (ms) for older and younger adults as a function of Target Location for Feature (c) and Conjunction (d) tasks. Mean RT (ms) for older and younger adults by number of distractors (5,10,15,20) for the Feature (e) and Conjunction (f) task. Error bars denote standard error.

3.3.3 Conjunction Visual Search Task

The approach used to analyse accuracy and RT data for the Feature Visual Search Task (above) was also used to analyse Conjunction Visual Search Task data.

Conjunction Visual Search Task and Target Location

Responses that were considered anticipatory (i.e., faster than 100ms) were excluded (0.25%). The mean accuracy data for each participant, analysed based on Target Location and group, showed accuracy scores across groups were comparable (F (1, 123) = 2.16, p = 0.144, ηp^2= 0.017), as illustrated in Figure 3.5. Accuracy scores for peripheral targets were reduced, leading to a significant main effect of Target Location (F (3.35, 411.63) = 6.41, p = <0.001, ηp^2= 0.050). Additionally, a Group x Target Location interaction was observed (F (3.35, 411.63) = 2.68, p = 0.041, ηp^2= 0.021). Pairwise comparisons showed comparable accuracy across at all Target Locations for older adults (p = 0.158), but for the younger group, while accuracy was comparable for central targets (near left, middle, near right), it was significantly reduced for peripheral targets (far left and far right, p < 0.05).

Inaccurate responses (2.97%) were omitted and the median RT data for each participant were entered for analysis. RTs were slower for older adults with a resulting significant main effect of Group (F (1, 123) = 154.33, p < 0.001, ηp^2= 0.556). The ANOVA also revealed a significant main effect of Target Location (F (2.91, 358.35) = 223.5, p<0.001, ηp^2= 0.645) and a Group x Target Location (F (2.91, 358.35) = 17.8, p <0.001, ηp^2=0.127). Individual group pairwise comparisons revealed both groups had significantly slower RTs for far left and far right targets when compared to central targets (p<0.001). Further, near left and middle target were comparable, but near right was significantly slower in both groups (p<0.001). Additionally, for young adults, RTs were significantly slower in far right

compared with the far left location (p = 0.002), while in older adults this was comparable. The results suggest pseudoneglect is present in both groups and is more pronounced for younger adults.

Conjunction Visual Search Task and Number of Distractors

Mean accuracy data for each participant, grouped by number of distractors and group, were analysed. Again, no significant Group effect was observed F (1, 123) = 2.28, p = 0.133, ηp^2= 0.018), with accuracy levels nearing the ceiling effect, as both groups performed similarly well. A resulting significant main effect of Distractors was revealed (F (2.19, 269.64) = 8.02, p < 0.001, ηp^2= 0.061), along with a Group x Distractors interaction, F (2.19, 269.64) = 5.02, p = 0.006, ηp^2=0.039). Pairwise comparisons were conducted for the two groups individually, indicating that younger adults had similar accuracy scores across all numbers of distractors. However, older adults demonstrated reduced performance as the number of distractors increased (p<0.001). Specifically, young and older adults showed comparable performance when there were 5 or 10 distractors, and similarly when there were 15 or 20 distractors. However, significant differences (p < 0.05) were found when comparing performance with fewer distractors (5 or 10) to performance with more distractors (15 or 20).

RTs were significantly slower for older adults, resulting in a significant main effect of Group (F (1, 123) = 178.23, p < 0.001, ηp^2= 0.592). Additionally, the ANOVA revealed a significant main effect of Distractors (F (2.39, 293.92) = 366.80, p <0.001, ηp^2= 0.749) and a Group x Distractors interaction (F (2.39, 293.92) = 23.72, p < 0.001, ηp^2= 0.162). Pairwise comparisons were conducted, demonstrating a highly significant difference between each level of distractors (5, 10, 15, 20) for older (p < 0.001) and younger adults (p

≤ 0.001), with RTs increasing as the number of distractors increased, as depicted in Figure 3.5.

3.3.4 Posner Cueing Task

In the Posner Cueing Task, the error percentage was 0.18% across both age groups and all conditions. As performance was at ceiling the accuracy data were not subjected to further analysis. Individual median RT data were analysed as a function of Target Location (Left, Right), Validity (Valid, Invalid), CTI (50, 150, 350, 650, 1050) and Age Group, excluding anticipatory responses (<100ms, 0.2% of data). Older adults showed significantly slower RTs than younger adults throughout (F (1,123) = 73.165, p<0.001, ηp^2= 0.373). A main effect of Target Location was observed (F (1,123) = 5.421, p = 0.022, ηp^2= 0.042), RTs for left targets were slower (mean = 376 ms) than right targets (mean = 370 ms). There was no Target Location x Group interaction (F (1, 123) = 0.841, p = 0.361, ηp^2= 0.007).

Invalid targets had slower RTs, showing a significant main effect of Validity (F(1, 123) = 82.562, p < 0.001, ηp^2= 0.402 and a Validity x Group interaction was found F (1,123) = 7.909, p = 0.006, ηp^2= 0.060); pairwise comparisons revealed that both groups were significantly slower to respond to invalidly cued targets compared to validly cued targets (p<0.001). There was no Target Location x Validity (F (1,123) = 2.136, p = 0.114, ηp^2= 0.017) or Target Location x Validity x Group (F (1,123) = 0.005, p = 0.944), interactions.

A significant main effect of CTI F (4, 492) = 7.599, p <0.001, ηp^2= 0.058 and a Validity x CTI interaction was noted (Validity x CTI (F (4, 4932) = 13.391, p<0.001, ηp^2= 0.098. Even though there were no CTI x Group or Validity x CTI x Group (F (4, 492) =0.533, p=0.712, ηp^2= 0.004) interactions, pairwise comparisons revealed distinct patterns IOR across age

groups. As illustrated in Table 3.3, both groups were significantly faster in valid trials until reaching the point of IOR, where RTs became comparable. Older adults showed IOR at longer CTIs (1050ms), while younger adults exhibited IOR at shorter CTIs (650ms). As can be seen in Figure 3.6, in younger adults, invalid trials were significantly faster than valid ones after this point.

	Older Adults			***Younger Adults***		
CTI	Mean Difference (Invalid-Valid)	Standard Error	Significance	Mean Difference (Invalid-Valid)	Standard Error	Significance
50	56.544*	16.058	<.001	50.559*	5.964	<.001
150	61.584*	9.335	<.001	39.647*	5.828	<.001
350	56.868*	8.621	<.001	37.265*	8.601	<.001
650	38.618*	9.920	<.001	4.618	9.789	0.639
1050	6.115	8.053	0.450	-16.225*	3.783	<.001

*Based on estimated marginal means, *. The mean difference is significant at the .05 level. Adjustment for multiple comparisons: Bonferroni.*

Table 0.3 Pairwise Comparison of Response Times for Invalid and Valid Trials Across Different CTIs in Older and Younger Adults

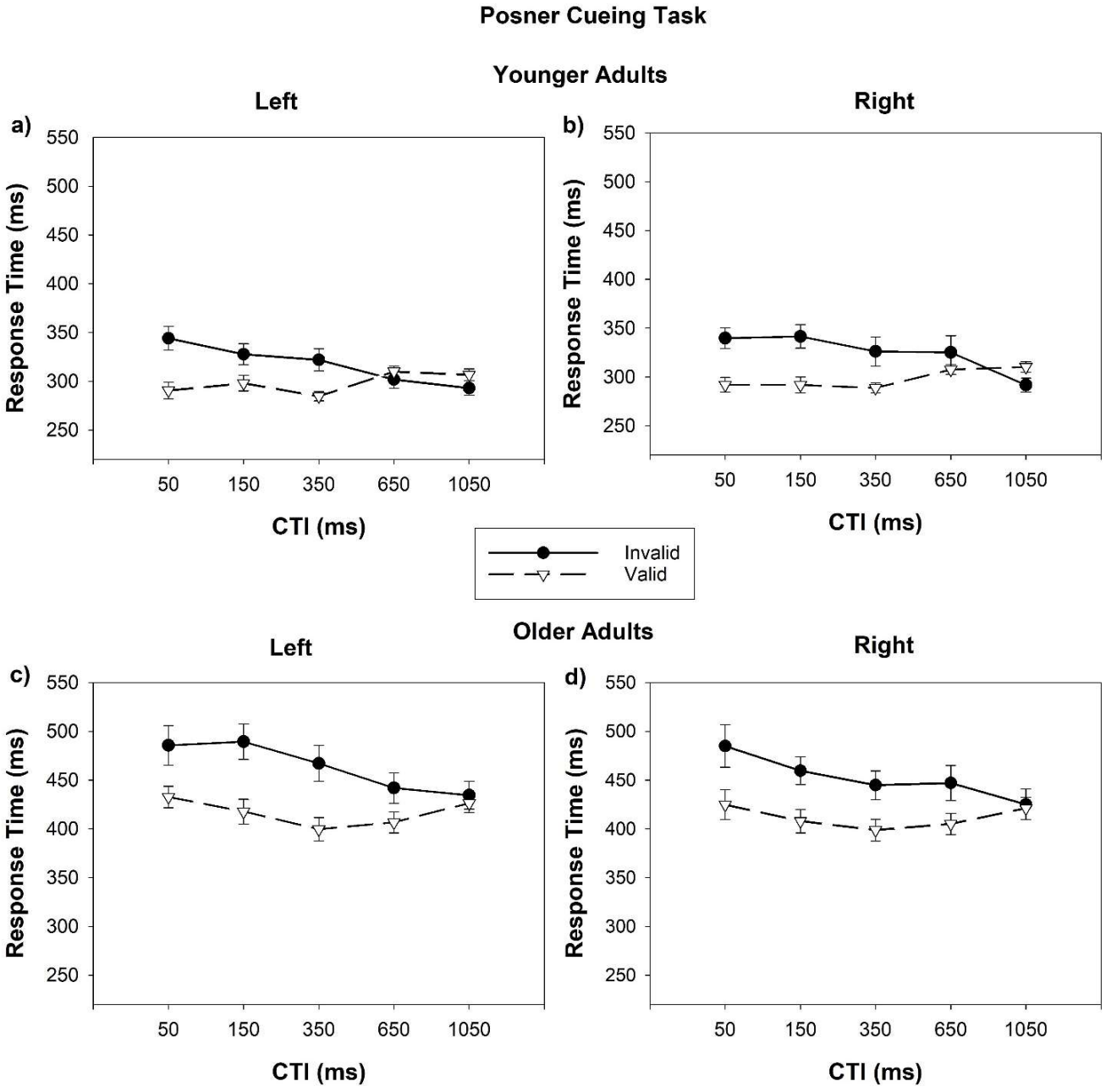

Figure 0.6. Response Time Variation by Target Location, CTI and Validity. Mean RTs (ms) as a function of CTI (50, 150, 350, 650, 1050) and Validity (Valid, Invalid) for younger (a, c) and older adults (b, d) for Left and Right Target Locations respectively. Error bars denote standard error.

3.3.5 Feedback Questionnaire

Task Preferences

A combination of qualitative and quantitative data were gathered to determine task preference, providing a comprehensive understanding that combines participants' perspectives and numerical responses. Participants' preferences for tasks varied based on factors such as perceived complexity, engagement level, and personal preferences. As presented in Table 3.4, the Conjunction Visual Search Task was most favoured (44.8%), with participants attributing their enjoyment to factors such as increased challenge, interesting elements, and a sense of accomplishment. Similarly, the Conjunction Visual Search Task was also characterised as the most difficult to perform (72%) due to increased complexity associated with the presence of distracting elements, challenges in distinguishing between shape and colour, and requiring longer processing time. Conversely, most of the participants considered the Posner task (37.3%) their least favourite due to discomfort with flashing cues, a sense of mindlessness, difficulty adapting to the task's setup, repetitive stimuli location, and a perception of it being less engaging and more boring than other tasks. It was also identified as the least challenging (43.7%), citing factors like the simplicity of Target Locations, straightforward identification, easy colour distinctions, the lack of distractors, and clear cue visibility, making it less challenging and more relaxing than other tasks.

Feedback	Group	Starry Night	Feature	Conjunction	Posner
Most Preferred	Older Adults	29.7	13.5	**44.6**	12.2
	Younger Adults	25.5	15.7	**45.1**	13.7
	Total	28	14.4	**44.8**	12.8
Least Preferred	Older Adults	17.6	14.7	30.9	**36.8**
	Younger Adults	19.6	11.8	31.4	**37.3**
	Total	18.5	13.4	31.1	**37**
Easiest	Older Adults	26.5	16.2	7.4	**50**
	Younger Adults	33.3	27.5	3.9	**35.3**
	Total	29.4	21	5.9	**43.7**
Most Difficult	Older Adults	16.4	4.5	**76.1**	3
	Younger Adults	11.8	7.8	**66.7**	13.7
	Total	14.4	5.9	**72**	7.6

Tasks with the highest scores are bolded.

Table 0.4 Participant Percentage of Preferences and Perceived Difficulty Across Tasks

User-Friendliness, Clarity and Duration

Most participants highly rated the tasks, with 69.6% considering them exceptionally user-friendly and 82.4% finding them notably easy to comprehend. Additionally, 84.8% of participants deemed the duration of the tasks appropriate, reflecting high acceptability and overall positive feedback on the user-friendliness, clarity, and duration of the tasks.

Search Strategies

The qualitative data on search strategy revealed that participants employed a variety of approaches across different tasks, with a predominant focus on the centre and peripheral vision. While some reported adopting specific scanning patterns such as left-to-right, V-shaped, or Z-shaped scans in tasks like the conjunction, others reported employing a more random scanning approach. Adaptability and task-specific adjustments were notable features of their search strategy reports; for instance, participants reported shifting from initially focusing on the centre to incorporating scanning. Some participants mentioned a double-scan strategy, especially in visual search tasks. In summary, the majority of participants reported that they were focusing on the centre of the screen relying on

peripheral vision for the Posner Cueing and Starry Night task. In contrast, for the Feature task, participants exhibited variability, with some focusing on the screen and others employing scanning techniques. Participants predominantly used scanning techniques for the Conjunction task highlighting their adaptability based on specific task requirements.

3.4 Discussion

The primary aim of this study was to establish normative data for a battery of CB tasks assessing visual attention in both younger and older unimpaired adults. By evaluating performance across multiple tasks within the same sample, this study provides a foundation for identifying impairment cut-offs and offers insights into age-related differences in task performance that may inform future research and potential clinical assessment.

The most obvious finding to emerge from the analysis was the observation that older adults were slower than younger adults. These findings are consistent with previous studies, which suggest that age-related slowing in RT may be attributed to a combination of factors and mechanisms, including reduced alertness (Ebaid & Crewther, 2019), decreased attentional capacity (Guest et al., 2015), slower stimuli perception and motor processes (Woods et al., 2015). Older adults demonstrated consistently slower RTs across all four tasks (Starry Night, Feature and Conjunction visual search tasks, and the Posner Cueing task), with a more pronounced effect observed as task complexity increased. Specifically, the difference in RTs between groups was less in simpler tasks such as the Posner or Starry Night task, and became more pronounced in the more complex tasks, like the Feature and Conjunction visual search tasks, see Table 3.2.

Accuracy scores remained near-maximum for both groups with no significant differences observed across most tasks, challenging the initial hypothesis predicting an age-related performance cost for both RT and accuracy. The high accuracy observed in both groups was perhaps not surprising, given the tasks were initially designed largely for assessing spatial attention in patients following BD. While some age-related differences were noted, the overall comparable accuracy between younger and older adults is valuable for clinical testing, simplifying interpretation and ensuring broad applicability without introducing significant age-related bias.

The impact of Target Location was evident across all the visual search tasks (i.e. Starry Night, Feature Visual Search and Conjunction Visual Search). As anticipated, our analysis consistently demonstrated slower responses for peripheral targets compared to more centrally located ones. Additionally, slower RTs for targets presented on the right side of the screen (compared to the left) was observed consistent with the phenomenon of pseudoneglect in both groups; this appeared to become more prominent as tasks became more demanding. The underlying mechanisms of pseudoneglect remain poorly understood and literature suggests task-related variations (Learmonth et al., 2015; Mitchell et al., 2020). Our results reflect those of Bartlett et al. (2020) supporting that more demanding tasks increase leftward bias, with the simpler Posner Cueing task showing no pseudoneglect trends, the Starry Night task revealing leftward bias only in younger adults, and both age groups exhibiting this bias in the more demanding Feature and Conjunction visual search tasks.

Pseudoneglect was more prominent in younger adults, as they showed greater differences in performance between left and right targets compared to older adults, who demonstrated more balanced results across both sides. While no group showed pseudoneglect in the

Posner Cueing task, only younger adults demonstrated a leftward bias in the Starry Night task. In the Feature task, pseudoneglect was evident in accuracy only for younger adults, while both groups exhibited RT bias in the Feature and Conjunction tasks, with the effect being more pronounced in younger adults. These findings suggest a stronger pseudoneglect bias in young adults, aligning with previous studies suggesting a reduction in pseudoneglect mechanisms with age (Benwell et al., 2014; Learmonth et al., 2017). This age-related decline in spatial bias may be explained by the HAROLD model (Cabeza, 2002), which suggests that older adults recruit bilateral brain regions to compensate for neural decline. However, age-related lateralised effects are not yet fully understood possibly due to diverse impact on multiple components (Friedrich et al., 2018). This age-related decline in spatial bias may also reflect a trade-off between speed and accuracy, where older adults might prioritize accuracy at the expense of response speed.

The impact of the number of distractors on RTs varied between the two visual search tasks, with the Conjunction task showing a substantial negative influence on performance as distractor numbers increased, while in the Feature did not show a clear pattern of influence. This observation aligns with Treisman and Gelade (1980) Feature Integration Theory, and is supported by subsequent studies utilizing more recent versions of visual search tasks (Ajana et al., 2023; Cosman et al., 2012). Our findings indicate an age-related variation in the set size effect on accuracy, as only older adults demonstrated a decrease in accuracy with increasing number of distractors. This result suggests that older individuals are more affected by increased stimuli load, which could impact high-demand tasks requiring visual attention and accuracy, such as driving, operating machinery, or monitoring complex environments. These results are in line with previous studies

highlighting that the set-size effect and increased visual load predominantly impact older adults (Müller-Oehring et al., 2013; Swan et al., 2015).

Age-related discrepancies were also observed in the Posner Cueing task, where both age groups showed significant RT effects of Cue Validity and CTI with older adults exhibiting a delayed IOR onset time compared to younger adults highlighting age-related differences in the temporal dynamics of attentional processes. These findings are consistent with the literature, suggesting that delayed disengagement from spatial cues is linked to altered attentional control mechanisms in older adults (Langley et al., 2011), and that delayed IOR onset time is associated with declines in cognitive function (Li et al., 2020) .

Each task in this study provided distinct insights into visual attention across age groups. The dynamic Starry Night task effectively manipulated Target Location dynamics, shedding light on peripheral effects (Deouell et al., 2005); but offered limited additional insights. The Feature and Conjunction visual search tasks introduced varying distractor numbers, notably influencing performance, particularly evident in the Conjunction task. This underscored the role of distractor complexity in assessing cognitive load and task difficulty (Erez et al., 2009). Despite its simplicity with only left and right Target Locations, the Posner Cueing task, enhanced by the addition of the CTI (Rengachary et al., 2009), revealed significant age-related differences in attentional dynamics and disengagement processes. Together, these tasks contributed to understanding visual attention mechanisms, emphasizing the importance of task design in depicting cognitive processes across different age groups. However, among these, the Conjunction task revealed the most pronounced age-related differences, highlighting the role of distractor complexity in assessing visual attention across age groups.

This CB task battery was designed considering both age-related and stroke-related cognitive dynamics, demonstrated high acceptability receiving positive individual feedback. It proved effective in delivering a sensitive and comprehensive visual attention assessment, providing strong normative data and demonstrating potential for integration into broader applications in clinical settings with stroke and typical visual attention assessment.

A major factor in cross-sectional aging research is the general slowing of processing speed in older adults compared to younger adults (Madden & Monge, 2019; Müller-Oehring et al., 2013). Although our analysis did not control for general slowing, the greater impact on attentionally demanding tasks suggests that the observed effects are not simply due to overall cognitive slowing but reflect specific declines in attentional processing. However, this remains a limitation of this study, and future research could address it by applying methods such as z-score standardisation or log transformation of RT data to account for general age-related slowing (Hedge et al., 2018; Kray & Lindenberger, 2000).

Another key limitation of this study is the lack of data on participants' demographic and educational background, which is particularly important when establishing normative data. This limits the external validity of our findings (Andrade, 2021), reduces the representativeness of the sample and its suitability for establishing normative databases (Jager et al., 2017). Also, it is possible that our sample, particularly among older participants, included a disproportionately high number of individuals with higher education levels. This is important to acknowledge, as higher education is associated with cognitive reserve and may influence performance on attention tasks (Opdebeeck et al., 2016; Thow et al., 2018). Future studies should recruit more demographically diverse samples, including detailed information on education, socioeconomic status, and ethnicity, to

improve generalisability and clinical applicability (Sharghi et al., 2024; Webber-Ritchey et al., 2021).

Conclusion

In conclusion, our study explored age-related effects of visual attention using a comprehensive CB task battery, revealing consistently reduced RT for older adults. Pseudoneglect tendencies were identified in both groups, with a diminished leftward bias in older adults, suggesting age-related reduction of the phenomenon or a potential speed-accuracy trade-off. Additionally, older adults were more susceptible to performance decline with increasing task demands. The study demonstrates the usability of these tasks across a relatively large number of participants, highlighting their adaptability of both unimpaired groups based on task demands. The positive feedback on the tasks' user-friendly design, clarity, and appropriate duration supports their adoption in clinical settings, providing valuable insights for optimizing visual attention assessment and addressing age-related and stroke-related cognitive dynamics. In future research, we will apply these tasks to a patient population in a clinical environment to assess the benefits and barriers of introducing this method, comparing it with conventional approaches.

CHAPTER 4

Computer-based assessment of visuo-spatial attention following stroke

Abstract

Background: USN is a common post-stroke cognitive impairment, characterized by a lack of contralesional spatial awareness. Traditional PnP assessments, such as those included in the BIT, are widely used but have limitations, especially in detecting milder cases of neglect. A strong body of evidence has demonstrated that CB tasks may provide more sensitive and precise alternatives for USN detection. This cross-sectional study aims to investigate the efficacy of different CB tasks in identifying USN in stroke survivors, comparing them with the conventional subtests of the BIT, and evaluate their feasibility for adoption in practice.

Methods: Twenty stroke survivors participated in the study, completing the BIT conventional subtests alongside versions of four CB tasks: the dynamic Starry Night task, the Feature and Conjunction Visual Search tasks, and the Posner Cueing task. The BIT total score served as the conventional method for assessing USN, while the CB tasks evaluated performance through accuracy (%) and RT (ms) for left- and right-sided targets. Quantitative data were analysed to compare the effectiveness of these tasks in identifying USN. Additionally, qualitative data were collected through patient feedback to capture their preferences and task acceptability.

Results: CB tasks were effective in identifying USN in stroke survivors. The more complex Conjunction Task was the most sensitive, detecting USN in 14 cases, while the simpler Posner Task identified the fewest cases (n=10). The battery of CB tasks detected neglect in all participants with sub-threshold BIT scores (n=7), highlighting notable lateralized differences between left and right targets that were not always captured by the BIT. Additionally, RT proved to be a more sensitive measure than accuracy in detecting neglect

symptoms. Participant feedback favoured the CB tasks over the BIT, highlighting a positive user experience, rating highly their ease of use, comprehensibility, and duration.

Conclusion: CB tasks, particularly the Conjunction Visual Search task, were more sensitive than traditional methods in detecting USN, with response time being a key indicator. These tasks offer a promising and user-friendly approach to more accurately assess USN in stroke survivors, with the potential to improve clinical diagnosis and rehabilitation planning.

4.1 Introduction

USN is one of the most common cognitive impairments observed following stroke, characterized by the inability or difficulty in attending to the contralesional side of space (Heilman et al., 1987). The prevalence of USN varies across studies, with estimates reaching as high as 80% in the acute phase of stroke (Stone et al., 1993), though this prevalence decreases in the chronic phase (Beis et al., 2004). USN is often associated with a reduced quality of life and significantly impacts the lives and independence of stroke survivors , as it substantially affects their ability to independently carry out activities of daily living, including mobility and personal care (Chen et al., 2015; Sobrinho et al., 2018; Tiwari et al., 2021). The findings of Moore et al. (2022b) highlight that not only do patients with neglect experience poorer functional outcomes compared to those without neglect, but different subtypes of neglect also affect daily life in distinct ways, with a combination of neglect types leading to the most severe functional impairments. However, a major challenge in addressing USN is that it is often not diagnosed or is misdiagnosed, which can delay appropriate treatment (Kleinman et al., 2007).

USN is heterogeneous disorder and varies in its presentation across patients, often coexisting with other conditions such as hemianopia, further complicating its detection (Li & Malhotra, 2015; Spaccavento et al., 2017). Several methods have been employed, such as the National Institutes of Health Stroke Scale (NIHSS), but found to have poor sensitivity, frequently failing to detect even severe cases of neglect and often misattributing neglect impairments to visual field deficits (Moore et al., 2019). Furthermore, there is no standardized method for assessing USN though it is commonly assessed using PnP methods, such as those found in the BIT (Halligan et al., 1991) or other batteries like the CBS (Azouvi et al., 2002). However, these traditional methods have limitations in their

ability to detect milder forms of neglect, especially in the chronic phase (Azouvi, 2017; Barrett et al., 2006; Williams et al., 2024).

The NICE (2023) guidelines recommend that all stroke patients with lesions in the non-dominant hemisphere be screened for USN, advising that assessments cover personal, reaching, and locomotor space, with particular emphasis on activities requiring spatial awareness, such as using wheelchairs, crossing roads, or returning to driving, and suggest using standardized batteries (e.g., the CBS). Similarly, members of the European Academy of Neurology Scientific Panel recommended cancellation tasks as the primary screening test for neglect, emphasizing the need to combine them with additional tests, such as line bisection and figure copying, as no single test was deemed sufficient (Moore et al., 2022a). However, while these assessments have many strengths, they often lack the sensitivity to detect more subtle forms of neglect, resulting in many mild cases going unnoticed, an issue that CB tasks can address (Bonato, 2012; Grattan et al., 2024).

In the past three decades, substantial research has explored the use of CB methods for the assessment of USN. These tasks offer several advantages over traditional PnP methods, particularly in terms of flexibility and sensitivity (Giannakou et al., 2022). CB tasks, with their ability to tailor assessment and adapt difficulty levels to minimize compensatory strategies usually employed by post-acute patients with some awareness of their conditions demonstrate superior sensitivity in detecting neglect, particularly in cases where traditional assessments may be insufficient (Bonato & Deouell, 2013; Pedroli et al., 2015). In contrast, CB tasks can adjust difficulty based on an individual's severity, while providing more detailed performance data, such as RTs and accuracy, and offering greater precision and reliability than fixed-condition PnP tests (Cavedoni et al., 2022; Massetti et al., 2023).

While CB assessments have been proven to be more sensitive and flexible, they still face significant barriers to widespread implementation in clinical settings. These barriers include the need for specialized equipment, the cost of implementing such systems, and the lack of familiarity with required technology among healthcare professionals (Bonato, 2012; Williams et al., 2024). Despite these challenges, CB tasks have the potential to improve the early detection of USN, especially for milder cases that might otherwise go undetected using traditional methods.

Over the years, efforts to enhance the accuracy, usability, and clinical relevance of CB tools for USN assessment have led to a wide range of tasks being developed. These tools vary in design, apparatus, and response modalities, as well as in cognitive and task demands, with some being more simple (e.g., computerized versions of PnP tasks) and others employing more complex paradigms (e.g., visual search or dual-task paradigms). In our systematic review (Chapter 2), we explored existing CB tasks for USN and identified the Posner cueing task (Rengachary et al., 2009), Starry Night (Deouell et al., 2005), and Feature and Conjunction (Erez et al., 2009) visual search tasks as among the most sensitive and well-supported. In this study, we adapted these tasks into a battery of CB assessments to evaluate comprehensively evaluate spatial attention biases, while ensuring practicality, with each task lasting no more than five minutes. We initially administered these tasks to unimpaired younger and older adults to establish normative data (see Chapter 3), and in this study, we have expanded the research to include stroke survivors, incorporating both CB and PnP tasks.

Balancing clinical impact and practicality, our primary aim was to evaluate the effectiveness and feasibility of CB tasks for assessing USN following stroke, with CB tasks designed and adapted for routine clinical use by minimizing task duration while retaining

depth of information gathered. Specifically, we aimed to detect lateralised visuo-spatial attentional impairments that may be overlooked by traditional PnP methods, using the BIT as the reference standard for comparison. Additionally, we aimed to explore the associated barriers and benefits for their implementation in clinical settings and patient populations. We hypothesized that CB tasks would demonstrate greater sensitivity in detecting visuo-spatial attention asymmetry in stroke survivors compared to the conventional method (BIT).

4.2 Methods

4.2.1 Study Design

A cross-sectional observational approach was employed in this study to assess the efficacy and feasibility of CB tasks for detecting USN in stroke survivors. The study was conducted in collaboration with the Birmingham Community Healthcare NHS Foundation Trust. The application was submitted via IRAS, and relevant ethics documents and participant information sheets, are provided in Appendix 2 and 3 respectively. Ethical approval for this study was obtained from the Health Research Authority (HRA) and Health and Care Research Wales (HCRW) and granted by the Essex Research Ethics Committee (REC) (REC reference: 23/EE/0268, IRAS Project ID: 327816). Additional approval was provided by the University of Birmingham Research Ethics Committee (Reference: RG_23-051).

4.2.2 Participants

As mentioned earlier, the prevalence of USN can range from 30% to 80%, depending on various factors such as lesion location, assessment method, and time post-stroke (Esposito et al., 2020; Stone et al., 1993). We conducted a power calculation for diagnostic accuracy based on prevalence ranges (30%-80%), and the suggested sample size varied from 129 to 273 participants respectively. This calculation assumed a sensitivity of 0.90 (the ability of the test to correctly identify 90% of true cases) and a specificity of 0.85 (correctly identifying 85% of individuals who do not have the condition), using a 95% confidence interval, and a margin of error of 0.10. These parameters were suggested in the literature for sample size calculation of diagnostic accuracy studies against a known gold standard (Buderer, 1996; Leeflang & Allerberger, 2019), as no gold standard currently exists for USN, we used the BIT as a reference due to its widespread use, while acknowledging its limitations in detecting lateralised deficits. Our final sample of 20 stroke survivors was underpowered, and this limitation should be considered when interpreting the results.

A total of 20 participants were recruited, consisting of 18 inpatients and 2 outpatients, aged between 46 and 86 years (M = 67.15, SD = 9.37; 30% female). Demographic information for the participants is presented in Table 4.1 (summarized) and Table 4.2 (individual). Participants were recruited from inpatient and outpatient populations at Moseley Hall Hospital. Informed consent was obtained through a multi-step process. Clinical teams from Moseley Hall Hospital identified and referred eligible stroke survivors to the research team, providing them with the necessary materials to consider participation. Patients were recruited from inpatient services (Ward 8) and outpatient services (Birmingham Neurological Rehabilitation Team, Community Stroke Team, and Early Supported

Discharge Team). Healthcare staff screened patient records to identify potential participants and determine if they met the inclusion and exclusion criteria. These criteria included:

Inclusion Criteria:

- Adults aged 18 years or older
- Formally diagnosed with stroke
- Able to use one hand to push a button
- Able to observe a computer screen for approximately 5 minutes at a time

Exclusion Criteria:

- Unable to follow simple instructions (e.g., one-stage commands), verbally or using gestures
- Unable to provide informed consent
- Unable to understand English or requiring translators

For inpatient participants, clinicians approached eligible patients, provided a Patient Information Sheet (PIS) (Appendix 3), and asked if they would like to share their contact details with the research team. If the patient agreed, they completed a Permission to Contact form. The research team then provided further study details, obtained consent, and conducted the research intervention. For outpatient participants, the process was similar, with clinicians approaching eligible patients during routine appointments, following the same procedure for recruitment. Patient records were accessed solely by healthcare providers to screen for eligibility, and the research team only approached referred patients after receiving a completed Permission to Contact form.

Variable	Mean ± Sd / N (%)	Range / Details
Sample Size (N)	20	
Age (years)	67.15 ± 9.37	46–86
Gender	Male: 14 (70%)	
Lesion Location		
- Right Hemisphere	14 (70%)	
- Left Hemisphere	5 (25%)	
- Bilateral/Subcortical	1 (5%)	
Time Since Stroke (days)	56.75 ± 47.5	21–208
Stroke Type		
- Ischemic	20 (100%)	
- Haemorrhagic	0 (0%)	
Behavioural Inattention Test (BIT) Scores	125 ± 26.5	51–146
Neglect Symptoms (BIT < 129)	7 (35%)	
Other Cognitive Scores		
- Addenbrooke's Cognitive Exam (ACE-III)	81.6 ± 12.5	42–97
Functional Assessments		
- NIH Stroke Scale (NIHSS)	5.4 ± 3.6	2–17
Handedness	Right: 18 (90%)	Left: 2 (10%)
Level of Computer-based skills	Basic: 16 (80%) Intermediate: 4 (20%)	

Table 0.1 Summary of Demographic Data

Participant	Age (years)	Gender	Lesion Location	Stroke Type	Time Since Stroke (days)	BIT Scores (BIT < 129)	Addenbrooke's Cognitive Exam (ACE-III)	NIH Stroke Scale (NIHSS)	Handedness	Level of Computer-based skills
2	55	Male	Both	Ischemic	53	146	85	2	Right	Basic
3	67	Male	Right	Ischemic	53	112	72	5	Right	Basic
4	63	Female	Left	Ischemic	42	138	67	10	Left	Intermediate
5	63	Male	Right	Ischemic	36	138	81	5	Right	Basic
6	81	Female	Right	Ischemic	55	142	89	8	right	Basic
7	86	Male	Right	Ischemic	38	110	79	3	Right	Basic
8	65	Male	Left	Ischemic	38	141	90	8	Left	Basic
10	69	Male	Right	Ischemic	25	142	82	8	Right	Basic
11	69	Male	Right	Ischemic	103	67	75	4	Right	Basic
12	62	Male	Right	Ischemic	62	100	88	6	Right	Intermediate
13	62	Male	Right	Ischemic	23	146	97	4	Right	Basic
14	68	Female	Right	Ischemic	32	146	94	3	Right	Intermediate
15	73	Male	Right	Ischemic	22	127	90	2	Right	Basic
16	76	Female	Right	Ischemic	31	142	72	0	Right	Basic
17	63	Female	Right	Ischemic	21	124	96	5	Right	Basic
18	80	Male	Left	Ischemic	31	145	82	3	Right	Basic
19	56	Male	Right	Ischemic	166	51	71	17	Right	Basic
20	76	Female	Left	Ischemic	208	134	86	7	Right	Basic
21	63	Male	Left	Ischemic	44	143	42	3	Right	Basic
22	46	Male	Right	Ischemic	52	146	93	4	Right	Intermediate

Table 0.2 Individual Demographic Data

4.2.3 Data Collection

Participants completed both CB tasks and traditional PnP tasks, as outlined below. The session lasted approximately 90 minutes, with the option for breaks and the possibility of splitting the session into multiple parts if needed upon request by the participant.

1. Demographic Information: A form was used to collect basic participant details, including age, sex, and stroke-related characteristics (e.g., lesion location, time since stroke, and stroke-related impairments).
2. Stroke Assessments: Participants completed the NIHSS and the Addenbrooke's Cognitive Examination (ACE) to evaluate cognitive function and stroke-related impairments.
3. CB Tasks: The core of the study involved completing four CB tasks that measured visuo-spatial attention. These tasks were conducted using E-Prime 3 software, with stimuli displayed on a 24” monitor at 1920 x 1080 resolution and a 60 Hz refresh rate. A *Chronos* (https://pstnet.com/products/chronos/) USB-based response box was used to respond and capture performance. For each task, both RTs (milliseconds) and accuracy (percentage) were recorded to evaluate participants' performance in visuo-spatial attention. The tasks included:
    - Posner Cueing Task: A task assessing RTs and accuracy in detecting cued stimuli.
    - Starry Night Task: Designed to assess spatial attention and awareness of the visual field in a dynamic environment.
    - Feature Visual Search Task: Involved locating a target among distractors based on a single feature.
    - Conjunction Visual Search Task: A more complex task requiring participants to identify a target by combining multiple features.

While versions of these tasks have been developed and tested previously with stroke survivors, each task was adapted to be completed within five minutes. This time frame was chosen to accommodate the practical constraints of clinical settings, ensuring that the tasks remain both efficient and effective in real-world settings. For more detailed descriptions of these tasks, please refer to Chapter 3.

4. PnP Tasks: Participants completed the conventional subtests of the BIT, widely used for many years in assessing USN.
5. Feedback Questionnaire: After completing the tasks, participants provided feedback on their experience with the CB tasks. The questionnaire gathered both quantitative data (e.g., perceived difficulty, engagement) and qualitative data (e.g., preferences, perceived usefulness). This feedback provided valuable insights into the feasibility and acceptability of CB assessments in clinical settings.

4.2.4 Data Analysis

The primary goal of the data analysis was to determine whether individual task results were indicative of impairment, rather than focusing on group differences, as these tasks were specifically designed to detect deficits in individuals.

- Descriptives: The average accuracy (%) and RT (ms) and CB tasks, along with standard deviations (SD), were calculated and tabulated. Left-right differences were also included where applicable.
- Normative Data: Normative data were presented alongside patient data and corresponding cut-off thresholds. These thresholds were determined by calculating one and two SDs from the normative data for average accuracy and RT on both left and right targets. An individual was classified as showing signs of USN if their RT or

accuracy deviated from the normative range by one SD (mild) or two SDs (severe). Cases where the left-right difference in RT was less than or equal to 100ms or the accuracy difference was less than or equal to 3 percent were excluded and not reported as lateralized differences, as these values were deemed too minimal to reflect clinically meaningful USN symptoms.

- Individual Performance: Individual performance measures for participants on the BIT and CB tasks were tabulated, categorized by lesion side. For each task, data were further divided by spatial location (Left vs. Right), with median RT and mean accuracy calculated as follows:
  - Starry Night Task: Data were categorized into "Left" (12 target positions: 8 for far left and 4 for near left) and "Right" (12 target positions: 8 for far right and 4 for middle right).
  - Feature and Conjunction Visual Search Tasks: Data were categorized into "Left" (10 target positions: 5 for far left and 5 for near left) and "Right" (10 target position: 5 for far right and 5 for near right).
  - Posner Cueing Task: Data were divided into "Left" and "Right," with each group containing five SOAs (50, 150, 350, 650, 1050).

Each data point represents performance from multiple trials within each task. For further details on the number of trials per task and target conditions, please refer to Chapter 3. For each participant, the median RT and mean accuracy were calculated for each task. To investigate lateralized biases in performance, a repeated measures paired t-test was conducted to compare performance between homologous locations on the left and right sides of the vertical meridian (e.g., Left vs. Right) for each task. The data pairs were entered as independent observations for the purpose of this

analysis. However, it is important to note that the paired t-test was supplementary to the other thresholding measures used in the study. Performance judgments were not solely based on these statistical comparisons, but rather integrated with the cut-off thresholds for identifying impairments, ensuring a more comprehensive assessment. A significance level of $p = 0.05$ (two-tailed) was used to identify statistically significant lateralized biases in RT and accuracy across tasks.

- Case Studies: Detailed analyses of three participants were conducted and presented to highlight individual performance profiles across all tasks.
- Diagnostic Accuracy: A diagnostic accuracy analysis was performed, with details including sensitivity, specificity, positive and negative likelihood ratios (LR+ and LR–), positive predictive value (PPV), and negative predictive value (NPV) tabulated. Additionally, a Receiver Operating Characteristic (ROC) curve analysis was visualised to illustrate diagnostic performance.
- Spearman correlations were conducted between total accuracy and RT of each CB task and performance scores on the BIT, ACE-III, and NIHSS to assess whether the tasks specifically measure spatial attention rather than general cognition or stroke severity.
- Feedback Questionnaire: Feedback data were analysed using both qualitative and quantitative methods to identify trends and areas for improvement.

4.3 RESULTS

4.3.1 Group Descriptive Statistics

The mean performance and SDs for each task are shown in Table 4.3, along with the left-right differences where relevant. These statistics are provided for each BIT subtest and each CB task, including accuracy and RT measures.

Task	Total	L-R Difference
Line Crossing	1.4 +/- 4.2	-6.7 +/- 10.6
Star Cancellation	7.6 +/- 11.7	-2.5 +/- 5.6
Letter Cancellation	6.8 +/- 8.9	-1.6 +/- 5.2
Shape errors	1 +/- 1.1	
Line bisection Distance	1.9 +/- 2.7	
Starry Night RT	626 +/- 267	126 +/- 320
Starry Night ACC	95.1 +/- 13.1	-6.3 +/- 17.4
Posner RT	542 +/- 166	66 +/- 156
Posner ACC	96.5 +/- 6.7	-3.5 +/- 8.6
Feature RT	939 +/- 414	11 +/- 201
Feature ACC	90.3 +/- 17.3	-7 +/- 19.8
Conjunction RT	1401 +/- 554	93 +/- 447
Conjunction ACC	83.3+/-27.8	-13.8 +/- 27.4

Table 0.3 Group Means and Standard Deviations for BIT Subtests and Computer-Based Tasks

4.3.2 Normative Data and Cutt-off threshold

In Tables 4.4 and 4.5, normative data, patient data, and corresponding cut-off thresholds (based on 1 and 2 SDs) for average accuracy and RT on left and right targets are presented.

Task	Starry Night		Feature		Conjunction		Posner	
Group	Left	Right	Left	Right	Left	Right	Left	Right
Older Adults (average +/- SD)	100 +/- 0.5	100 +/- 0.51	99 +/- 1.60	98 +/- 2.32	96 +/- 6.94	97 +/- 5.14	100 +/- 0.32	100 +/- 0.39
Stroke survivors (average +/- SD)	93 +/- 18.8	99 +/- 3.3	87 +/- 22.5	94 +/- 9.7	77 +/- 32.7	91 +/- 19.6	94 +/- 8.1	98 +/- 3.9
Threshold (1sd)	99.5	99.5	98.4	97.7	93.1	94.9	99.5	99.5
Threshold(2sd)	99	99	96.8	95.3	86.1	89.7	99	99

Table 0.4 Accuracy Scores for Older Adults and Stroke Survivors

Task	Starry Night		Feature		Conjunction		Posner	
Group	LEFT	Right	Left	Right	Left	Right	Left	Right
Older Adults (average +/- SD)	445 +/- 108	452 +/- 113	638 +/- 190	696 +/- 187	986 +/- 205	1073 +/- 193	418 +/- 91	412 +/- 92
Stroke survivors (average +/- SD)	534 +/- 418	506 +/- 189	944 +/- 437	934 +/- 452	1207 +/- 520	1236 +/- 457	491 +/- 198	483 +/- 110
Threshold (1sd)	557	565	825	884	1179	1266	510	504
Threshold(2sd)	670	677	1013	1071	1372	1459	603	596

Table 0.5 Average RT Scores for Older Adults and Stroke Survivors

4.3.3 Individual Data

The individual performance measures on the BIT and CB tasks were tabulated (see Table 4.6.).

Participant	Lesion Side	*Behavioural Inattention Test*										*Computer-Based Tasks*															
		Line Crossing		Letter Cancellation		Star Cancellation		Line Bisection	Figure and Shape Copying	Representational Drawing	Total	Starry Night				Feature Search				Conjunction Search				Posner Cueing			
												Accuracy		Response Time		Accuracy		Response Time		Accuracy		Response Time		Accuracy		Response Time	
		L	R	L	R	L	R					L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
2	Both	18	18	20	20	27	27	9	4	3	146	100	100	521	539	100	100	367	423	100	97	750	800	100	100	492	542*
3	Right	18	18	12	11	21	19	9	1	3	112	100	100	744	509	87	100	1042	1033	11***	85	2064***	990	100	100	804*	538
4	Left	18	18	20	19	27	27	3	3	3	138	100	100	557	744***	100	97	588	777	100	100	1013	1516**	100	100	481	485
5	Right	18	18	19	20	24	26	7	3	3	138	71.6*	100	1543*	502	80	97	1198**	702	88*	100	1642**	939	91.2*	100	959***	474
6	Right	18	18	19	18	27	26	9	4	3	142	97.9	100	722	521	93	97	997	910	90	94	1783	1757	93.4	100	644*	474
7	Right	17	15	17	14	14	21	6	3	3	110	87.5	97.9	1618**	796	75	71	1652	1675	34**	88	2830	1980*	78	95.6	813**	573
8	Left	18	18	19	17	26	27	9	4	3	141	100	100	405	386	100	100	536	637	97	100	924	1213	100	100	389	396
10	Right	18	18	16	20	27	27	9	4	3	142	100	100	497*	402	93	100	756	741	97	100	1180	961	100	100	476	432
11	Right	13	18	2	10	2	19	4	0	0	67	84.8	94.5	1312**	800	65	72	2194	2256	12**	40	2102	2587	93.4	83.8	771	737
12	Right	18	18	1	18	12	23	4	3	1	100	82.7*	100	1459***	636	74**	100	1464**	825	25***	87	1565	1260	75.8**	100	1040*	762
13	Right	18	18	20	20	27	27	6	3	3	146	100	100	480	413	100	97	475	487	100	100	898	1200	100	100	338	340
14	Right	18	18	20	19	27	27	9	4	3	146	100	100	390	394	100	100	546	616	97	100	1080	1052	100	100	400	442*
15	Right	18	18	19	20	22	20	9	3	3	127	100	100	636	594	97	100	882	752	100	97	1435	1287	100	100	561	583
16	Right	18	18	20	19	27	25	6	4	3	142	100	100	897	965	100	100	1199	1347*	100	97	1614	1572	100	100	639	613
17	Right	18	18	16	14	22	26	9	4	3	124	100	91	629	747	97	97	913	875	93	100	1790**	1316	100	100	553	516
18	Left	18	18	19	20	27	27	3	4	3	145	100	100	412	437	100	100	778	820	90	100	1275	1840***	100	100	403	448
19	Right	0	18	0	15	0	15	9	2	1	51	18.7***	97.3	1355***	586	1***	91	1298	1066	28***	90	1691*	1234	78*	100	483	420
20	Left	18	18	17	16	26	26	0	2	1	134	92.4	88.2	704	946	72	76	1136	1757**	64	27**	1897	2046	89	93.4	541	624
21	Left	18	18	20	20	27	27	9	3	2	143	100	97.9	408	607*	90	82	839	1087	98	100	673	728	97.8	93.4	429	580**
22	Right	18	18	20	20	27	27	9	3	3	146	100	100	471	418	100	100	604	622	100	100	1223	1352	100	100	370	363

*Table 0.6 Individual Performance Measures on the BIT and Computer-Based Tasks. Participants are categorized by lesion side. BIT scores include total scores and subscores for Line Crossing, Letter Cancellation, Star Cancellation, and Line Bisection, Figure and Shape Copying and Representational Drawing. BIT scores exceeding the threshold are highlighted in red. Maximum scores and cutoffs for each BIT subtest are as follows: Total Score (146/129), Line Crossing (maximum: 36 [18 L, 18 R], cutoff: 34), Letter Cancellation (maximum: 40 [20 L, 20 R], cutoff: 3), Star Cancellation (maximum: 54 [27 L, 27 R], cutoff: 51), Line Bisection (maximum: 9 cutoff: 7), Figure and Shape Copying (maximum: 4, cutoff: 3), Representational Drawing (maximum: 3, cutoff: 2). Scores exceeding the cut-off thresholds are highlighted in red and orange, indicating severe and mild levels of impairment, respectively (defined as 2 and 1 SDs from normative unimpaired adult data). Performance on CB tasks is reported as accuracy and RT for left (L) and right (R) target locations. Asterisks indicate significant lateralised differences in left vs. right RT performance (*p < 0.05, **p < 0.01, ***p < 0.001).*

4.3.3.1 Neglect Symptoms Identified by Task

- Starry Night Task
    - 11 cases identified based on accuracy (7) and RT (11)
    - 6 with low BIT scores (P3, P7, P11, P12, P17, P19).
    - Left USN: P3, P5, P6, P7, P11, P12, P19
    - Right USN: P4, P17, P20, P21 (mild),
- Feature Task
    - 12 cases identified based on accuracy (10) and RT (9)
    - 6 with low BIT scores (P3, P7, P11, P12, P15, P19).
    - Left USN: P3, P5, P6 (mild), P7, P10, P11, P12, P15 (mild), P19
    - Right USN: P16, P20, P21
- Conjunction Task
    - 14 cases identified based on accuracy (10) and RT (12)
    - 7 with low BIT scores (P3, P7, P11, P12, P15, P17, P19).
    - Left USN: P3, P5, P6, P7, P10 (mild), P11, P12, P15, P17, P19
    - Right USN: P4, P18, P20, P22 (mild)
- Posner Task
    - 10 cases identified based on accuracy (8) and RT (7)
    - 5 with low BIT scores (P3, P7, P11, P12, P19).
    - Left USN: P3, P5, P6, P7, P11, P12, P19
    - Right USN: P2 (mild), P20, P21

4.3.3.2 Comparison of Computer-Based Tasks in Detecting Neglect

Across the tasks, as expected, left-sided neglect was more commonly identified than right-sided neglect. The Conjunction Task was the most sensitive task, identifying the highest number of cases (14) and demonstrating greater sensitivity overall, followed by the Feature Task (12). Additionally, the Starry Night task detected 11 cases, while the Posner task identified the fewest cases (10). In total, P3, P5, P6, P7, P11, P12, and P19 exhibited left-sided neglect across all tasks, while P4 and P21 exhibited right-sided neglect across most tasks. There were discrepancies between the tasks; for example, the Conjunction task identified participants P17 and P18, which were missed by the Feature task, while the Feature task identified P16 and P21.While the Posner Task and the Starry Night task failed to detect neglect in some cases with normal BIT scores (e.g., P10), and low BIT scores (e.g., P15), the Feature and Conjunction tasks successfully identified spatial biases in these individuals. Interestingly, P17 showed both right and left neglect, depending on the task; however, the participant showed a similar pattern on the BIT. Additionally, RT was found to be a more sensitive measure than accuracy in detecting neglect symptoms across the tasks. Overall, accuracy detected 35 cases across all tasks, RT identified 39 cases, indicating greater sensitivity. While accuracy scores from CB tasks provided more insight than those from PnP tasks, RT demonstrated greater sensitivity overall. It effectively identified cases with high accuracy (above the cutoff threshold) or with lateralized differences below the limit set for this study (equal to or less than 3%), likely reflecting milder forms of neglect, as seen in participants P15, and P16.

4.3.3.3 Comparison of Computer-Based Tasks with the BIT

USN symptoms were identified in all participants with low BIT scores, with the Conjunction being the only task detecting neglect in all seven participants (P3, P7, P11, P12, P15, P17,

P19). In some cases, like P17 in the Feature and Posner tasks, neglect was not detected, possibly due to the BIT not showing a lateralized difference. This suggests that while the BIT identified neglect in most participants, its cut-off scores may not fully capture neglect symptoms, especially in cases where spatial bias is less pronounced.

4.3.4 Case Studies

4.3.4.1 Right Hemisphere Damage with Normal BIT Score

Participant 5, with RBD and a BIT score of 138, showed no evidence of neglect according to conventional methods. However, significant deficits were observed in all CB tasks. In the Starry Night task, both accuracy and RT were severely impaired for left-sided targets, with significant lateralized differences. In the Feature Search task, accuracy was severely impaired for left-sided targets and mildly impaired for right-sided targets, while RT was severely slower for right-sided targets, with significant lateralized differences. In the Conjunction Search task, accuracy was mildly impaired, and RT was severely delayed for left-sided targets, with significant lateralized differences for both. In the Posner cueing task, accuracy was severely impaired for left-sided targets, and RT was significantly slower for left-sided targets, again with marked lateralized differences. The data for participant 5 data are visualised in Figure 4.1.

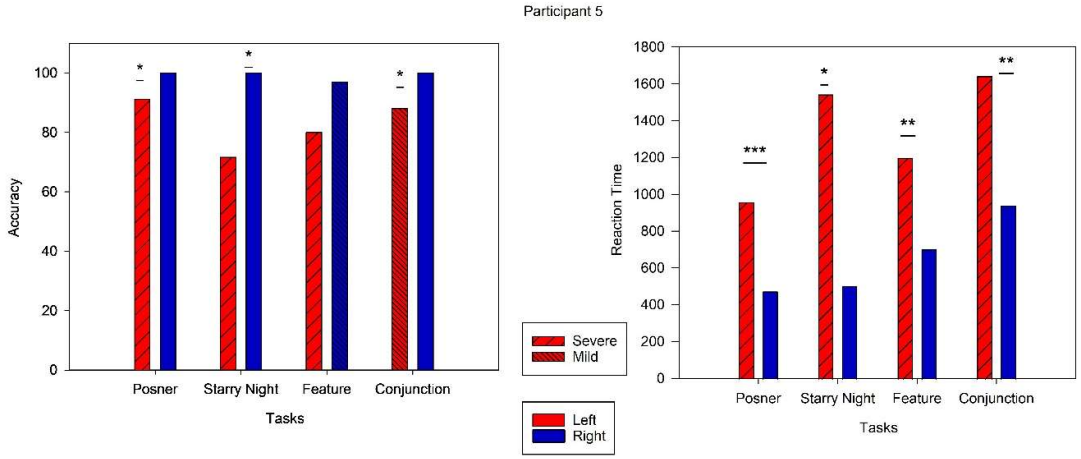

*Figure 0.1 Participant 5: Accuracy and Response time Deficits Across Left and Right Targets. RT (milliseconds) and accuracy (percentage) across left- and right-sided targets in CB tasks. Deficit severity is categorized as mild or severe based on normative cut-offs, with significant lateralized differences marked by asterisks (*p < 0.05, **p < 0.01, ***p < 0.001).*

4.3.4.2 Right Hemisphere Damage with Low BIT Score

Participant 12, with RBD and a BIT score of 100, indicating neglect. More specifically, the Line Crossing score was 36, and the Figure and Shape Copying score was 3, both above thresholds. In the Letter Cancellation subtest, the participant scored 19, with 1 on the left and 18 on the right, showing a notable lateralized difference. The Star Cancellation score was 35 (12 left, 23 right), indicating a clear lateralized difference. The Representational Drawing score was 1, below threshold, and the Line Bisection score was 6, with a rightward bias.

The CB tasks confirmed a lateralised deficit, as a clear asymmetry in performance was observed, even though impairments were also noted on the ipsilesional side relative to the control group. In the Starry Night task, accuracy was severely impaired on the left side with significant lateralized differences, and RT was severely impaired on the left side and mildly impaired on the right, both showing significant lateralized differences. In the Feature

Search task, accuracy and RT were both severely impaired on the left side, with significant lateralized differences. In the Conjunction Search task, accuracy was severely impaired on both the left and right sides, with significant lateralized differences, while RT was severely impaired on the left side. In the Posner cueing task, accuracy was severely impaired on the left side with significant lateralized differences, and RT was severely impaired on both sides, again with significant lateralized differences. Participant 12 presented with bilateral reductions in attention, with performance falling below the 2 SD cut-off on both sides in some cases. However, the presence of significant lateralised differences suggests a more severe impairment on the left side, indicating left USN coexisting with a general bilateral inattention or possible extinction. The data for participant 12 data are visualised in Figure 4.2.

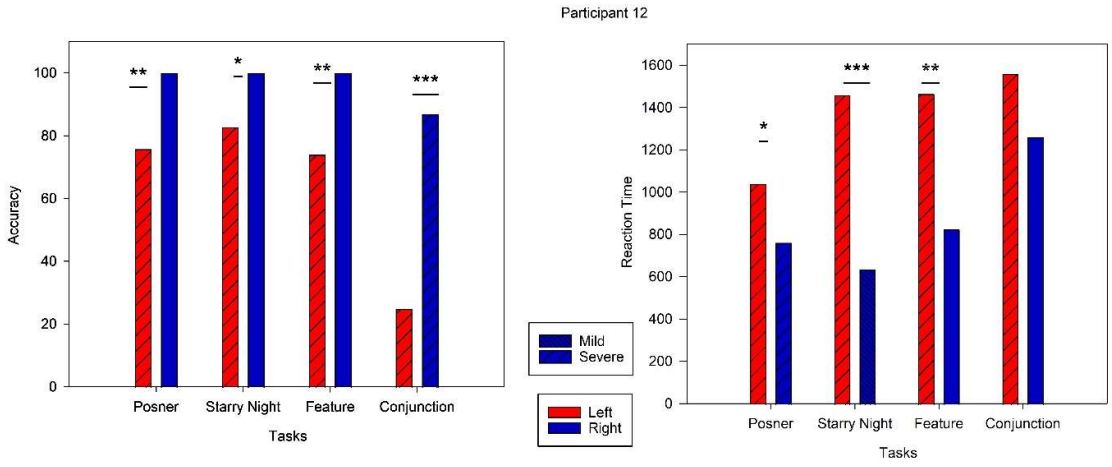

Figure 0.2. Participant 12: Accuracy and Response time Deficits Across Left and Right Targets. The graph follows the same approach as for Participant 5, highlighting significant lateralised deficits in both accuracy and RT.

4.3.4.3 Left Hemisphere Damage with Normal BIT Score

Participant 21, who had LBD, achieved a BIT score of 143, suggesting no neglect according to conventional methods. However, performance on the CB tasks revealed significant deficits. In the Starry Night task, accuracy was severely impaired on the right, and RT showed mild impairment for right-sided targets with significant lateralized differences. For the Feature Search task, accuracy was severely impaired for both sides, with greater impairment on the right, while RT was severely impaired for right-sided targets. Performance on the Conjunction Search task was normal, which is notable given its typical sensitivity in detecting neglect symptoms. This task relies more on top-down, goal-directed attention, while the Feature Search and Starry Night tasks depend on bottom-up, stimulus-driven processes, this pattern might suggest greater difficulties with bottom-up attention in this participant. For this participant, the task was completed last, and factors contributing to better performance could include familiarity with the procedure. Additionally, they reported finding it the most challenging among the others, which may have prompted increased concentration/vigilance. In the Posner cueing task, accuracy was severely impaired for both left- and right-sided targets, with greater impairment on the right, while RT showed severe impairment for right-sided targets, again with significant lateralized differences. The data for participants 21 are visualised in Figure 4.3.

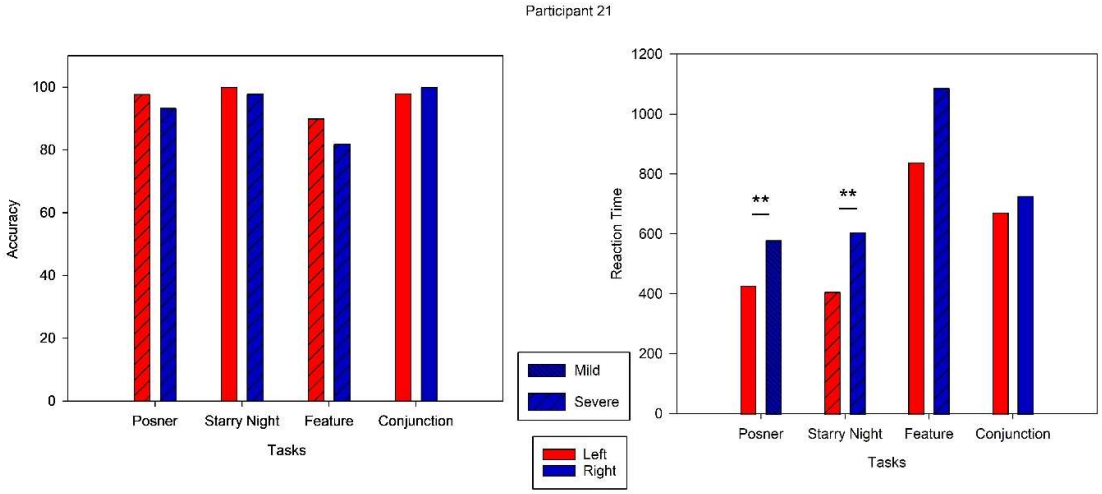

Figure 0.3. Participant 21: Accuracy and Response time Deficits Across Left and Right Targets. The graph follows the same approach as for Participant 5, highlighting significant lateralised deficits in both accuracy and RT.

4.3.5 Diagnostic Evaluation of the CB Task Battery

4.3.5.1 Diagnostic Accuracy Against BIT Reference Standard

To further evaluate diagnostic performance, a diagnostic accuracy analysis was conducted for each CB task using the BIT as the reference standard, with results summarised in Table 4.7 and ROC curves presented in Figure 4.4. The Conjunction task showed the highest sensitivity (1.00) and NPV (1.00), meaning it correctly identified all participants with neglect and had no false negatives. However, it had the lowest specificity (0.46), indicating more false positives. The Starry Night and Feature tasks both had moderate sensitivity (0.86), and higher specificity than the Conjunction (0.54). The Posner task had the lowest sensitivity (0.71), but with the Starry Night they presented the highest specificity (0.62). Area under the curve (AUC) values from ROC analysis ranged from 0.67 (Posner) to 0.74

(Starry Night), suggesting fair diagnostic accuracy across all tasks, with none reaching strong or excellent power.

These findings suggest that while the Conjunction task is particularly sensitive in detecting neglect symptoms, it may also over-identify impairment in some cases when compared with the BIT. Conversely, tasks like Starry Night and Posner may be more conservative but risk missing subtler signs of neglect. While this process of considering diagnostic accuracy against the currently most common test used in practice may be of interest, as the latter has been extensively criticised for its lack of sensitivity (Azouvi et al., 2002; Bonato & Deouell, 2013), the associated lack of specificity shown by the CB tasks needs to be interpreted with this in mind.

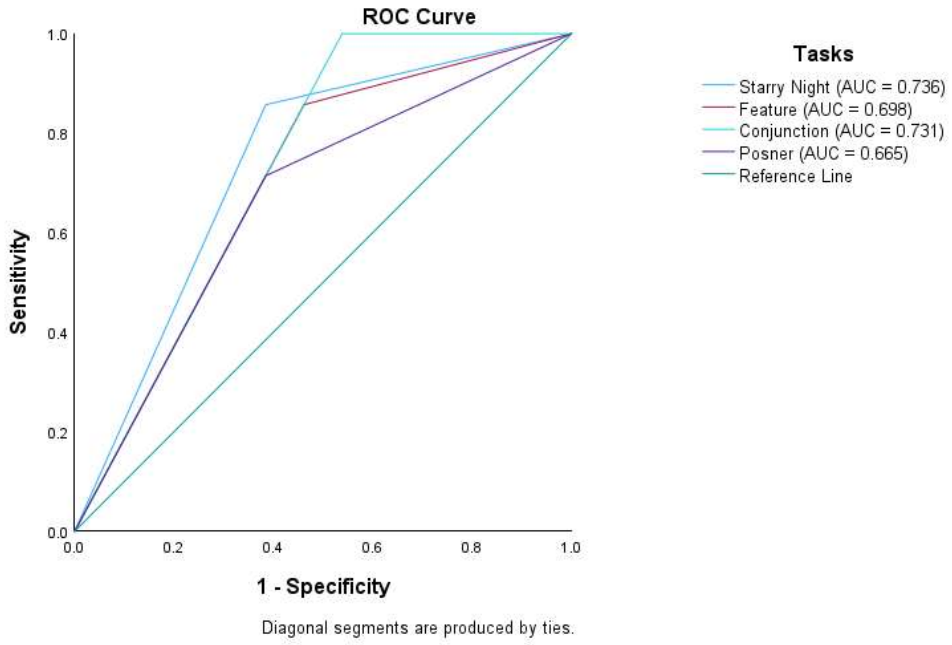

Figure 4.4. ROC Curves for CB Tasks Compared Against the BIT Reference Standard. Each curve represents the sensitivity (true positive rate) plotted against 1 – specificity (false positive rate) for the Starry Night, Feature, Conjunction, and Posner tasks. The AUC values indicate the overall discriminative ability of each task.

	STARRY NIGHT	FEATURE	CONJUNCTION	POSNER
SENSITIVITY	0.86	0.86	1.00	0.71
SPECIFICITY	0.62	0.54	0.46	0.62
LR+	2.23	1.86	1.86	1.86
LR-	0.23	0.27	0.00	0.46
PPV	0.55	0.50	0.50	0.50
NPV	0.89	0.88	1.00	0.80
AUC	0.74	0.70	0.73	0.67

Table 4.7. Diagnostic Accuracy of CB Tasks Against the BIT Reference Standard.
This table presents the diagnostic accuracy indices for each CB task when compared to the BIT, used as the reference standard. Reported metrics include sensitivity (the ability to correctly identify those with USN), specificity (correctly identifying those without USN), positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+), negative likelihood ratio (LR–), and area under the ROC curve (AUC) as a summary measure of overall diagnostic performance.

4.3.5.2 Discriminant Validity Analysis

A discriminant validity analysis was conducted to assess whether performance on the CB tasks was more strongly associated with spatial attention (as measured by the BIT) than with general cognition (ACE-III) or overall stroke severity (NIHSS). Average RTs and accuracy scores from the four CB tasks were correlated with total scores from the BIT, ACE-III, and NIHSS. As Shapiro–Wilk tests indicated non-normal distributions ($p < 0.05$), Spearman's correlations were used. Results are presented in Table 4.8 (RT) and Table 4.9 (accuracy). Strong negative correlations were observed between RTs and BIT scores for the Starry Night ($\rho = –.678$, $p = 0.001$), Feature Search ($\rho = –.740$, $p < 0.001$), and Posner ($\rho = –.602$, $p = 0.005$) tasks, indicating that slower RTs were associated with greater spatial neglect. Accuracy also showed strong positive correlations with BIT scores for these tasks: $\rho = .689^{**}$ ($p < 0.001$), $\rho = .838^{**}$ ($p < 0.001$), and $\rho = .700^{**}$ ($p < 0.001$),

respectively. The Conjunction task showed a moderate negative correlation for RT (ρ = –.412, p = 0.071), which did not reach significance, though accuracy showed a strong positive correlation with the BIT (.621**, p = 0.004). In contrast, correlations with ACE-III were generally weaker, with only Feature Search RT showing a significant association (ρ = –.511, p = 0.021). All correlations with NIHSS for both RT and accuracy were non-significant. These findings support the discriminant validity of the CB tasks, as they were more strongly associated with spatial attention deficits than with general cognitive function or stroke severity.

CB TASK (RT)	BIT	ACE-III	NIHSS
STARRY NIGHT	–.678** (p = 0.001)	–.432 (p = 0.057)	.093 (p = 0.698)
FEATURE	–.740** (p < 0.001)	–.511* (p = 0.021)	.090 (p = 0.705)
CONJUNCTION	–.412 (p = 0.071)	–.206 (p = 0.383)	.110 (p = 0.644)
POSNER CUEING	–.602** (p = 0.005)	–.367 (p = 0.111)	–.069 (p = 0.772)

*Table 4.8. Spearman Correlations Between CB Task Response Times and Standardised Clinical Measures. Significance levels: * p < .05, ** p < .01.*

CB TASK (ACC)	BIT	ACE-III	NIHSS
STARRY NIGHT	0.689** (p<.001)	0.236 (p = 0.236)	-.339 (p = 0.143)
FEATURE	0.838** (p<0.001)	.429 (p= 0.059)	-.367 (p= 0.143)
CONJUNCTION	.621** (p= 0.004)	.267 (p= 0.254)	-.189 (p= 0.425)
POSNER CUEING	.700** (p<0.001)	.355 (p= 0.124)	-194 (p= 0.412)

*Table 4.9. Spearman Correlations Between CB Task Accuracy (ACC) and Standardised Clinical Measures. Significance levels: * p < .05, ** p < .01.*

4.3.6 Feedback Questionnaires

4.3.6.1 Participant Preferences Across Computer-Based Tasks

Participants rated their enjoyment of the tasks, revealing varying preferences. The Starry Night task was the most enjoyed (35%, 7/20), followed by the Posner task (25%, 5/20), the Conjunction task (20%, 4/20), and the Feature task (10%, 2/20). One participant (5%) had no preference. Starry Night was favoured for its engagement and challenge, while Posner was appreciated for its simplicity. The Conjunction Task was the least enjoyed (55%, 11/20) due to its difficulty and repetitiveness, followed by the Posner Task (20%, 4/20) for being too simple. The Starry Night Task (15%, 3/20) was criticized for causing fatigue and being challenging, while the Feature Task was the least preferred (5%, 1/20) as it was found less engaging. Additionally, 5% (1/20) of participants had no preference. Overall, preferences were influenced by task complexity, with some participants valuing challenge and others favouring ease.

4.3.6.2 Perceived Task Ease

The Conjunction Task was identified as the most difficult by 75% (15/20) of participants, mentioning factors such as the need to differentiate between multiple shapes and colours, frequent target changes, and overall complexity, while the Starry Night Task was considered the most difficult by 20% (4/20) due to its dynamic nature and challenging contrasts. In contrast, the Posner Task was deemed the easiest by 60% (12/20) of participants for its simplicity and reduced complexity, followed by the Feature and Starry Night tasks, each identified by 15% (3/20) for their clarity and visual contrast.

4.3.6.3 User Experience Evaluation

In terms of user-friendliness, the majority of participants rated the tasks highly, with scores mostly ranging between 7 and 10, and an average score of 8.3/10. When evaluating practicality, the tasks were positively received, with an average score of 8.5/10, indicating strong approval regarding their applicability. Regarding comprehensibility, the instructions were generally easy to follow, with an average score of 9.0/10. For task length and duration, around 60% (12/20) of participants felt the duration was "about right," while 35% (7/20) considered the tasks "too long". Additionally, 5% (1/20) had no opinion. This suggests that while most participants were comfortable with the length of the tasks, a small portion found them to be somewhat lengthy.

4.3.6.4 Task Preference and Difficulty: Pen-and-Paper vs. Computer-Based

When comparing the CB tasks to the traditional PnP tasks, 55% (11/20) of participants favoured the CB tasks. They cited reasons such as ease of use, the simplicity of pressing buttons instead of drawing. Some found the CB tasks more straightforward and manageable. In contrast, 40% (8/20) of participants preferred the PnP tasks, appreciating the familiarity and tactile experience of interacting with paper. One participant did not report a preference. Some also found PnP tasks more straightforward or offered a greater variety of tasks. Additionally, participants reported that factors such as comfort with technology and fine motor skills played a significant role in their enjoyment.

Regarding task difficulty, 60% (12/20) of participants found the PnP tasks more challenging, primarily due to the drawing requirement, which posed difficulties for individuals with motor impairments. Others mentioned stroke-related challenges and the need for increased precision. On the other hand, 30% (6/20) found the CB tasks more

difficult, often due to the added focus required for managing buttons and visual stimuli. Some participants also mentioned the flashing lights and other visual effects in the CB tasks as contributing to the difficulty. The remaining 10% (2/20) of participants felt that both types of tasks were equally easy and similarly challenging.

4.4 Discussion

This study aimed to evaluate the effectiveness of CB tasks compared to traditional PnP methods, such as the BIT, in detecting USN following stroke. By analysing accuracy and RT across a battery of adapted versions of well-established CB tasks, we conducted a comprehensive assessment of spatial attention deficits in twenty stroke survivors. The findings highlight the potential of CB tasks to complement or improve upon conventional methods, particularly in detecting subtle cases of USN. These results offer insight into potential improvements in post-stroke spatial attention assessment.

All CB tasks demonstrated an ability to identify participants with impaired performance where this was not captured by any of the BIT conventional tasks. Accordingly, the CB tasks demonstrated greater sensitivity. Among these, the Conjunction Task emerged as the most sensitive, identifying a greater number of cases of neglect compared to the other tasks, particularly the Posner Cueing Task. This finding is somewhat surprising given the foundational work by Posner et al. (1984) on the role of the parietal cortex in spatial attention, which established the Posner Cueing Task as a key paradigm for detecting attentional deficits. More recent studies, such as Rengachary et al. (2009), have further demonstrated its sensitivity in identifying USN. However, the Conjunction Task's superior sensitivity suggests that factors beyond basic attentional cueing, such as increased

demands on visual search and feature integration, may play a critical role in revealing spatial attention deficits. The task's complexity and the increased cognitive demands it places on participants may explain its superior performance in detecting these deficits (Andres et al., 2019; Ricci et al., 2016). In contrast, the Posner Cueing Task was less effective at identifying neglect, potentially due to its reliance on basic covert attentional shifts, which primarily assess the ability to redirect attention rather than engaging the more complex processes involved in overt spatial exploration and feature integration that are captured by more demanding tasks. However, despite its overall sensitivity, the Conjunction Task failed to detect neglect in one case study where all other CB tasks identified a deficit. While this may partly reflect an order effect and increased concentration towards the end of the session, it is also possible that this participant experienced greater difficulty with bottom-up, stimulus-driven attention, rather than top-down, goal-directed search, which the Conjunction Task demands. This suggests that attentional systems can be independently affected, demonstrating variability in attentional mechanisms among individuals with USN, highlighting the complexity of USN and suggesting that different tasks may be more effective for different individuals (Pinto et al., 2013). These differences underscore the importance of task design, particularly the interplay between task complexity, target saliency, and cognitive load, in eliciting measurable USN symptoms (Bonato, 2012; Ptak & Bourgeois, 2024). Understanding how these elements affect the detection of neglect is critical for optimizing diagnostic tools (Karnath & Niemeier, 2002; Sarri et al., 2009).

Among the two outcome measures, RT proved to be a more sensitive indicator of USN, revealing deficits that accuracy alone did not capture. For example, the Conjunction and Posner tasks identified lateralized RT differences even when accuracy was normal. This

supports previous research suggesting that prolonged RTs reflect delays in spatial attention processing or compensatory strategies (Bartolomeo et al., 2001). Unlike accuracy, which can approach normative values or maximum and may become less sensitive especially in detecting milder forms of neglect, RT offers a continuous measure of cognitive processing. Including RT in clinical assessments could enhance diagnostic precision, particularly for mild or task-dependent deficits (Rengachary et al., 2009; Schendel & Robertson, 2002). Furthermore, the discriminant validity analysis revealed that RTs and accuracy scores from the CB tasks were strongly associated with BIT scores, but not with general cognitive ability (ACE-III) or stroke severity (NIHSS). These results demonstrate the relevance of RT and accuracy as a spatially sensitive outcome, rather than generalised cognitive impairment or overall stroke severity.

While the BIT remains widely used in clinical settings, its reliance on static stimuli and limited task variety, along with its total score not distinguishing lateralized differences (Azouvi et al., 2002; Deouell et al., 2005), can lead to the under-detection of subtle or chronic USN. In some cases, individuals were identified as having neglect based on a low BIT score, but there were no lateralized differences detected within the individual BIT tests. This suggests that the BIT can not fully capture the lateralized nature of attentional biases. The total BIT score, relies on six subtests, based on cutoff scores that do not account for left/right asymmetry. A scoring approach that incorporates lateralized differences could offer a more precise understanding of spatial attention deficits. The CB tasks can overcome this limitation, among others, such as the limited sensitivity of PnP tasks, which likely arises from their static, paper-based format. In our study we confirmed that tasks with dynamic and complex stimuli (e.g., Starry Night, Conjunction), are particularly effective at identifying lateralized attentional biases, further supporting findings from

previous research (Bonato & Deouell, 2013; Bonato et al., 2011). Unlike previous research, which has not directly compared different CB tasks, this study contrasts these tasks to demonstrate how each captures spatial attention, highlighting their unique strengths in identifying subtle neglect symptoms and revealing lateralized deficits that traditional methods like the BIT fail to distinguish.

These findings suggest CB assessments may be a useful addition to current assessment tools. Our results support previous research, showing that rather than replacing conventional methods, they should be viewed as complementary tools that overcome the limitations of static, paper-based tests and enhance detection of subtle and chronic lateralised attentional deficits (Bonato & Deouell, 2013) By utilizing effectively four different CB tasks in clinical settings with stroke survivors, our study demonstrates that these assessments are not only feasible but they also offer a more sensitive and dynamic approach to spatial attention evaluation.

Consistent with previous studies, left-sided neglect was more prevalent than right-sided neglect across all tasks, likely due to the right hemisphere's dominance in spatial attention processing and the more severe consequences of right-hemispheric lesions on attentional networks (Corbetta & Shulman, 2011). However, the sample was predominantly composed of patients with RBD, with 78.6% (11/14) showing signs of neglect in at least one task, comparable to the 80% (4/5) of LBD participants, aligning with Stone et al. (1991), who reported similar rates of neglect in both RBD and LBD patients early after stroke. These findings highlight the heterogeneity of USN and the need for assessment protocols that capture this variability. Given the variability in lateralization patterns, employing multiple tasks in USN assessment has been deemed essential by previous research. Tasks that vary in complexity, saliency, and attentional demands provide a more comprehensive

understanding of neglect symptoms, supporting tailored rehabilitation strategies (Bonato, 2012; Guilbert, 2023). In our study, we demonstrated that the Conjunction task had the highest sensitivity (1.00), successfully identified all participants with USN and had the highest NPV across a range of patient profiles. This may suggest that a single task, as sensitive as the Conjunction task, can provide a robust and reliable measure of USN, challenging the need for multiple tasks to assess USN, which is valuable in clinical screening, where the priority is to minimise missed cases. However, its low specificity (0.46) albeit when pitted against the BIT, may suggest a higher rate of false positives, raising the risk of over-identifying USN. In contrast, tasks like Starry Night and Posner presented lower sensitivity (0.86 and 0.71, respectively), but higher specificity (both 0.62), indicating fewer false positives but a greater chance of missing milder cases. These findings reflect a common trade-off in diagnostic tools between accurate detection of all true cases and exclusion of non-cases (Parikh et al., 2008; Shreffler & Huecker, 2025). As discussed in Chapter 2, many previous studies have prioritised sensitivity without addressing the potential consequences of lower specificity. Additionally, the absence of a gold standard for USN diagnosis complicates the interpretation of specificity, as conventional PnP tasks like the BIT have been shown to have limited sensitivity, particularly for subtle or chronic neglect, potentially leading to underestimation of true impairment and increasing false positives when used as the reference standard (Bonato & Deouell, 2013; Deouell et al., 2005).

Participants generally found the CB tasks to be user-friendly, practical, and appropriately timed, with clear and easy-to-follow instructions. These tasks received positive ratings for their ease of use and applicability. Participants reported that the CB tasks were generally easy to follow and complete, with some participants founding the CB tasks more enjoyable

and easier to perform compared to PnP, particularly appreciating the simplicity of pressing buttons over engaging in drawing tasks. This preference is consistent with prior research, which suggests that CB and VR assessments enhance patient engagement and compliance due to their interactive nature (Tsirlin et al., 2009). These advantages make CB tasks not only more appealing to participants but also well-suited for clinical settings, where they can improve assessment accuracy and reliability, especially for patients with diverse cognitive and motor impairments (Bonato et al., 2011). Additionally, the widespread use of computers in daily life makes these tasks not only appealing to participants but also relatively easy to implement in clinical settings. In our study, most participants had basic computer skills, making these assessments well-suited for individuals with diverse cognitive and motor impairments.

The findings of this study may offer useful insights for clinical assessment of USN. Incorporating RT measures provides a more detailed assessment of cognitive processing, helping to guide personalized rehabilitation strategies. Furthermore, the engaging nature of these tasks, coupled with the positive feedback from participants regarding their usability and ease of use, may enhance patient compliance and reduce fatigue, improving assessment reliability compared to traditional methods. Finally, the adaptability of CB tasks makes them suitable for widespread use, with portable devices enabling assessments in diverse settings, including bedside, outpatient, and telehealth environments (Terruzzi et al., 2024). The high sensitivity of CB tasks suggests they could be crucial for the early detection of USN, even when symptoms are mild or subtle enabling timely interventions (Giannakou et al., 2022). As discussed earlier, USN is not a degenerative condition and is often subject to spontaneous recovery, with most recovery occurring within the first three months post-stroke (Moore et al., 2021; Overman et al., 2024; Winters et al., 2017).

However, early identification remains important, including in cases where it may otherwise go unnoticed, as it could allow for more tailored and potentially more effective interventions during this critical window for recovery (Tsujimoto et al., 2020; Yoshida et al., 2022).

In order to evaluate the presence of USN or attentional impairment, we used 1 SD (mild) and 2 SD (severe) cut-off scores based on normative data, applied separately to left and right performance. This approach was chosen to facilitate visualisation, tabulation, and the identification of performance patterns, considering the exploratory nature of the study and the small and heterogenous sample. While future studies may prefer the use of left–right difference scores as a more direct measure of spatial asymmetry in accuracy and RT, our approach allowed for the detection of both lateralised and bilateral reductions in performance. Additionally, using 1 SD as a cutoff aligns with previous studies aimed at detecting mild impairments. However, this approach has been criticised for potentially including cases that fall within the normal variability of performance (Busse et al., 2006; Dalrymple-Alford et al., 2011; Trittschuh et al., 2011). In our study, findings suggest that only a small proportion of older adults may exhibit lateralised differences using this approach, as across all tasks only 3.4% for accuracy and 3.7% for RT were below the 1 SD cutoff.

Another limitation of this study is the age differences between the normative control sample and the clinical group. Normative data were collected from unimpaired older adults aged 65 and over to provide an age-matched baseline for the stroke survivors. However, 9 out of 20 stroke participants were younger than 65, which may affect the accuracy of comparisons and classification of impairment. Future studies should aim to collect more comprehensive demographic and normative data, including age-corrected norms closely matched to the clinical sample (Heaton et al., 2009) .

A limitation of the study is that the study was underpowered, limiting the generalisability of the findings, as we did not reach the required sample size as indicated by the power analysis for a diagnostic accuracy analysis. Future studies should replicate these findings with larger, more diverse populations, such as outpatients or chronic cases, and include patients with varying lesion locations and severities (Andrade, 2020). Longitudinal designs could provide valuable insights into performance changes over time (Farrington, 1991). Another promising direction for future research is integrating this battery of CB tasks with neuroimaging techniques, such as fMRI or electroencephalography (EEG). This approach could deepen our understanding of the neural mechanisms underlying USN.

Conclusion

This study is the first to our knowledge to compare different CB tasks for detecting USN in stroke survivors within clinical settings. Our findings highlight the superior sensitivity of CB tasks, particularly the Conjunction Task, in identifying subtle and chronic spatial attention deficits, offering a more dynamic approach compared to traditional PnP assessments like the BIT. We demonstrated that a single, sensitive task such as the Conjunction Task can reliably detect USN, challenging the need for multiple tasks. Additionally, our results showed that RT was a more sensitive indicator of neglect than accuracy, capturing deficits that accuracy alone missed. Participants reported that the CB tasks were user-friendly, engaging, and easy to use, improving compliance, reducing fatigue, suggesting their potential to complement traditional assessment approaches. These results emphasize the value of integrating these tasks into clinical practice to improve diagnostic precision, support personalized rehabilitation strategies, and ultimately enhance the quality of care for stroke survivors. By addressing the limitations of conventional method and utilizing

technological advancements, CB assessments may contribute to advancing the evaluation of USN.

CHAPTER 5

Does transcranial direct current stimulation (tDCS) of the right parietal lobe affect spatial attention?

Abstract

Lesions of the right PPC are known to cause deficits in detecting contralateral stimuli as observed in USN and spatial extinction. The role of the PPC in differentiating between single and competing stimuli remains a subject of ongoing investigation. This study aimed to examine the effects of tDCS on spatial attention of unimpaired individuals by targeting the right PPC, partially replicating methodology reported by Filmer et al. (2015). Their study indicated that anodal tDCS disrupts the detection of single contralateral stimuli, while both anodal and cathodal tDCS impair bilateral stimulus detection.

We recruited 63 neurologically healthy adults, randomised into three groups receiving either anodal, cathodal, or sham tDCS to the right PPC. Participants completed a staircase detection task to establish a 70% accuracy threshold before engaging in the three phases of the main task (pre-stimulation, immediate post-stimulation, and 20 minutes post-stimulation). Our analysis revealed a significant effect of stimulus location ($F(2, 110) = 20.917$, $p < 0.001$), with participants showing greater accuracy for single stimuli than bilateral stimuli. A significant phase effect was also found ($F(1, 55) = 6.457$, $p = 0.014$), indicating decreased accuracy immediately following stimulation in all groups. However, no significant effects of stimulation type or interactions were observed.

In contrast to Filmer et al. (2015), the anticipated effects were not elicited. Our findings suggest that, under the present stimulation parameters and task conditions, tDCS over the right parietal cortex did not produce significant modulations in spatial attention in healthy participants and highlight the need for further research to demonstrate it's effect. These results highlight the need for further research to clarify whether and under what conditions tDCS can reliably influence spatial attention mechanisms.

5.1 Introduction

Spatial attention refers to the brain's ability to selectively focus on specific stimuli while disregarding others. This process is essential for effectively managing the brain's capacity to process information and prevent sensory overload (Kastner & Ungerleider, 2000; Petersen & Posner, 2012). Accordingly, spatial attention allows the brain to prioritize relevant stimuli in a busy environment and is essential for efficiently handling competing sensory inputs (Carrasco, 2018). Attention may be cued in two primary ways. Exogenous attention refers to when external stimuli capture our focus, functioning as a *bottom-up* process (Corbetta & Shulman, 2002). In contrast, endogenous attention is goal-directed and operates through a top-down approach (Nguyen et al., 2020). The balance between these two systems is influenced by intention and the environment, allowing the brain to adaptively shift between them as required (Chica et al., 2013).

The brain's limited attentional capacity makes it challenging to process multiple stimuli simultaneously (Marois & Ivanoff, 2005). Research has shown that multitasking or managing several stimuli negatively impacts performance compared to focusing on a single stimulus (Koch et al., 2018; Schumacher et al., 2018). This effect is evident in studies showing that participants become slower and less accurate when presented with two target stimuli simultaneously rather than sequentially, primarily due to increased competition, cognitive load and divided attention (Butcher & Cavanagh, 2008; de Haan et al., 2015; Hilgetag et al., 2003). Additionally, the concept of visual clutter suggests that excessive information may overwhelm the brain, increasing the difficulty of processing stimuli (Beck et al., 2010; Still, 2019).

The ability to shift attention is a crucial cognitive skill, allowing us to transition our focus on different stimuli, especially in environments with competing inputs (Lindsay, 2020). Posner (1980) introduced a model of attention shifting comprising three key steps: disengaging from the initial focus, redirecting attention, and engaging with the new target. The study demonstrated that RTs were faster when the target stimulus followed a cue in the same location; however, delays in cues reinitiate the attention shift, resulting in longer RTs; This phenomenon, later termed IOR, indicates a bias against returning attention to previously attended locations (Klein, 2000). Numerous subsequent studies have supported these findings in unimpaired and patient populations (Feher da Silva & Baldo, 2015; Hayward & Ristic, 2013).

Key brain regions involved in attention include the frontal and parietal lobes, with the fronto-parietal network playing a crucial role in voluntary allocation of attentional resources (Corbetta, 1998). The posterior parietal cortex is particularly important for processing spatial attention signals (Malhotra et al., 2009) and studies show that PPC neurons respond more strongly to targets compared to distractors (Gottlieb & Snyder, 2010; Murray et al., 2017). Damage to the PPC can result in spatial attention deficits, such as difficulties in disengaging or shifting attention (Posner et al., 1984).

Spatial attention disorders can result from lesions in one hemisphere of the brain, commonly due to conditions such as stroke. Among the most prevalent disorders are USN, where individuals completely ignore or have difficulty detecting stimuli on the contralesional side of space (Gammeri et al., 2020), and extinction, where a contralesional stimulus is not reported when presented alongside an ipsilesional stimulus (Rorden et al., 2009). These disorders are known to be more severe following right hemisphere damage

and may coexist, although have been considered to occur independently (Li & Malhotra, 2015).

tDCS is a non-invasive technique that modulates neural excitability by applying a small electrical current through scalp electrodes. It can depolarize neurons (anodal stimulation) to increase firing or hyperpolarize them (cathodal stimulation) to decrease excitability, often resulting in temporary behavioural effects (Thair et al., 2017). The approach has become popular for enhancing learning, memory, and skill acquisition due to minimal side effects, low cost, and ease of use in clinical and home settings (Medeiros et al., 2012).

The exact mechanisms by which tDCS induces longer term behavioural changes remain unclear. However, repeated sessions may enhance synaptic plasticity by strengthening neural pathways through long-term potentiation or weakening them via long-term depression (Vestring et al., 2024). Clinical studies have focused on tDCS applications in treating psychiatric disorders, showing benefits for depression, schizophrenia, obsessive compulsive disorder (OCD), and attention deficit hyperactivity disorder (ADHD) (Fregni et al., 2021; Tortella et al., 2015), as well as alleviating pain in conditions like fibromyalgia (Moshfeghinia et al., 2023).

Recent studies examining tDCS in the context of spatial attention have yielded promising results, particularly regarding stimulation targeting the PPC. Evidence suggests that bilateral stimulation of PPC, utilizing right cathodal and left anodal tDCS can induce neglect-like symptoms in healthy individuals, underscoring the PPC's critical role in spatial attention (Tsujimoto et al., 2022).

Other research investigating unilateral stimulation of the PPC demonstrated that tDCS of the right PPC can affect participants' performance on visual detection tasks (Filmer et al.,

2015; Lo et al., 2019). In contrast, stimulation of the left PPC in these studies did not yield such effects. These findings indicate a greater involvement of the right hemisphere in spatial attention, consistent with evidence showing more severe and persistent attention deficits following damage to the right hemisphere (Malhotra et al., 2009).

tDCS applied to the ipsilesional hemisphere in stroke survivors has been shown to have functional benefits, improving motor and learning skills when applied safely (Allman et al., 2016; Fritsch et al., 2024; Hamoudi et al., 2018). Additionally, studies exploring tDCS effects on USN have employed inhibitory cathodal stimulation to the contralesional hemisphere, anodal stimulation to the ipsilesional hemisphere, or bilateral protocols aimed at rebalancing interhemispheric activity, or anodal ipsilateral (Allman et al., 2016; Kim et al., 2013; Sunwoo et al., 2013). Evidence from stroke populations demonstrates that both unilateral and bilateral parietal tDCS protocols can reduce USN symptoms, typically measured via tasks such as line bisection and cancellation (da Silva et al., 2022; Yi et al., 2016)

While tDCS has shown promising findings in treating disorders like USN, results are inconsistent. Some reviews suggest moderate efficacy, especially when tDCS is combined with other therapies. However, optimal treatment parameters, such as current polarity, intensity, and timing, remain unclear (González-Rodriguez et al., 2022). Additionally, concerns about publication bias and small sample sizes highlight the need for replication and perhaps more rigorous studies evaluating the impact of tDCS in modulating cognitive functions (Medina & Cason, 2017).

The present study, while conducted in healthy participants, used a similar approach by targeting the right PPC, similar to the ipsilesional hemisphere in typical cases of USN

following right hemisphere stroke. The rationale aligns with clinical protocols where right PPC stimulation has been investigated for the rehabilitation of spatial deficits in stroke survivors. The objective of the study was to explore whether right parietal stimulation could enhance spatial attention mechanisms under controlled conditions with the potential of informing the development of future interventions in clinical populations.

The aim of this study was also to partially replicate Filmer et al. (2015) work by investigating the effects of tDCS on spatial attention, specifically targeting the right PPC. The study aimed to determine whether tDCS influences the detection of both single and competing visual stimuli in neurologically unimpaired participants. Findings may then provide insights into potential outcomes for patients with spatial attention deficits, particularly in understanding how tDCS may be tailored to enhance attention mechanisms in clinical settings.

In 2015, Filmer and colleagues explored the role of the PPC in processing visual stimuli by applying tDCS to either the left or right PPC. Their study found that stimulation of the left PPC had no significant effect on detection. Conversely, right PPC stimulation significantly disrupted detection of contralateral and bilateral stimuli, particularly when anodal stimulation was applied. Specifically, anodal tDCS impaired the detection of both contralateral and bilateral stimuli, while cathodal tDCS affected only bilateral stimuli. These findings highlight the critical role of the right PPC in visual attention and suggest that it may employ different mechanisms for processing single versus competing stimuli.

Building on these findings, this study hypothesized that anodal tDCS applied to the right PPC would disrupt detection of both contralateral and bilateral stimuli, while cathodal tDCS would mainly affect the detection of bilateral stimuli, consistent with Filmer et al. (2015).

However, while Filmer et al. did not report overall poorer performance for bilateral stimuli, we expected to see a greater decline in performance when detecting competing stimuli compared to single stimuli , aligning with broader evidence on attentional capacity limits and competition effects in visual processing (Han & Marois, 2014; Hilgetag et al., 2003). The study protocol was registered on DOI: 10.17605/OSF.IO/HVS8F.

5.2 Methods

5.2.1 Participants

Sixty-three neurologically healthy adult participants with normal or corrected-to-normal visual acuity were recruited to the study (thirty-two women, average age 28 (SD =12.54)). The study was approved by the University of Birmingham's Science, Technology, Engineering and Mathematics Ethical Review Committee (ERN 18-2077P). All participants completed a health and safety questionnaire and provided written consent. Participants were equally and pseudo-randomly divided into three groups (twenty-one in each group) based on the type of stimulation they received; anodal, cathodal, or sham. The sample size was selected to achieve sufficient statistical power based on the power calculation, with the goal of achieving an 80% probability of detecting an effect size comparable to that of the original study (Filmer et al., 2015), using a repeated measures ANOVA with a between-subject factor, and controlling for a 5% Type I error rate.

5.2.2 Procedure

We closely adhered to the procedure followed by Filmer et al. (2015) study to ensure replication integrity. While modifications were made, we maintained consistency by using

the same procedures, software for stimuli presentation and task design (courtesy of Filmer; Filmer et al., 2015). The outline of an experimental session is shown in Figure 5.1. At the beginning of each session, participants completed a thresholding block using a parameter estimation by sequential testing (PEST) staircase (Taylor & Creelman, 1967) to determine the noise contrast required to achieve ~70% accuracy in detecting and localizing single stimulus events. On average, participants required a contrast of 49.2 (SD=17, with 0 representing minimum contrast and 100 maximum contrast). Following thresholding, participants completed the main experimental task, consisting of three blocks conducted sequentially: one before, one immediately after, and one 20 minutes after stimulation. Each block included 150 trials (50 trials for each of the three stimulus locations: left only, right only, and bilateral stimuli). The trial outline completed is depicted in Figure 5.2. Stimuli were presented on a 24.5" Liquid Crystal Display (LCD) monitor with a refresh rate of 100 Hz, against a mid-grey background (RGB: 128, 128, 128).

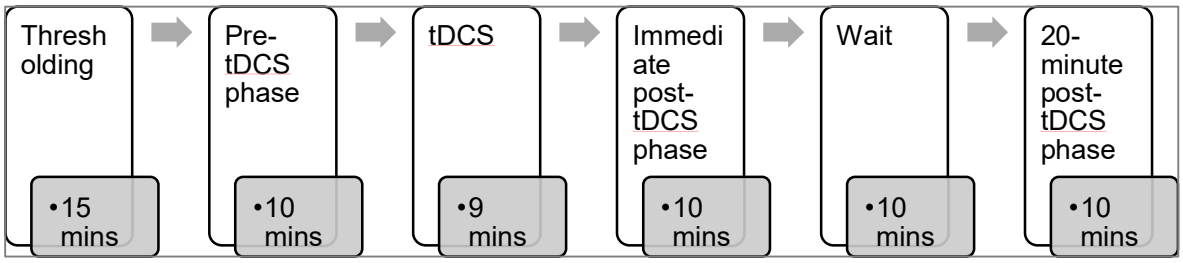

Figure 0.1 Experimental Session Outline.

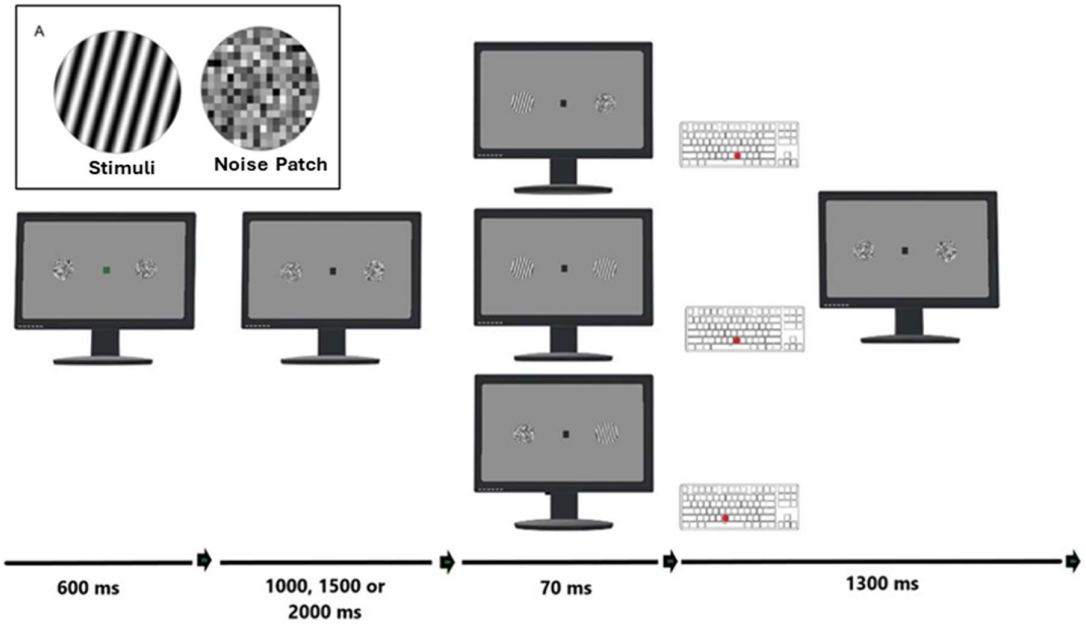

Figure 0.2 A. Stimuli and noise patch displayed at the average contrast level (49.2), as determined by the staircase task. B. Trial Outline. Participants were presented with a fixation square and two circular disks (6° in diameter) containing static noise (randomly generated grey squares within a specified contrast range) in both visual hemifields located 12° to the left and right of fixation. Participants were instructed to keep their gaze on the fixation square throughout each trial. Each trial began with a green fixation square accompanied by static noise patches presented for 600 ms. After this period, the fixation square turned black, and the noise patches began to change every 10 ms. After 1, 1.5, or 2 seconds, target gratings (same size as the noise patches) appeared for 70 ms (20 ms ramp-on, 30 ms full opacity, 20 ms ramp-off). Targets could appear on the left, right, or both sides simultaneously. Following the target display, the noise patches continued to change for an additional 1300 ms before the next trial began. During this period participants had to press a key to indicate whether the target stimuli appeared on the left only (B), right only (M), or both sides (N). If participants failed to respond within this timeframe or pressed the wrong key, the trial was marked as inaccurate.

5.2.3 tDCS

As with the original study (Filmer et al., 2015), ours was conducted in a single-blind manner, with the experimenter aware of the stimulation type but participants blinded. Electrode placement followed the 10–20 system (Klem et al., 1999). In each session, the target electrode was positioned over P4 of the right posterior parietal cortex, while the reference electrode was placed over CZ. Electrodes were 5×5 cm² in size. For anodal and

cathodal tDCS sessions, we applied nine minutes of tDCS (including 30 s ramping up and 30 s ramping down) at an intensity of 1.5 mA. For the sham session, the same stimulation procedure was used, but the constant current lasted for only 15 s.

5.2.4 Methodological differences from the original study

To ensure coherence to the original study's methodology we aimed to minimise adjustments and potential influences from the protocol modifications. However, several methodological adaptations were made to the original study design, which may have influenced comparability and outcomes. These adjustments were implemented to address practical limitations and align the study more closely with broader methodological standards in the field. Below, we outline each key difference and consider its potential impact.

One of the main differences was implementing stimulation type as a between-subjects factor, dividing participants into three groups (anodal, cathodal, and sham stimulation) and deviating from the original within-subject factor approach comprising three sessions per participant. This modification was employed to facilitate the recruitment process by reducing the number of sessions and to minimise carry-over, and order effects. However, this approach does not incorporate the within-subject approach's benefits of controlling individual differences and increasing statistical power, making it more difficult to detect subtle stimulation effects (Charness et al., 2012).

Another key difference was that we chose not to stimulate the left PPC due to the lack of significant effects previously observed. Filmer et al. (2015) recruited twenty-eight neurologically healthy participants (22 female, average age 22 years), divided into two groups of left and right PPC stimulation, with 14 participants receiving stimulation to the right PPC. In contrast our study included 21 participants in each of the three groups (n=63

in total). While this decision was made to enhance feasibility and focus on the hemisphere more consistently associated with spatial attention, it limits the ability to directly replicate and compare hemispheric effects.

Another distinction was the 1.5 mA tDCS intensity applied in our study compared to the original 0.7 mA. This change ensured greater comparability with most other studies in the field, 1.5 mA being considered a moderate intensity with the majority of studies using between 1.0 and 2.0 mA (Bikson et al., 2016; Smucny, 2021). Although moderate stimulation intensities like 1.5 mA are widely considered safe and effective, this difference may have influenced the neural response and limits the direct comparability of findings.

Finally, the experiment was conducted on a larger monitor (24.5" compared to the original 19"). While the refresh rate remained the same (100Hz), and both the target and noise sizes were scaled according to the monitor size to maintain visual angles, slight perceptual differences cannot be entirely ruled out. However, we expect the impact of this change to be minimal.

5.2.5 Data Analysis

The primary analysis focused on changes in response accuracy from pre- to immediately post-tDCS, following the approach used in Filmer et al. (2015). Additionally, we examined changes in RT, which was not included in the original study. Both accuracy and RT were explored in relation to stimulation type and stimulus location using a consistent data analysis approach.

Outliers were handled using standard procedures, including investigation, data transformation where needed, and, in rare cases, exclusion of extreme outliers. Performance in the pre-tDCS phase varied greatly across participants, with scores ranging

from 41% to 98% and a mean accuracy of 81.7% To remove outliers and reduce variability, participants with pre-tDCS accuracy of 60% or less were excluded from the analysis to ensure a baseline level of competence. This led to the exclusion of 5 participants (4 from the Cathodal group and 1 from the Sham group), increasing the average pre-tDCS accuracy to 84.1%. Inaccurate responses (19.13%) were excluded from the RT analysis, including non-responses (11.99%) and incorrect key presses (7.14%). Additionally, responses faster than 200ms (0.14%) were excluded from the analysis as they were considered anticipatory.

To investigate the change in response accuracy from pre- to immediately post-tDCS, ANOVA was conducted in the original study, utilising the Stimulation Hemisphere (Left, Right) as a between-subjects factor. In our analysis, Stimulation Type (Anodal, Cathodal, Sham) functioned as a between-subjects factor instead of a within-subjects factor and there was no Stimulation Hemisphere factor as only the right PPC was stimulated.

A mixed-design ANOVA was conducted; mean accuracy data were analysed as a function of the Phase (Pre- and Immediately post-tDCS), Stimulus Location relative to stimulated hemisphere (Contralateral, Ipsilateral, Bilateral) and Stimulation Type (Anodal, Cathodal, Sham). The same analysis was conducted for median RT data.

5.3 Results

5.3.1 Stimulation Type

Across the study, accuracy was comparable for the different stimulation groups no resulting significant main effect of Stimulation Type (F (2,55) = 1.155, p=0.323, η_p^2=0.40). This was also the case for the RT analysis (F (2,55) = 0.127, p=0.881, ηp²=0.005).

5.3.2 Phase Effect

There was a significant main effect of Phase was found for accuracy (F (1, 55) = 6.457, p=0.014, η_p^2=0.105), with accuracy decreasing by 2.7%, and similarly observed for RT (F (1,55) = 5.981, p = 0.018, ηp² = 0.098), with RT increasing by 11ms post-stimulation. However, no significant Stimulation Type × Phase interaction was found for either accuracy or RT.

5.3.3 Stimulus Location Effect

A significant effect of Stimulus Location was detected for both accuracy (F (2, 110) = 20.917, p<0.001, ηp2=0.276) and RT (F (2,110) = 99.121, p<0.001, ηp²=0.643). Pairwise comparisons revealed that both single stimuli conditions, resulted in significantly faster and more accurate responses compared to bilateral stimuli (p<0.001 for both).

5.3.4 No Stimulus Location x Phase x Stimulation Type Interaction

A significant three-way Stimulus Location x Phase x Stimulation Type interaction was not demonstrated in our analysis for accuracy (F (4, 110) = 0.529, p=0.715, ηp2=0.019) or observed in the additional analysis of RT (F (4,110) = 1.111, p=0.355, ηp²=0.039).

Stimulus location	*Type of tDCS*	*Experiment phase*					
		Pre	**SD**	**Immediate post**	**SD**	**20 mins Post**	**SD**
Contralateral	Anodal	87.43	8.51	83.43	14.55	80.95	15.87
	Cathodal	88.47	10.24	83.41	11.44	80.82	15.69
	Sham	87.70	7.66	88.50	12.14	82.20	20.97
Ipsilateral	Anodal	82.00	11.85	79.43	11.85	76.19	15.96
	Cathodal	87.18	7.72	83.29	7.72	80.94	13.70
	Sham	87.90	7.75	85.10	7.75	79.30	20.97
Bilateral	Anodal	80.10	14.30	77.52	14.52	69.52	16.98
	Cathodal	75.53	15.21	70.71	17.41	67.29	20.51
	Sham	80.60	10.84	81.10	13.51	68.28	21.47

Table 0.1 Mean accuracy (%) and standard deviation (SD) for each stimulus location, type of tDCS, and phase of the experiment

Stimulus location	*Type of tDCS*	*Experiment phase*					
		Pre	**SD**	**Immediate post**	**SD**	**20 mins Post**	**SD**
Contralateral	Anodal	657	85.5	646	89.3	648	89.3
	Cathodal	628	72.2	627	82.7	624	99.5
	Sham	650	86.2	641	94.4	627	87.2
Ipsilateral	Anodal	663	86.7	654	108.1	654	108.1
	Cathodal	638	76.3	627	86.5	648	104.8
	Sham	645	87.3	637	82.2	624	77.4
Bilateral	Anodal	731	114.9	719	107.4	730	119.0
	Cathodal	743	90.0	728	89.9	722	89.9
	Sham	749	104.8	710	90.7	713	91.7

Table 0.2 Mean Response time (ms) and standard deviation (SD) for each stimulus location, type of tDCS, and phase of the experiment.

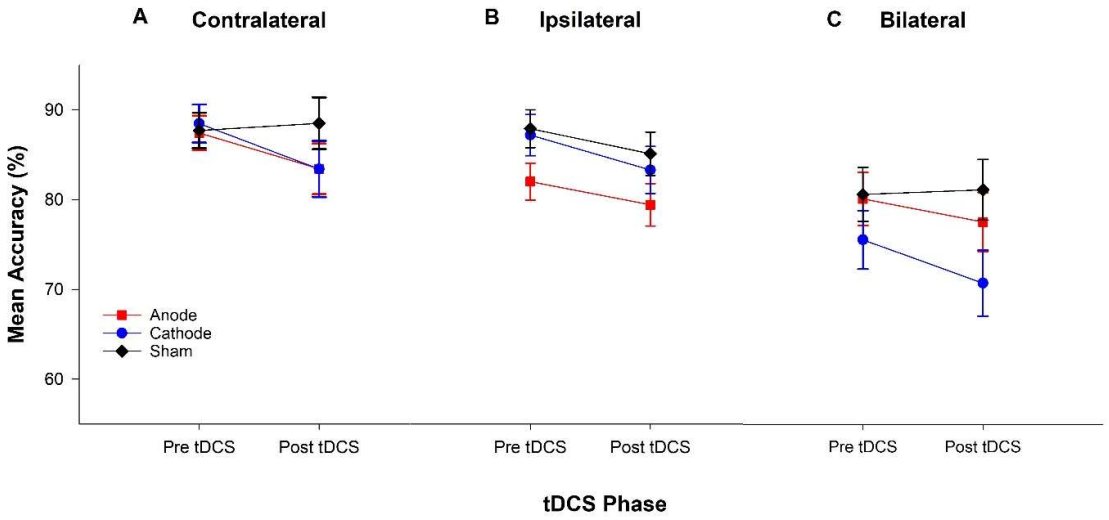

Figure 0.3 Mean accuracy (% correct) of responses both before and immediately after tDCS over the right PPC. Stimulation conditions are visualised as follows: Anodal (red line), cathodal (blue line), or sham (black line). (A) Performance for single stimuli presented contralateral to tDCS. (B) Performance for single stimuli presented ipsilateral to the tDCS. (C) Performance for bilateral stimuli presented across the two hemifields.

5.3.5 No Differential effects of tDCS over right PPC for single versus bilateral stimuli

To investigate the differential effects of tDCS on single and bilateral visual stimuli, we conducted three separate two-way ANOVA analyses, each corresponding to a different stimulus location (Contralateral, Ipsilateral, Bilateral). The factors in these analyses were Phase (Pre- and Immediately post-tDCS) and Stimulation Type (Anodal, Cathodal, Sham). The Phase x Stimulation Type interaction was not significant for ipsilateral ($F(2,55) = 0.069$, $p=0.933$, $\eta p^2=0.003$), contralateral ($F(2,55) = 1.428$, $p=0.249$, $\eta p^2=0.049$), or bilateral stimuli ($F(2,55) = 1.246$, $p=0.296$, $\eta p^2=0.043$). Similarly, the RT analysis revealed no modulation of performance with no Phase x Stimulation Type interaction for ipsilateral ($F(2,55) = 0.027$, $p=0.973$, $\eta p^2=0.001$), contralateral ($F(2,55) =0.222$, $p=0.802$, $\eta p^2=0.008$), and bilateral stimuli ($F(2,55) =1.379$, $p=0.260$, $\eta p^2=0.048$). For mean

accuracy scores before and after tDCS for each stimulation type and both single and bilateral stimuli, see Figure 5.3 and Table 5.1. For RT see Table 5.2.

EFFECT	RESULTS	FILMER ET AL. 2005	CONSISTENCY
Stimulation Type	No effect ($p = 0.323$)	No effect ($p = 0.27$)	Consistent
Phase	Significant decrease post-tDCS ($p= 0.014$)	No effect ($p = 0.26$)	Not Consistent
Stimulus Location	Single > Bilateral accuracy ($p < 0.001$)	No effect ($p = 0.46$)	Not Consistent
Stimulus x Phase x Type	No interaction ($p = 0.715$)	Significant interaction ($p < 0.05$)	Not Consistent
Phase x Stimulus	No interaction	Significant modulation for Anodal contralateral ($p < 0.01$). Anodal and Cathodal bilateral ($p<0.05$).	Not Consistent
Phase (Pre vs 20mins Post)	No effect ($p = 0.604$)	No effect ($p = 0.261$)	Consistent

Table 0.3 Comparison of Key Findings: Current Study vs. Filmer et al. (2015)

5.3.6 Pre- versus delayed-post

To compare performance in the pre- and delayed-post phases and assess residual effects, mean accuracy data and median RT were analysed as function of Stimulation Type, Phase, and Stimulus Location. There was no significant interaction between Stimulation Type, Phase, and Stimulus Location for accuracy ($F (4,110) = 0.684$, $p=0.604$, $\eta p^2=0.024$). Further analysis revealed the same for RT $F (2,108) = 1.120$, $p=0.351$, $\eta p^2=0.040$). Therefore, there was no evidence of any residual effect on performance 20 minutes after the stimulation.

5.4 Discussion

The present study aimed to investigate the effects of tDCS on spatial attention by targeting the right PPC, partially replicating the work of Filmer et al. (2015). Our main hypothesis was that anodal tDCS over the right PPC would impair the detection of both contralateral and bilateral stimuli, while cathodal tDCS would primarily affect bilateral stimuli. Additionally, we anticipated a greater performance decline when detecting competing bilateral stimuli compared to single stimuli.

A significant phase effect was observed, indicating a decline in both accuracy and RT from pre- to immediately post-tDCS across all groups may simply reflect participant fatigue rather than a temporary tDCS effect, given this was the case across all stimulation types, including sham. This contrasts with Filmer et al. (2015), who did not observe such an effect. Previous research has similarly found that prolonged cognitive tasks can lead to performance drops due to fatigue and reduced engagement (Mangin et al., 2022; Meier et al., 2024). These findings underscore the impact of cognitive load and task duration on performance outcomes.

An important finding in this study was the absence of a three-way interaction between Stimulus Location, Phase, and Stimulation Type, contrasting with the central finding of Filmer et al. (2015), who reported that anodal tDCS impaired detection of single contralateral stimuli, while both anodal and cathodal tDCS affected bilateral stimulus detection. This failure to replicate raises questions about the consistency of tDCS effects on attention and suggests that the conditions under which tDCS produce reliable effects need to be more clearly defined in future research (see Table 5.3 for a direct comparison of results between the current study and Filmer et al. (2015)).

Several methodological differences may explain these discrepancies and require consideration. Our study employed a between-subjects design, with distinct groups for each stimulation type (anodal, cathodal, and sham), in contrast to Filmer et al.'s within-subjects design, where each participant experienced all stimulation types. This change was made to minimize carry-over and order effects, and to facilitate recruitment logistics. However, this design increases inter-individual variability and reduces the statistical power to detect subtle effects, potentially not revealing true stimulation effects (Charness et al., 2012).

Another significant deviation from the original study was the increase in stimulation intensity, chosen to align with common standards in current tDCS research (Bikson et al., 2016; Smucny, 2021). Although this change aimed to improve comparability with broader literature, it may have altered the neuromodulatory impact, influencing outcomes differently than in the original study.

Minor differences in monitor size could have influenced task performance by affecting the visual properties of the stimuli, though stimuli were scaled accordingly, could also have minimally affected visual perception and task performance. However, overall consistency of the experimental design makes it unlikely that this had a substantial impact to the observed discrepancies.

Additionally, achieving a consistent threshold at the beginning of the experiment proved challenging, and there was high variability in pre-tDCS task performance, a difficulty not reported in the original study. While these methodological factors may contribute to the observed differences, it nevertheless offers caution to the confidence with which tDCS

may be considered to reliably modulate cognitive performance in tasks requiring attention to multiple stimuli.

Participants responded more quickly and accurately to single stimuli (whether contralateral or ipsilateral) compared to bilateral stimuli, in line with our prediction but in contrast to the findings of Filmer et al. (2015). This aligns with attentional competition theories, which suggest that the brain's limited capacity forces multiple stimuli to compete for attentional resources, leading to slower and less accurate responses (Marois & Ivanoff, 2005). Research has consistently shown that multitasking or managing multiple stimuli impairs performance compared to focusing on a single stimulus (Koch et al., 2018; Schumacher et al., 2018). This results also align with previous studies, demonstrating that RT and accuracy both decline when two stimuli are presented simultaneously due to increased cognitive load and divided attention (Butcher & Cavanagh, 2008; de Haan et al., 2015).

Our findings contribute to the literature on the right PPC's role in spatial attention, revealing a decline in performance following tDCS, especially in bilateral trials. However, the similar decline observed in the sham group suggests that task demands, rather than tDCS effects may explain the performance drop, highlighting the limited nature of attentional resources and the strain of stimulus competition suggesting that attentional resources are limited, and that stimulus competition can strain cognitive processing (Carrasco, 2018). Clinically, while our results did not replicate those of Filmer et al. (2015), they indicate the need for further exploration of tDCS in relation to attention deficits, such as USN. Future studies should further explore tDCS's potential applications, emphasizing the importance of standardized protocols in stimulation intensity, electrode placement, and task design.

In conclusion, our study investigated the effects of tDCS on spatial attention in the right PPC revealing a significant stimulus location effect, where single stimuli were processed more efficiently than competing bilateral stimuli. Additionally, we observed a phase effect, with performance declining from pre- to post-tDCS across all groups. However, we did not replicate the expected tDCS effects reported by Filmer et al. (2015), and the absence of a significant interaction between Stimulus Location, Phase, and Stimulation Type in this study raises doubts about tDCS's reliability in affecting attentional mechanisms. Furthermore, the lack of residual effects post-stimulation suggests that any cognitive benefits may be temporary. These findings underscore the need for further research to explore the efficacy of tDCS, particularly in clinical populations with attention-related deficits, and to optimize stimulation protocols for better outcomes.

CHAPTER 6.

General Discussion

6.1 Summary of experimental chapters

In recent years, there has been growing recognition of the need for more sensitive and clinically applicable diagnostic tools for assessing USN, particularly following stroke. Traditional PnP assessments, while widely used, face limitations in detecting subtle symptoms of neglect and often lack ecological validity. This thesis aimed to address these shortcomings by developing and testing a CB task battery designed to enhance diagnostic accuracy and improve the detection of mild and chronic neglect cases.

The first stage of this process explored the advantages of CB tasks over traditional methods for assessing USN, specifically through a systematic review of existing research on CB tasks and their effectiveness in capturing neglect-related deficits (Chapter 2). Based on the insights gathered, Chapter 3 focused on establishing normative data by testing unimpaired individuals using the newly developed CB task battery, which combined well-established tasks identified in Chapter 2. The goal was to define performance benchmarks and assess age-related differences in task performance, which would serve as a foundation for understanding performance in stroke survivors.

In Chapter 4, the CB task battery was tested on stroke survivors. The chapter aimed to evaluate the battery's clinical utility and its potential to enhance diagnostic accuracy by comparing the performance of stroke patients against conventional PnP methods. Additionally, patient data were compared with the established age-matched normative data from Chapter 3. In Chapter 4, the objective was to evaluate whether the CB task battery could not only confirm cases identified by traditional assessments but also uncover more subtle neglect symptoms that might be missed by PnP methods, ultimately enhancing diagnostic accuracy and supporting early intervention strategies.

Finally, Chapter 5 explored the potential of tDCS applied to the right PPC as a tool for modifying spatial attention in unimpaired individuals, as a basis for developing a related intervention for potential use in patients with USN.

6.2 Main findings

The strengths and limitations of CB assessments for USN were highlighted in Chapter 2. While CB adaptations of conventional tasks are common, more advanced designs, such as incorporating controlled exposure, cueing and dynamic stimuli, offer greater sensitivity and improve diagnostic accuracy. Outcome measures like RT and accuracy were reported to be particularly effective. Additionally, the systematic review highlighted variability in task duration and apparatus, and the optimal parameters remain unclear. However, minimizing task duration and motor demands may make tasks more tolerable for a broader range of patients while preventing biases related to other impairments. CB tasks offer greater flexibility, richer data, and improved sensitivity compared to conventional methods. However, challenges in standardization, equipment requirements, and limited evidence on specificity remain. Despite these issues, CB methods are feasible, valid, and should be integrated into clinical settings alongside conventional assessments, which remain highly effective for acute and severe cases.

Building on insights from Chapter 2, where existing CB tasks were identified by the systematic review, we developed a CB task battery comprising modified versions of four of these validated tasks: the Posner Cueing task, the dynamic Starry Night task, and the Feature and Conjunction visual search tasks. In Chapter 3, after testing younger and older adults, we found that older adults exhibited slower response times across all tasks, with

the difference being more pronounced in the more complex tasks like the Conjunction visual search task, although accuracy remained similar across groups. Pseudoneglect was observed in both groups, with a stronger leftward bias in younger adults, especially in more demanding tasks. Older adults were more affected by increasing distractor numbers, particularly in the Conjunction task, indicating greater vulnerability to visual load. The Posner Cueing task revealed delayed IOR onset in older adults, highlighting age-related differences in attentional control. Overall, the computer-based task battery effectively detected age-related changes in visuospatial attention, with the Conjunction task showing the most pronounced differences. The battery received positive feedback from participants regarding its design, clarity, and duration, supporting its potential for clinical integration in assessing visual attention in both unimpaired and stroke populations.

Chapter 4 evaluated the effectiveness of a CB task battery in detecting visuospatial attention deficits following stroke, comparing it to the widely used traditional PnP method via BIT conventional subtests. Patient data were compared to age-matched unimpaired data (Chapter 3), and the results highlighted the CB tasks' high sensitivity in detecting neglect, particularly the more demanding Conjunction task. This task outperformed others, such as the Posner Cueing task, by identifying a higher number of neglect cases. RT was found to be a more sensitive indicator of USN than accuracy, with RT often revealing lateralized deficits even when accuracy remained within normal limits. All cases identified by the BIT were also verified by the CB tasks, further validating the effectiveness of these tasks in detecting neglect, both as a battery and independently. The BIT, although widely used, failed to capture lateralized attentional biases in many cases, likely due to its reliance on a non-lateralized total score, static stimuli, and limited task variety. In contrast, the dynamic nature of CB tasks allowed for a more detailed assessment of attentional

biases, suggesting these tasks have valuable complementary utility in clinical settings. Additionally, participants found the CB tasks more user-friendly, suggesting greater patient engagement and improved compliance compared to traditional methods. These findings support the integration of CB assessments into clinical practice to enhance diagnostic precision, provide more personalized rehabilitation strategies, and ultimately improve stroke care.

Finally, in Chapter 5 we aimed to partially replicate the study by Filmer et al. (2015), which reported that anodal tDCS over the right PPC impaired detection of contralateral stimuli, while both anodal and cathodal stimulation affected bilateral stimulus detection. Our findings indicate that tDCS over the right PPC did not produce a noticeable impact on visuospatial attention, as participants performed similarly under anodal, cathodal and sham stimulation. While we observed a decline in performance from pre- to post-tDCS across all groups, this was likely due to participant fatigue rather than a direct tDCS effect. Despite the decline in performance observed in the bilateral trials, similar drops were also seen in the sham group, suggesting that task demands, rather than tDCS effects were responsible. These results highlight the complexity of tDCS effects and suggest that further research is needed to define the conditions under which tDCS may reliably modulate spatial attention, particularly in clinical contexts, such as its potential use as a rehabilitation tool for USN in stroke survivors.

6.3 Discussion of findings from the thesis

6.3.1 Beyond the Results: What They Mean and what they tell us?

The findings presented in this thesis provide valuable insights into the use of CB assessment for USN, their advantages and limitations, and their role alongside traditional methods. This research is strengthened by the large number of participants tested, allowing for a comprehensive evaluation of CB tasks across different populations. Rather than reiterating the results, this section explores their broader implications, both theoretically and clinically.

Theoretical Implications

The results contribute to our understanding of visuospatial attention, age-related differences, and the effectiveness of CB tasks in capturing attentional biases. The observation that older adults exhibited slower response times, particularly in tasks with greater visual load (e.g., the Conjunction task), aligns with theories of age-related declines in attentional control (Müller-Oehring et al., 2013). Similarly, the presence of pseudoneglect across all groups, with a stronger leftward bias in younger adults, suggests that pseudoneglect declines with age, reflecting a potential shift in hemispheric asymmetry (Benwell et al., 2014). In the context of USN, the greater sensitivity of CB tasks, particularly RT measures, emphasizes the importance of dynamic assessments over static paper-based methods (Bonato et al., 2013). The failure of the BIT to capture lateralized attentional deficits in some cases further supports the idea that neglect is not a singular deficit but a complex, task-dependent phenomenon (Bonato, 2012). These findings highlight the need for more sensitive assessment tools that can detect subtle attentional biases beyond those identified by conventional methods.

The results of the tDCS study further underscore the complexity of neuromodulation effects. While prior studies (e.g., Filmer et al., 2015) suggested that anodal tDCS over the right PPC could modulate spatial attention, our findings did not replicate these effects. Instead, performance declined across all groups, likely due to fatigue rather than direct stimulation effects. This highlights the challenge of translating tDCS findings into clinically meaningful interventions and raises questions about the reliability of non-invasive brain stimulation in modulating attention (González-Rodriguez et al., 2022).

Clinical Implications

From a clinical perspective, these findings suggest that CB tasks could serve as valuable complementary tools in the assessment and monitoring of USN. While traditional methods like the BIT remain effective for detecting severe neglect, they may lack the sensitivity needed for identifying milder deficits. CB tasks, particularly those incorporating RT measures, offer a more detailed picture of attentional biases and can improve diagnostic accuracy. The positive feedback from participants regarding the usability of the CB battery also suggests that these tasks are well tolerated and engaging, potentially increasing compliance in clinical settings. The study also reinforces the importance of task design in ensuring accessibility and feasibility for stroke survivors. While CB tasks offer richer data and improved sensitivity, challenges such as standardization, equipment availability, and potential training requirements must be addressed before widespread clinical adoption. Furthermore, making the tasks open source with immediate access to results for clinicians and practitioners will be essential for facilitating their use in clinical settings. Additionally, minimizing task duration and motor demands remains a crucial consideration to accommodate patients with varying levels of impairment.

The tDCS study further complements the behavioral findings by exploring potential neuromodulatory approaches to alter spatial attention. Although the expected stimulation effects were not observed, the exploration of brain stimulation effects bridges the gap between cognitive assessment and intervention. Clinical population like stroke survivors, could potentially benefit from the combination of sensitive assessment tools like CB tasks with targeted interventions like brain stimulation to manage spatial attention deficits.

6.3.2 Context within Existing Research

Understanding the impact of our findings would benefit from placing these in the broader context of visuospatial attention and neglect research. This section explores how our work aligns with previous research.

Previous research highlights the complexity of USN, with variations in symptoms, severity, and underlying mechanisms (Durfee & Hillis, 2023). As discussed earlier, conventional assessments like cancellation tests and line bisection are widely used but often lack sensitivity to subtle deficits (Deouell et al., 2005; Kaufmann et al., 2020). In contrast, CB assessments have been shown to offer greater precision through measures like RT and more dynamic task design (Rengachary et al., 2009). Our research builds on these insights by developing a CB task battery with modified versions of validated tasks designed to detect attentional biases and spatial deficits with potentially wide application to clinical practice. Contributions include: (i) confirming age-related differences in visuospatial processing, which informs normative baselines for future clinical comparisons; (ii) demonstrating CB tasks' superior sensitivity in detecting lateralized attention deficits compared to traditional assessments, and (iii) assessing the feasibility and usability of CB tasks in large samples of both unimpaired adults and stroke survivors. These contributions

reinforce previous findings on the advantages of CB methods while addressing the need for standardised tests to be readily available and applicable for use in clinical practice (Vaes et al., 2015; Van der Stoep et al., 2013).

Additionally, the tDCS study, targeting the right PPC, although using unimpaired individuals instead of stroke survivors, aligned with clinical protocols using anodal stimulation over the ipsilesional hemisphere to promote recovery (Allman et al., 2016; da Silva et al., 2022; Yi et al., 2016). Chapter 5 explores these effects by testing right parietal stimulation in a controlled setting, with the aim of enhancing our understanding of stimulation effects and variability, which could inform protocols to clinical populations.

6.3.3 Current Guidance & Practical Considerations

The growing body of research on USN has led to various assessment guidelines and recommendations. However, despite these efforts, challenges remain in determining how best to integrate different assessment approaches into clinical practice. This section explores the current state of guidance, the role of CB assessments alongside traditional methods, and key practical considerations for their implementation.

Several reviews have highlighted the potential of CB methods for assessing USN due to their sensitivity (Bonato & Deouell, 2013; Gammeri et al., 2020). However, current formal clinical guidelines not yet explicitly recommend CB tasks, and no widely available, standardised CB battery is currently in routine clinical use (NICE, 2023; Canadian Stroke Best Practice Recommendations, 2019). However, a significant challenge remains in translating these recommendations into practical, clinically feasible assessments. While CB methods are gaining recognition for their enhanced sensitivity and richer data outputs, their integration into routine clinical practice is still limited (Young et al., 2022). This raises

an ongoing debate about how clinicians and researchers can best take advantage of existing guidance to optimize USN assessment in a way that is both effective and feasible in clinical settings. Addressing this requires a balanced approach that considers the strengths of CB methods, the need for standardization, and the practical constraints of clinical environments (Guilbert, 2023).

A key consideration is how CB batteries align with current guidelines. While conventional PnP tasks remain the standard, their limitations, raise concerns about relying solely on such tasks in clinical assessments. Existing recommendations often lack detailed guidance on incorporating newer, more sensitive CB measures. Addressing this gap requires a structured approach that outlines how CB tasks can complement traditional assessments while ensuring practical feasibility in clinical settings.

PnP tasks, such as those used in the BIT, provide a well-established method for diagnosing severe cases USN. However, as highlighted in previous chapters, their reliance on static stimuli and total scoring methods often results in missed cases. Unlike CB tasks, which can capture RT and dynamic attentional shifts, PnP assessments often lack the sensitivity needed for early detection or detailed deficit profiling (Rengachary et al., 2009; Schendel & Robertson, 2002). Despite these limitations, PnP tasks remain highly effective for severe cases and serve as a practical option in resource-limited settings (Azouvi et al., 2002). To bridge this gap, CB methods should be standardised and incorporated into assessment protocols where possible. Their ability to provide richer data and improved sensitivity makes them valuable complementary tools, particularly in cases where PnP tasks are not effective. However, challenges such as standardisation, equipment requirements, and accessibility must be addressed before widespread clinical adoption.

6.3.4 Role of Computer-Based Assessments

CB assessments have gained increasing recognition as valuable tools for evaluating USN. While traditional PnP methods remain widely used and clinically accepted, CB tasks offer unique advantages that can enhance both assessment accuracy and patient monitoring. We explored the role of CB assessments, their integration with existing guidance, and their application in both diagnostic and rehabilitative settings.

Complementing traditional methods

PnP assessments, such as those included in the BIT, have long acted as a gold standard for USN diagnosis (Marques et al., 2019). They are accessible, easy to administer, and provide a well-established method for identifying severe neglect. However, as highlighted in earlier chapters, PnP tasks have limitations, particularly in their ability to detect subtle or even distinguish lateralized deficits.

Our results confirm that CB assessments can address the limitations of traditional PnP tasks by offering several advantages. They provide increased sensitivity, especially through the use of RT measures allowing for a more precise evaluation of attentional biases, even when accuracy may remain intact. CB tasks also generate richer data outputs, capturing detailed response patterns that are difficult to measure with PnP tasks (Andres et al., 2019). Additionally, they offer dynamic and adaptive testing, where task complexity and stimuli presentation can be manipulated, providing a more tailored assessment (Ten Brink et al., 2020; Van Kessel, Van Nes, et al., 2013). Given these strengths, we believe that CB assessments should not replace PnP tasks but rather complement them. Integrating CB assessments into clinical workflows would create a more comprehensive approach to evaluation, utilizing the strengths of both methods.

Fitting CB Assessments Within Existing Guidance

Current guidelines for USN assessment emphasize the need for standardized, evidence-based tools (NICE, 2023). However, many recommendations primarily focus on conventional methods, with limited guidance on incorporating CB approaches. Given their demonstrated validity and feasibility, CB assessments should be included more in future revisions of assessment guidelines, particularly in cases where PnP tasks produce unclear results. For example, if a star cancellation task shows no impairment or borderline impairment, the Conjunction visual search task could be used to compare accuracy and RT between the left and right sides, providing additional insight into spatial attention deficits. To ensure effective integration, guidance should address several key points. First, it should define when to use CB tasks, such as in cases of mild neglect or for tracking recovery over time. Second, standardized scoring and interpretation should be established, with clear criteria for understanding CB-obtained data, especially RT-based measures. Finally, practical implementation should be considered, with recommendations on how CB tasks can be feasibly introduced into various clinical settings, considering resource availability and patient needs. By refining existing guidance to include CB methods, clinicians will have clearer protocols for incorporating these tools into both research and practice.

Assessment in Practice and Monitoring Response to Intervention

Beyond initial diagnosis, CB tasks offer significant potential for monitoring neglect progression and response to intervention. Their ability to provide continuous, detailed data allows for more precise tracking of recovery, making them valuable for evaluating rehabilitation strategies (Bonato & Deouell, 2013). CB tasks can detect small changes over

time, unlike static PnP tasks, enabling the capture of gradual improvements in attentional control (List et al., 2008). For instance, if initial PnP tasks show minimal impairment, CB tasks could identify subtle lateralised differences, such as slower RT or accuracy. This indicates that CB tasks are appropriate tools for detecting short- and long-term effects of neuromodulatory interventions, like tDCS. Additionally, by identifying specific attentional deficits, interventions may be tailored to the patient's individual needs. The interactive nature of many CB tasks may also improve patient engagement and compliance, potentially enhancing motivation throughout long-term rehabilitation (Ulm et al., 2013).

Given these benefits, CB assessments should be considered not only for initial diagnosis but also as ongoing tools for evaluating treatment efficacy. Integrating them into clinical practice could enhance patient care by providing more detailed insights into neglect recovery.

6.4 Future Directions

As research on USN continues to evolve, it is crucial to reflect on the current state of assessment and intervention strategies. While existing guidance provides a foundation for clinical practice, there remain gaps in standardization, sensitivity, and implementation that must be addressed. This section outlines key areas for future research, evaluates whether current guidance is optimal, and explores the potential trajectory of USN assessment over the coming decades.

6.4.1 Evaluating Current Guidance: Is It Optimal?

Current recommendations for USN assessment rely heavily on traditional PnP tasks, which, while clinically effective for severe neglect, may lack the sensitivity needed for detecting more subtle impairments (Cavedoni et al., 2022; Halligan et al., 1989) . While CB assessments have demonstrated their feasibility, they are not yet fully integrated into clinical guidelines. The absence of clear protocols for incorporating CB tools means that many clinicians continue to rely on conventional methods, potentially missing many cases of neglect (Checketts et al., 2021).

To optimize current guidance, future work should focus on several key areas. First, clear criteria should be established for selecting assessment methods based on the severity of neglect, the clinical context, and factors such as time constraints (Evald et al., 2021; Fisher et al., 2024). Second, CB assessments should be recognized as complementary tools to PnP tasks, rather than alternatives. Third, addressing the challenges of standardization is crucial to ensure consistency across various CB platforms. By refining guidance to integrate CB assessments and emerging technologies more effectively, assessment strategies can be made more comprehensive, adaptable, and clinically impactful, ultimately enhancing patient care.

Additionally, the lack of the expected effects in the tDCS study suggests that future research focusing on clinical protocols, should consider the potential impact of fatigue, individual variability in responsiveness, and the importance of optimising task design and stimulation parameters when aiming for clinical applications.

6.4.2 Key Recommendations for Advancing USN Research

To improve assessment and rehabilitation approaches, future research should focus on several key areas. Future directions for CB Integration are illustrated in figure 6.1. First, refining CB task design is essential to create tasks that balance sensitivity, practicality, and ease of use in clinical settings. Based on our findings, the Conjunction visual search task appears best suited as a frontline CB assessment, particularly in cases where PnP tasks produce inconclusive results. Second, standardization and validation of CB assessment protocols should be prioritized to ensure consistency in data interpretation. Third, exploring the integration of CB tasks with rehabilitation strategies will be crucial, as they can serve not only for diagnosis but also as interactive tools for rehabilitation. Additionally, conducting longitudinal studies that utilize CB tasks will provide valuable insights into how neglect symptoms progress over time and how various interventions impact recovery trajectories (Farrington, 1991). Finally, investigating the neurophysiological and neuroimaging correlates of CB task performance will provide deeper insights into the underlying neural mechanisms, further refining diagnostic precision and treatment approaches (Corbetta & Shulman, 2011).

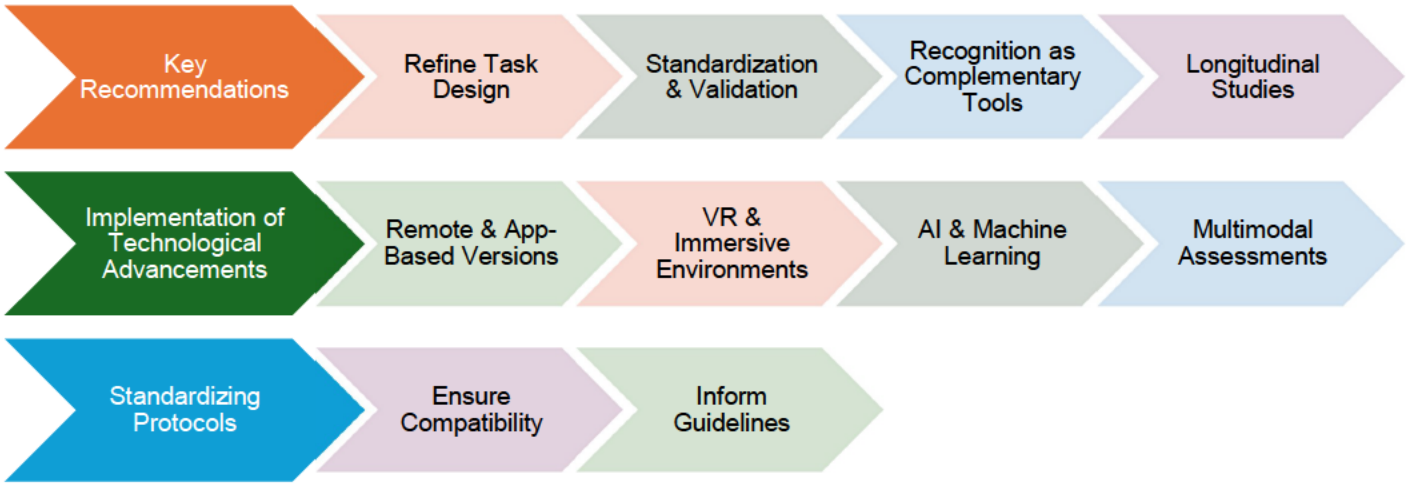

Figure 6.1 Future Directions for Computer-Based Task Integration

6.4.3 Looking Forward: The Next 40 Years

Over the past 40 years, primarily in the research domain but also in clinical settings, there has been a gradual shift from static, paper-based assessments to more dynamic, technology-driven methods, incorporating CB and VR tools. Looking ahead, the future of USN assessment and treatment holds exciting possibilities. We can expect greater use of AI and machine learning, which could improve diagnostic accuracy through predictive modelling, enabling more personalized rehabilitation strategies (Gala et al., 2024). For example, by analysing patterns in large datasets, such as RT or accuracy, to identify subtle neglect symptoms, or by using response patterns to predict the effectiveness of specific interventions based on patient characteristics (Dresser & Kohn, 2023; Javed et al., 2023). Additionally, app-based and remote assessments may allow for continuous monitoring of neglect symptoms, providing better long-term care and enabling patients to manage their condition from home (Ahsun et al., 2024; Bonura et al., 2022). The integration of multimodal assessments, combining behavioural, neuroimaging, and physiological data, will offer a more holistic understanding of USN, enhancing diagnostic precision.

Furthermore, VR applications could create more immersive and ecologically valid environments for assessments and rehabilitation, improving patient engagement and treatment effectiveness (Pedroli et al., 2015; Salatino et al., 2023). If these technological advancements are successfully integrated, the future of USN assessment and treatment could be more precise, accessible, and tailored to individual needs, ultimately improving outcomes for patients.

Current guidance offers a foundation for USN assessment but does not fully address the complexity of the syndrome or incorporate all available tools, particularly CB methods. Future research should focus on refining CB assessments, improving standardization, and exploring innovative technologies that could transform how neglect is diagnosed and treated. With continued advancements, the next 40 years could see a transformative shift in USN assessment, transitioning toward more dynamic, data-driven, and patient-centred approaches.

6.5 Final Remarks

Together, the findings of this thesis provide strong evidence for the efficacy of CB assessment tools in improving the detection of USN, particularly in mild or subclinical cases. These results contribute to bridging the gap between research and clinical practice, offering new opportunities for better diagnosing and treating USN in stroke survivors.

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APPENDIX

APPENDIX 1. List of Excluded Citations with Reasons for Exclusion

List of excluded citations	Reasons for exclusion
Anderson, B., Mennemeier, M., and Chatterjee, A. (2000). Variability not ability: Another basis for performance decrements in neglect. Neuropsychologia 38(6), 785-796. doi: 10.1016/S0028-3932(99)00137-2.	Absence or unclear evaluation of the task or comparison with conventional tool.
Anton, H.A., Hershler, C., Lloyd, P., and Murray, D. (1988). Visual neglect and extinction: A new test. Archives of Physical Medicine and Rehabilitation 69(12), 1013-1016.	Out of scope.
Arguin, M., and Bub, D. (1993). Modulation of the directional attention deficit in visual neglect by hemispatial factors. Brain and Cognition 22(2), 148-160.	Out of scope.
Bartolomeo, P., Chokron, S., and Sieroff, E. (1999). Facilitation instead of inhibition for repeated right-sided events in left neglect. NeuroReport: For Rapid Communication of Neuroscience Research 10(16), 3353-3357.	Absence or unclear evaluation of the task or comparison with conventional tool.
Baylis, G.C., Baylis, L.L., and Gore, C.L. (2004). Visual neglect can be object-based or scene-based depending on task representation. Cortex 40(2), 237-246. doi: 10.1016/S0010-9452(08)70119-9.	Absence or unclear evaluation of the task or comparison with conventional tool.
Behrmann, M., and Tipper, S.P. (1999). Attention Accesses Multiple Reference Frames: Evidence From Visual Neglect. Journal of Experimental Psychology: Human Perception & Performance 25(1), 83-101.	Absence or unclear evaluation of the task or comparison with conventional tool.
Beis, J.M., André, J.M., and Saguez, A. (1994). Detection of visual field deficits and visual neglect with computerized light emitting diodes. Archives of Physical Medicine and Rehabilitation 75(6), 711-714. doi: 10.1016/0003-9993(94)90201-1.	Absence of or unclear information regarding the design of the task (e.g.,

	apparatus, task demands).
Benson, V., Ietswaart, M., and Milner, D. (2012). Eye movements and verbal report in a single case of visual neglect. PLoS ONE 7(8).	Out of scope.
Bergego, C., Azouvi, P., Deloche, G., Samuel, C., Louis-Dreyfus, A., Kaschel, R., et al. (1997). Rehabilitation of unilateral neglect: A controlled multiple-baseline-across-subjects trial using computerised training procedures. Neuropsychological Rehabilitation 7(4), 279-294. doi: 10.1080/713755548.	Out of scope.
Blini, E., Romeo, Z., Spironelli, C., Pitteri, M., Meneghello, F., Bonato, M., et al. (2016). Multi-tasking uncovers right spatial neglect and extinction in chronic left-hemisphere stroke patients. Neuropsychologia 92, 147-157. doi: 10.1016/j.neuropsychologia.2016.02.028.	Absence or unclear evaluation of the task or comparison with conventional tool.
Borsotti, M., Mosca, I.E., Di Lauro, F., Pancani, S., Bracali, C., Dore, T., et al. (2020). The Visual Scanning Test: a newly developed neuropsychological tool to assess and target rehabilitation of extrapersonal visual USN. Neurol Sci 41(5), 1145-1152. doi: 10.1007/s10072-019-04218-2.	Absence or unclear evaluation of the task or comparison with conventional tool.
Bourgeois, A., Chica, A.B., Migliaccio, R., de Schotten, M.T., and Bartolomeo, P. (2012). Cortical control of inhibition of return: Evidence from patients with inferior parietal damage and visual neglect. Neuropsychologia 50(5), 800-809. doi: 10.1016/j.neuropsychologia.2012.01.014.	Absence or unclear evaluation of the task or comparison with conventional tool.
Bublak, P., Finke, K., Krummenacher, J., Preger, R., Kyllingsbaek, S., Müller, H.J., et al. (2005). Usability of a theory of visual attention (TVA) for parameter-based measurement of attention II: evidence from two patients with frontal or parietal damage. J Int Neuropsychol Soc 11(7), 843-854. doi: 10.1017/s1355617705050988.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Carter, A.R., McAvoy, M.P., Siegel, J.S., Hong, X., Astafiev, S.V., Rengachary, J., et al. (2017). Differential white matter involvement associated with distinct visuospatial deficits after right hemisphere stroke. Cortex 88, 81-97. doi: 10.1016/j.cortex.2016.12.009.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Champod, A.S., Taylor, K., and Eskes, G.A. (2014). Development of a new computerized prism adaptation procedure for visuo-spatial neglect. Journal of Neuroscience Methods 235, 65-75. doi: 10.1016/j.jneumeth.2014.05.023.	Absence or unclear evaluation of the task or comparison with conventional tool.

Cheyne, J.A., Solman, G.J.F., Carriere, J.S.A., and Smilek, D. (2009). Anatomy of an error: A bidirectional state model of task engagement/disengagement and attention-related errors. COGNITION 111(1), 98-113. doi: 10.1016/j.cognition.2008.12.009.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Chiba, Y., Yamaguchi, A., and Eto, F. (2006). Assessment of sensory neglect: A study using moving images. Neuropsychological Rehabilitation 16(6), 641-652. doi: 10.1080/09602010543000073.	Absence or unclear evaluation of the task or comparison with conventional tool.
Clatworthy, P.L., Warburton, E.A., Tolhurst, D.J., and Baron, J.C. (2013). Visual contrast sensitivity deficits in 'normal' visual field of patients with homonymous visual field defects due to stroke: A pilot study. Cerebrovascular Diseases 36(5-6), 329-335. doi: 10.1159/000354810.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Cohen, A., Ivry, R.B., Rafal, R.D., and Kohn, C. (1995). Activating Response Codes by Stimuli in the Neglected Visual Field. Neuropsychology 9(2), 165-173.	Absence or unclear evaluation of the task or comparison with conventional tool.
Corbetta, M., Kincade, M.J., Lewis, C., Snyder, A.Z., and Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. Nature Neuroscience 8(11), 1603-1610. doi: 10.1038/nn1574.	Out of scope.
Coslett, H.B. (1997). Neglect in vision and visual imagery: a double dissociation. Brain 120 (Pt 7), 1163-1171. doi: 10.1093/brain/120.7.1163.	Absence or unclear evaluation of the task or comparison with conventional tool.
Costantini, M., Bueti, D., Pazzaglia, M., and Aglioti, S.M. (2007). Temporal Dynamics of Visuo-Tactile Extinction Within and Between Hemispaces. Neuropsychology 21(2), 242-250.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Crewther, S.G., Wijesundera, C., Wijeratne, T., Kong, G., and Vingrys, A.J. (2018). High prevalence of visual field impairments in acute stroke patients. INVESTIGATIVE OPHTHALMOLOGY & VISUAL SCIENCE 59(9).	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Crottaz-Herbette, S., Fornari, E., and Clarke, S.(2014). Prismatic Adaptation Changes Visuospatial Representation in the Inferior Parietal Lobule. Journal of Neuroscience 34(35), 11803-11811. doi: 10.1523/jneurosci.3184-13.2014.	Not focusing (or clarifying focusing) on assessing the

	presence or severity of USN.
Crottaz-Herbette, S., Tissieres, I., Fornari, E., Rapin, P.-A., and Clarke, S. (2019). Remodelling the attentional system after left hemispheric stroke: Effect of leftward prismatic adaptation. Cortex 115, 43-55. doi: 10.1016/j.cortex.2019.01.007.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Cullen, B., Brennan, D., Manly, T., and Evans, J.J. (2016). Towards Validation of a New Computerised Test of Goal Neglect: Preliminary Evidence from Clinical and Neuroimaging Pilot Studies. PloS one 11(1), e0148127. doi: 10.1371/journal.pone.0148127.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
D'Erme, P., Robertson, I., Bartolomeo, P., Daniele, A., and Gainotti, G. (1992). Early rightwards orienting of attention on simple reaction time performance in patients with left-sided neglect. Neuropsychologia 30(11), 989-1000. doi: 10.1016/0028-3932(92)90050-V.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Dalmaijer, E.S., Van der Stigchel, S., Nijboer, T.C., Cornelissen, T.H., and Husain, M. (2015). CancellationTools: All-in-one software for administration and analysis of cancellation tasks. Behavior research methods 47(4), 1065-1075.	Absence or unclear evaluation of the task or comparison with conventional tool.
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Donnelly, N., Guest, R., Fairhurst, M., Potter, J., Deighton, A., and Patel, M. (1999). Developing algorithms to enhance the sensitivity of cancellation tests of visuospatial neglect. Behavior Research Methods Instruments & Computers 31(4), 668-673. doi: 10.3758/bf03200743.	Absence or unclear evaluation of the task or comparison with conventional tool.
Dove, M., Eskes, G., Klein, R., and Shore, D. (2007). A left attentional bias in chronic neglect: A case study using temporal order judgments. Neurocase 13(1), 37-49. doi: 10.1080/13554790601174146.	Out of scope.
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of object motion. Neuroreport 10(5), 1041-1047. doi: 10.1097/00001756-199904060-00027.	
Egly, R., Driver, J., and Rafal, R.D. (1994). Shifting Visual Attention Between Objects and Locations: Evidence From Normal and Parietal Lesion Subjects. Journal of Experimental Psychology: General 123(2), 161-177.	Out of scope.
Esterman, M., McGlinchey-Berroth, R., and Milberg, W. (2000). Preattentive and Attentive Visual Search in Individuals With Hemispatial Neglect. Neuropsychology 14(4), 599-611.	Absence or unclear evaluation of the task or comparison with conventional tool.
Fellrath, J., and Ptak, R. (2015). The role of visual saliency for the allocation of attention: Evidence from spatial neglect and hemianopia. Neuropsychologia 73, 70-81. doi: 10.1016/j.neuropsychologia.2015.05.003.	Absence or unclear evaluation of the task or comparison with conventional tool.
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Fortis, P., Goederth, K.M., and Barrett, A.M. (2011). Prism adaptation differently affects motor-intentional and perceptual-attentional biases in healthy individuals. Neuropsychologia 49(9), 2718-2727. doi: 10.1016/j.neuropsychologia.2011.05.020.	Out of scope.
Friedrich, F.J., Egly, R., Rafal, R.D., and Beck, D. (1998). Spatial Attention Deficits in Humans: A Comparison of Superior Parietal and Temporal-Parietal Junction Lesions. Neuropsychology 12(2), 193-207.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Grabowska, A., Marchewka, A., Seniów, J., Polanowska, K., Jednoróg, K., Królicki, L., et al. (2011). Emotionally negative stimuli can overcome attentional deficits in patients with visuo-spatial hemineglect. Neuropsychologia 49(12), 3327-3337. doi: 10.1016/j.neuropsychologia.2011.08.006.	Absence or unclear evaluation of the task or comparison with conventional tool.
Grimsen, C., Hildebrandt, H., and Fahle, M. (2008). Dissociation of egocentric and allocentric coding of space in visual search after right middle cerebral artery stroke. Neuropsychologia 46(3), 902-914. doi: 10.1016/j.neuropsychologia.2007.11.028.	Out of scope.
Guest, R., Fairhurst, M., and Potter, J. (2002). Diagnosis of Visuo-Spatial Neglect Using Dynamic Sequence Features from a Cancellation Task. Pattern Analysis & Applications 5, 261-270.	Absence or unclear evaluation of the task or comparison

	with conventional tool.
Halligan, P.W., and Marshall, J.C. (1989). Two techniques for the assessment of line bisection in visuo-spatial neglect: A single case study. Journal of Neurology Neurosurgery and Psychiatry 52(11), 1300-1302. doi: 10.1136/jnnp.52.11.1300.	Absence or unclear evaluation of the task or comparison with conventional tool.
Habekost, T., and Bundesen, C. (2003). Patient assessment based on a theory of visual attention (TVA): Subtle deficits after a right frontal-subcortical lesion. Neuropsychologia 41(9), 1171-1188. doi: 10.1016/S0028-3932(03)00018-6.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN..
Halligan, P.W., and Marshall, J.C. (1989). Two techniques for the assessment of line bisection in visuo-spatial neglect: A single case study. Journal of Neurology Neurosurgery and Psychiatry 52(11), 1300-1302. doi: 10.1136/jnnp.52.11.1300.	Absence or unclear evaluation of the task or comparison with conventional tool.
Hill, N.J., Mooney, S.W.J., Ryklin, E.B., and Prusky, G.T. (2019). Shady: A software engine for real-time visual stimulus manipulation. Journal of neuroscience methods 320, 79-86. doi: 10.1016/j.jneumeth.2019.03.020.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN..
Hillis, A.E., Mordkoff, J.T., and Caramazza, A. (1999). Mechanisms of spatial attention revealed by hemispatial neglect. Cortex 35(3), 433-442. doi: 10.1016/s0010-9452(08)70811-6.	Out of scope.
Hillis, A.E., Rapp, B., Benzing, L., and Caramazza, A. (1998). Dissociable coordinate frames of unilateral spatial neglect: "viewer-centered" neglect. Brain Cogn 37(3), 491-526. doi: 10.1006/brcg.1998.1010.	Out of scope.
Hopfner, S., Kesselring, S., Cazzoli, D., Gutbrod, K., Laube-Rosenpflanzer, A., Chechlacz, M., et al. (2015). Neglect and Motion Stimuli--Insights from a Touchscreen-Based Cancellation Task. PLoS One 10(7), e0132025. doi: 10.1371/journal.pone.0132025.	Absence or unclear evaluation of the task or comparison with conventional tool.
Ishiai, S., Koyama, Y., Nakano, N., Seki, K., Nishida, Y., and Hayashi, K. (2004). Image of a line is not shrunk but neglected. Absence of crossover in unilateral spatial neglect. Neuropsychologia 42(2), 251-256. doi: 10.1016/s0028-3932(03)00153-2.	Not focusing (or clarifying focusing) on assessing the presence or severity of unilateral spatial neglect.

Kaizer, F., Korner-Bitensky, N., Mayo, N., Becker, R., and Coopersmith, H. (1988). Response time of stroke patients to a visual stimulus. Stroke 19(3), 335-339. doi: 10.1161/01.STR.19.3.335.	Absence or unclear evaluation of the task or comparison with conventional tool.
Kerkhoff, G., and Marquardt, C. (1995). VS - A new computer program for detailed offline analysis of visual-spatial perception. Journal of Neuroscience Methods 63(1-2), 75-84. doi: 10.1016/0165-0270(95)00090-9.	Absence or unclear evaluation of the task or comparison with conventional tool.
Kim, E.J., Lee, B.H., Park, K.C., Suh, M.K., Ku, B.D., Heilman, K.M., et al. (2009). Consecutive versus return motor perseveration during line cancellation task in hemispatial neglect. Cogn Behav Neurol 22(2), 122-126. doi: 10.1097/WNN.0b013e3181a7227f.	Out of scope.
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Kurylo, D.D., Waxman, R., and Kezin, O. (2006). Spatial-temporal characteristics of perceptual organization following acquired brain injury. Brain injury 20(3), 237-244. doi: 10.1080/02699050500487415.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Làdavas, E., Paladini, R., and Cubelli, R. (1993). Implicit associative priming in a patient with left visual neglect. Neuropsychologia 31(12), 1307-1320. doi: 10.1016/0028-3932(93)90100-E.	Out of scope.
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Machado, L., and Rafal, R.D. (2004). Control of Fixation and Saccades in Humans With Chronic Lesions of Oculomotor Cortex. Neuropsychology 18(1), 115-123.	Out of scope.

Marshall, J.C., and Halligan, P.W. (1991). A STUDY OF PLANE BISECTION IN 4 CASES OF VISUAL NEGLECT. Cortex 27(2), 277-284. doi: 10.1016/s0010-9452(13)80132-3.	Out of scope.
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McGeorge, P., Beschin, N., and Sala, S.D. (2006). Representing Target Motion: The Role of the Right Hemisphere in the Forward Displacement Bias. Neuropsychology 20(6), 708-715.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Mondor, T.A., and Amirault, K.J. (1998). Effect of Same- and Different-Modality Spatial Cues on Auditory and Visual Target Identification. Journal of Experimental Psychology: Human Perception & Performance 24(3), 745-755.	Out of scope.
Nijboer, T.C.W., Olthoff, L., Van Der Stigchel, S., and Visser-Meily, J.M.A. (2014). Prism adaptation improves postural imbalance in neglect patients. NeuroReport 25(5), 307-311. doi: 10.1097/WNR.0000000000000088.	Out of scope.
Nogueira, R.G., Silva, G.S., Lima, F.O., Yu-Chih, Y., Fleming, C., Branco, D., et al. (2017). The FAST-ED App: A Smartphone Platform for the Field Triage of Patients With Stroke. Stroke (00392499) 48(5), 1278-1284. doi: 10.1161/STROKEAHA.116.016026.	Absence or unclear evaluation of the task or comparison with conventional tool.
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Olivers, C.N.L., and Humphreys, G.W. (2004). Spatiotemporal Segregation in Visual Search: Evidence From Parietal Lesions. Journal of Experimental Psychology: Human Perception & Performance 30(4), 667-688.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Pashler, H. (1991). Shifting Visual Attention and Selecting Motor Responses: Distinct Attentional Mechanisms. Journal of	Out of scope.

Experimental Psychology: Human Perception & Performance 17(4), 1023-1040.	
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Plummer, P., Dunai, J., and Morris, M.E. (2006). Understanding the effects of moving visual stimuli on unilateral neglect following stroke. Brain and Cognition 60(2), 156-165. doi: 10.1016/j.bandc.2005.11.001.	Absence or unclear evaluation of the task or comparison with conventional tool.
Posner, M.I., Cohen, Y., and Rafal, R.D. (1982). Neural systems control of spatial orienting. Philos Trans R Soc Lond B Biol Sci 298(1089), 187-198. doi: 10.1098/rstb.1982.0081.	Absence or unclear evaluation of the task or comparison with conventional tool.
Pouget, A., and Sejnowski, T.J. (2001). Simulating a lesion in a basis function model of spatial representations: comparison with hemineglect. Psychol Rev 108(3), 653-673. doi: 10.1037/0033-295x.108.3.653.	Out of scope.
Ptak, R., and Schnider, A. (2010). The dorsal attention network mediates orienting toward behaviorally relevant stimuli in spatial neglect. J Neurosci 30(38), 12557-12565. doi: 10.1523/jneurosci.2722-10.2010.	Absence or unclear evaluation of the task or comparison with conventional tool.
Ro, T., and Beauchamp, M. (2020). Ipsilesional perceptual deficits in hemispatial neglect: Case reports. Cortex 122, 277-287. doi: 10.1016/j.cortex.2019.03.022.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Rorden, C., and Karnath, H.-O. (2010). A simple measure of neglect severity. Neuropsychologia 48(9), 2758-2763. doi: 10.1016/j.neuropsychologia.2010.04.018.	Absence or unclear evaluation of the task or comparison with conventional tool.

Ro, T., Cohen, A., Ivry, R.B., and Rafal, R.D. (1998). Response channel activation and the temporoparietal junction. Brain and cognition 37(3), 461-476. doi: 10.1006/brcg.1998.1008.	Out of scope.
Sacchetti, D.L., Goedert, K.M., Foundas, A.L., and Barrett, A. (2015). Ipsilesional neglect: Behavioral and anatomical correlates. Neuropsychology 29(2), 183-190.	Absence or unclear evaluation of the task or comparison with conventional tool.
Sacher, Y., Serfaty, C., Deouell, L., Sapir, A., Henik, A., and Soroker, N. (2004). Role of disengagement failure and attentional gradient in unilateral spatial neglect -- a longitudinal study. Disability & Rehabilitation 26(12), 746-755. doi: 10.1080/09638280410001704340.	Absence or unclear evaluation of the task or comparison with conventional tool.
Saj, A., Cojan, Y., Assal, F., and Vuilleumier, P. (2019). Prism adaptation effect on neural activity and spatial neglect depend on brain lesion site. Cortex 119, 301-311. doi: 10.1016/j.cortex.2019.04.022.	Absence or unclear evaluation of the task or comparison with conventional tool.
Saj, A., Cojan, Y., Vocat, R., Luauté, J., and Vuilleumier, P. (2013). Prism adaptation enhances activity of intact fronto-parietal areas in both hemispheres in neglect patients. Cortex 49(1), 107-119. doi: 10.1016/j.cortex.2011.10.009.	Out of scope.
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Shimodozono, M., Matsumoto, S., Miyata, R., Etoh, S., Tsujio, S., and Kawahira, K. (2006). Perceptual, premotor and motor factors in the performance of a delayed-reaching task by subjects with unilateral spatial neglect. Neuropsychologia 44(10), 1752-1764. doi: 10.1016/j.neuropsychologia.2006.03.012.	Out of scope.
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dorsal and ventral parietal cortices. Experimental Brain Research 206(2), 197-208. doi: 10.1007/s00221-010-2326-z.	on assessing the presence or severity of USN.
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Smit, M., Van der Stigchel, S., Visser-Meily, J.M.A., Kouwenhoven, M., Eijsackers, A.L.H., and Nijboer, T.C.W. (2013). The feasibility of computer-based prism adaptation to ameliorate neglect in sub-acute stroke patients admitted to a rehabilitation center. Frontiers in Human Neuroscience (JUL). doi: 10.3389/fnhum.2013.00353.	Absence or unclear evaluation of the task or comparison with conventional tool.
Snow, J.C., and Mattingley, J.B. (2008). Central Perceptual Load Does Not Reduce Ipsilesional Flanker Interference in Parietal Extinction. Neuropsychology 22(3), 371-382.	Out of scope.
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Stachowiak, F.J. (1993). Micro-computers in the assessment and rehabilitation of brain-damaged patients. Technology and health care : official journal of the European Society for Engineering and Medicine 1(1), 19-43. doi: 10.3233/THC-1993-1104.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Stuss, D.T., Binns, M.A., Murphy, K.J., and Alexander, M.P. (2002). Dissociations Within the Anterior Attentional System: Effects of Task Complexity and Irrelevant Information on Reaction Time Speed and Accuracy. Neuropsychology 16(4), 500-513.	Not focusing (or clarifying focusing) on assessing the presence or severity of USN.
Ten Brink, A.F., van der Stigchel, S., Visser-Meily, J.M.A., and Nijboer, T.C.W. (2016). You never know where you are going until you know where you have been: Disorganized search after stroke. Journal of Neuropsychology 10(2), 256-275. doi: 10.1111/jnp.12068.	Absence or unclear evaluation of the task or comparison with conventional tool.
Thimm, M., Fink, G.R., Kuest, J., Karbe, H., and Sturm, W. (2006). Impact of alertness training on spatial neglect: A behavioural and fMRI study. Neuropsychologia 44(7), 1230-1246. doi: 10.1016/j.neuropsychologia.2005.09.008.	Out of scope.
Tipper, S.P., and Behrmann, M. (1996). Object-Centered Not Scene-Based Visual Neglect. Journal of Experimental	Absence of or unclear information regarding the design

Psychology: Human Perception & Performance 22(5), 1261-1278.	of the task (e.g., apparatus, task demands).
Toba, M.N., Rabuffetti, M., Duret, C., Pradat-Diehl, P., Gainotti, G., and Bartolomeo, P. (2018). Component deficits of visual neglect: "Magnetic" attraction of attention vs. impaired spatial working memory. Neuropsychologia 109, 52-62. doi: 10.1016/j.neuropsychologia.2017.11.034.	Out of scope.
Tonin, L., Pitteri, M., Leeb, R., Zhang, H., Menegatti, E., Piccione, F., et al. (2017). Behavioral and Cortical Effects during Attention Driven Brain-Computer Interface Operations in Spatial Neglect: A Feasibility Case Study. Frontiers in Human Neuroscience 11. doi: 10.3389/fnhum.2017.00336.	Absence or unclear evaluation of the task or comparison with conventional tool.
Treccani, B., Cubelli, R., Sellaro, R., Umiltà, C., and Della Sala, S. (2012). Dissociation between awareness and spatial coding: evidence from unilateral neglect. J Cogn Neurosci 24(4), 854-867. doi: 10.1162/jocn_a_00185.	Absence or unclear evaluation of the task or comparison with conventional tool.
Trombini, M., Vestito, L., Morando, M., Mori, L., Trompetto, C., Bandini, F., et al. (2020). "Unilateral spatial neglect rehabilitation supported by a digital solution: two case-studies," in 42nd Annual International Conferences of the Ieee Engineering in Medicine and Biology Society: Enabling Innovative Technologies for Global Healthcare Embc'20.), 3670-3675.	Out of scope.
Vaes, N., Lafosse, C., Hemelsoet, D., Tichelt, E.V., Oostra, K., and Vingerhoets, G. (2015). Contraversive neglect? A modulation of visuospatial neglect in association with contraversive pushing. Neuropsychology 29(6), 988-997. doi: 10.1037/neu0000205.	Absence or unclear evaluation of the task or comparison with conventional tool.
Van der Stoep, N., Visser-Meily, J.M.A., Kappelle, L.J., de Kort, P.L.M., Huisman, K.D., Eijsackers, A.L.H., et al. (2013). Exploring near and far regions of space: Distance-specific visuospatial neglect after stroke. Journal of Clinical and Experimental Neuropsychology 35(8), 799-811. doi: 10.1080/13803395.2013.824555.	Absence or unclear evaluation of the task or comparison with conventional tool.
Van Vleet, T., and Robertson, L. (2009). Implicit representation and explicit detection of features in patients with hemispatial neglect. Brain : a journal of neurology 132, 1889-1897. doi: 10.1093/brain/awp109.	Absence or unclear evaluation of the task or comparison with conventional tool.
Verfaellie, M., Milberg, W.P., McGlinchey-Berroth, R., and Grande, L. (1995). Comparison of Cross-Field Matching and	Out of scope.

Forced-Choice Identification in Hemispatial Neglect. Neuropsychology 9(4), 427-434.	
Vossel, S., Eschenbeck, P., Weiss, P., and Fink, G. (2010). Assessing visual extinction in right-hemisphere stroke patients with and without neglect. Klinische Neurophysiologie. Conference 41(1).	Out of scope.
Webster, J.S., McFarland, P.T., Rapport, L.J., Morrill, B., Roades, L.A., and Abadee, P.S. (2001). Computer-assisted training for improving wheelchair mobility in unilateral neglect patients. Arch Phys Med Rehabil 82(6), 769-775. doi: 10.1053/apmr.2001.23201.	Out of scope.
Williamson, J.B., Haque, S., Burtis, B., Harciarek, M., Lamb, D., Zilli, E., et al. (2014). The influence of stimulus proximity on judgments of spatial relationships in patients with chronic unilateral right or left hemisphere stroke. Journal of Clinical and Experimental Neuropsychology 36(8), 787-793. doi: 10.1080/13803395.2014.940855.	Absence or unclear evaluation of the task or comparison with conventional tool.
Zimmermann, P., and Fimm, B. (2002). "A test battery for attentional performance."), 110-151.	Absence or unclear evaluation of the task or comparison with conventional tool.

APPENDIX 2. Integrated Research Application System (IRAS)

Welcome to the Integrated Research Application System

IRAS Project Filter

The integrated dataset required for your project will be created from the answers you give to the following questions. The system will generate only those questions and sections which (a) apply to your study type and (b) are required by the bodies reviewing your study. Please ensure you answer all the questions before proceeding with your applications.

Please complete the questions in order. If you change the response to a question, please select 'Save' and review all the questions as your change may have affected subsequent questions.

Please enter a short title for this project (maximum 70 characters)
CBASS

1. Is your project research?

(●) Yes ( ) No

2. Select one category from the list below:

( ) Ionising Radiation for combined review of clinical trial of an investigational medicinal product

( ) Ionising Radiation and Devices form for combined review of combined trial of an investigational medicinal product and an investigational medical device

( ) Clinical investigation or other study of a medical device

( ) Other clinical trial to study a novel intervention or randomised clinical trial to compare interventions in clinical practice

(●) Basic science study involving procedures with human participants

( ) Study administering questionnaires/interviews for quantitative analysis, or using mixed quantitative/qualitative methodology

( ) Study involving qualitative methods only

( ) Study limited to working with human tissue samples (or other human biological samples) and data (specific project only)

( ) Study limited to working with data (specific project only)

( ) Research tissue bank

( ) Research database

If your work does not fit any of these categories, select the option below:

( ) Other study

2a. Will the study involve the use of any medical device without a UKCA/CE UKNI/CE Mark, or a UKCA/CE UKNI/CE marked device which has been modified or will be used outside its intended purposes?

( ) Yes (●) No

2b. Please answer the following question(s):

a) Does the study involve the use of any ionising radiation? ( ) Yes (●) No

b) Will you be taking new human tissue samples (or other human biological samples)? ( ) Yes (●) No

c) Will you be using existing human tissue samples (or other human biological samples)? ○ Yes ◉ No

d) Will the study involve any other clinical procedures with participants (e.g. MRI, ultrasound, physical examination)? ◉ Yes ○ No

3. In which countries of the UK will the research sites be located? *(Tick all that apply)*

- [x] England
- [ ] Scotland
- [ ] Wales
- [ ] Northern Ireland

3a. In which country of the UK will the lead NHS R&D office be located:

- ◉ England
- ○ Scotland
- ○ Wales
- ○ Northern Ireland
- ○ This study does not involve the NHS

4. Which applications do you require?

- [x] IRAS Form
- [ ] Confidentiality Advisory Group (CAG)
- [ ] HM Prison and Probation Service (HMPPS)

Most research projects require review by a REC within the UK Health Departments' Research Ethics Service. Is your study exempt from REC review?

○ Yes ◉ No

5. Will any research sites in this study be NHS organisations?

◉ Yes ○ No

5a. Are all the research costs and infrastructure costs (funding for the support and facilities needed to carry out the research e.g. NHS support costs) for this study provided by a NIHR Biomedical Research Centre (BRC), NIHR Applied Research Collaboration (ARC), NIHR Patient Safety Translational Research Centre (PSTRC), or an NIHR Medtech and In Vitro Diagnostic Co-operative (MIC) in all study sites?

Please see information button for further details.

○ Yes ◉ No

Please see information button for further details.

5b. Do you wish to make an application for the study to be considered for NIHR Clinical Research Network (CRN) Support and inclusion in the NIHR Clinical Research Network Portfolio?

Please see information button for further details.

○ Yes ◉ No

The NIHR Clinical Research Network (CRN) provides researchers with the practical support they need to make clinical studies happen in the NHS in England e.g. by providing access to the people and facilities needed to carry out research "on the ground".

If you select yes to this question, information from your IRAS submission will automatically be shared with the NIHR CRN. ***Submission of a Portfolio Application Form (PAF) is no longer required.***

6. Do you plan to include any participants who are children?

○ Yes ◉ No

7. Do you plan at any stage of the project to undertake intrusive research involving adults lacking capacity to consent for themselves?

○ Yes ◉ No

Answer Yes if you plan to recruit living participants aged 16 or over who lack capacity, or to retain them in the study following loss of capacity. Intrusive research means any research with the living requiring consent in law. This includes use of identifiable tissue samples or personal information, except where application is being made to the Confidentiality Advisory Group to set aside the common law duty of confidentiality in England and Wales. Please consult the guidance notes for further information on the legal frameworks for research involving adults lacking capacity in the UK.

8. Do you plan to include any participants who are prisoners or young offenders in the custody of HM Prison Service or who are offenders supervised by the probation service in England or Wales?

○ Yes ◉ No

9. Is the study or any part of it being undertaken as an educational project?

◉ Yes ○ No

Please describe briefly the involvement of the student(s):
Part of the proposed work will contribute to doctoral research undertaken by Ioanna Giannakou (HCPC registered physiotherapist)

9a. Is the project being undertaken in part fulfilment of a PhD or other doctorate?

◉ Yes ○ No

10. Will this research be financially supported by the United States Department of Health and Human Services or any of its divisions, agencies or programs?

○ Yes ◉ No

11. Will identifiable patient data be accessed outside the care team without prior consent at any stage of the project (including identification of potential participants)?

○ Yes ◉ No

Integrated Research Application System
Application Form for Basic science study involving procedures with human participants

IRAS Form (project information)

Please refer to the E-Submission and Checklist tabs for instructions on submitting this application.

The Chief Investigator should complete this form. Guidance on the questions is available wherever you see this symbol displayed. We recommend reading the guidance first. The complete guidance and a glossary are available by selecting Help.

Please define any terms or acronyms that might not be familar to lay reviewers of the application.

Short title and version number: (maximum 70 characters - this will be inserted as header on all forms)
CBASS

Please complete these details after you have booked the REC application for review.

REC Name:
East of England - Essex Research Ethics Committee

REC Reference Number:
23/EE/0268

Submission date:
20/11/2023

PART A: Core study information

1. ADMINISTRATIVE DETAILS

A1. Full title of the research:

Computer-based assessment of visuo-spatial attention following stroke

A2-1. Educational projects

Name and contact details of student(s):

Student 1

	Title	Forename/Initials	Surname
	Ms	Ioanna	Giannakou
Address	University Of Birmingham Edgbaston		
Post Code	B15 2TT		
E-mail			
Telephone			
Fax			

Give details of the educational course or degree for which this research is being undertaken:

Name and level of course/ degree:
PhD at School of Sport, Exercise and Rehabilitation Sciences

Name of educational establishment:
University of Birmingham

Name and contact details of academic supervisor(s):

Academic supervisor 1

	Title	Forename/Initials	Surname
	Dr	David	Punt
Address	School of Sport, Exercise and Rehabiliation Sciences University of Birmingham Edgbaston Birmingham UK		
Post Code	B15 2TT		
E-mail			
Telephone			
Fax			

Please state which academic supervisor(s) has responsibility for which student(s):
Please click "Save now" before completing this table. This will ensure that all of the student and academic supervisor details are shown correctly.

Student(s)	Academic supervisor(s)
Student 1 Ms Ioanna Giannakou	☐ Dr David Punt

A copy of a current CV for the student and the academic supervisor (maximum 2 pages of A4) must be submitted with the application.

A2-2. Who will act as Chief Investigator for this study?

- ○ Student
- ◉ Academic supervisor
- ○ Other

A3-1. Chief Investigator:

	Title	Forename/Initials	Surname
	Dr	David	Punt
Post	Senior Lecturer (U of Bham) / Honorary Physiotherapist (BCHT)		
Qualifications	Graduate Diploma (Physiotherapy) - 1990 MSc (Clinical Neuroscience) - 1998 PhD (Psychology) - 2004		
ORCID ID	0000 0003 2384 3193		
Employer	University of Birmingham		
Work Address	School of Sport, Exercise and Rehabiliation Sciences University of Birmingham Edgbaston Birmingham UK		
Post Code	B15 2TT		
Work E-mail			

* Personal E-mail	
Work Telephone	
* Personal Telephone/Mobile	
Fax	

** This information is optional. It will not be placed in the public domain or disclosed to any other third party without prior consent.*
A copy of a current CV (maximum 2 pages of A4) for the Chief Investigator must be submitted with the application.

A4. Who is the contact on behalf of the sponsor for all correspondence relating to applications for this project?
This contact will receive copies of all correspondence from REC and HRA/R&D reviewers that is sent to the CI.

	Title	Forename/Initials	Surname
	Dr	Birgit	Whitman
Address	Head of Research Ethics, Governance and Integrity Birmingham Research Park, University of Birmingham 97 Vincent Drive, Edgbaston, Birmingham, B15 2SQ		
Post Code	B15 2SQ		
E-mail	researchgovernance@contacts.bham.ac.uk		
Telephone			
Fax			

A5-1. Research reference numbers. *Please give any relevant references for your study:*

Applicant's/organisation's own reference number, e.g. R & D (if available):	RG_23-051
Sponsor's/protocol number:	RG_23-051
Protocol Version:	1
Protocol Date:	03/11/2023
Funder's reference number (enter the reference number or state not applicable):	RG_23-051
Project website:	

Registry reference number(s):
The UK Policy Framework for Health and Social Care Research sets out the principle of making information about research publicly available. Furthermore: Article 19 of the World Medical Association Declaration of Helsinki adopted in 2008 states that "every clinical trial must be registered on a publicly accessible database before recruitment of the first subject"; and the International Committee of Medical Journal Editors (ICMJE) will consider a clinical trial for publication only if it has been registered in an appropriate registry. Please see guidance for more information.

International Standard Randomised Controlled Trial Number (ISRCTN):
ClinicalTrials.gov Identifier (NCT number):

Additional reference number(s):

Ref.Number Description	Reference Number

A5-2. Is this application linked to a previous study or another current application?

◯ Yes ◉ No

Please give brief details and reference numbers.
This study is not related to a previous or another current application.

2. OVERVIEW OF THE RESEARCH

To provide all the information required by review bodies and research information systems, we ask a number of specific questions. This section invites you to give an overview using language comprehensible to lay reviewers and members of the public. Please read the guidance notes for advice on this section.

A6-1. Summary of the study. *Please provide a brief summary of the research (maximum 300 words) using language easily understood by lay reviewers and members of the public. Where the research is reviewed by a REC within the UK Health Departments' Research Ethics Service, this summary will be published on the Health Research Authority (HRA) website following the ethical review. Please refer to the question specific guidance for this question.*

This study aims to address the challenge of assessing unilateral spatial neglect (USN), a neurological condition often observed in stroke survivors. USN can significantly impact a patient's rehabilitation outcome and daily functioning, yet there is no universally accepted screening method, leading to potential misdiagnosis and poor rehabilitation planning. To address this gap, the research explores the use of computer-based assessments to detect and measure the severity of USN symptoms. This method has been demonstrated to identify subtle cases often overlooked by traditional methods.

The study will involve recruiting inpatient and outpatient adult stroke survivors who can use one hand and interact with a computer. Inpatient study sessions will be conducted at the hospital, while outpatient sessions will take place at the university or the participant's home, depending on their preference. The study procedures will include performing a battery of computer-based tasks designed to evaluate their visuo-spatial attention. These tasks have been chosen based on their previously determined sensitivity and/or diagnostic accuracy and have been shown to outperform traditional pen-and-paper tests. Our aim is to assess the performance of stroke survivors on these computer-based tasks and compare this with conventional assessment methods.

Quantitative data, such as response times and accuracy in task performance, will be collected to examine how well these computer-based assessments can detect USN symptoms and classify patients according to the severity of their condition. The study will also collect qualitative data through feedback questionnaires to understand participants' preferences and perspectives on the different assessment methods.

Overall, this research aims to determine which computer-based tasks are most effective in identifying visual attention deficits in stroke survivors. It also seeks to assess the feasibility and acceptability of computer-based tasks compared to traditional pen-and-paper methods. By addressing these questions, the study intends to provide valuable insights into improving the diagnosis and management of USN in stroke survivors, ultimately enhancing their quality of life and rehabilitation outcomes.

A6-2. Summary of main issues. *Please summarise the main ethical, legal, or management issues arising from your study and say how you have addressed them.*

Not all studies raise significant issues. Some studies may have straightforward ethical or other issues that can be identified and managed routinely. Others may present significant issues requiring further consideration by a REC, HRA, or other review body (as appropriate to the issue). Studies that present a minimal risk to participants may raise complex organisational or legal issues. You should try to consider all the types of issues that the different reviewers may need to consider.

One of the main study-related issues that may arise is associated with potential risks related to participants' involvement in this study, which include the possibility of experiencing fatigue during assessments, whether they are paper-based or computer-based. Additionally, participants may encounter physical challenges due to stroke-related impairments and have sensory sensitivities to consider.
In cases where participants feel fatigued, overwhelmed, or require rest, they will have the option to take a break before resuming, or, if necessary, to stop the session. Similarly, to address potential challenges such as frustration, anxiety, or reduced motivation that stroke survivors may encounter during the assessments, we will provide reassurance and remind them that they have the option to pause the session and complete the tasks at their convenience should they choose to do so.
It's essential to note that the researcher collecting the data is an HCPC-registered physiotherapist, ensuring the highest level of expertise, care, and safety throughout the study.
Furthermore, the study is strongly committed to maintaining participants' privacy and security. Rigorous data protection measures are in place to safeguard participants' information, effectively minimizing potential risks.
Additionally, the study is well-prepared to adjust the assessments to accommodate participants' specific needs and offer support to mitigate any challenges that may arise.

3. PURPOSE AND DESIGN OF THE RESEARCH

A7. Select the appropriate methodology description for this research. *Please tick all that apply*:

- ☐ Case series/ case note review
- ☐ Case control
- ☑ Cohort observation
- ☐ Controlled trial without randomisation
- ☑ Cross-sectional study
- ☐ Database analysis
- ☐ Epidemiology
- ☐ Feasibility/ pilot study
- ☑ Laboratory study
- ☐ Metanalysis
- ☑ Qualitative research
- ☑ Questionnaire, interview or observation study
- ☐ Randomised controlled trial
- ☐ Other (please specify)

A10. What is the principal research question/objective? *Please put this in language comprehensible to a lay person.*

The primary objective of this study is to investigate the performance of stroke survivors on a series of four computer-based tasks and explore how different tasks capture visual attention.

Primary research question:

"Which computer-based tasks are optimal for identifying visual attention deficits among stroke survivors in clinical settings?"

A11. What are the secondary research questions/objectives if applicable? *Please put this in language comprehensible to a lay person.*

The secondary aim of this study is to explore the psychometric properties (e.g., sensitivity, specificity) and acceptability of the computer-based tasks among stroke survivors and in comparison, with conventional assessment methods such as pen-and-paper testing.

Secondary research questions:

"How feasible and acceptable are computer-based tasks compared to pen-and-paper tasks for the evaluation of USN in stroke survivors?"

"What are the challenges of introducing computer-based tasks for the assessment of USN to the clinical setting?"

A12. What is the scientific justification for the research? *Please put this in language comprehensible to a lay person.*

The main challenges in detecting Unilateral Spatial Neglect (USN) are related to the limitations of the existing standardized tests. Traditional tests like the Behavioral Inattention Test (BIT) and Catherine Bergego Scale (CBS) have been in use for several decades (Azouvi et al., 2017; Checketts et al., 2021; Wilson et al., 1987). However, they have certain drawbacks, including a lack of precision, limited sensitivity, and a high rate of false-negative results (Ting et al., 2011; Williams et al., 2021).

In contrast, numerous studies over the past two decades have indicated that computer-based assessments offer a more sensitive and accurate means of identifying mild and chronic USN symptoms that may not be detected by pen-and-paper tests (Bonato et al., 2012; Deouell et al., 2005; List et al., 2008; Rengachary et al., 2009). These computer-

based tests provide several advantages, such as reducing ceiling effects and being less affected by compensatory techniques (Bonato & Deouell, 2013).

While pen-and-paper tests may effectively identify severe cases of USN, they often miss subtle cases, which can significantly impact the daily lives and rehabilitation outcomes of stroke survivors (Azouvi et al., 2002; Klinke et al., 2016). The demand for more sensitive assessment methods is evident, and research has consistently demonstrated the potential of computer-based assessments to fulfill this need (Gammeri et al., 2020; Villarreal et al., 2021).

Extensive research in the field of cognitive science, including studies on spatial attention, supports the use of computer-based assessments as robust tools, both in unimpaired individuals and in patient groups like stroke survivors, despite their known limitations (Sternin et al., 2019; Zhang et al., 2023).

Even though there is substantial evidence to support their superiority, computer-based assessments for USN have not been widely integrated into clinical practice.

To identify the most widely accepted and advantageous computer-based tasks, we conducted a systematic review (Giannakou et al., 2022). This review assessed practicality, acceptability, feasibility, and sensitivity, ultimately identifying four computer-based tasks that may offer significant utility for clinical practice: the Starry Night task (Deouell et al., 2005), the Posner Cueing task (Rengachary et al., 2009), and Feature and Conjunction Visual Search tasks (Erez et al., 2009). These tasks were adapted into a computer-based battery of tests for this study.

References:

Azouvi, P. (1996). Functional Consequences and Awareness of Unilateral Neglect: Study of an Evaluation Scale. Neuropsychological Rehabilitation 6(2), 133-150. doi: 10.1080/713755501.
Bonato, M., and Deouell, L.Y. (2013). Hemispatial neglect: computer-based testing allows more sensitive quantification of attentional disorders and recovery and might lead to better evaluation of rehabilitation. Frontiers in Human Neuroscience 7(162). doi: ARTN 162 10.3389/fnhum.2013.00162.
Checketts, M., Mancuso, M., Fordell, H., Chen, P., Hreha, K., Eskes, G.A., et al. (2020). Current clinical practice in the screening and diagnosis of spatial neglect post-stroke: Findings from a multidisciplinary international survey. Neuropsychol Rehabil, 1-32. doi: 10.1080/09602011.2020.1782946.
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Erez, A., Katz, N., Ring, H., and Soroker, N. (2009). Assessment of spatial neglect using computerised feature and conjunction visual search tasks. Neuropsychol Rehabil 19(5), 677-695. doi: 10.1080/09602010802711160.
Gammeri, R., Iacono, C., Ricci, R., and Salatino, A. (2020). Unilateral Spatial Neglect After Stroke: Current Insights. Neuropsychiatr Dis Treat 16, 131-152. doi: 10.2147/ndt.S171461.
Giannakou, I., Lin, D., and Punt, D. (2022). Computer-based assessment of unilateral spatial neglect: A systematic review. Frontiers in Neuroscience 16. doi: 10.3389/fnins.2022.912626.
List, A., Brooks, J.L., Esterman, M., Flevaris, A.V., Landau, A.N., Bowman, G., et al. (2008). Visual hemispatial neglect, re-assessed. Journal of the International Neuropsychological Society 14(2), 243-256. doi: 10.1017/S1355617708080284.
Rengachary, J., d'Avossa, G., Sapir, A., Shulman, G.L., and Corbetta, M. (2009). Is the posner reaction time test more accurate than clinical tests in detecting left neglect in acute and chronic stroke? Arch Phys Med Rehabil 90(12), 2081-2088. doi: 10.1016/j.apmr.2009.07.014.
Sternin, A., Burns, A., and Owen, A.M. (2019). Thirty-Five Years of Computerized Cognitive Assessment of Aging-Where Are We Now? Diagnostics (Basel) 9(3). doi: 10.3390/diagnostics9030114.
Villarreal, S., Linnavuo, M., Sepponen, R., Vuori, O., Jokinen, H., and Hietanen, M. (2020). Dual-Task in Large Perceptual Space Reveals Subclinical Hemispatial Neglect. J Int Neuropsychol Soc 26(10), 993-1005. doi: 10.1017/s1355617720000508.
Wilson, B., Cockburn, J., and Halligan, P. (1987). Development of a behavioral test of visuospatial neglect. Arch Phys Med Rehabil 68(2), 98-102.
Zhang, Q., Wei, J.H., Fu, X., Liu, X., Li, X.Y., Liu, W., et al. (2023). Can we trust computers to assess the cognition of stroke patients? A systematic review. Front Neurol 14, 1180664. doi: 10.3389/fneur.2023.1180664.

A13. Please summarise your design and methodology. *It should be clear exactly what will happen to the research participant, how many times and in what order. Please complete this section in language comprehensible to the lay person. Do not simply reproduce or refer to the protocol. Further guidance is available in the guidance notes.*

Hypothesis:
Null Hypothesis (H0): There is no significant difference between computer-based and pen-and-paper tasks in

detecting visuo-spatial attention asymmetry in stroke survivors.

Alternative Hypothesis (H1): Computer-based tasks are more effective at detecting visuo-spatial attention asymmetry in stroke survivors compared to pen-and-paper tasks.

The alternative hypothesis is selected to investigate the potential advantages of computer-based assessments over traditional methods. This is important to explore because if computer-based tasks prove to be more effective, they could have significant implications for improving the assessment and treatment of stroke survivors with visuo-spatial attention deficits, supporting their implementation in clinical settings.

Sample and Sampling Techniques:

Recruitment will be based on a convenience sample size technique, enrolling participants willing to participate and meeting eligibility criteria. This approach, despite some controversy regarding its validity due to its non-probability nature, is favored for its cost-effectiveness and efficiency.

Clinical teams at Moseley Hall Hospital will refer eligible stroke survivors to the research team from both inpatient and outpatient services. Patients will receive information and time to consider participation. Clinical teams will identify potential participants and check for eligibility. In the case of inpatient services, clinicians will approach eligible patients, provide them with a patient information sheet, and ask if they wish to share contact details with the research team. For outpatients, clinicians will introduce the study during appointments and provide information sheets. If interested, patients can complete a permission to contact form.

Members of the patient's clinical care team will access patient records to determine eligibility. Only after a consent to contact form is completed, members of the research team will approach eligible participants referred to the study and provide them with additional study-related information to answer their queries.

This multi-step recruitment approach balances the need for screening, informed consent, and flexibility in patient engagement. It aligns with ethical considerations and ensures that patients are fully informed and willing participants in the study.

The study aims to recruit 50 to 100 participants over eight months, achieving a balance between inpatient and outpatient stroke survivors. This approach is informed by our prior research with unimpaired adults and the findings of the systematic review, while also considering the annual admission numbers of stroke survivors.

Study Procedures:

The study procedures involve sessions lasting approximately 60 minutes, with flexibility for participant-determined breaks, not exceeding 90 minutes. The data collection includes a demographic form (2-5 minutes), a basic stroke assessment (15-20 minutes), a battery of four computer-based tasks (15-20 minutes), pen-and-paper tasks (Behavioural Inattention Test) (10-15 minutes), and a feedback questionnaire (2-5 minutes).

The demographic form will include questions about demographics and medical history (e.g., age, gender, days since stroke, lesion type, computer experience).

An HCPC-registered physiotherapist will conduct the basic stroke assessment utilizing two standardized assessments, the National Institutes of Health Stroke Scale (NIHSS) and Addenbrooke's Cognitive Examination(ACE-R).

Participants will engage in four computer-based tasks lasting 15-20 minutes, with each task not exceeding five minutes. Participants will be offered breaks during and in between tasks. These tasks replicate the Starry Night, Posner Cueing, Feature, and Conjunction Visual Search tasks.
- Starry Night Task: Participants respond to visual stimuli by detecting a target (a red star) in a dynamic display.
- Posner Cueing Task: Participants identify a target (a white star) within two squares.
- Feature and Conjunction Visual Search Task: This task evaluates attention by detecting a red circle among distractors; blue circles at the Feature tasks and blue circles and red squares at the Conjunction task. There are variations in the number of distractors and target locations.
Data collection and task presentation will be managed by the specialist software E-Prime® 3.0, developed by Psychology Software Tools, Inc. This software is widely recognized and used in cognitive psychology research.

The pen-and-paper tasks will involve using one of the most commonly used standardized assessment tools for USN, the conventional subtest of the Behavior Inattention Test (BIT). This subtest includes six items: line crossing, letter cancellation, star cancellation, figure and shape copying, line bisection, and representational drawing.

At the end of the session, participants respond to a feedback questionnaire capturing their perceptions of computer-based and pen-and-paper tasks. The questionnaire contains both quantitative and qualitative questions to assess acceptability, preferences, and any recommendations.

The study design and methodology have been carefully chosen based on established and standardized methods with a robust research background, particularly for the basic stroke assessment and pen-and-paper tasks. The computer-based tasks are well-supported by extensive research. To ensure the effectiveness of our design, we conducted a study involving 125 unimpaired younger and older adults, confirming the feasibility and acceptability of the procedures. Importantly, our study design is adaptable, allowing for modifications, such as the provision of regular breaks, to accommodate the specific needs and safety of the participants.

Broad study timetable:

Data collection is expected to extend up to 8 months, concluding when the last set of data is gathered. Data analysis may continue beyond this point.
Subsequently, the research will transition to data analysis, study completion, and dissemination of findings, a phase that may extend for approximately five months.
The final research report is scheduled for submission 12 months after the study's conclusion.

A14-1. In which aspects of the research process have you actively involved, or will you involve, patients, service users, and/or their carers, or members of the public?

- ☐ Design of the research
- ☐ Management of the research
- ☑ Undertaking the research
- ☐ Analysis of results
- ☐ Dissemination of findings
- ☐ None of the above

Give details of involvement, or if none please justify the absence of involvement.
We have been running similar studies with more than 50 younger and older adults in each age group. In these studies, the participants have performed the same computer-based tasks that we are planning to use and completed similar questionnaires.
This has demonstrated the study's feasibility and acceptability among similar age groups, by receiving positive feedback on the computer-based tasks, questionnaires, participant information sheets, and on the duration of the study.

4. RISKS AND ETHICAL ISSUES

RESEARCH PARTICIPANTS

A15. What is the sample group or cohort to be studied in this research?

Select all that apply:

- ☐ Blood
- ☐ Cancer
- ☐ Cardiovascular
- ☐ Congenital Disorders
- ☐ Dementias and Neurodegenerative Diseases
- ☐ Diabetes
- ☐ Ear
- ☐ Eye

- [ ] Generic Health Relevance
- [ ] Infection
- [ ] Inflammatory and Immune System
- [ ] Injuries and Accidents
- [ ] Mental Health
- [ ] Metabolic and Endocrine
- [ ] Musculoskeletal
- [ ] Neurological
- [ ] Oral and Gastrointestinal
- [ ] Paediatrics
- [ ] Renal and Urogenital
- [ ] Reproductive Health and Childbirth
- [ ] Respiratory
- [ ] Skin
- [x] Stroke

Gender:	Male and female participants
Lower age limit: 18	Years
Upper age limit:	No upper age limit

A17-1. Please list the principal inclusion criteria (list the most important, max 5000 characters).

We are interested in testing adults, who:
- Are 18 years old or older
- Have formally been diagnosed with stroke.
- Are able to use one hand to push a button.
- Are able to observe a computer screen for approximately 5 minutes at a time.

A17-2. Please list the principal exclusion criteria (list the most important, max 5000 characters).

Individuals who are:
- Not able to follow very simple instructions (e.g., one stage commands), either verbally or using gesture.
- Not able to give informed consent.
- Not able to understand English or require translators.

RESEARCH PROCEDURES, RISKS AND BENEFITS

A18. Give details of all non-clinical intervention(s) or procedure(s) that will be received by participants as part of the research protocol. *These include seeking consent, interviews, non-clinical observations and use of questionnaires.*

Please complete the columns for each intervention/procedure as follows:

1. Total number of interventions/procedures to be received by each participant as part of the research protocol.
2. If this intervention/procedure would be routinely given to participants as part of their care outside the research, how many of the total would be routine?
3. Average time taken per intervention/procedure (minutes, hours or days)
4. Details of who will conduct the intervention/procedure, and where it will take place.

Intervention or procedure	1	2	3	4
Identify potential participant	1		2minutes	Member of

			the Clinical staff
Eligibility check	1	5minutes	Member of the Clinical staff
Approach potential participant and hand Participant Information Sheet	1	5minutes	Member of the Clinical staff
Obtain permission to be contacted by the researcher	1	5minutes	Member of the Clinical staff
Approach potential participant to discuss study	1	15minutes	PhD student or a delegated member of the research team
Take informed consent	1	20minutes	PhD student or a delegated member of the research team
CRF/eCRF completion including data transfer and query resolution	1	5minutes	Member of the Clinical staff
Demographic Questionnaire form Completion	1	2-5minutes	PhD student or a delegated member of the research team
Computer-based visuo-spatial attention assessment. The four tasks will be approximately 5min each, with total screentime limited to 15-20min. Participants will be offered in-between breaks.	1	20minutes	PhD student or a delegated member of the research team
Feedback Questionnaire	1	2-5minutes	PhD student or a delegated member of the research team

A19. Give details of any clinical intervention(s) or procedure(s) to be received by participants as part of the research protocol. *These include uses of medicinal products or devices, other medical treatments or assessments, mental health interventions, imaging investigations and taking samples of human biological material. Include procedures which might be received as routine clinical care outside of the research.*

Please complete the columns for each intervention/procedure as follows:

1. Total number of interventions/procedures to be received by each participant as part of the research protocol.
2. If this intervention/procedure would be routinely given to participants as part of their care outside the research, how many of the total would be routine?
3. Average time taken per intervention/procedure (minutes, hours or days).
4. Details of who will conduct the intervention/procedure, and where it will take place.

Intervention or procedure	1	2	3	4
National Institutes of Health Stroke Scale (NIHSS)	1		10minutes	PhD student or a delegated member of the research team
Addenbrooke's Cognitive examination (ACE-R)	1		10minutes	PhD student or a delegated member of the research team
Behavioural Inattention Test	1		15minutes	PhD student or a delegated member of the research team

A21. How long do you expect each participant to be in the study in total?

The whole session is anticipated to take approximately an hour, in some cases it might be 90 minutes, depending on the duration of the breaks the participant is required between the tasks.

A22. What are the potential risks and burdens for research participants and how will you minimise them?

For all studies, describe any potential adverse effects, pain, discomfort, distress, intrusion, inconvenience or changes to lifestyle. Only describe risks or burdens that could occur as a result of participation in the research. Say what steps would be taken to minimise risks and burdens as far as possible.

The main study activity will involve looking at a computer screen for around 20 minutes. This period will be broken down into tasks no longer than five minutes long with breaks taken in between. The duration of these breaks will be at the participant's discretion.
As stated in previous sections there are some potential risks associated with participants' involvement in this study including the possibility of experiencing fatigue during assessments, which can be related to a paper-based or computer-based activity. Additionally, the challenges participants face may differ based on the stroke's severity, leading to physical and sensory challenges. Another challenge is that stroke survivors may experience frustration, anxiety, or reduced motivation during assessments. We are committed to prioritizing the participants' well-being and comfort. In situations where participants may feel fatigued, overwhelmed, or in need of rest, we will provide reassurance and they will have the autonomy to pause and take a break before resuming the session. If necessary, the session will entirely discontinue, and participants will be provided with the option to schedule another session at their convenience to continue the tasks if they wish.
We would like to emphasize that the researcher collecting the data is an HCPC-registered physiotherapist with experience in patient care, committed to prioritizing the participants' well-being and safety throughout the study. Furthermore, the study is dedicated to upholding participant privacy and security, with robust data protection measures in place to minimize potential risks effectively. Additionally, the study is designed to adapt the assessment to meet participants' individual needs and provide support to address any challenges that may arise.

A24. What is the potential for benefit to research participants?

The tasks involved are primarily designed as assessments rather than interventions, and therefore, there are no immediate or obvious benefits to participating. However, based on prior experiences, some participants may find the tasks interesting. It's important to note that there is a potential indirect benefit to participation. If these tasks are demonstrated to be effective through the study, they can contribute to the development of new assessment tools for stroke survivors, which could be introduced in clinical settings to improve their care and outcomes.

RECRUITMENT AND INFORMED CONSENT

In this section we ask you to describe the recruitment procedures for the study. Please give separate details for different study groups where appropriate.

A27-1. How will potential participants, records or samples be identified? Who will carry this out and what resources will be used?*For example, identification may involve a disease register, computerised search of GP records, or review of medical records. Indicate whether this will be done by the direct healthcare team or by researchers acting under arrangements with the responsible care organisation(s).*

Clinical teams at Moseley Hall Hospital will identify and refer eligible stroke survivors to the research team for recruitment. Patients will have the opportunity to decide their participation after considering the provided materials and

information. Eligible participants will be sourced from two service categories:

- Inpatient services, specifically Ward 8.
- Outpatient services, which include the Birmingham Neurological Rehabilitation Team (BNRT), Community Stroke Team (CST), and Early Supported Discharge Team (ESDT).
Clinical teams will initially review admission and referral lists, along with patient records, to identify potential participants and ensure they meet the necessary inclusion and exclusion criteria.

For stroke survivors recruited from inpatient services:

Clinicians will introduce them to the study. If the patient expresses interest, they will be provided with a patient information sheet (PIS). Clinicians will inquire about the patient's willingness to share their contact information with the research team for further discussion. If the patient agrees to be contacted, they will complete a permission to contact form, which clinicians will share with the research team either via post or in person. The clinical team will notify the research team when a patient agrees to participate. A member of the research team, typically the PhD student or a designated team member, will meet with the patient to provide further information about the study, obtain their consent to participate and carry out the research intervention. These activities may span one or two visits.

For stroke survivors recruited from outpatient services:

Clinicians will approach eligible patients either during routine clinical appointments or by sending the patient information sheet (PIS) and the permission to contact form. Patients encountered during appointments will receive an introduction to the study and a PIS. They will also be asked whether they wish to share their contact details with the research team for further discussion. If the patient agrees to be contacted, they will complete the permission to contact form, which clinicians will then share with the research team via post or in person. Patients who receive study information by post must complete the permission to contact form if they wish to participate and return it to the research team using a provided prepaid envelope.
The research team will supply all necessary recruitment materials, including prepaid envelopes.

To sum up, access to patient records is restricted to the patient's current clinical care team, who will assess the patient's clinical details and medical records to determine whether they meet the eligibility criteria for the study.

The first point of contact with potential participants will be made by a member of the clinical care team. Following the completion of permission to contact form, the PhD student or a designated member of the research team can approach eligible participants who have been referred to the study and provide them with further information about the study and obtain informed consent.

A27-2. Will the identification of potential participants involve reviewing or screening the identifiable personal information of patients, service users or any other person?

(●) Yes ( ) No

Please give details below:
The identification of potential participants will involve reviewing or screening identifiable personal information of patients. However, access to this personal information will be limited to the direct members of the clinical staff who are responsible for their patient care to maintain privacy and confidentiality.

A27-3. Describe what measures will be taken to ensure there is no breach of any duty of confidentiality owed to patients, service users or any other person in the process of identifying potential participants.*Indicate what steps have been or will be taken to inform patients and service users of the potential use of their records for this purpose. Describe the arrangements to ensure that the wishes of patients and service users regarding access to their records are respected. Please consult the guidance notes on this topic.*

Measures to ensure there is no breach of confidentiality include restricting access to identifiable information to only the members of the clinical care team involved in patient care and research. Participants will be informed about the potential use of their records when considering participation, and their informed consent will be obtained, indicating their awareness that specific information from their records will be shared with the research team.

The information that will be shared with the research team is included in the Case Report Form (CRF) and consists of non-identifiable data, including age, gender, history of stroke (days since stroke, type of stroke, lesion type, lesion side, major symptoms following stroke), and standardized stroke assessments. It's important to note that the research team will not have direct access to the participants' complete medical records, but will only have access to the CRF form.

Upon obtaining informed consent from participants, each participant will be assigned an anonymized participant code. This code ensures that the data in the CRF remains non-identifiable, and the participants' privacy and confidentiality are maintained throughout the research process.

A27-4. Will researchers or individuals other than the direct care team have access to identifiable personal information of any potential participants?

○ Yes ◉ No

A28. Will any participants be recruited by publicity through posters, leaflets, adverts or websites?

○ Yes ◉ No

A29. How and by whom will potential participants first be approached?

Patient records can solely be viewed by the patient's current clinical care team without the need for explicit consent. They will determine whether patients align with the inclusion criteria, relying on clinical information and medical records to ascertain their eligibility.
Initial contact with potential participants will be initiated by a clinical care team member. Only after completing a consent to contact form can the PhD student or a designated research team member approach eligible participants referred to the study to furnish them with additional information related to the study.

Clinical teams from Moseley Hall Hospital will identify and refer eligible participants (stoke survivors) to the research team. Eligible patients will be given time to consider whether they wish to participate in the study based on the material and the information provided. Patients will be identified from:
• Inpatient services: Ward 8
• Outpatient services: Birmingham Neurological Rehabilitation Team (BNRT), Community Stroke Team (CST) and Early Supported Discharge Team (ESDT).

Clinical teams will initially screen admission/ referral lists and patient records to identify potential participants and check they meet inclusion and exclusion criteria.

• For patients recruited from inpatient services: Clinicians will approach eligible patients to introduce them to the study and provide them with a patient information sheet (PIS). They will also ask them if they would like to share their contact details with the research team to discuss the research further. If the patient agrees to be contacted, they will complete the permission to contact form which the clinician will then share with the research team (via post or in person). The PhD student will inform the clinical team when a patient has agreed to participate and arrange a time to visit the patient with the clinical team to (1) meet the patient to discuss the study further, (2) consent them into the study and (3) undertake the research intervention. These activities may take place during 1 or 2 visits.

• For patients recruited from outpatient services: Clinicians will approach eligible patients either (1) during routine clinical appointments or (2) post to them the patient information sheet (PIS) and the permission to contact form. If a patient is approached during a routine appointment, the clinician will introduce them to the study and provide them with a patient information sheet (PIS). They will also ask them if they would like to share their contact details with the research team to discuss the research further. If the patient agrees to be contacted, they will complete the permission to contact form which the clinician will then share with the research team (via post or in person). For the patient's that receive the study information by post, they will need to complete the permission to contact form if they are interested in taking part and return this to the research team using a prepaid envelope provided.

Inpatients:
Clinical teams from Moseley Hall Hospital will screen admission and referral lists and patient records to identify potential participants among inpatients in Ward 8. Clinicians will approach eligible inpatients, provide them with a patient information sheet (PIS), and ask if they would like to share their contact details with the research team. If the patient agrees to be contacted, they will complete the permission to contact form, which the clinician will then share with the research team. The PhD student or a delegated member of the research team will coordinate with the clinical team to visit the patient. During this visit, they will meet with the patient to discuss the study, obtain their consent, and administer the research intervention if the patient agrees.

Similarly for outpatient:
Clinicians from Moseley Hall Hospital will approach eligible patients from outpatient services, including the

Birmingham Neurological Rehabilitation Team (BNRT), Community Stroke Team (CST), and Early Supported Discharge Team (ESDT). This can occur during routine clinical appointments or by sending the patient information sheet (PIS) and permission to contact form by post. During a routine appointment, the clinician will introduce eligible outpatients to the study and provide them with the PIS. They will inquire if the patients would like to share their contact details with the research team. If the patient agrees, they will complete the permission to contact form, which the clinician will then share with the research team. For outpatients who receive study information by post, they will need to complete the permission to contact form if they are interested in participating and return it to the research team using a prepaid envelope provided.

A30-1. Will you obtain informed consent from or on behalf of research participants?

(●) Yes ( ) No

If you will be obtaining consent from adult participants, please give details of who will take consent and how it will be done, with details of any steps to provide information (a written information sheet, videos, or interactive material). Arrangements for adults unable to consent for themselves should be described separately in Part B Section 6, and for children in Part B Section 7.

If you plan to seek informed consent from vulnerable groups, say how you will ensure that consent is voluntary and fully informed.

The PhD student or a delegated member of the research team will be responsible for taking informed consent and will be duly authorised, trained and competent to participate according to the ethically approved protocol, principles of Good Clinical Practice (GCP) and Declaration of Helsinki.
Informed consent will be obtained prior to the participant undergoing any study-related procedures and out standard routine care at the participating site (including the collection of identifiable participant data).
The participant will have the right to refuse participation without giving reasons and will remain free to withdraw at any time from the study without giving reasons and without prejudicing their further treatment and they will be provided with a contact point where they may obtain further information about the study. Data and samples collected up to the point of withdrawal may be removed from the data set, up to the point that the data has not been anonymized. Participants will be aware of that prior to providing informed consent.
In case participants are required to re-consent or new information is required to be provided to a participant the researchers will ensure this is done in a timely manner.
The research team takes responsibility for ensuring that all participants are protected and willing to participate voluntarily in an environment free from coercion or undue influence.
We will not recruit participant population who cannot understand English, require translators, or cannot give informed consent. The Participant Information Sheets (PIS) are in a format easily understood by the participant population. In the case that the participants cannot write we will include a witness to sign on a participant's behalf or allowing someone to date the form on behalf of the participant.
The process will involve:
• discussion between the potential participant and an individual knowledgeable about the research about the nature and objectives of the study and possible risks (we do not foresee any risks) associated with their participation.
• the presentation of written material (e.g., PIS and consent document which will be approved by the REC and be in compliance with GCP, local regulatory requirements and legal requirements
• the opportunity for potential participants to ask questions.
• assessment of capacity. For consent to be ethical and valid in law, participants must be capable of giving consent for themselves. A capable person will:
o understand the purpose and nature of the research.
o understand what the research involves, its benefits (or lack of benefits), risks and burdens.
o understand the alternatives to taking part.
o be able to retain the information long enough to make an effective decision.
o be able to make a free choice.
o be capable of making this particular decision at the time it needs to be made (though their capacity may fluctuate, and they may be capable of making some decisions but not others depending on their complexity).
A person is assumed to have the mental capacity to make a decision unless it is shown to be absent. We plan to recruit only participants who have mental capacity and are able to give consent. If a participant is able to consent to the study but later becomes incapacitated, the participant will be excluded from the study.

If you are not obtaining consent, please explain why not.

Informed consent will be obtained and recorded.

Please enclose a copy of the information sheet(s) and consent form(s).

A30-2. Will you record informed consent (or advice from consultees) in writing?

◉ Yes ○ No

A31. How long will you allow potential participants to decide whether or not to take part?

Participants will be approached by a member of the clinical staff, who will introduce the study and provide them with a Participant Information Sheet. Subsequently, participants will have ample time to review the provided information at their own pace and determine if they wish to proceed with the study. If they are interested in learning more, they can give consent to be contacted by the researcher.

Following this initial contact, the researcher will get in touch with the participants, offering further details and addressing any queries or concerns they may have. Participants will be given as much time as they need to carefully consider their decision to participate.

Should they choose to take part, participants will provide informed consent before officially joining the study and will then still have the right to withdraw at any point. While participants may withdraw at any time without giving a reason, our approach to the timescale of this is to state that this is “any time to the point where your participation is complete”.

A32. Will you recruit any participants who are involved in current research or have recently been involved in any research prior to recruitment?

◉ Yes
○ No
○ Not Known

If Yes, please give details and justify their inclusion. If Not Known, what steps will you take to find out?

Participans will be given a choice to participate if they want, considering the burden of participation in more than one study and the psychological impact and given a recovery period.

A33-1. What arrangements have been made for persons who might not adequately understand verbal explanations or written information given in English, or who have special communication needs?*(e.g. translation, use of interpreters)*

Participants who cannot comprehend verbal instructions in English or require translation services will not be eligible for inclusion in the study, as outlined in our exclusion criteria.

A35. What steps would you take if a participant, who has given informed consent, loses capacity to consent during the study? *Tick one option only.*

○ The participant and all identifiable data or tissue collected would be withdrawn from the study. Data or tissue which is not identifiable to the research team may be retained.
◉ The participant would be withdrawn from the study. Identifiable data or tissue already collected with consent would be retained and used in the study. No further data or tissue would be collected or any other research procedures carried out on or in relation to the participant.
○ The participant would continue to be included in the study.
○ Not applicable – informed consent will not be sought from any participants in this research.
○ Not applicable – it is not practicable for the research team to monitor capacity and continued capacity will be assumed.

Further details:

Participants who lose capacity after providing informed consent will be excluded from the study. If a participant must withdraw from the study, any identifiable data collected with prior consent will be retained for study purposes, but there will be no further data collection or related research procedures associated with that participant.

If you plan to retain and make further use of identifiable data/tissue following loss of capacity, you should inform participants about this when seeking their consent initially.

CONFIDENTIALITY

In this section, personal data means any data relating to a participant who could potentially be identified. It includes pseudonymised data capable of being linked to a participant through a unique code number.

Storage and use of personal data during the study

A36. Will you be undertaking any of the following activities at any stage (including in the identification of potential participants)?*(Tick as appropriate)*

- ☐ Access to medical records by those outside the direct healthcare team
- ☐ Access to social care records by those outside the direct social care team
- ☐ Electronic transfer by magnetic or optical media, email or computer networks
- ☐ Sharing of personal data with other organisations
- ☐ Export of personal data outside the EEA
- ☐ Use of personal addresses, postcodes, faxes, emails or telephone numbers
- ☐ Publication of direct quotations from respondents
- ☐ Publication of data that might allow identification of individuals
- ☐ Use of audio/visual recording devices
- ☑ Storage of personal data on any of the following:
  - ☑ Manual files (includes paper or film)
  - ☑ NHS computers
  - ☐ Social Care Service computers
  - ☐ Home or other personal computers
  - ☑ University computers
  - ☐ Private company computers
  - ☐ Laptop computers

Further details:
The research team will be responsible for keeping the electronic data saved in password-protected university computers and the documents in a locked cabinet within the institution. All data access from personal devices will be conducted solely through a secure VPN login, with adherence to protocols ensuring that no data is downloaded or stored on personal computers. Additionally, for added security, research data may also be securely stored within the Research Data Store university service. Copies of the original documents will be saved in a separate locked cabinet within the University and the original electronic data will be backed-up in password protected systems.

The sponsor will use an unambiguous participant identification code that allows identification of all the data reported for each participant. Sponsor will be responsible for ensuring compliance with the requirements outlined above when tasks are subcontracted. There will be no loss of quality if an electronic system is used in place of a paper system.

Direct access will be granted only to the researchers, the Sponsor (University of Birmingham), and the regulatory authorities to permit study-related monitoring, audits, and inspections, all conducted in line with participant consent.

Demographic data, including age and gender, will be saved in the software used for participants' computer-based tasks. However, the demographic data will be saved anonymously, with participants being allocated unique identification numbers at the beginning of the study.

A37. Please describe the physical security arrangements for storage of personal data during the study?

Data files will be electronically stored on a password-protected computer for a period of 10 years, at which point they will be destroyed/deleted. Only the researchers (student) and the CI (David Punt) will have access to these data. Consent forms, demographic forms, questionnaires and the pen-paper tasks will be stored in a locked cabinet and only be accessed by the researchers.

A38. How will you ensure the confidentiality of personal data? *Please provide a general statement of the policy and procedures for ensuring confidentiality, e.g. anonymisation or pseudonymisation of data.*

All information acquired from this study will be kept confidential. Once consent has been given, a different number will be assigned to each participant and this number will be written on the consent form that will be stored in a locked cabinet or locked computer file, accessed only by the researchers. From this point forwards data files will be assigned a number rather than a name. Data from the experiment may be published but the participants will not be recognizable from this.

A40. Who will have access to participants' personal data during the study? *Where access is by individuals outside the direct care team, please justify and say whether consent will be sought.*

Personal data will be accessible to the patient's healthcare team, and specific information will only be shared with authorized members of the research team after obtaining consent from the patient. Participants can decide to be contacted and receive study-related information by signing a "Permission to Contact" form, granting the healthcare team permission to share their contact details with the researchers. Should they choose to participate, participants will be required to provide informed consent, acknowledging that certain details from their medical records may be disclosed.

Direct access to the patient's full medical records and folders will be exclusively granted to the healthcare team, ensuring only they have access to all relevant medical information. The research team will have access only to the information relevant to the study, specifically the data contained in the Case Report Form, such as the patient's history of stroke.

Storage and use of data after the end of the study

A41. Where will the data generated by the study be analysed and by whom?

The data generated by the study will be analysed by the researchers at the University of Birmingham.

A42. Who will have control of and act as the custodian for the data generated by the study?

	Title	Forename/Initials	Surname
	Dr	David	Punt
Post	Senior Lecturer (U of Bham) / Honorary Physiotherapist (BCHT)		
Qualifications	Graduate Diploma (Physiotherapy) - 1990 MSc (Clinical Neuroscience) - 1998		
Work Address	School of Sport, Exercise and Rehabiliation Sciences University of Birmingham Edgbaston Birmingham UK		
Post Code	B15 2TT		
Work Email			
Work Telephone			
Fax			

A43. How long will personal data be stored or accessed after the study has ended?

◯ Less than 3 months

○ 3 – 6 months
○ 6 – 12 months
○ 12 months – 3 years
◉ Over 3 years

If longer than 12 months, please justify:
In a study period of 8 months, we expect to have completed participant recruitment and data collection. Data analysis, study completion and dissemination of findings will then possibly be completed within a five-month time-frame.
Archiving will be authorised by the sponsor (University of Birmingham) following submission of the end of study report. The sponsor will be responsible for archiving the consent form, the demographic questionnaire and the feedback questionnaire form (which trial documents the site will be responsible for archiving).
The documents will be saved in a locked cabinet in the University of Birmingham and the electronic data in a password protected university computer. 10 years after the completion of the study the data will be destroyed with the authorisation from the Sponsor (University of Birmingham).
In a similar manner electronic data will be saved in a password protected computer at the Birmingham Community Healthcare trust for a period of 10 years after the completion of the study. After that the data will be deleted. The trust will maintain an electronic basic site file which will include a screening log.
Data

A44. For how long will you store research data generated by the study?

Years: 10
Months:

A45. Please give details of the long term arrangements for storage of research data after the study has ended. *Say where data will be stored, who will have access and the arrangements to ensure security.*

Data files will be electronically stored on a password-protected computer for a period of 10 years, at which point they will be destroyed/deleted. Only the researchers (students) and the PI (David Punt) will have access to these data.
In a similar manner electronic data will be saved in a password protected computer at the Birmingham Community Healthcare trust for a period of 10 years after the completion of the study. After that the data will be deleted. The trust will maintain an electronic basic site file which will include a screening log.

INCENTIVES AND PAYMENTS

A46. Will research participants receive any payments, reimbursement of expenses or any other benefits or incentives for taking part in this research?

◉ Yes ○ No

If Yes, please give details. For monetary payments, indicate how much and on what basis this has been determined.
Participants will not receive payment for participation in the study. Reasonable travel expenses (with a limit of £50 per participant) will be reimbursed to outpatient participants if they choose to conduct the study at the university.

A47. Will individual researchers receive any personal payment over and above normal salary, or any other benefits or incentives, for taking part in this research?

○ Yes ◉ No

A48. Does the Chief Investigator or any other investigator/collaborator have any direct personal involvement (e.g. financial, share holding, personal relationship etc.) in the organisations sponsoring or funding the research that may give rise to a possible conflict of interest?

○ Yes ◉ No

NOTIFICATION OF OTHER PROFESSIONALS

A49-1. Will you inform the participants' General Practitioners (and/or any other health or care professional responsible for their care) that they are taking part in the study?

○ Yes ◉ No

If Yes, please enclose a copy of the information sheet/letter for the GP/health professional with a version number and date.

PUBLICATION AND DISSEMINATION

A50. Will the research be registered on a public database?

The UK Policy Framework for Health and Social Care Research sets out the principle of making information about research publicly available. Furthermore: Article 19 of the World Medical Association Declaration of Helsinki adopted in 2008 states that "every clinical trial must be registered on a publicly accessible database before recruitment of the first subject"; and the International Committee of Medical Journal Editors (ICMJE) will consider a clinical trial for publication only if it has been registered in an appropriate registry. Please see guidance for more information.

◉ Yes ○ No

Please give details, or justify if not registering the research.
The research will be registered, but we have not yet confirmed the specific database in which it will be registered.

Please ensure that you have entered registry reference number(s) in question A5-1.

A51. How do you intend to report and disseminate the results of the study? *Tick as appropriate:*

- ☑ Peer reviewed scientific journals
- ☑ Internal report
- ☑ Conference presentation
- ☑ Publication on website
- ☐ Other publication
- ☐ Submission to regulatory authorities
- ☐ Access to raw data and right to publish freely by all investigators in study or by Independent Steering Committee on behalf of all investigators
- ☐ No plans to report or disseminate the results
- ☐ Other (please specify)

A52. If you will be using identifiable personal data, how will you ensure that anonymity will be maintained when publishing the results?

No personally identifiable data will be employed. Once participants have provided informed consent, they will be assigned non-identifiable participant numbers.

A53. How and when will you inform participants of the study results?

If there will be no arrangements in place to inform participants please justify this.
Participants will be given the choice to receive their personal data immediately upon completing the study, as outlined in the Participant Information Sheet (PIS). Participants will not be able to access their individual data after anonymization. However, they will have been informed in the PIS that they can contact the researchers to obtain the publication containing summaries of the anonymized data.

5. Scientific and Statistical Review

A54. How has the scientific quality of the research been assessed? *Tick as appropriate:*

- ☐ Independent external review
- ☐ Review within a company
- ☐ Review within a multi−centre research group
- ☑ Review within the Chief Investigator's institution or host organisation
- ☑ Review within the research team
- ☑ Review by educational supervisor
- ☐ Other

Justify and describe the review process and outcome. If the review has been undertaken but not seen by the researcher, give details of the body which has undertaken the review:
The scientific quality of the study was assessed through a review process conducted within the Chief Investigator's institution and within the research team itself. The research team consists of members with substantial experience in conducting similar studies.

For all studies except non-doctoral student research, please enclose a copy of any available scientific critique reports, together with any related correspondence.

For non-doctoral student research, please enclose a copy of the assessment from your educational supervisor/ institution.

A56. How have the statistical aspects of the research been reviewed? *Tick as appropriate:*

- ☐ Review by independent statistician commissioned by funder or sponsor
- ☐ Other review by independent statistician
- ☐ Review by company statistician
- ☐ Review by a statistician within the Chief Investigator's institution
- ☐ Review by a statistician within the research team or multi−centre group
- ☑ Review by educational supervisor
- ☑ Other review by individual with relevant statistical expertise
- ☐ No review necessary as only frequencies and associations will be assessed – details of statistical input not required

In all cases please give details below of the individual responsible for reviewing the statistical aspects. If advice has been provided in confidence, give details of the department and institution concerned.

	Title	Forename/Initials	Surname
	Dr	David	Punt
Department	School of Sport, Exercise and Rehabiliation Sciences		
Institution	University of Birmingham		
Work Address	School of Sport, Exercise and Rehabiliation Sciences University of Birmingham Edgbaston Birmingham UK		
Post Code	B15 2TT		
Telephone			
Fax			
Mobile			
E-mail			

Please enclose a copy of any available comments or reports from a statistician.

A57. What is the primary outcome measure for the study?

The primary outcome measure of the study are data collected by the computer-based tasks including Reaction Time (ms) and Accuracy (%). This data will highlight any visuospatial assymetries detected and accept or regect the hypothesis

A58. What are the secondary outcome measures?*(if any)*

The secondary outcome measures involve participants completing a questionnaire that assesses both quantitative data, focusing on aspects like acceptability and user-friendliness, and qualitative data, designed to capture participants' perspectives on various tasks and search strategies.

A59. What is the sample size for the research? *How many participants/samples/data records do you plan to study in total? If there is more than one group, please give further details below.*

Total UK sample size: 50

Total international sample size (including UK):

Total in European Economic Area:

Further details:
Our target is to enroll a minimum of 50 participants, with the potential to include up to 100, over the span of eight months. Considering that approximately 125 stroke survivors are admitted to Moseley Hall Ward 8 annually, we expect to recruit around 25 inpatients and 25 outpatients during this eight-month period. We would also like to maintain consistency with our previous research involving 74 unimpaired older adults and 51 younger adults, ensuring balanced data. Additionally, our systematic review revealed that studies in a similar domain have featured sample sizes ranging from fewer than 10 to over 190 participants. If recruitment progresses more rapidly, we will seek permission from the trust to extend the study duration up to a maximum of eight months or until we reach the target of 100 participants.

A60. How was the sample size decided upon? *If a formal sample size calculation was used, indicate how this was done, giving sufficient information to justify and reproduce the calculation.*

In Mosely Hall Ward 8, about 125 stroke survivors are admitted to the hospital each year. In an eight-month timeframe, we anticipate being able to enroll at least 25 inpatients and 25 outpatients stroke survivors. We also selected these numbers in order to balance the data from previous research we have conducted with 74 unimpaired older and 51 younger adults. Also, according to our systematic review, sample sizes of research papers with a similar focus could range from less than 10 to over 190 participants (Giannakou et al., 2022).
If the recruitment process is extremely successful and we complete the required number of participants in a short period of time (for example, three months), we will notify the trust and request permission to continue the study until we reach the maximum study period (8 months) or the maximum number of participants (100).

A61. Will participants be allocated to groups at random?

○ Yes ◉ No

A62. Please describe the methods of analysis (statistical or other appropriate methods, e.g. for qualitative research) by which the data will be evaluated to meet the study objectives.

Plans for statistical analyses of the primary outcome including:
• Group summary and individual measures of reaction time (ms) and accuracy (%) will be reported as means, medians.
• Reaction time will be measured in milliseconds as the time interval between the appearance of the stimuli and the response of the participant. Accuracy will be reported as the percentage of the targets detected correctly.
• Reaction Time data from catch trials will not be included in the analysis and outliers exceeding two standard deviations will be removed, this method is demonstrated to produce less bias compared to other methods.

• Individual and group mean scores of the basic stroke assessment and pen-and-paper task scores will be tabulated. Our main aim is to explore whether computer-based tasks can be used to highlight visuo-spatial attention deficits and classify patients into distinct groups according to their symptoms.
Patients could be divided into categories, depending on the lesion's side (left or right), if neglect is present (positive or negative), and the severity of neglect symptoms as determined by the pen-and-paper tests (severe, moderate, mild, and no neglect).
Group and individual patient data analysis will be carried out, in order to investigate the relationship between performance of computer-based and paper-and-pencil tasks (e.g., Pearson correlation coefficient).
A series of multiple Anova analyses, will be utilised to examine how different patient and control groups' reaction time and accuracy are affected by the following parameters:
Series of multiple Anova analysis could be performed to investigate how the performance of different patient and control groups is affected by:
- Target position (e.g., Left vs Right or Left, Middle Left, Middle, Middle Right, Right).
- Different computer-based tasks.
- Different task demands (e.g., number of distractors numbers)

6. MANAGEMENT OF THE RESEARCH

A63. Other key investigators/collaborators. *Please include all grant co-applicants, protocol co-authors and other key members of the Chief Investigator's team, including non-doctoral student researchers.*

Title	Forename/Initials	Surname
Dr	Ned	Jenkinson

Post	Senior Lecturer (U of Bham)
Qualifications	Undergraduate degree in Neuroscience PhD in Neuroscience focused on cerebellum function Extensive research experience of undertaking and supervising experimental studies in clinical and non-clinical populations. Member of the supervisory team for the applicant.
Employer	University of Birmingham
Work Address	School of Sport, Exercise and Rehabiliation Sciences University of Birmingham Edgbaston Birmingham UK
Post Code	B15 2TT
Telephone	
Fax	
Mobile	
Work Email	

A64. Details of research sponsor(s)

A64-1. Sponsor

Lead Sponsor

Status:
- ○ NHS or HSC care organisation
- ◉ Academic
- ○ Pharmaceutical industry
- ○ Medical device industry
- ○ Local Authority

Commercial status: Non-Commercial

◯ Other social care provider (including voluntary sector or private organisation)

◯ Other

If Other, please specify:

Contact person

Name of organisation	University of Birmingham
Given name	Birgit
Family name	Whitman
Address	Head of Research Ethics, Governance and Integrity
Town/city	Birmingham Research Park, University of Birmingham
Post code	B15 2SQ
Country	United Kingdom
Telephone	
Fax	
E-mail	researchgovernance@contacts.bham.ac.uk

Legal representative for clinical investigation of medical device (studies involving Northern Ireland only)
Clinical Investigations of Medical Devices that take place in Northern Ireland must have a legal representative of the sponsor that is based in Northern Ireland or the EU

Contact person

Name of organisation	
Given name	
Family name	
Address	
Town/city	
Post code	
Country	
Telephone	
Fax	
E-mail	

A65. Has external funding for the research been secured?

Please tick at least one check box.

☑ Funding secured from one or more funders

☐ External funding application to one or more funders in progress

☐ No application for external funding will be made

What type of research project is this?

- ◯ Standalone project
- ◯ Project that is part of a programme grant
- ◯ Project that is part of a Centre grant
- ◯ Project that is part of a fellowship/ personal award/ research training award
- ◉ Other

Other – please state:
Funding provided by the University of Birmingham

Please give details of funding applications.

Organisation	University of Birmingham
Address	University Of Birmingham Edgbaston
Post Code	B15 2TT
Telephone	+44 (0)121 414 3344
Fax	
Mobile	
Email	researchgovernance@contacts.bham.ac.uk

Funding Application Status: ◉ Secured ◯ In progress

Amount: 2000

Duration
Years:
Months:

If applicable, please specify the programme/ funding stream:

What is the funding stream/ programme for this research project?

A66. Has responsibility for any specific research activities or procedures been delegated to a subcontractor (other than a co-sponsor listed in A64-1) ? *Please give details of subcontractors if applicable.*

◯ Yes ◉ No

A67. Has this or a similar application been previously rejected by a Research Ethics Committee in the UK or another country?

◯ Yes ◉ No

Please provide a copy of the unfavourable opinion letter(s). You should explain in your answer to question A6-2 how the reasons for the unfavourable opinion have been addressed in this application.

A68-1. Give details of the lead NHS R&D contact for this research:

	Title	Forename/Initials	Surname
		Priti	Parmar
Organisation	Research and Innovation Birmingham Community Healthcare NHS Foundation Trust		
Address	Unit 3, Priestley Wharf, 20 Holt Street Birmingham		
Post Code	B7 4BN		
Work Email	bchc.researchinnovation@nhs.net		
Telephone	0121 466 6000		
Fax			
Mobile			

Details can be obtained from the NHS R&D Forum website: http://www.rdforum.nhs.uk

A69-1. How long do you expect the study to last in the UK?

Planned start date: 12/12/2023
Planned end date: 11/09/2024
Total duration:
Years: 0 Months: 8 Days: 0

A71-1. Is this study?

- ○ Single centre
- ◉ Multicentre

A71-2. Where will the research take place? *(Tick as appropriate)*

- ☑ England
- ☐ Scotland
- ☐ Wales
- ☐ Northern Ireland
- ☐ Other countries in European Economic Area

Total UK sites in study 2

Does this trial involve countries outside the EU?
○ Yes ◉ No

A72. Which organisations in the UK will host the research?*Please indicate the type of organisation by ticking the box and give approximate numbers if known:*

☑ NHS organisations in England	1
☐ NHS organisations in Wales	
☐ NHS organisations in Scotland	
☐ HSC organisations in Northern Ireland	
☐ GP practices in England	
☐ GP practices in Wales	
☐ GP practices in Scotland	

☐ GP practices in Northern Ireland	
☐ Joint health and social care agencies (eg community mental health teams)	
☐ Local authorities	
☐ Phase 1 trial units	
☐ Prison establishments	
☐ Probation areas	
☐ Independent (private or voluntary sector) organisations	
☑ Educational establishments	1
☐ Independent research units	
☐ Other (give details)	
Total UK sites in study:	2

A73-1. Will potential participants be identified through any organisations other than the research sites listed above?

◯ Yes ◉ No

A76. Insurance/ indemnity to meet potential legal liabilities

***Note:** in this question to NHS indemnity schemes include equivalent schemes provided by Health and Social Care (HSC) in Northern Ireland*

A76-1. What arrangements will be made for insurance and/or indemnity to meet the potential legal liability of the sponsor(s) for harm to participants arising from the management of the research? *Please tick box(es) as applicable.*

Note: Where a NHS organisation has agreed to act as sponsor or co-sponsor, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For all other sponsors, please describe the arrangements and provide evidence.

☐ NHS indemnity scheme will apply (NHS sponsors only)

☑ Other insurance or indemnity arrangements will apply (give details below)

The University has in force a Public Liability Policy and/or Clinical Trials policy which provides cover for claims for "negligent harm" and the activities here are included within that coverage.

Please enclose a copy of relevant documents.

A76-2. What arrangements will be made for insurance and/ or indemnity to meet the potential legal liability of the sponsor(s) or employer(s) for harm to participants arising from the design of the research? *Please tick box(es) as applicable.*

Note: Where researchers with substantive NHS employment contracts have designed the research, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For other protocol authors (e.g. company employees, university members), please describe the arrangements and provide evidence.

☐ NHS indemnity scheme will apply (protocol authors with NHS contracts only)

☑ Other insurance or indemnity arrangements will apply (give details below)

The University has in force a Public Liability Policy and/or Clinical Trials policy which provides cover for claims for "negligent harm" and the activities here are included within that coverage.

Please enclose a copy of relevant documents.

A76-3. What arrangements will be made for insurance and/ or indemnity to meet the potential legal liability of investigators/collaborators arising from harm to participants in the conduct of the research?

Note: Where the participants are NHS patients, indemnity is provided through the NHS schemes or through professional indemnity. Indicate if this applies to the whole study (there is no need to provide documentary evidence). Where non-NHS sites are to be included in the research, including private practices, please describe the arrangements which will be made at these sites and provide evidence.

☑ NHS indemnity scheme or professional indemnity will apply (participants recruited at NHS sites only)

☐ Research includes non-NHS sites (give details of insurance/ indemnity arrangements for these sites below)

We recruit only NHS patients for this study.

Please enclose a copy of relevant documents.

A78. Could the research lead to the development of a new product/process or the generation of intellectual property?

◯ Yes ◉ No ◯ Not sure

PART C: Overview of research sites

Please enter details of the host organisations (Local Authority, NHS or other) in the UK that will be responsible for the research sites. *For further information please refer to guidance.*

Investigator identifier	Research site		Investigator Name	
IN3	◉ NHS/HSC Site ○ Non-NHS/HSC Site		Forename Middle name Family name Email	Shawab Mir
	Organisation name	BCHC COMMUNITY MEDICAL ASSESSMENT UNIT	Qualification (MD...)	Clinical Specialist Neuro Physiotherapist
	Address	MOSELEY HALL HOSPITAL ALCESTER ROAD BIRMINGHAM WEST MIDLANDS	Country	United Kingdom
	Post Code	B13 8JL		
	Country	ENGLAND		
IN4	○ NHS/HSC Site ◉ Non-NHS/HSC Site		Forename Middle name Family name Email	David Punt
	Institution name	University of Birmingham	Qualification (MD...)	Senior Lecturer School of Sport, Exercise and Rehabilitation Sciences University of Birmingham Honorary Physiotherapist Birmingham Community Healthcare
	Department name	School of Sport, Exercise and Rehabilitation Sciences		
	Street address	University Of Birmingham		
	Town/city	Edgbaston		
	Post Code	B15 2TT		
	Country	United Kingdom	Country	United Kingdom

PART D: Declarations

D1. Declaration by Chief Investigator

1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it.
2. I undertake to fulfil the responsibilities of the chief investigator for this study as set out in the UK Policy Framework for Health and Social Care Research.
3. I undertake to abide by the ethical principles underlying the Declaration of Helsinki and good practice guidelines on the proper conduct of research.
4. If the research is approved I undertake to adhere to the study protocol, the terms of the full application as approved and any conditions set out by review bodies in giving approval.
5. I undertake to notify review bodies of substantial amendments to the protocol or the terms of the approved application, and to seek a favourable opinion from the main REC before implementing the amendment.
6. I undertake to submit annual progress reports setting out the progress of the research, as required by review bodies.
7. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of patient or other personal data, including the need to register when necessary with the appropriate Data Protection Officer. I understand that I am not permitted to disclose identifiable data to third parties unless the disclosure has the consent of the data subject or, in the case of patient data in England and Wales, the disclosure is covered by the terms of an approval under Section 251 of the NHS Act 2006.
8. I understand that research records/data may be subject to inspection by review bodies for audit purposes if required.
9. I understand that any personal data in this application will be held by review bodies and their operational managers and that this will be managed according to the principles established in the Data Protection Act 2018.
10. I understand that the information contained in this application, any supporting documentation and all correspondence with review bodies or their operational managers relating to the application:
    - Will be held by the REC (where applicable) until at least 3 years after the end of the study; and by NHS R&D offices (where the research requires NHS management permission) in accordance with the NHS Code of Practice on Records Management.
    - May be disclosed to the operational managers of review bodies, or the appointing authority for the REC (where applicable), in order to check that the application has been processed correctly or to investigate any complaint.
    - May be seen by auditors appointed to undertake accreditation of RECs (where applicable).
    - Will be subject to the provisions of the Freedom of Information Acts and may be disclosed in response to requests made under the Acts except where statutory exemptions apply.
    - May be sent by email to REC members.
11. I understand that information relating to this research, including the contact details on this application, may be held on national research information systems, and that this will be managed according to the principles established in the Data Protection Act 2018.
12. Where the research is reviewed by a REC within the UK Health Departments Research Ethics Service, I understand that the summary of this study will be published on the website of the Health Research Authority (HRA) together with the contact point for enquiries named below. Publication will take place no earlier than 3 months after the issue of the ethics committee's final opinion or the withdrawal of the application.

Contact point for publication*(Not applicable for R&D Forms)*

HRA would like to include a contact point with the published summary of the study for those wishing to seek further

information. We would be grateful if you would indicate one of the contact points below.

- (•) Chief Investigator
- ( ) Sponsor
- ( ) Study co-ordinator
- ( ) Student
- ( ) Other – please give details
- ( ) None

Access to application for training purposes *(Not applicable for R&D Forms)*

Optional – please tick as appropriate:

☐ I would be content for members of other RECs to have access to the information in the application in confidence for training purposes. All personal identifiers and references to sponsors, funders and research units would be removed.

This section was signed electronically by Dr David Punt on 23/01/2024 15:39.

Job Title/Post:	Associate Professor
Organisation:	University Of Birmingham
Email:	

D2. Declaration by the sponsor's representative

If there is more than one sponsor, this declaration should be signed on behalf of the co-sponsors by a representative of the lead sponsor named at A64-1.

I confirm that:

1. This research proposal has been discussed with the Chief Investigator and agreement in principle to sponsor the research is in place.
2. An appropriate process of scientific critique has demonstrated that this research proposal is worthwhile and of high scientific quality.
3. Any necessary indemnity or insurance arrangements, as described in question A76, will be in place before this research starts. Insurance or indemnity policies will be renewed for the duration of the study where necessary.
4. Arrangements will be in place before the study starts for the research team to access resources and support to deliver the research as proposed.
5. Arrangements to allocate responsibilities for the management, monitoring and reporting of the research will be in place before the research starts.
6. The responsibilities of sponsors set out in the UK Policy Framework for Health and Social Care Research will be fulfilled in relation to this research.

   Please note: *The declarations below do not form part of the application for approval above. They will not be considered by the Research Ethics Committee.*
7. Where the research is reviewed by a REC within the UK Health Departments Research Ethics Service, I understand that the summary of this study will be published on the website of the National Research Ethics Service (NRES), together with the contact point for enquiries named in this application. Publication will take place no earlier than 3 months after issue of the ethics committee's final opinion or the withdrawal of the application.
8. Specifically, for submissions to the Research Ethics Committees (RECs) I declare that any and all clinical trials approved by the HRA since 30th September 2013 (as defined on IRAS categories as clinical trials of medicines, devices, combination of medicines and devices or other clinical trials) have been registered on a publically accessible register in compliance with the HRA registration requirements for the UK, or that any deferral granted by the HRA still applies.

This section was signed electronically by Dr Birgit Whitman on 23/01/2024 15:32.

Job Title/Post:	Research Governance Officer
Organisation:	University of Birmingham
Email:	researchgovernance@contacts.bham.ac.uk

D3. Declaration for student projects by academic supervisor(s)

1. I have read and approved both the research proposal and this application. I am satisfied that the scientific content of the research is satisfactory for an educational qualification at this level.

2. I undertake to fulfil the responsibilities of the supervisor for this study as set out in the UK Policy Framework for Health and Social Care Research.

3. I take responsibility for ensuring that this study is conducted in accordance with the ethical principles underlying the Declaration of Helsinki and good practice guidelines on the proper conduct of research, in conjunction with clinical supervisors as appropriate.

4. I take responsibility for ensuring that the applicant is up to date and complies with the requirements of the law and relevant guidelines relating to security and confidentiality of patient and other personal data, in conjunction with clinical supervisors as appropriate.

Academic supervisor 1

This section was signed electronically by Dr David Punt on 23/01/2024 15:41.

Job Title/Post:	Associate Professor
Organisation:	University Of Birmingham
Email:	

APPENDIX 3.

Participant Information Sheet (PIS) Outpatients CBASS

Study title
Computer-Based Assessment of visuo-Spatial attention following Stroke (CBASS).

Invitation and brief summary

You are invited to take part in this study that is being undertaken as part a PhD. You have been approached due to your history of surviving a stroke. Before you decide to take part or not, it is important that you understand why the study is being conducted and what you are being asked to do.

Please take time to read this information leaflet and ask any questions you may have.

In this study we aim to explore visual attention in stroke survivors in order to gain a better understanding of the applicability, challenges, and acceptability of computer-based assessment tasks.

What's involved?

It has been shown that computer-based tasks have many benefits when employed to assess different aspects of human performance. In this study, participants will complete a series of computerized tasks that are designed to measure visual attention, gathering data relating to the speed and accuracy of performance. The aim of the study is to compare pen-and-paper tasks to computer-based tasks to explore their effectiveness.

We are interested in testing adults who have suffered a stroke and are thought able to complete these computer-based tasks. You have been invited to take part as we believe you meet these broad criteria. All participants should be able to use one hand to push a button and observe a computer screen for approximately 5 minutes at a time. Overall, you will be required to look at a computer screen for approximately 15-20 minutes. You will also be asked to complete some pen and paper tasks. With breaks in between the different tasks, we anticipate the whole session lasting approximately 60–90 minutes.

Do I have to take part?

It is up to you to decide whether or not to take part. If upon reading this information you decide not to take part, you can do so without giving reason; your care will not be affected. If you think you might be interested in taking part, please sign a permission to contact form. The research team will then provide you with more information and be available to answer any queries you may have. If you then decide to take part, you remain free to withdraw at any time (without giving a reason) up to the point that all tasks are completed.

What would taking part involve?

If you choose to participate, you'll have the option to complete the study either at the University of Birmingham, or in the comfort of your own home. If you opt for the latter, you'll be asked to provide your address to the researcher and all usual safeguarding procedures will be followed in relation to home visits. The study session will be scheduled at your convenience, and before it commences, you'll be required to complete a consent form.
The assessment session will take place in a quiet room. You will be asked to complete a questionnaire, including questions about your age, gender, stroke history, and other relevant topics. This will also involve a brief stroke-based assessment of impairments and function (the National Institutes of Health Stroke Scale Stroke Scale and the Addenbrooke's Cognitive Examination). You will then be asked to complete a series of four computer-based tasks that includes approximately 15-20 min of screen time. All these tasks have previously been completed by other stroke survivors. As part of the study, you will be required to respond to different targets on a computer screen. Responses may include touching a screen, pressing a key, or responding verbally into a microphone. After the computer-based task, you will be asked to complete six pen and paper tasks that require you to find targets and copy simple figures. Following the tasks, you will be asked to complete a brief feedback questionnaire about your thoughts regarding the tasks. The whole session is anticipated to take approximately 60 minutes and no more than 90 minutes. In some cases (for example if the participants are not able to complete the research in one session) they might be asked to schedule a second session.

What are the possible benefits of taking part?

There are no obvious benefits of taking part, but you may find the research interesting. We can provide you with an indication of your results should you wish. If this is the case, we will liaise with the stroke care team who will explain any implications that arise from these. Additionally, the study aims to enhance stroke care in the future and by taking part, you will be contributing to this. Once the study is completed, a summary of the study including the overall findings will be made available to the stroke care team. Participants may then contact the team should they wish to receive this summary.

What are the possible disadvantages and risks of taking part?

You may feel tired or fatigued during the study. If so, you can take a break before continuing or even stop the session if necessary. We will prioritize your comfort and well-being during your participation in this research. You can take a short break at any point you wish. You may also take a longer break and continue the tasks at another appointment scheduled at your convenience if you wish to do so.
The researcher is an HCPC registered physiotherapist, experienced working with individuals who have had a stroke.
We are committed to safeguarding your privacy and security, with robust data protection measures in place.
We want you to be aware that we've implemented measures to minimize these potential risks. We are ready to adjust the assessments to meet your specific requirements and offer support to mitigate any potential challenges.

Will there be any payment or reimbursement for taking part in this study?

If you choose the option of attending the University of Birmingham to complete the study, reasonable travel expenses will be covered up to a limit of £50.

What if there is a problem?

If you have any concerns about this study, please speak to a member of the research team in the first instance; contact details can be found towards the end of this sheet.

If you remain unhappy with their response and wish to make a complaint, please contact the Patients Advice and Liaisons Service (PALS) at your treating NHS Trust on < **Address:** Alcester Road, Birmingham, B13 8JL **Phone:** 0800 917 2855 >.

If you have any concerns or wish to make a complaint about how your information is being used, please contact the University's Data Protection Officer via email: dataprotection@contacts.bham.ac.uk

How will we use information about you?

We will need to use information from you and from your medical records for this research project. This information will include:

- your name
- contact details
- basic details including your age, gender, and stroke history.

People will use this information to do the research or to check your records to make sure that the research is being done properly. People who do not need to know who you are will not be able to see your name or contact details. Your data will have a code number instead. We will keep all information about you safe and secure. Once we have finished the study, we will keep some of the data so we can check the

results. We will write our reports in a way that no-one can work out that you took part in the study.

What are your choices about how your information is used?

You can stop being part of the study at any time, without giving a reason. If you choose to withdraw from the study after a certain point when your data has been anonymized, please be aware that the data collected about you may be retained within the study. We will keep information about you that we already have. We need to manage your records in specific ways for the research to be reliable. This means that we won't be able to let you see or change the data we hold about you.

Where can you find out more about how your information is used?

- You can find out more about how we use your information at www.hra.nhs.uk/information-about-patients/
- by asking one of the research team
- by sending an email to [redacted] or
- by ringing us on [redacted]
- by contacting the University's Data Protection Officer via email: dataprotection@contacts.bham.ac.uk

What will happen to the data and results of the study?

At the conclusion of this study, we place a strong emphasis on the secure management of your data, maintaining the utmost privacy and confidentiality. Your

data will be carefully stored and managed. Electronic data files will be stored on a password-protected computer and paper-based data on a locked cabinet for a period of 10 years, at which point they will be destroyed/deleted. Only the authorized personnel will have access to these data. Data from the research may be published but you will not be recognizable from this. The results will be analysed and used to write a research report. Furthermore, the results could form part of a paper submitted for publication in a scientific journal or presented at a conference.

How can you access publications?

If you are interested in accessing publications related to this study, please feel free to contact our study team. We are here to assist you in obtaining the relevant publications or guide you to their sources.

How will your data be shared?

In some instances, your anonymised data may be shared with collaborative partners in institutes, within the UK or abroad for future use in ethically approved research. You will be given the option to consent to your anonymised data being shared for this purpose. Any shared data would be governed by comprehensive data protection measures and confidentiality agreements.

Who is sponsoring, insuring and funding the study?

This study is sponsored by and has received financial support from the University of Birmingham.

The University of Birmingham has in place Clinical Trials indemnity coverage for this study which provides cover to the University for harm which comes about through the University's, or its staff's, negligence in relation to the design or management of the

study and may alternatively, and at the University's discretion provide cover for non-negligent harm to participants.

With respect to the conduct of the study at Site and other clinical care of the patient, responsibility remains with the NHS organisation responsible for the clinical site and is therefore indemnified through NHS Resolution. The NHS have a duty of care to participants whether or not the participant is taking part in a clinical trial and the normal NHS complaints mechanisms will still be available to you.

Who has reviewed the study?

This study has been reviewed in line with NHS Research Ethics Committee and given a favourable opinion. A group of participants who have not had a stroke have already completed this research in a study reviewed by The University of Birmingham's Research Ethics Committee and also given a favourable opinion. Young and old unimpaired adults who have completed the study as part of this research have confirmed its acceptability and feasibility.

Contact details.

Should you have any questions regarding the study or what is asked of you please do not hesitate to contact Ioanna Giannakou (Student Researcher) or Dr. David Punt (Project Supervisor):

Ioanna Giannakou

[redacted]

[redacted]

Dr. David Punt

[redacted]

[redacted]

Thank you for considering taking part in this study. If you wish to take part, please inform the researcher and you will be provided with your own copy of this information sheet and asked to sign a consent form.