Diagnostic Validation of the Computerised Extrapersonal Neglect Test (CENT) in Stroke Survivors

Petar Stermsek

Candidate Registration Number: 100071909/2

Primary Supervisor: Dr Stephanie Rossit

Secondary Supervisor: Dr Catherine E. L. Ford

Faculty of Medicine and Health Sciences

University of East Anglia

Thesis submitted in partial fulfilment of the degree of

Doctorate in Clinical Psychology

Date of Submission: 05th March 2024

Thesis Portfolio Word Count: 23,148

Contents

List of Tables 5

List of Figures 6

Acknowledgements 7

Thesis Portfolio Abstract 8

Chapter 1. Introduction to the Thesis Portfolio 9

Chapter 2: Systematic Review 18

Abstract 19

1. Introduction 20

2. Method 23

2.1. Search Strategy 23

2.2. Eligibility Criteria 25

2.3. Study Selection and Data Extraction 25

2.4. Quality Assessment 25

2.5. Data Synthesis 26

3. Results 28

3.1. Quality Appraisal 30

3.2. Study Characteristics 32

4. Synthesis 46

4.1. Types of Diagnostic Test 46

4.2. Psychometric properties 46

4.2.1. Diagnostic Accuracy 46

4.2.2. Content (Face) Validity 47

4.2.3. Criterion Validity 48

4.2.3.1. Concurrent Validity 48

4.2.4. Construct Validity 49

4.2.4.1. Convergent Validity 49

4.2.4.2. Discriminant Validity 50

4.2.5. Internal Consistency 51

4.2.6. Test-Retest Reliability 52

4.2.7. Interrater Reliability 52

4.3. Computerised versus Non-Computerised Tests 53

4.3.1 Computerised Tests 53

4.3.2. Non-computerised tests 54

4.4. Practical Considerations 55

5. Discussion 56

6. Conclusions 59

7. Funding ... 59
8. Conflict of Interest ... 59
9. Availability of data ... 59
10. References ... 60
Chapter 3: Bridging Chapter ... 68
Chapter 4: Empirical Paper ... 69
Abstract ... 70
1. Introduction ... 71
2. Methodology ... 74
2.1. Design ... 74
2.2 Participants ... 74
2.3. Apparatus ... 76
2.3.1. CENT ... 76
2.3.2. Pen-and-Paper Tests ... 77
2.4. Measures ... 77
2.4.1. Computerised Extrapersonal Neglect Test (CENT) ... 77
2.4.2. Star Cancellation Test (Behavioural Inattention Test - BIT) ... 77
2.3.3. Line Bisection Task ... 77
2.4.4. Oxford Cognitive Screen (OCS) ... 78
2.4.5. Spatial Neglect Visual Analogue Rating Scale ... 78
2.4.6. Stroke Impact Scale ... 78
2.4.7. One-item Extended Test ... 78
2.5. Procedure ... 78
2.6. Analysis ... 82
2.7. Participant and public involvement ... 83
2.8. Ethical Approval ... 83
3. Results ... 84
3.1. Screening ... 84
3.2. Sample Characteristics ... 84
3.3. Psychometric Properties ... 86
3.3.1. Concurrent Validity ... 86
3.3.2. Discriminant Validity ... 87
3.3.3. Ecological Validity ... 88
3.3.4. Internal Consistency ... 88
3.3.5. Diagnostic Accuracy ... 90
3.3.4.1. CENT Cancellation and Star Cancellation ... 91
3.3.4.2. CENT Cancellation and OCS Cancellation ... 92

3.3.4.3. CENT Cancellation and Line Bisection 92
3.3.4.4. CENT Allocentric Score and Line Bisection 93
3.3.4.5. CENT Allocentric Score and OCS Allocentric Score 93
3.3.4.6. CENT Egocentric Score and OCS Egocentric Score 93
4. Discussion 93
5. Conclusions 97
6. References 98
Chapter 5: Critical Appraisal and Discussion 106
Main Findings 106
Systematic Review 106
Empirical Paper 106
Strengths and Limitations 108
Systematic Review 108
Empirical Paper 109
Conclusions 112
Chapter 6: Additional Results 113
Additional ROC Results 113
Additional Spearman correlation results 117
Portfolio References 141
Appendices 147
Appendix A. Submission Guidelines for Neuropsychologia 147
Appendix B. Prospero Registration (Registration ID: CRD42023491317) 157
Appendix C. PRISMA Checklist 158
Appendix D. Quality Assessment of Validity Studies (QAVALS) Form (Gore, 2017) 161
Appendix E. C-Sight Study Information Sheet (Aphasia Friendly) 162
Appendix F. C-Sight Study Consent Form (Aphasia Friendly) 182
Appendix G. C-Sight Trial Ethical Approval 187

List of Tables

Chapter One: Introduction to Thesis Portfolio

Table 1. Definitions of Reliability……………………………………………………….….……16

Table 2. Definitions of Validity and Diagnostic Accuracy……………………………………..……16

Chapter Two: Systematic Review

Table 1. Search Strategy………………………………………………………………….……24

Table 2. Eligibility Criteria………………………………………………………….…..…25

Table 3. Definitions and Tests of Validity and Diagnostic Accuracy…………………………….…....27

Table 4. Definitions and Tests of Reliability……………………………………………………..….28

Table 5. QAVALS item scores for each study………………………………………………..…...31

Table 6. Study characteristics……………………………………………………………..…33

Table 7. Test Validity and Diagnostic Accuracy……………………………………………….…....38

Table 8. Test Reliability……………………………………………………………….…..…42

Table 9. Tests and Subtests Identified…………………………………………………......…44

Chapter Four: Empirical Paper

Table 1. Inclusion and Exclusion Criteria for C-Sight Trial……………………………………………75

Table 2. CENT Variables……………………………………………………………….....…82

Table 3. Sample Characteristics…………………………………………………………..…85

Table 4. Spatial Neglect Subtype Rates in Stroke Survivor Sample……………………………..….86

Table 5. Spearman Correlations: CENT Cancellation Accuracy and conventional tests……………......87

Table 6. Spearman Correlations: CENT Cancellation Accuracy and OCS domains………………..…87

Table 7. Spearman Correlations: CENT Cancellation Accuracy and SIS domains……………....…88

Table 8. 2x2 table reporting cross-classification of subjects and combined reference tests……………90

Chapter Six: Additional Results

Table 3. All computed Spearman correlations for Oxford Cognitive Scale variables……………..….117

Table 4. All computed Spearman correlations for spatial neglect comparator tests………………..…124

Table 5. All computed Spearman correlations for Stroke Impact Scale……………………………..…129

Table 6. All computed Spearman correlations for CENT variables………………………………..…134

List of Figures

Chapter One. Introduction to Thesis Portfolio

Figure 1. Regions of space in which spatial neglect symptoms manifest……………………..…..…….11

Figure 2. Egocentric and allocentric neglected areas of space……………………………….....…….12

Chapter Two. Systematic Review

Figure 1. PRISMA flow diagram illustrating the identification, screening, and inclusion process…...29

Chapter Four. Empirical Paper

Figure 1. CENT Validation Sample Flow Chart……………………………………………………..75

Figure 2. CENT Broken Mugs Cancellation Task Example…………………………….…………….80

Figure 3. CENT Line Bisection Task Example……………………………….………………….....80

Figure 4. Spearman Correlation Plots (Bonferroni Corrected)…………………….……………......90

Figure 5. AUC graphs for CENT compared with the Star Cancellation test…………………..….........91

Figure 6. AUC graph for CENT compared with OCS Broken Hearts Cancellation Subtest…..………92

Chapter Six. Additional Results

Figure 3. CENT Cancellation and Line Bisection………………………………………………..…...113

Figure 4. CENT Allocentric Score and Line Bisection………………………………………..…...114

Figure 5. CENT Allocentric Score and OCS Allocentric Score…………………………………...….115

Figure 6. CENT Egocentric Score and OCS Egocentric Score…………………………………...…...116

Acknowledgements

First and foremost, I would like to thank the stroke survivors who bravely took part in our research, and volunteered their time and effort, during a difficult period in their lives.

I would like to thank Dr Stephanie Rossit not only for her unwavering support and invaluable knowledge over the last few years, but also for entrusting me with a project that I know she holds so close to her heart. I would like to thank the wider research team - Dr Helen Morse, and Dr Catherine Ford for their invaluable guidance and Andreas Michaelides for his hard work throughout.

I also like to thank my partner, friends, and family, those that are here and those that are no longer here for inspiring me to pursue achievements I never thought I could.

Thesis Portfolio Abstract

Background: Spatial neglect is a syndrome commonly experienced by stroke survivors and associated with range of difficulties including higher risk of falls and longer lengths of hospital stay. Most neuropsychological tests for spatial neglect are primarily focused in the peripersonal space (within arm's reach), resulting in the potential underdiagnosis of extrapersonal neglect (beyond arm's reach).

Aim: This thesis aimed to investigate the currently available tests for extrapersonal spatial neglect with established psychometric properties before exploring the psychometric properties of the novel Computerised Extrapersonal Neglect Test (CENT).

Methods: For the systematic review, 2522 studies were screened for eligibility. The remaining studies were critically appraised using the Quality Assessment of Validity Studies (QAVALS) tool. A narrative synthesis approach was then utilised to systematically analyse the findings of the selected studies. A cross-sectional diagnostic validation study was then completed within stroke-survivor's homes to explore the psychometric properties of the CENT.

Results: The systematic review identified 22 validation studies, revealing limitations in reported psychometric properties and methodological rigor, highlighting the need for more robust validation studies and the further development of diagnostic tools for extrapersonal spatial neglect. The diagnostic validation study that followed, demonstrated that the CENT, particularly the CENT cancellation task, had excellent diagnostic accuracy, and high concurrent validity, ecological validity, internal consistency, and discriminant validity. Notably, 11% of stroke-survivors were identified as having extrapersonal spatial neglect only.

Conclusions: Currently available validation studies for diagnostic tests for extrapersonal spatial neglect vary substantially in their quality and reported psychometric properties. The diagnostic validation study presented in this thesis suggests that the CENT has promising psychometric properties. Moreover, this study underscores the importance of formal extrapersonal spatial neglect testing, as potentially one in ten stroke survivors may be being overlooked without proper diagnosis.

Chapter 1. Introduction to the Thesis Portfolio

This thesis portfolio presents research on the diagnostic assessment of the neuropsychological syndrome of extrapersonal neglect. Chapter one introduces stroke, post-stroke spatial neglect, tests for spatial neglect and the psychometric properties of neuropsychological tests. The systematic review in Chapter two synthesizes and evaluates the evidence supporting available tests for extrapersonal neglect post-stroke. Chapter three serves to bridge the narrative between the systematic review and the empirical paper. The empirical paper (Chapter four) presents the novel Computerised Extrapersonal Neglect Test (CENT), evaluating its psychometric properties using receiver operator characteristic (ROC) curve analyses and the pattern of its correlations with widely used spatial neglect tests. Chapter five critically evaluates and discusses the theoretical and clinical implications of this thesis portfolio. Chapter six presents the additional findings of the empirical paper.

Background and Rationale

Stroke is a cerebrovascular event that occurs if the blood supply to the brain becomes occluded or ruptures (Portegies, Koudstaal & Ikram, 2016). A recent World Stroke Organisation review estimated that one in four adults will experience stroke in their lifetimes, with 62% of strokes occurring in people below the age of 70 (Feigin, Brainin, Norrving, Martins, Sacco, Hacke, Fisher, Pandian & Lindsay, 2022). An estimated 143 million years of healthy life is lost per year due to stroke-related death and disability (Feigin et al., 2022). The rate of stroke occurring each year has almost doubled globally, as nowadays someone experiences a stroke every three seconds somewhere in the world (Feigin et al., 2022). The total annual worldwide cost of stroke is estimated at 721 billion U.S. dollars (Feigin et al., 2022). Stroke causes damage to the brain and results in cerebral lesions. These lesion areas are associated with a wide range of cognitive and physical impairments in stroke survivors (Sachdev, Brodaty, Valenzuela, Lorentz, & Koschera, 2004).

Spatial neglect is a neuropsychological syndrome, and common consequence of brain injury that impacts a person's attention and spatial awareness (Longley, Woodward-Nutt, Turton, Stocking, Checketts, Bamford, Douglass, Taylor, Woodley, Moule, Vail & Bowen, 2023). Approximately 30% of stroke survivors will experience spatial neglect (Esposito, Shekhtman, & Chen, 2021). Spatial neglect is characterised by an inability to respond to sensory stimuli in the opposite side to the location of the lesion (the contralesional side). Studies have demonstrated that individuals experiencing spatial neglect are more likely to have poor functional outcomes, higher risk of falls (Wee & Hopman, 2008; Chen, Hreha, Kong & Barrett, 2015), longer lengths of stay in hospital and are more likely to be discharged into nursing care settings rather than be discharged home (Hammerbeck, Gittins, Vail, Paley, Tyson & Bowen, 2019).

For centuries, people have attempted to better understand the spatial neglect to support individuals in their recovery, but also to better understand the enigmatic inner workings of the brain. One of the first documented accounts of spatial neglect was a single case report by Hughlings Jackson in 1876, in which he grouped spatial disorientation, visual neglect and dressing apraxia under the term "imperception" (Halligan & Marshall, 1993). By 1883, several German neurologists had documented an inability of some people with right hemisphere stroke to perceive their left limbs and the inattention to objects and events occurring in their left visual field (Halligan & Marshall, 1993). As time went on, researchers coined multiple overlapping terms to describe spatial neglect-like symptoms, for example, psychic paralysis of gaze, neglect dyslexia or dyschiria (Halligan & Marshall, 1993).

A direct consequence of the First World War was that many young soldiers experienced acute and localised cerebral lesions, allowing for further study of spatial neglect. This led to the conceptualisation of spatial neglect as an attentional condition. During this time Poppeireuter (1917) began exploring ways of distinguishing "hemi-inattention" from hemianopia, by directing attention to the neglected side, but found they can compensate for each other. The term "neglect" began to be used widely in the 1930's but it was not until the Second World War, and another influx of wartime casualties, that Brain (1941) documented spatial neglect as a distinct sub-classification of what at the time was widely referred to as "visual disorientation", paving the way for formal diagnostic assessment.

In the period of 1944-1960, the first diagnostic testing procedures were developed by Oliver Zangwill and colleagues, including the clock drawing, spontaneous drawing and copying tasks as well as pointing tasks (Halligan & Marshall, 1993). The development of these tasks paved the way for discussions around how personal neglect and extrapersonal neglect appear distinct. At the time "extrapersonal" referred to any neglect outside of the body, not to be confused with the contemporary definition, in which extrapersonal refers to space beyond arms reach (Butler, Eskes & Vandorpe, 2004).

The 1970-1990s saw a resurgence in spatial neglect research and considerable evidence emerged documenting distinct sub-presentations of neglect including personal (i.e. body neglect), peripersonal (within arms-reach neglect), extrapersonal (beyond arms-reach neglect) and neglect in different reference frames (i.e. allocentric or egocentric neglect) (Bisiach & Luzzatti 1978; Halsband, Gruhn & Ettlinger, 1985; Meador, Loring, Bowers & Heilman, 1987). Figure 1 demonstrates the regions of space in which neglect is thought to separately manifest.

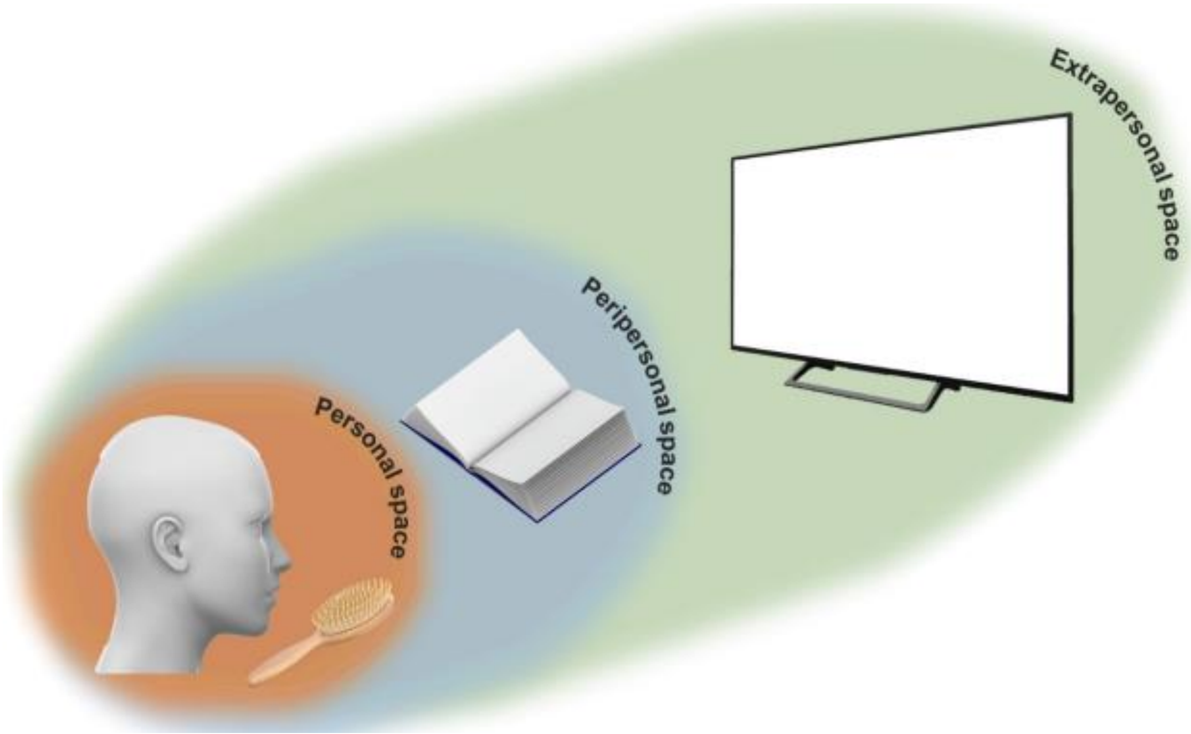


Figure 1. Regions of space in which spatial neglect symptoms manifest. Personal space (orange) represents one's own body and is associated with activities such as brushing one's hair or shaving one's beard. Peripersonal space (blue) represents all space within arm's reach, associated with activities such as eating food on a plate, or reading a book. Extrapersonal space (green) is all space beyond arm's reach, associated with activities such as watching television or crossing the road. Figure from Morse (2023).

It is theorised that there are also two distinct frames of reference when encoding information in space. If someone is perceiving an object using the egocentric frame of reference, they are encoding the object from the perspective of their own body. On the other hand, if using the allocentric frame of reference, one perceives the object based on other objects in that space, independent of his or her position. (Klatzky, Loomis, Beall, Chance & Golledge, 1998). How this might impact neglected areas of space in individuals with allocentric versus egocentric neglect is illustrated in figure 2.

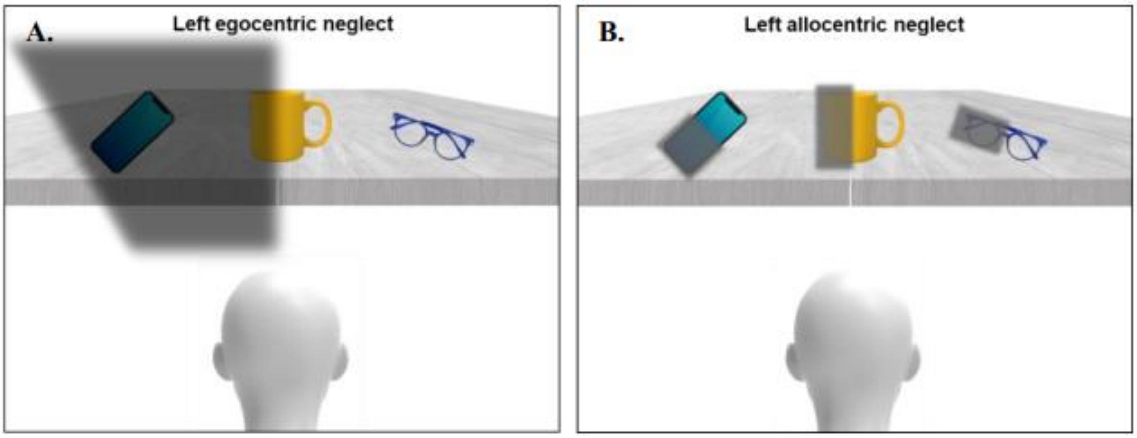


Figure 2. Representation of how egocentric and allocentric may impact neglected areas of space differently. A. represents left egocentric neglect. B. represents left allocentric neglect. Grey areas represent areas of inattention. Figure from Morse (2023).

In terms of the neuroanatomical evidence for spatial neglect, Moore, Milosevich, Mattingley, Demeyere & Au (2023) recently published a systematic review of 34 lesion-symptom mapping studies, totalling 2713 stroke survivors and highlighted five main areas in the right hemisphere most frequently linked to egocentric neglect, including subcortical white matter (superior longitudinal fasciculus), parietal (supramarginal gyri, post central gyri, angular gyri) and posterior frontal lobe (precentral gyri). Lesions in the angular gyrus in the left hemisphere parietal lobe were also linked to right egocentric neglect. Interestingly, distinct lesion areas in the left hemisphere, such as the temporal (insular cortex) and frontal lobe (Brodmann's area 6 and frontal operculum), were associated with right egocentric neglect. Right-hemisphere lesions associated with allocentric neglect were the posterior temporal lobe (middle temporal gyrus), while left-hemisphere allocentric neglect was associated with subcortical areas (external capsule, anterior limb of internal capsule). It appears therefore, that allocentric and egocentric neglect depend on distinct neuroanatomical areas, implying they are dissociable conditions. Chechlacz, Rotshtein, Bickerton, Hansen, Deb & Humphreys (2010) suggest that when allocentric and egocentric neglect present together, it may be due to damage to subcortical white matter, potentially disrupting communication between the areas selecting spatial reference frames.

Moore et al. (2023) did not find enough lesion mapping studies investigating the neuroanatomical differences between spatial regions (personal/peripersonal/extrapersonal) to draw any anatomical conclusions. Other studies, however, such as Ten Brink, Biesbroek, Oort, Visser-Meily & Nijboer (2019) found overlapping lesions in the frontal, parietal and temporal lobes associated with neglect in both extrapersonal (presented 120cm) and peripersonal (presented 30cm) space, suggesting a lack of dissociation. Committeri, Pitzalis, Galati, Patria, Pelle, Sabatini, Castriota-Scanderbeg, Piccardi, Guariglia & Pizzamiglio (2007), investigated peripersonal and personal neglect demonstrated that they were dissociable as personal neglect was linked to damage in parietal regions involved in proprioceptive and somatosensory processing, while peripersonal neglect was associated with frontal lobe damage. Lane, Ball, Smith, Schenk & Ellison (2013) supported these findings further with Transcranial Magnetic Stimulation experiments, indicating the involvement of the right posterior parietal cortex in peripersonal space and the right ventral occipital cortex in extrapersonal space. These results align with the Goodale & Milner (1992) two visual stream model, suggesting a preferential bias for dorsal visual stream processing in near space for action guidance and ventral stream processing in far space for object identification and interaction (Lane et al., 2013).

The period of 1970s to early 2000s also saw the development of a number of different cognitive diagnostic tests attempting to detect these newly documented presentations, including the Line Bisection tasks (Schenkenberg, Bradford & Ajax, 1980), drawing tasks including the Copy of Complex Drawing task (Gainotti & Tiacci, 1970); and cancellation tasks including the Letter Cancellation (Diller, Ben-Yishay, Gerstman, Goodkin, Gordon & Weinberg, 1974), Star Cancellation (Wilson, Cockburn & Halligan, 1987), Bells test (Gauthier, Dehaut, & Yves, 1989) tests. Line Bisection tasks require the participant to judge the midpoint of a series of horizontal lines presented in the centre, to the left or to the right of the midpoint of the participant's body. They tend to be quick to administer and among the most popular tests used to assess spatial neglect clinically (Checketts, Mancuso, Fordell, Chen, Hreha, Eskes, Vuilleumier, Vail & Bowen, 2020). Drawing tasks require participants to copy drawings presented in front of them (aligned with their midline), or from memory. Cancellation tasks comprise of a series of target stimuli presented on a page which participants must cross out. The target stimuli are usually surrounded by distractor stimuli as this increases attentional demand and has been found to increase test sensitivity (Ferber & Karnath, 2001).

One of the challenges of assessing spatial neglect is that other common post-stroke conditions such as hemianopia can present similarly on these tests (line bisection; Barton & Black, 1998), and to complicate things further, these conditions can present comorbidly, making it difficult to differentiate between them (Kerkhoff, Rode & Clarke, 2021). On the other hand, the presence of spatial neglect can impact performance on neuropsychological tests of other cognitive abilities such as memory and arithmetic ability (Lezak, 2004), as individuals are not attending to the stimuli presented. This further demonstrates the importance of formally assessing spatial neglect and the careful consideration of visual field deficits.

Another important factor to acknowledge is the impact of age on neglect. Gottesman, Kleinman, Davis, Heider-Gary, Newhart, Kannan & Hillis (2008) reported that 69.6% of stroke survivors over 65 years of age had spatial neglect compared to 49.4% of stroke survivors aged below 65. In addition, they report the chance of experiencing spatial neglect post-stroke are 1.84 times more likely for every additional 10 years of age past 65. Additionally, prevalence and severity studies have not found any statistically significant differences in terms of gender and spatial neglect (Kleinman, Gottesman, Davis, Newhart, Heidler-Gary & Hillis, 2008).

From the 2000s to the present, as technology has developed and become more readily available and inexpensive, there has been a significant surge in the development of computerised neuropsychological assessments (Parsey & Schmitter-Edgecombe, 2013), these are becoming increasingly feasible in clinical settings (Giannakou, Punt & Lin, 2022). Some potential benefits of computerised tests are that they allow for the automation of scoring and can provide millisecond precision. In principle, this can reduce the risk of human error, the clinical time spent scoring, and potentially facilitate providing immediate feedback. Within the field of spatial neglect diagnostic tests, computerised tests appear more sensitive compared to pen-and-paper tests (Giannakou et al., 2022).

The Neurolab team at the University of East Anglia have developed the Computerised Extrapersonal Neglect Test (CENT) comprising of two tasks, a cancellation task and a line bisection task presented beyond arm's reach in order to assess spatial neglect in the extrapersonal space. The test also includes allocentric and egocentric variables. Morse, Jolly, Browning, Clark, Pomeroy & Rossit (2023) also provided age-related norms and cut-off scores for healthy adults but did not evaluate clinical validity or reliability. Morse et al. (2023) recommend future research explores the validity of CENT.

At present, the National Institute of Clinical Excellence (NICE, 2023) recommends the use of standardised assessments in combination with behavioural observations to assess visual inattention. This is likely because there is no currently agreed 'gold-standard' diagnostic test for spatial neglect and its subtypes (Moore, Milosevich, Beisteiner, Bowen, Checketts, Demeyere, Fordell, Godefroy, Laczo, Rich, Williams, Woodward-Nutt & Husain, 2022), so a multi-test approach appears the most diagnostically sensitive. No clear guidelines exist around how to classify spatial neglect severity, so Lindell, Jalas, Tenoyuo, Brunila, Voeten & Hamalainen (2007) propose mild spatial neglect as showing impairment on one to three cognitive spatial neglect tests and severe showing impairment on four or more cognitive spatial neglect tests.

The term 'psychometric properties' encompasses a range of types of validity, reliability, and diagnostic accuracy. There appears to be a general lack of consensus among professionals in the field of psychological testing around some of these definitions, particularly within the area of validity (Camargo, Herrera & Traynor, 2018). This ambiguity could lead to issues such as oversimplification, inadequate validation and ultimately misunderstanding (Newton, 2012). For clarity, the definitions of diagnostic accuracy, reliability and validity used throughout this thesis portfolio are outlined in tables 1 and 2.

Table 1. Definitions of Reliability (Souza, Alexandre & Guirardello, 2017).

Type of Reliability	Definition
Test-Retest Reliability	Consistency of repetitions, that is, the stability of measurement over time.
Internal Consistency	Consistency of measurement across items measured by the average correlation between items.
Interrater Reliability	The degree of concordance between raters on the same measurement tool.

Table 2. Definitions of Validity and Diagnostic Accuracy (Souza et al., 2017; Eusebi, 2013).

Type of Validity	Subtype	Definition
Content		The degree in which a test includes all the necessary items to represent the concept to be measured
Criterion		Assessed when a result can be compared to a 'gold standard'
	Concurrent	Evaluated using both the target-test and the 'gold standard', at the same time.
	Predictive	First the target-test is applied, and then, the 'gold standard'.
Construct		Extent to which a set of variables represent the construct that was projected to be measured.
	Convergent	Obtained through the correlation between the instrument and another instrument that assesses a similar construct, expecting high correlation results between them.
	Discriminant	Obtained through the correlation between the instrument and another instrument that assesses a dissimilar construct, expecting negative or no correlation between them.
Diagnostic Accuracy		Ability of a test to discriminate between and/or predict disease and health.
	Sensitivity	The proportion of true positive (TP) subjects with the disease in a total group of subjects with the disease
	Specificity	The proportion of true negative (TN) subjects without the disease with a negative test result in a total group of subjects without the disease
	Positive Predictive Value (PPV)	Proportion of patients with a positive test result in a total group of subjects with a positive result
	Negative Predictive Value (NPV)	Probability of not having a disease for a subject with a negative test result.
	Likelihood Ratios	The ratio of the probability of an expected test result in subjects with the disease to the probability in the subjects without the disease

TP = true positive, subjects with the condition of interest with the value of a parameter of interest above the cut-off; FP = false positive, subjects without the condition of interest with the value of a parameter of interest above the cut-off; TN = true negative, subjects without the condition with the value of a parameter of interest below the cut-off; FN = false negative subjects with the condition of interest with the value of a parameter of interest below the cut-off (Eusebi, 2013).

Thesis Rational and Outline

This thesis will investigate the currently available tests for extrapersonal spatial neglect with established psychometric properties before exploring the psychometric properties of a novel Computerised Extrapersonal Neglect Test (CENT). The test itself aims to bridge the clinical gap in available diagnostic testing in the extrapersonal space, as current neuropsychological diagnostic tests for spatial neglect are largely based on pen-and-paper assessments, which evaluate neglect in the peri-personal space.

The systematic review is presented first, followed by the bridging chapter and then the empirical paper. After the empirical paper, a critical discussion chapter then converges the findings of the systematic review and the empirical paper, highlighting methodological strengths and limitations, clinical and theoretical impact, and recommendations for future research. An additional result chapter presents the tables and figures of the remaining findings not presented in the empirical paper.

The empirical paper in this thesis portfolio presents my work on the Stroke Association funded C-SIGHT trial led by my primary supervisor, Dr Stephanie Rossit, investigating a rehabilitation intervention and assessment measure. Dr Helen Morse and Mr Andreas Michaelides also collected data for the C-SIGHT trial, for the preliminary analysis of CENT data (part of Helen Morse's UEA PhD thesis) and a separate analysis of the feasibility randomised controlled trial of the rehabilitation intervention (Mr Andreas Michaelides' UEA ClinPsyD Thesis). Data collection for these three projects was joint in nature, but each project addressed separate research questions and the write-up and analysis were completed separately.

Chapter 2: Systematic Review

Review Article

A systematic review of assessment tools for extrapersonal spatial neglect post-stroke.

Petar Stermsek[a], Andreas Michaelides[a], Catherine Elaine Longworth Ford[a], Stephanie Rossit[b]

[a]Department of Clinical Psychology and Psychological Therapies, Norwich Medical School, University of East Anglia, UK

[b]Faculty of Psychology, University of East Anglia, UK

Abstract word count: 273

Manuscript word count: 9,957

Disclaimer: this manuscript has been formatted for submission to Neuropsychologia. In accordance with this guidance, the maximum word count limit is 26,000 words. Please see appendix A for the publication guidance.

Abstract

BACKGROUND: Spatial neglect is a common syndrome experienced by stroke survivors. As literature around the clinical subtypes of neglect has continued to emerge, so too has a need for clinicians to be able to diagnose them, to inform rehabilitation and risk management. The aim of this systematic review was to synthesize research validating tests of post-stroke extrapersonal spatial neglect and their psychometric properties.

METHODS: Studies including adult stroke survivors, that evaluated the psychometric properties of a diagnostic test of extrapersonal spatial neglect; were in English; and included primary research, were selected. Databases (n = 10) and relevant reviews were used to identify relevant studies (search date: 28/12/2023). The Quality Assessment of Validity Studies (QAVALS) was used to appraise the quality of included studies and a narrative synthesis approach was utilised.

RESULTS: Having screened 2522 potential studies, a total of 22 studies were included validating 19 individual diagnostic tests on 1118 participants. The average study evaluated less than two types of validity and reliability covered within the scope of this review. The quality appraisal of these studies demonstrated notable limitations in methodological rigor and reporting of psychometric properties. The extent of computerisation and overall psychometric properties of these diagnostic tests were explored.

DISCUSSION: More rigorous diagnostic validation studies of tests for extrapersonal spatial neglect are urgently needed along with more consistency in the reporting of psychometric properties. This would allow clinicians to compare diagnostic tests for extrapersonal spatial neglect more easily and evaluate whether the different options are appropriate for their service context and available resources.

OTHER: This review is registered on PROSPERO (registration number: CRD42023491317)

HIGHLIGHTS:

- 22 studies validated 19 different extrapersonal spatial neglect diagnostic tests.
- Average validation study evaluated less than two types of validity and reliability.
- Studies had marked limitations in methodology and psychometric property reporting.
- Future diagnostic tests should consider finding a balance between computerisation and associated costs and technical support needs.
- Future diagnostic validation studies should consider evaluating more psychometric properties and robust diagnostic accuracy analyses.
- Clinicians should consider that spatial neglect may present exclusively outside of arm's reach, thus not being captured by standard pen and paper diagnostic tests.

KEYWORDS: Stroke; Spatial Neglect; Extrapersonal; Test; Computerised; Validation.

1. Introduction

Stroke is the third-leading cause of death and disability combined in the world, estimated to affect one in four adults during their lifetime (Feigin, Brainin, Norrving, Martins, Sacco, Hacke, Fisher, Pandian & Lindsay, 2022). A common consequence of stroke is spatial neglect, characterised by a failure to attend to, look at and respond to stimuli presented in, typically, an individual's contralesional side (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005). Spatial neglect can occur for different types of stimuli, for example, visual, auditory, tactile or mental representation, and many stroke survivors experience more than one form of neglect. It has been estimated that approximately one third of stroke survivors experience spatial neglect post-stroke (Esposito, Shekhtman & Chen, 2021). It arises during acute stroke, resolving spontaneously for less than half of those affected (Farne, Buxbaum, Ferraro, Frassinetti, Whyte, Veramonti, Angeli, Coslett & Ladavas, 2004), but persisting over time for many stroke survivors (Bonato, 2015; Nijboer, Kollen & Kwakkel, 2013). The severity of spatial neglect is associated with reduced likelihood of being discharged home from hospital and individuals with spatial neglect symptoms have been found to be 6.5 times more likely to experience falls (Chen, Hreha, Kong & Barrett, 2015). Moreover, spatial neglect is associated with increased caregiver burden and stress (Chen, Fyffe & Hreha, 2017) and the severity of neglect symptoms predicts scores on the family burden questionnaire more accurately than the number of lesioned cerebral regions did (Buxbaum, Ferraro, Veramonti, Ferne, Whyte, Ladavas, Frassinetti & Coslett, 2004).

Research has identified clinical subtypes of neglect that appear to be distinct from each other and therefore spatial neglect, cannot be explained exclusively by type of deficit or one neurological lesion area (Moore, Milosevich, Mattingley, Demeyere & Au, 2023). The main distinct subtypes of spatial neglect, as reported in a recent scoping review by Williams, Kernot, Hillier & Loetscher (2021), can be divided into three main dimensions. The first, frame of reference, refers to the perspective or viewpoint affected by neglect. Egocentric neglect, or body-centred neglect involves omission of stimuli on the contralesional side from the viewpoint of the individual whereas allocentric neglect (known as stimulus-centred or object centred neglect) is neglect of the contralesional side of objects regardless of their location. The second dimension, processing stage, classifies neglect into perceptual, representational, and motor processing stages. Perceptual neglect can be divided into visual, auditory, and tactile depending on the type of stimuli being omitted, representational neglect (also known as imaginal neglect) is a distortion or loss of mental images and internal representations, which can have an impact on spatial memory and motor neglect refers to both impaired movement of the contralesional limbs, and/or a deficit in movement towards the contralesional side. The third dimension, spatial sector, classifies neglect according to distance from body distinguishing personal neglect of one's own body (also known as body surface neglect) from peripersonal neglect of within-arm's-reach space and extrapersonal neglect of the space beyond reaching distance, or far space.

Currently, there is no "gold standard" tool for diagnosing spatial neglect (Moore, Milosevich, Beisteiner, Bowen, Checketts, Demeyere, Fordell, Godefroy, Laczo, Rich, Williams, Woodward-Nutt & Husain, 2022). Research has focussed instead on the development of tools to measure different neglect subtypes. Although it is generally agreed that there are separable, doubly dissociative subtypes of neglect (Beschin, Basso, Sala & Della, 2000; Guilbert, 2022; Halligan, Fink, Marshall & Vallar, 2003; Ortigue, Megevand, Perren, Landis & Blanke, 2006), with distinct lesion-deficit associations (Committeri, Pitzalis, Galati, Patria, Pelle, Savatini, Castriota-Scanderbeg, Piccardi, Guariglia & Pizzamiglio, 2007; Lane, Ball, Smith, Schenk & Ellison, 2013; Moore et al., 2023; Rode, Fourtassi, Pagliari, Pisella & Rossetti, 2017), the field lacks consensus in the terminology used for these subtypes (Williams et al., 2021). A recent scoping review attempted to group definitions for neglect subtypes to support clinicians to identify and use appropriate measures (Williams et al., 2021). Williams et al., (2021) found 13 separate terms for extrapersonal neglect in the literature, and even then, researchers sometimes used the term 'extrapersonal' to mean in 'far space' or 'outside of reach' and sometimes to mean 'within arm's reach space' (i.e. more widely referred to in the literature as peripersonal neglect). Accurate and reliable diagnosis is also important in clinical research evaluating the efficacy of treatments for specific spatial neglect subtypes.

Pen-and-paper tests are widely used in clinical settings (Checketts, Mancuso, Fordell, Chen, Hreha, Eskes, Vuilleumier, Vail & Bowen, 2020) often at hospital discharge, with less than one percent of clinicians reporting repeat assessments at follow-up (Menon-Nair, Korner-Bitensky & Ogourtsova, 2007). Common standardised tests of spatial neglect include bisection tasks, where the individual must indicate the midpoint of stimuli presented in different parts of the person's visual field and cancellation tasks, where individuals must identify target stimuli in both fields, sometimes while ignoring distractor stimuli (Li & Malhotra, 2015). Cancellation tasks (especially computerised versions) also permit useful qualitative or quantitative observations, such as scanning pattern, intersections, and search time (Dalmaijer, Van Der Stigchel, Nijboer, Cornelissen & Husain, 2015; Plummer, Morris & Dunai, 2003). Another approach to spatial neglect testing uses copying and drawing tasks, though these have been criticised as insensitive (Friedman, 1991), difficult to interpret (Bailey, Riddoch & Crome, 2000; Halligan, Marshall & Wade, 1989) and with questionable validity (Lieberman, Galinsky & Fried, 1999). Functional tasks, for example direct observations of participants completing everyday tasks (Chen, Hreha, Fortis, Goedert & Barrett, 2012) such as brushing their hair or making a cup of tea, are also used to detect neglect. Standardised functional assessments usually require the therapist to be trained (Plummer et al., 2003) and have necessary equipment so may not be feasible for some practitioners (Grattan & Woodbury, 2017). Unstandardised, observation-based functional tasks are widely used by occupational therapists in clinical settings (Checketts et al., 2020), with some studies finding them more sensitive than any single test alone (Azouvi, Samuel, Louis-Dreyfus, Bernati, Bartolomeo, Beis, Chokron, Leclercq, Marchal, Martin, De Montety, Olivier, Perennou, Pradat-Diehl, Prairial, Rode, Sieroff, Wiart &

Rousseaux, 2002). A recent international multidisciplinary survey found that 82% of stroke professionals use cognitive tests to measure spatial neglect, of which cancellation and drawing tasks are the most popular (Checketts et al., 2020). While standardised pen-and-paper tests may be accurate in detecting peripersonal, allocentric and egocentric neglect with considerable specificity and sensitivity (e.g., the Broken Hearts test; Demeyere, Riddoch, Slavkova, Bickerton & Humphreys, 2015), these tests do not measure neglect in extrapersonal space.

Multiple test use was recommended by researchers (Esposito et al., 2021; Guariglia, Matano & Piccardi, 2014) and combining standardised assessments with behavioural observations as recommended by the National Institute of Clinical Excellence (NICE, 2023) may support detection of both peripersonal and extrapersonal forms of neglect. However, clinicians may rely on subjective observations more than standardised batteries of tests (Evald, Wilms & Nordfang, 2021), or single test approaches to detect spatial neglect. Similarly in research a recent systematic review found that 59% of studies used a single test to identify spatial neglect, with 83% using non-ecological assessments, defined as assessments unrelated to activities of daily living (e.g. bisection and cancellation tests and observation of basic limb movement in the contralesional and ipsilesional sides of space; Esposito et al., 2021).

In clinical settings, computerised diagnostic assessments could offer considerable benefits over pen-and-paper tests. Automatic scoring and millisecond precision reduce human error (Gauthier, Dehaut & Joanette, 1989; Hannaford, Gower, Potter, Guest & Fairhurst, 2003; Liang, Fairhurst, Guest & Potter, 2010), and time and resource consumption (Hannaford, et al., 2003; Liang et al., 2010; Stone, Wilson, Wroot, Halligan, Lange, Marshall, Greenwood & Bartholomew, 1991); computer equipment is easily accessible in most settings; and computerised testing may also limit the use of compensatory strategies (Giannakou, Lin & Punt, 2022). Furthermore, computerised diagnostic tests may be more accurate in detecting milder cases of spatial neglect (Villarreal, Linnavuo, Sepponen, Vuori, Jokinen & Hietanen, 2020), with better psychometric properties than pen-and-paper diagnostic alternatives (Bonato, 2012; Villarreal, Linnavuo, Sepponen, Vuori, Bonato, Jokinen & Hietanen, 2021).

Extrapersonal neglect is seldom evaluated in clinical practice (Azouvi, Bartolomeo, Beis, Perennou, Pradat-Diehl & Rousseaux, 2006; Serino, Bonifazi, Pierfederici & Ladavas, 2007). This is concerning because extrapersonal neglect is prevalent and can occur in the absence of other neglect syndromes. Spaccavento, Cellamare, Falcone, Loverre & Nardulli (2017) found that 69% of their stroke survivor sample had extrapersonal neglect (determined using relevant subtests in the Extrapersonal Neglect Scale, Zoccolotti & Antonucci, 1992), often in combination with other forms of neglect but 11% had extrapersonal neglect alone. Similarly, Van der Stoep, Visser-Meily, Kappelle, De Kort, Huisman, Eijsackers, Kouwenhoven, Van Der Stigchel & Nijboer (2013), found that up to 25% of stroke survivors tested, had extrapersonal neglect exclusively (determined using shape cancellation, letter cancellation, and a line bisection task administered in far space). Missed opportunities to detect and treat extrapersonal neglect in clinical practice are also concerning as the syndrome has considerable associated risks and impact on everyday life, including in relation to road safety (Aravind & Lamontagne, 2014). Kim, Ku, Chang, Park, Lim, Han, Kim & Kim (2010) developed a virtual reality extrapersonal neglect test depicting a real street crossing to test the ability to react appropriately to ensure the safety of an avatar. Stroke survivors with extrapersonal spatial neglect performed considerably worse than those without spatial neglect. Moreover, some evidence suggests that extrapersonal neglect is associated with a smaller chance of spontaneous recovery compared to personal neglect (Appelros, Nydevik, Karlsson, Thorwalls & Seiger, 2004) further highlighting the importance of accurate diagnostic tools.

There is currently no systematic review of diagnostic tests for extrapersonal neglect and their psychometric properties to guide clinicians and researchers. The current review aimed therefore to appraise research validating diagnostic tests for extrapersonal spatial neglect using the Quality Assessment of Validity Studies (QAVALS; Gore, 2017) and use narrative synthesis to summarise and compare their psychometric properties, tool characteristics and features to support clinicians and researchers to select appropriate tests of extrapersonal neglect.

2. Method

In line with PRISMA systematic review guidelines (Moher, 2015), the protocol for this systematic review was registered with the International Register of Prospective Systematic Reviews (PROSPERO) (registration number: CRD42023491317). See appendix B for PROSPERO registration protocol, and appendix C for the PRISMA Checklist.

2.1. Search Strategy

Ten electronic bibliographic databases (MEDLINE, EMBASE, CINAHL Ultimate, Web of Science Core Collection, APA Psychinfo, APA PsycArticles, Academic Search Ultimate, SPORTDiscus with Full Text, AMED – The Allied and Complementary Medicine Database, IEEE Xplore Digital Library) were searched on 28 December 2023. The search strategy aimed to identify all published validation studies of diagnostics tests of extrapersonal neglect. The search strategy focussed on key elements for formulating psychometric reviews (Munn, Moola, Riitano & Lisy 2014) as shown in table 1.

Table 1. Search Strategy.

Construct of Interest	Extrapersonal neglect	Extrapersonal neglect OR Far space neglect OR extrapersonal space neglect OR neglect in far extrapersonal space OR neglect in far space OR extra-personal neglect OR extrapersonal (far) space neglect OR far space USN OR Spatial neglect in extrapersonal space OR USN in extrapersonal space OR Far peri-personal neglect OR spatial neglect in far space OR spatial extrapersonal hemineglect OR far space OR far-space OR out of reach OR out-of-reach
Population	Stroke	Stroke OR poststroke OR post-stroke OR cerebrovasc* OR Brain Vasc* OR Brain infarction OR Lacunar OR Intracranial OR haemorrhage OR CVA OR Cerebrovascular Accident OR Subarachnoid OR Intracerebral OR Cerebr* OR Acquired Brain Injury OR ABI OR Ischaemia OR Ischemia OR Ischaemic stroke OR Ischemic stroke
Measurement Properties	Validity Reliability Diagnostic Accuracy	"Sensitivity and Specificity" OR Psychometric properties OR specificity OR sensitivity OR Reliab* OR Valid* OR Clinimetric OR Diagnostic Accuracy OR Construct OR Face OR Criterion OR Content OR Minimum Detectable Difference OR Test-Retest OR Floor Effects OR Ceiling Effects OR Internal Consistency OR Intra-rater OR Inter-rater OR Concurrent OR Predictive OR Convergent OR Divergent OR Responsi*

2.2. Eligibility Criteria

The study selection criteria are outlined in table 2.

Table 2. Eligibility Criteria

	Inclusion Criteria	Exclusion Criteria
Participants	Stroke survivors. Adults, 18 years or older.	Neglect resulting from any other condition.
Concept	Any assessment of extrapersonal spatial neglect, that has documented psychometric properties.	Any assessment that does not include a test of extrapersonal spatial neglect.
Context	Assessment of neglect in any setting or stage post-stroke. Primary Research. Published in the English language.	Published in a language other than English. Any secondary research.

2.3. Study Selection and Data Extraction

The identified studies were imported into a reference manager (RAYYAN) and duplicates removed. Title and abstracts were individually screened against eligibility criteria. A second reviewer (AM) independently reviewed a random sample of 10% of titles and abstracts to confirm inclusion criteria were met. The full texts of remaining studies were screened similarly, with 10% screened by a second independent reviewer (AM). Any discrepancy regarding study eligibility was resolved through discussion with a third author (CF). The bibliographies of relevant recent reviews were also manually reviewed using the same process to ensure any additional relevant papers were included (Greenhalgh & Peacock, 2005).

The following data were extracted from full published papers by a single author and collated:

Study: Design, authors, year, country/setting.

Population: Sample size; stroke characteristics including type of stroke; age; gender.

Assessment Tool: Test name; test type (i.e. cancellation); syndrome tested: extrapersonal neglect only or extrapersonal neglect and other subtypes; duration of test administration; equipment required; reference tests; computerised or non-computerised; description of tool and protocols followed.

Psychometric Properties: test sensitivity and specificity; any measures of validity or reliability

2.4. Quality Assessment

The studies were be appraised using the Quality Assessment of Validity Studies (QAVALS), an appraisal tool used specifically for validation research studies, devised by Gore (2017) with excellent test-retest reliability (k = 0.80-0.84, 95% CI = 0.76-0.90) and good overall inter-rater reliability (K = 0.70, 95% CI = 0.61=0.79) (Gore et al., 2021). It consists of 24 items covering: design; content validity; criterion validity; and construct validity (convergent and discriminant). This measure was selected as it has demonstrated good psychometric properties and the measure itself covers a broader range of types of validity than other popular validation study appraisal criteria (such as the QUADAS-2, Whiting, Rutjes, Westwood, Mallett, Leeflang, Reitsma, Deeks, Sterne & Bossuyt, 2014). Each study was evaluated and assigned a score between zero and 24 points (see Appendix D for a list of all 24 items). A second reviewer (AM) independently appraised a random sample of 50% of papers and where necessary, consensus reached through discussion with a third author. Inter-rater reliability was documented for transparency.

2.5. Data Synthesis

A narrative synthesis was conducted, following guidance by Popay, Roberts, Sowden, Petticrew, Arai, Rodgers, Britten, Roen & Duffy (2006) to consider similarities and differences between studies and the extrapersonal neglect tests investigated. Initially, study characteristics including sample composition, study setting, and diagnostic tests validated, were examined. Secondly, psychometric properties of each test were summarised and diagnostic tests and tasks characterised by type of spatial neglect tested (e.g. personal, extrapersonal, peripersonal), task type (e.g. cancellation, line bisection, navigation), and number of subtests involved. Tests were then grouped and considered with reference to psychometric properties, degree of computerisation and practical considerations for clinicians deciding which diagnostic test to administer within clinical settings.

Tables 3 and 4 provide the definitions used in this review regarding test validity (content, concurrent, predictive, discriminant and convergent), reliability (internal consistency, interrater reliability and test-retest reliability) (Souza, Alexandre & Guirardello, 2017) and diagnostic accuracy (including sensitivity and specificity) (Eusebi, 2013). Moreover, table 3 identifies the role of Receiver Operator Characteristic (ROC) analyses in evaluating diagnostic accuracy. These are considered the most appropriate and useful measures of diagnostic accuracy, as they elucidate optimal cut-off values and compare alternative diagnostic tests (Hajian-Talaki, 2013; Linden, 2006).

Table 3. Definitions and Tests of Validity and Diagnostic Accuracy (Eusebi, 2013; Souza et al., 2017).

Type of Validity	Subtype	Definition	Statistical Test
Content		The degree in which a test includes all the necessary items to represent the concept to be measured	Qualitative approach (experts committee) Or Quantitative approach (content validity index, IVC)
Criterion		Assessed when a result can be compared to a 'gold standard'	
	Concurrent	Evaluated using both the target-test and the 'gold standard', at the same time.	Correlations
	Predictive	First the target-test is applied, and then, the 'gold standard'.	Correlations
Construct		Extent to which a set of variables represent the construct that was projected to be measured.	
	Convergent	Obtained through the correlation between the instrument and another instrument that assesses a similar construct, expecting high correlation results between them.	Correlations
	Discriminant	Obtained through the correlation between the instrument and another instrument that assesses a dissimilar construct, expecting negative or no correlation between them.	Correlations
Diagnostic Accuracy		Ability of a test to discriminate between and/or predict disease and health.	
	Sensitivity	The proportion of true positive (TP) subjects with the disease in a total group of subjects with the disease	ROC Or TP / (TP + FN)
	Specificity	The proportion of true negative (TN) subjects without the disease with a negative test result in a total group of subjects without the disease	ROC Or TN / (TN + FP)
	Positive Predictive Value (PPV)	Proportion of patients with a positive test result in a total group of subjects with a positive result	PPV = TP / (TP + FP)
	Negative Predictive Value (NPV)	Probability of not having a disease for a subject with a negative test result.	NPV = TN / (TN + FN)
	Likelihood Ratios	The ratio of the probability of an expected test result in subjects with the disease to the probability in the subjects without the disease	LR+ = sensitivity /(1 – specificity) LR- =(1-sensitivity) / specificity

TP = true positive, subjects with the condition of interest with the value of a parameter of interest above the cut-off; FP = false positive, subjects without the condition of interest with the value of a parameter of interest above the cut-off; TN = true negative, subjects without the condition with the value of a parameter of interest below the cut-off; FN = false negative subjects with the condition of interest with the value of a parameter of interest below the cut-off (Eusebi, 2013).

Table 4. Definitions and Tests of Reliability (Souza et al., 2017).

Type of Reliability	Definition	Statistical Test
Test-Retest Reliability	Consistency of repetitions, that is, the stability of measurement over time.	Intraclass correlation coefficient (ICC)
Internal Consistency	Consistency of measurement across items measured by the average correlation between items.	Cronbach's Alpha (Continuous variables) Kuder-Richardson (Dichotomous variables)
Interrater Reliability	The degree of concordance between raters on the same measurement tool.	Inter-Observer Reliability (Kappa)

3. Results

Database searching identified 2522 articles. Prior to screening, duplicates were identified using RAYYAN software and resolved manually, resulting in the removal of 279 duplicate studies. After reviewing the titles and abstracts of 2243 remaining studies, the full texts of 227 studies were reviewed for eligibility. The bibliographies and supplementary materials of relevant reviews (Cavedoni, Cipresso, Mancuso, Bruni & Pedroli, 2022; Pedroli, Serino, Cipresso, Pallavicini & Riva, 2015; Williams et al., 2021) were reviewed (n = 524) using the same process, resulting in an additional 4 studies. A total of 22 studies met the eligibility criteria to be included in this systematic review (see figure 1 for a PRISMA screening flow diagram of included studies). During the screening process, 10% (n = 252) of studies were screened independently by a second rater. Raters had 100% overlap of studies identified for exclusion and inclusion, demonstrating that eligibility criteria were clear and well understood.

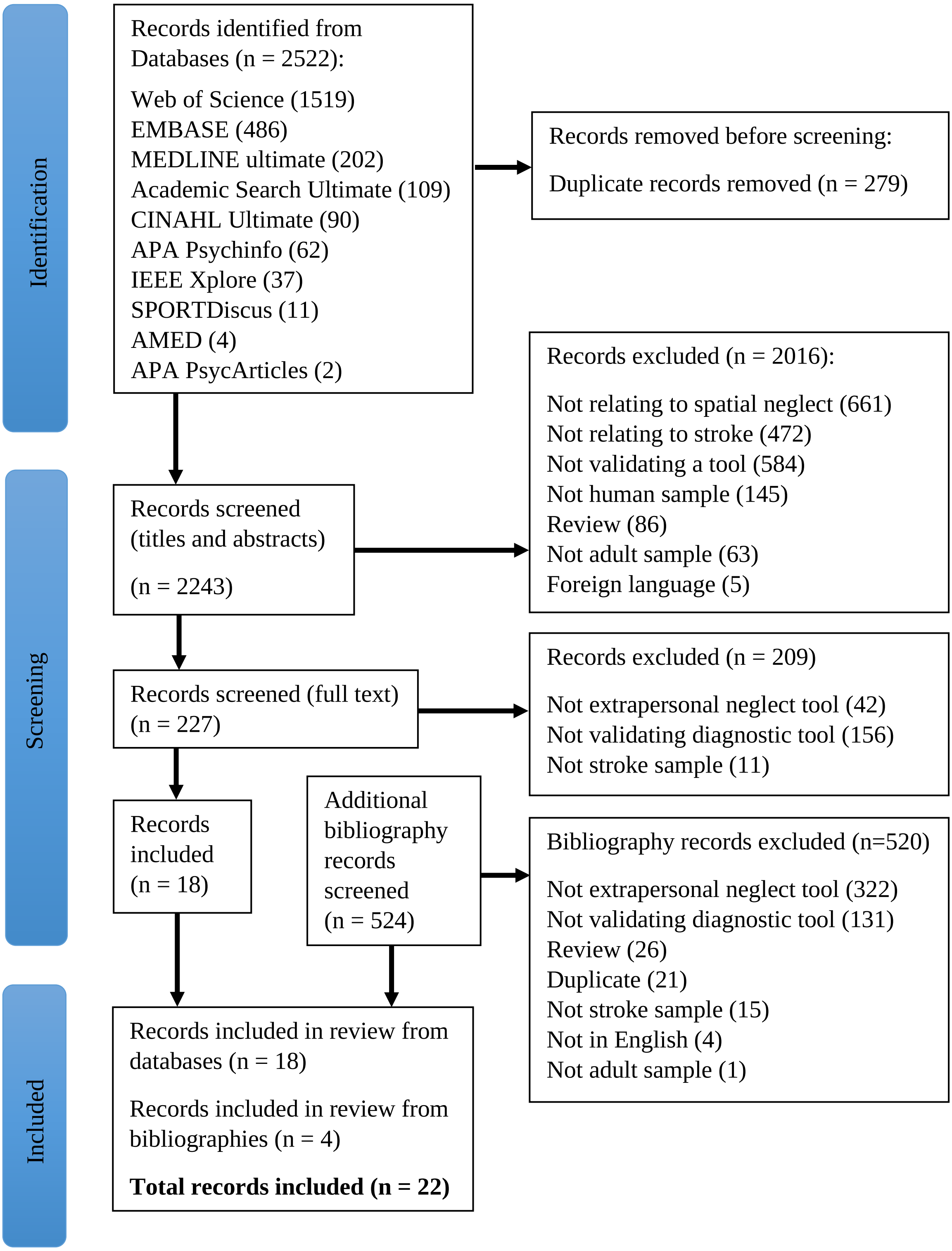


Figure 1. A PRISMA flow diagram illustrating the identification, screening, and inclusion process.

3.1. Quality Appraisal

The two independent raters had an inter-rater reliability of 98.11% (259/264 ratings). All discrepancies related to a single QAVALS item (item 17) and whether this was rated “no” or “not applicable”. Following discussion, consensus was reached, and it was agreed that this item had not been recorded in the studies involved.

Half of the studies did not give a clear description of the study design, or the type of validity being tested (n = 11, 50%). Approximately a quarter clearly described the study setting and the timeframe of participant recruitment (n = 6, 27.27%). A priori sample size calculations to determine power were only reported in five studies (22.73%). Half of the studies described and or justified sample attrition (n = 10, 45.45%), and half reported the use of statistical adjustments to account for multiple comparisons and control for the likelihood of a type 1 error (n = 10, 45.45%). Half of the studies clearly identified potential confounding variables and the measures taken to adjust for them (n = 11, 50%).

One study reported face validity (4.55%) but did not satisfy the associated QAVALS item (item 17) as they did not describe the process of selecting an expert panel or their qualifications.

Regarding construct validity, four studies reported discriminant validity, all of which satisfied the associated QAVALS item (item 24, n = 4, 18.18%) as they used measures of constructs separate to spatial neglect, for example, non-lateralised attentional deficits. Four studies reported convergent validity (18.18%). Most of the studies used appropriate standardised diagnostic reference tests for spatial neglect (n = 18, 81.82%). However, only half of studies were able to satisfy the item pertaining to the homogeneity of different groups at baseline (n = 12, 54.55%).

For criterion validity, although most studies provided an appropriate rationale for the selection of the reference standard (n = 18, 81.82%), only a fraction of studies used multiple blinded raters (n = 5, 22.73%) or reported the interrater reliability of the index test (n = 4, 18.18%). While most studies reported appropriate inclusion and exclusion criteria (n = 17, 77.27%), a quarter of the studies reported a clear description of how the sample was recruited, allowing confidence that the participants were representative of the sample population (n = 6, 27.27%). All but two of the studies utilised a standardised testing procedure for all participants, clearly described the index test’s outcomes and clearly reported their main findings (90.9%).

The highest rated studies were Qiang, Sonoda, Suzuki, Okamoto & Saitoh (2005), and Nishida, Mizuno, Tahara, Shindo, Watanabe, Ebata & Tsuji (2021) with total QAVALS score of 18/24. The lowest rated study was Berti, Smania, Rabuffetti, Ferrarin, Spinazzola, D’Amico, Ongaro & Allport (2002) with a QAVALS score of 6. Mean QAVALS score of the studies was 13.91. See table 5 for each selected study’s QAVALS score.

Table 5. QAVALS item scores for each study (n = 22).

Study	Item 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Aimola (2012)	N	N	N	Y	Y	Y	Y	N	N	N	Y	N	N	Y	N	Y	NR	N	NR	NR	Y	Y	NR	NR	9
Aravind (2015)	N	N	N	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	Y	NR	Y	NR	N	Y	N	NR	Y	13
Azouvi (2003)	Y	Y	N	N	N	Y	Y	Y	N	N	Y	N	N	Y	Y	Y	NR	Y	Y	NR	Y	N	Y	NR	13
Berti (2002)	N	N	N	Y	N	Y	N	N	N	N	Y	NR	Y	Y	NR	Y	NR	NR	NR	NR	NR	N	NR	NR	6
Buxbaum (2008)	N	N	N	Y	Y	Y	Y	Y	N	NR	Y	Y	Y	Y	Y	Y	NR	Y	NR	NR	Y	Y	Y	NR	14
Buxbaum (2012)	N	Y	N	Y	Y	Y	Y	Y	N	NR	Y	Y	Y	Y	Y	Y	N	Y	NR	NR	Y	NR	NR	Y	14
Dawson (2008)	N	Y	N	Y	Y	Y	Y	Y	N	NR	Y	Y	Y	Y	Y	Y	NR	Y	NR	NR	Y	NR	Y	Y	15
Fordell (2011).	Y	Y	N	Y	Y	Y	Y	Y	N	NR	Y	NR	Y	Y	Y	Y	NR	Y	Y	NR	NR	Y	NR	NR	15
Kim (2010)	N	N	N	Y	Y	Y	Y	Y	N	NR	Y	NR	Y	Y	Y	Y	NR	Y	NR	NR	Y	Y	NR	NR	13
Mesa-Gresa (2011)	N	N	N	N	Y	Y	Y	Y	N	NR	Y	N	Y	Y	Y	Y	NR	Y	NR	NR	Y	NR	NR	Y	12
Nishida (2021)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	NR	Y	Y	Y	NR	Y	NR	Y	Y	N	Y	NR	18
Ogourtsova (2018a)	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y	Y	Y	NR	Y	NR	NR	Y	Y	NR	NR	17
Ogourtsova (2018b)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	NR	Y	NR	N	Y	Y	NR	NR	17
Qiang (2005)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	NR	Y	Y	Y	NR	Y	Y	Y	Y	NR	NR	NR	18
Spreij (2020)	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	Y	NR	Y	NR	NR	Y	N	NR	NR	15
Thomasson (2023)	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y	NR	NR	Y	Y	NR	NR	16
Van Der Stoep (2013)	N	N	N	Y	Y	Y	Y	Y	N	NR	Y	Y	NR	Y	N	Y	NR	Y	NR	NR	NR	Y	NR	NR	11
Van Kessel (2010)	N	N	Y	Y	Y	Y	Y	Y	N	NR	Y	NR	Y	Y	NR	Y	NR	Y	NR	NR	NR	Y	NR	NR	12
Van Kessel (2013)	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	NR	Y	Y	Y	Y	NR	Y	NR	NR	Y	Y	NR	NR	14
Whitehouse (2019)	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	NR	Y	Y	Y	NR	Y	NR	NR	Y	Y	Y	NR	17
Zoccolotti (1991)	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	N	N	Y	Y	Y	NR	N	Y	Y	Y	Y	NR	NR	14
Zoccolotti (1992)	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	N	N	Y	Y	Y	NR	N	Y	Y	Y	NR	NR	NR	13
Total	11	11	6	17	16	22	20	20	5	10	22	10	11	22	18	22	0	18	5	4	15	12	5	4	

*Y/Green = Yes; N/Red = No; NR/Yellow = Not Applicable/Not Reported

3.2. Study Characteristics

Most studies recruited their sample from a single clinical setting such as hospitals and rehabilitation centres (n = 17, 77.27%), two studies recruited from three different hospitals (9.09%), and three did not specify (13.64%). Study samples were drawn from Canada (n=5), Netherlands (n=4), Italy (n=4), USA (n=3), China, France, Japan, Spain, South Korea and Sweden (each n=1).

Study sample sizes were small to moderate, ranging between 12-137 participants with a combined total of 1118 (combined mean = 50.82). The mean age of study sample groups ranged from 51.2-74.1 years (weighted mean age = 59.75 years), with one study not reporting age. Generally, samples included slightly more men than women, with two studies not reporting the number of males to females (combined total men = 676; 60.47%;). Twelve studies (54.45%) had a control group of healthy, non-stroke participants, and 10 studies (45.45%) did not have a healthy non-stroke control group. Twenty studies had an experimental group consisting only of stroke survivors (90.91%), and two studies (9.09%) included other conditions and procedures (tumour, Mesa-Gresa, Lozano, Llorens, Alcaniz, Navarro, Noe & Navarro, 2011; spontaneous haematoma surgically removed/sustained head injury/ haematoma surgically removed; Zoccolotti & Antonucci 1992). See table 6. for a summary of study characteristics.

Psychometric properties investigated were determined by the type of analyses the study used and not restricted to the mention of a given psychometric property. In total, 18 studies (81.82%) reported on at least one aspect of criterion validity (including 18 studies investigating concurrent validity and none investigating predictive validity), eight studies (36.36%) reported on at least one aspect of construct validity (including five studies investigating convergent validity and four discriminant validity), one study commented on content validity (4.55%), five evaluated internal consistency (22.72%), one investigated test-retest reliability (4.55%), and four reported interrater reliability (18.18%). The average study reported 1.74 different types of validity or reliability. See tables 7 and 8 for a summary of reported psychometric properties.

Table 6. Study characteristics

Study ID	Setting, Country	Sample (n)	Sample Age	Sample Gender	Test Name	Test Type	Test Time	Test Requirements	Computer	Comparator Tests
Aimola (2012)	Clinic, Italy	52 total: 38 right hemisphere damaged stroke survivors (5 tumour); 14 age-matched healthy controls	*M* = 65 (*SD* = 12.12) HC = 67.93 (SD = 1.93)	M = 25; F = 13 HC: M = 6; F = 8	Line Bisection (far) Bells Test (far)	Line Bisection task and Cancellation task	NR	Laser pointer; projector.	No	Line Bisection (near) and Bells Test (near)
Aravind (2015)	Inpatient Rehabilitation Centre, Canada	12 first-time unilateral supratentorial stroke survivors with visuospatial neglect	*M* = 60.67 (*SD*=8.56)	M = 4; F = 8	Virtual Reality-Based Navigation Task	Cancellation /Detection task and Navigation task	NR	nVisor SX60 head mounted display; CAREN-3tm virtual reality software; Joystick (Attack3).	Yes	Motor Free Visual Perceptual Test (MVPT); Letter Cancellation Test; Bells test; Line Bisection test.
Azouvi (2003)	Rehabilitation Unit, France	83 first time unilateral RH stroke survivors	*M* = 54.5 (*SD*=14.1)	M = 56; F = 29	CBS	Functional	NR	10 question questionnaire.	No	Bells test, copy picture, read short task.
Berti (2002)	Clinic, Italy	13 ischemic stroke survivors (6 “neurologically intact”; 7 right-brain-damaged)	NR	NR	Line bisection (far), Door bisection (walking task)	Line Bisection task and Functional/ Navigational/ Line Bisection task	NR	Doorway + Laser pointer.	No	NR
Buxbaum (2008)	Magee Rehabilitation Hospital, USA	13 total: 9 RH post-acute stroke survivors; 4 healthy control participants	Stroke survivors: *M* = 57.3 (*SD* = 14.6) Control: *M* = 67.2 (Range 65-73)	Stroke Survivors: M = 7, F = 2 Control: M = 1, F = 3	Virtual reality wheelchair navigation task (this became VRLAT)	Navigation/ Cancellation (examiner navigated or participant navigated) task	NR	Motorized wheelchair; a joystick mounted on wheelchair right arm; wheelchair treadmill interfaced through digital encoder device to Pentium R 4 CPU 2.4 Ghz PC with 74.5 GB HD and 512 MB RAM; a 3Dforce 4 Ti4600 NVIDIA Video card; 42 by 31” flat-screen display.	Yes	Visual field + extinction task; Letter Cancellation & Line Bisection & Picture Scanning & Menu Reading (BIT); Bell Test; Dual Task Test; Fluff test; Laser Line Bisection, Moss-Magee Wheelchair navigation Test.
Buxbaum (2012)	Moss Rehabilitation Research Institute, USA	80 total: 70 post-acute RH stroke survivors; 10 control participants	Stroke Survivors: *M* = 59.5 (range 21-79)	Stroke Survivors: M = 39, F = 31	Virtual Reality Lateralized Attention Test (VRLAT)	Navigation/ Cancellation (examiner navigated or	NR	PC; Logitech Attack 3 joystick; flat-screen video display; VRLAT Programme.	Yes	Bells and Letter Cancellation tests; Line Bisection [RBIT*]; Fluff test;

Study ID	Setting, Country	Sample (n)	Sample Age	Sample Gender	Test Name	Test Type	Test Time	Test Requirements	Computer	Comparator Tests
			Control: *M* = 61.5 (range 34-78)	Control: M = 5, F = 5		participant navigated) task				laser line bisection; RWN*
Dawson (2008)	Moss Rehabilitation Research Institute, USA	18 RH stroke survivors	*M* = 58.6 (*SD*=10.2)	M = 10; F = 8	Virtual Reality Lateralized Attention Test (VRLAT)	Navigation/ Cancellation (examiner navigated or participant navigated) task	NR	PC with Intel Core 2 Duo processor at 1.86 GHz with 2 GB RAM and a NVidia GeForce 7950 GX2 dual video card with 512 MB RAM; 15.5 by 27.5” flat screen display; Logitech Attack 3 joystick; VRLAT Programme.	Yes	Bells test; Letter cancellation test; line bisection; laser line bisection; Fluff test; Dual Task Test.
Fordell (2011).	Stroke Unit, University Hospital, Sweden	31 stroke survivors (9 neglect; 22 non-neglect)	Total*:* *M* = 74.1 (*SD*=11) Neglect: *M* = 73.3 (*SD*=12) Non-Neglect: *M* = 74.4 (*SD*=10.8)	Total: M = 23, F = 9 Neglect: M = 6, F = 3 Non-Neglect: M = 16, F = 6	VR-DiSTRO: VR-Star Cancellation Test (VR-SCT); VR-Line Bisection (VR-LB); VR-Visual Extinction (VR-EXT); VR-Baking Tray Task (VR-BTT)	Cancellation task, Line Bisection task, Functional task, Extinction task.	NR	Standard desktop monitor; CRT monitor; eye shutter stereoscopic glasses; force feedback interface; software.	Yes	Star Cancellation; Line Bisection; Baking Tray Task (BTT); Visual Extinction; RBIT*.
Kim (2010)	South Korea	21 RH stroke survivors (16 neglect – three haemorrhagic lesions and eight had cortical infarction; 16 non-neglect)	Neglect: *M* = 52.9 (*SD*=16.8) Non-Neglect: *M* = 60.1 (*SD*=12.1)	Neglect: M = 10, F = 6 Non-Neglect: M = 11, F = 5	Three-Dimensional Virtual Street Assessment	Detection task	NR	Computer; 3D graphics acceleration card; speakers; Head mounted display; head tracking system; test software.	Yes	Line Bisection, Letter Cancellation
Mesa-Gresa (2011)	Spain	25 RH/LH brain lesion survivors (12 haemorrhagic stroke, 10 ischemic stroke and 3 brain tumours)	*M* = 51.2 (*SD*=12.62)	M = 14; F = 11	Virtual Reality Street Crossing Test (VRSCT)	Navigation task	NR	Panoramic 47” LCD monitor; 5.1 surround sound system; joystick; optical tracking system (TRACKIR); hat with three reflective marks; USB infrared camera.	Yes	BIT; Colour Trail Making Task (CTT); Conners’ Continuous Performance Test-II (CPT-II)

Study ID	Setting, Country	Sample (n)	Sample Age	Sample Gender	Test Name	Test Type	Test Time	Test Requirements	Computer	Comparator Tests
Nishida (2021)	Rehabilitation Hospital, Japan	45 total (KF-NAP group (n=22) CBS group (n=23))	KF-NAP: *M* = 65.4 (*SD*=13.5) CBS: *M* = 64.4 (*SD*=12.2)	KF-NAP: M = 17, F = 5 CBS: M = 17, F = 6	Kessler Foundation Neglect Assessment Process - Japanese (KF-NAP-J)	Functional	NR	10 criteria scoring sheet, each criteria has a 4-point scale ranging from 0 (no neglect) to 3 (severe neglect).	No	CBS; BIT; FIM
Ogourtsova (2018a)	3 Hospitals, Canada	45 total (30 stroke survivors (15 with neglect [UNS+], 15 without neglect [UNS-]); 15 age matched healthy controls)	UNS+: *M*=60.2 (*SD*=8.8) UNS-: *M*=58.5 (*SD*=13.2) Control: *M*=61 (*SD*=11.3)	UNS+: M=12; F=3 UNS-: M=13; F=2 Control: M=7; F=8	Goal-directed VR locomotion task	Navigation task and Detection task	NR	3D virtual viewer-centred environment (created using Softimage XSI and controlled by CAREN-3), VR head mounted display (NVisor[tm]), 12-camera Vicon 512 motion capture system, passive reflective markers, joystick.	Yes	Line Bisection Test (near); Star Cancellation Test (near); Apple Cancellation Test.
Ogourtsova (2018b)	3 Hospitals, Canada	36 total: (27 stroke survivors (UNS+ = 12; UNS- = 15); 9 age-matched healthy controls)	UNS+: *M*=60.7 (*SD*=9.09) UNS-: *M*=50.5 (*SD*=13.2) Control: *M*=56.3 (*SD*=13.2)	UNS+: M=9; F=3 UNS-: M=13; F=2 Control: M=4; F=5	Ecological VR-based Evaluation of Neglect Symptoms (EVENS)	Navigation task and Detection task	30min	2 virtually generated scenes (complex and simple) in Unity game engine. Helmet mounted display NVisor. Fixed joystick (Logitech, Attack3)	Yes	Line Bisection Test (near); Star Cancellation Test; Apple Cancellation Test.
Qiang (2005)	Rehabilitation unit, China	30 total (19 patients with LH stroke survivors. 11 healthy controls)	Stroke: *M* = 65.2 (*SD*=10.9)	M = 12 F = 7	Wheelchair Collision Test (WCT)	Functional task	10min	Wheelchair with armrests and footrests. Four round chairs (45cm height and 31cm diameter) arranged in two parallel lines (two front row and two back row). Distance between front and back chairs was 120cm (trial 1) and 140cm (trial 2).	No	CBS; FIM
Spreij (2020)	Inpatient Rehabilitation Centre, Netherlands	121 stroke survivors (Left-sided VSN+: 33; Right-sided VSN+: 7; Left-sided	Left-sided VSN+:*M* = 58.83 (*SD*=9.18);	Left-sided VSN+: M = 22, F = 11;	Simulated Driving Task	Navigation task	2 min task (+1 min	Projector + screen or large screen (2.13 x 3.18m); table; computer steering wheel.	Yes	CBS; Shape cancellation task.

Study ID	Setting, Country	Sample (n)	Sample Age	Sample Gender	Test Name	Test Type	Test Time	Test Requirements	Computer	Comparator Tests
		R-VSN: 7; Left-sided VSN-: 53 Healthy Controls: 21)	Right-sided VSN+:*M* = 54.75 (*SD*=11.48); Left-sided R-VSN:*M* = 54.47 (*SD*=14.69); Left-sided VSN-: *M* = 58.86 (*SD*=12.14); Control: *M* = 58.77 (*SD*=9.86)	Right-sided VSN+: M = 6, F = 1; Left-sided R-VSN: M = 4, F = 3; Left-sided VSN-: M = 40, F = 13; Control: M = 11, F = 10			practice trial)			
Thomasson (2023)	Switzerland/ Canada	79 total (28 RH stroke patients, 11 LH stroke patients, 40 healthy controls)	RH: *M* = 60.1 (*SD*=7.9) LH: *M* = 61.2 (*SD*=12.62) Control: *M* = 49.5 (*SD*=7.8)	RH: M = 20; F = 8; LH: M = 5; F = 6; Control:M = 24; F = 16	Immersive VR-based task	Cancellation task	8min. (*M* = 8.91 min, SD=25.72s)	Minemaze programme; 360' virtual forest; Oculus Rift DK2 head-mounted display; computer keyboard	Yes	Apple Cancellation Test; Bells cancellation, figure copy, overlapping figures, clock drawing, line bisection, reading and writing, CBS.
Van Der Stoep (2013)	Rehabilitation centre, Netherlands	137 total (61 stroke survivors with neglect. 48 stroke survivors without neglect. 28 healthy controls.)	Neglect: *M* = 58.25 (*SD*=1.59) No neglect: *M* = 59.06 (*SD*=1.74) Control: *M* = 42.32 (*SD*=20.31)	Neglect: M = 40; F = 21; No neglect: M = 28; F = 20; Control: M = 16, F = 12	Shape Cancellation, Letter Cancellation and Line Bisection (in far space)	Two Cancellation tasks and a Line Bisection task	NR	Small monitor and large monitor. Mouse and computer.	Yes	Shape Cancellation; Letter Cancellation; Line Bisection (pen-and-paper versions)
Van Kessel (2010)	Sint Maartenskliniek rehabilitation centre, Netherlands	65 total (20 healthy control subject; 21 LH stroke survivors; 24 RH stroke survivors.)	LH: *M* = 58.8 (range 34-80) RH: *M* = 61.2 (range 38-72) Control: *M* = 60.4 (range 38-81)	LH: M = 11; F = 10; RH: M = 15; F = 9; Control: M = 5; F = 15	Simulated Driving Task	Detection/ Cancellation task	5 min	Chair; 2.13m high x 3.18m wide rear projection screen (90cm from subject). Video projector; steering wheel with two buttons on it, fixed to a small table. 240x40cm White wooden board to cover table; MS-DOS PC.	Yes	BIT
Van Kessel (2013)	Sint Maartenskliniek rehabilitation	63 total (22 LH Stroke survivors, 21 RH Stroke survivors, 20 Healthy Controls)	LH: *M* = 59.9 (*range* = 34-80) RH: *M* = 60.2 (*range* = 38-71)	LH: M = 12, F = 10; RH: M = 13, F = 8;	Simulated Driving Task	Detection/ Cancellation task, Navigation task, and a	10-15mins	2.13m x 3.18m projection screen; video projector; steering wheel; small table;	Yes	BIT

Study ID	Setting, Country	Sample (n)	Sample Age	Sample Gender	Test Name	Test Type	Test Time	Test Requirements	Computer	Comparator Tests
	centre, Netherlands		Control: *M* = 60.4 (*range* = 38-81)	Control: M = 5, F = 15		Detection/ Cancellation / Navigation task				
Whitehouse (2019)	Tertiary Care Rehabilitation Unit, Canada	48 total (15 RH stroke inpatients; 14 healthy controls; 19 additional healthy controls)	Stroke: *M* = 63.2 (*SD*=13.4) Control: *M* = 67.8 (*SD*=6.5) Additional Control: *M* = 57.8 (*SD*=9.2)	Stroke: M = 12; F = 3; Control: M = 8; F = 6; Additional Control: M = 5; F = 14	Halifax Visual Scanning Test (HVST) – Wall Subtest	Cancellation task	10min	Board mounted on wall (250cm away); 36 pre-determined words among distractor symbols (stars)	No	BIT; Judgement of Line Orientation
Zoccolotti (1991)	Rehabilitation Clinic, Italy	26 RH patients (24 with stroke and 2 had spontaneous haematoma)	*M* = 69 (*SD*=8.9)	NR	Semi-structured scale for the functional evaluation of the hemi-inattentive disorder	Functional	15min	Description of environment: room full of objects on both sides (armchairs, pictures, lamps) explorative behaviours evaluated by clinician (3 levels).	No	Letter Cancellation; Line Cancellation; Wundt-Jastrow test
Zoccolotti (1992)	Rehabilitation Clinic, Italy	75 patients (70 stroke survivors; 3 spontaneous haematoma surgically removed; 2 sustained head injury + haematoma surgically removed) Of those: 55 hemineglect; 20 without hemineglect.	Hemineglect: *M* = 67 (*SD*=9.3) Without Hemineglect: *M* = 66.1 (*SD*=9.1)	Hemineglect: M = 23; F = 32; Without Hemineglect: M = 14; F = 6	Semi-structured extrapersonal evaluation scale	Functional	15min	Description of environment: room full of objects on both sides (armchairs, pictures, lamps) explorative behaviours evaluated by clinician (3 levels).	No	Letter cancellation; Line Cancellation; Wundt-Jastrow test; Sentence reading test.

**M* = mean; SD = Standard Deviation; M = Male; F = Female; RBIT = Rivermead Behavioural Inattention Test. BIT = Behavioural Inattention Test; Catherine Bergego Scale = CBS; RWN = Moss Real World Navigation test; NR = Not Reported; VSN+ = with visuospatial neglect; VSN- = Without visuospatial neglect; R-VSN = recovered visuospatial neglect; LH = Left Hemisphere; RH = Right Hemisphere; KF-NAP = Kessler Foundation Neglect Assessment Process; FIM = Functional Activities of Daily Living Instrument;

Table 7. Test Validity and Diagnostic Accuracy

Study ID	Test	Criterion Validity		Construct Validity		Content Validity	Diagnostic Accuracy (Specificity, Sensitivity, ROC, PPV, NPV, Likelihood Ratio)
		Concurrent	Predictive	Convergent	Discriminant		
Aimola (2012)	Line Bisection (far)	NR	NR	NR	NR	NR	Sensitivity = 88.9% [16/ (16+2)] Specificity = 71.4% [5 / (5+2)]
	Bells Test (far)	NR	NR	NR	NR	NR	Sensitivity = 87.5% [7 / (7+1)] Specificity = 33.3% [3 / (3+6)]
Aravind (2015)	Virtual Reality-Based Navigation Task	Bells test: (contralesional r = -0.51, head-on r = -0.43 and ipsilesional r = -0.23) Line Bisection: (contralesional r = -0.65, head-on r = -0.61 and ipsilesional r = -0.40). None sig.	NR	NR	Trail making B test and distance at detection (contra. r = -0.55*, head-on r = -0.70**, ipsi. r = -0.60*). Trail making B test and distance at onset of strategy (contra. r = -0.63%)	NR	NR
Azouvi (2003)	CBS	Bells test: r = -0.76***. figure copy: r = 0.70***. Text reading: r = 0.54***.	NR	Anosognosia correlated with neglect severity on CBS (r = 0.79***) and bells, figure copy and text reading (r range = 0.43–0.72**).	NR	NR	NR (Insufficient information to calculate)
Berti (2002)	Line Bisection (far)	NR	NR	NR	NR	NR	NR (Insufficient information to calculate)
	Door Bisection (walking task)	NR	NR	NR	NR	NR	NR (Insufficient information to calculate)
Buxbaum (2008)	VRLAT	Bell Cancellation: r = 0.87**. Letter Cancellation = 0.95**. Line Bisection = -0.87**. Picture = 0.91**. Menu = 0.91**.	NR	Dual Task Base, L: r = -0.97**; Dual Task Dual, L: r = -0.93**; Dual Task Interference: r = 0.82**; MMWNT: r = -0.85**.	NR	NR	NR (insufficient information to calculate)
Buxbaum (2012)	VRLAT	Bell cancel left, r = 0.43**; Letter cancel left, r = 0.59**, Letter cancel right, r = 0.49**; Fluff test left, r = 0.41**	NR	NR	Multiple regression: VRLAT neglect patients: no significant link to visual deficits (p = 0.52). Comparator test neglect: significantly associated with visual deficits (p = 0.041). VRLAT sensitive to non-lateralised attention deficits:	VRLAT tasks bear a transparent relationship to the types of tasks patients need to perform	Sensitivity = 69% [24 / 24+11] Specificity = 64% [55 / 55+31]

Study ID	Test	Criterion Validity		Construct Validity		Content Validity	Diagnostic Accuracy (Specificity, Sensitivity, ROC, PPV, NPV, Likelihood Ratio)
		Concurrent	Predictive	Convergent	Discriminant		
					only left Bell and letter scores (adjusted r^2 = 0.55, β = 0.78***) and not right Bell and letter scores (adjusted r^2 = 0.29, β = -0.05).	(face validity).	
Dawson (2008)	VRLAT	Bell/letter cancellation: r = 0.83**, Line bisection: r = -0.5, Laser line bisection: r = -0.85**.	NR	Dual task dual = -0.86***; Dual task interference = -0.88***	Multiple regression, mean left-sided Bell + Letter Cancellation approached significance (β = 0.46**). Removing right-sided Bell + Letter Cancellation and visual field deficit improved the model (F(1,16) = 36.6***), with mean left-sided Bell + Letter Cancellation strongly predicting VRLAT performance (β = 0.52***).	NR	Sensitivity = 55.6% [5 / (5+4)] Specificity = 64.3% [9 / (9+5)]
Fordell (2011)	VR-DiSTRO	VR-DiSTRO subtest and corresponding comparator test was: BTT (K = 0.85***); LB (K = 0.47*); SCT (K = 0.56**); EXT (K = 0.65**).	NR	NR	NR	NR	**VR Total Score:** Sensitivity: 100% (CI 72-100) Specificity: 82% (CI 62-94) Likelihood Ratio: 5.5 (2.3-13.4)
Kim (2010)	3D Virtual Street Assessment	LBT: 0.633**.	NR	NR	NR	NR	NR
Mesa-Gresa (2011)	VRSCT	No significant correlations between any VRSCT measures and BIT scores.	NR	NR	VRSCT total time (non-neglect group): CTT-A (r^2 = 0.802**); CTT-B (r^2 = 0.506*). CPT-II (HIT Rt ISI) and the total VRSCT task duration (r^2= 0.613**)	NR	NR (insufficient information to calculate)
Nishida (2021)	KF-NAP-J	BIT total: r = -0.405, P = 0.062, R^2 = 0.592.	NR	FIM total: r = -0.521*, R^2= 0.266. FIM Motor: r = -0.565*, R^2 = 0.280; FIM cognition: r = -0.334; R^2= 0.011.	NR	NR	NR (insufficient information to calculate)

Study ID	Test	Criterion Validity		Construct Validity		Content Validity	Diagnostic Accuracy
		Concurrent	Predictive	Convergent	Discriminant		(Specificity, Sensitivity, ROC, PPV, NPV, Likelihood Ratio)
Ogourtsova (2018a)	EVENS	Negligible correlations with LBT/SCT in near space (r = 0.42*/r = –0.34*), SCT in far space (r = –0.30*), and SCT near/far time performances (r = 0.28*/r = 0.26*).	NR	NR	NR	NR	NR (insufficient information to calculate)
Ogourtsova (2018b)	EVENS	Navigation time LBT near: 0.43** LBT far: 0.40** SCT near: -0.40** SCT near time: -0.43** SCT far: -0.42** SCT far time: -0.48*** APT total: -0.39** APT allocentric: 0.49**	NR	NR	NR	NR	Sensitivity = 58% [7 / (7+5)] Specificity = 80% [12 / (12+3)]
Qiang (2005)	WCT	WCT (120cm) and CBS: r = 0.72***. WCT (140cm) and CBS: r = 0.75**.	NR	NR	NR	NR	NR (insufficient information to calculate)
Spreij (2020)	Simulated Driving Task	SC: r = 0.47** CBS: r = 0.53**	NR	NR	NR	NR	Left-sided VSN+: ROC = 0.844. Right-sided VSN+: ROC = 0.429. Left-sided VSN, PPV = 85%, Left-sided VSN, NPV = 75.8%. Right-sided VSN, PPV = 40%, Right-sided VSN, NPV = 90.9%.
Thomasson (2023)	Immersive VR-based task	Reading omission total and exploration time L-R level 4 (r = -0.51**). Reading omission L-R and exploration time L-R level 4 (r = -0.56***). No other sig correlations.	NR	NR	NR	NR	Sensitivity = 75% [9 / (9+3)] Specificity = 73% [22 / (22+8)]
Van Der Stoep (2013)	Shape Cancellation (virtual, far)	NR	NR	NR	NR	NR	Sensitivity = 89.3% [75 / (75+9)] Specificity = 76.3% [29 / (29+9)]
	Letter Cancellation (virtual, far)	NR	NR	NR	NR	NR	Sensitivity = 70.5% [43 / (43+18)] Specificity = 40% [6 / (6+9)]

Study ID	Test	Criterion Validity		Construct Validity		Content Validity	Diagnostic Accuracy
		Concurrent	Predictive	Convergent	Discriminant		(Specificity, Sensitivity, ROC, PPV, NPV, Likelihood Ratio)
	Line Bisection (virtual, far)	NR	NR	NR	NR	NR	Sensitivity = 86.4% [57 / (57+9)] Specificity = 12.5% [1 / (1+7)]
Van Kessel (2010)	Simulated Driving Task	NR	NR	NR	NR	NR	Sensitivity = 63.6% [7 / (7+4)] Specificity = 92.3% [12 / (12+1)]
Van Kessel (2013)	Simulated Driving Task	Total BIT scores and contralesional omissions for CVRT (r (19) = -0.54*) and CVRT-D (r (19) = -0.62**). Total BIT + CVRT-D contralesional omissions was significant (r (20) = -0.72, p < 0.001). BIT and contralesional omissions on CVRT was r (20) = -0.41.	NR	NR	NR	NR	NR (insufficient information to calculate)
Whitehouse (2019)	HVST	HVST wall subtest and BIT Star Cancellation (r = 0.61, α = 0.01); LC (r = 0.33; α > 0.05); and line crossing (r = 0.42, α > 0.05).	NR	HVST Wall subtest and Wheelchair Course Direct Hits: r = -0.67**.	NR	NR	Sensitivity = 78% [14 / 14+4] Specificity = 100% [1 / 1+0]
Zoccolotti (1991)	Semistructured extrapersonal evaluation scale	Extrapersonal items with Letter Cancellation (Tau = -0.513***); Line Cancellation (Tau = -0.522***); Wundt-Jastrow Test (Tau = 0.286*).	NR	NR	NR	NR	NR (insufficient information to calculate)
Zoccolotti (1992)	Semistructured extrapersonal evaluation scale	Extrapersonal items with Line Cancellation (tau = -0.60***); Letter Cancellation (tau = -0.52***); Wundt-Jastrow (tau = 0.20*); Sentence Reading (tau = -0.041***).	NR	NR	NR	NR	NR (insufficient information to calculate)

* = $p < 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$; NR = Not Reported

Table 8. Test Reliability

Study ID	Test	Internal Consistency	Interrater	Test-Retest
Aimola (2012)	Line Bisection (far)	NR	NR	NR
	Bells Test (far)	NR	NR	NR
Aravind (2015)	Virtual Reality-Based Navigation Task	NR	NR	NR
Azouvi (2003)	CBS	CBS 10 item correlation coefficients range: 0.48 -0.73***. PCA with varimax rotation = 65.8% of total variance explained by single factor. Rasch analysis and factorial analysis resulted in satisfactory item reliability index (0.93). Rasch analysis: Only 'neglect in dressing' obtained fit values < 0.6. Overall, mean fit scores were near 1, indicating uni-dimensionality. Also, high positive point biserial correlation coefficients between each item score and the cumulative score obtained across the whole sample.	NR	NR
Berti (2002)	Line bisection (far)	NR	NR	NR
	Door bisection (walking task)	NR	NR	NR
Buxbaum (2008)	VRLAT	NR	NR	NR
Buxbaum (2012)	VRLAT	All three array levels of VRLAT highly internally consistent (Cronbach's α = 0.97). Corrected item-total correlations were all > 0.92.	NR	NR
Dawson (2008)	VRLAT	NR	NR	NR
Fordell (2011).	VR-DiSTRO	NR	NR	NR
Kim (2010)	3D Virtual Street Assessment	NR	NR	NR
Mesa-Gresa (2011)	VRSCT	NR	NR	NR
Nishida (2021)	KF-NAP-J	KF-NAP group: α = 0.969. CBS group: α = 0.904. High consistency.	Weighted kappa results show each subscale was in better agreement with the KF-NAP (0.921) than with the CBS (0.852). In the KF-NAP, all eight subscales in which weighted kappa could be calculated were in significant agreement, and two were almost in perfect agreement.	NR
Ogourtsova (2018a)	EVENS	NR	NR	NR

Study ID	Test	Internal Consistency	Interrater	Test-Retest
Ogourtsova (2018b)	EVENS	NR	NR	NR
Qiang (2005)	WCT	NR	The rate of agreement tested by Kappa statistics between the WCT and CBS was higher when distance between chairs was 120 cm (0.68) than 140 cm (0.58).	Intraclass correlation coefficient (ICC) scores ranged from 0.68 (substantial agreement) to 0.97 (almost perfect agreement) in different situations in the WCT.
Spreij (2020)	Simulated Driving Task	NR	NR	NR
Thomasson (2023)	Immersive VR-based task	NR	NR	NR
Van Der Stoep (2013)	Shape Cancellation (virtual, far)	NR	NR	NR
	Letter Cancellation (virtual, far)	NR	NR	NR
	Line Bisection (virtual, far)	NR	NR	NR
Van Kessel (2010)	Simulated Driving Task	NR	NR	NR
Van Kessel (2013)	Simulated Driving Task	NR	NR	NR
Whitehouse (2019)	HVST – Wall Subtest	NR	NR	NR
Zoccolotti (1991)	Semi-structured scale for the functional evaluation of the hemi-inattentive disorder	Agglomeration coefficients were evaluated: clear differentiation present between trials relative to object use and all others. Presence of small increases in agglomeration coefficients indicates that both clusters have internal high similarity.	All subtests showed high correlations between two judges (tau median = 0.92; tau range = 0.71-1.00; all ***).	NR
Zoccolotti (1992)	Semistructured extrapersonal evaluation scale	Kendall's tau, ranged from 0.44 – 0.71 (All ***).	All subscales of the Extrapersonal Scale, high correlations observed between two judges (tau range = 0.92-0.97; all ***). Correlation between the total score was 0.96***.	NR

* = $p < 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$.

Table 9. Tests and Subtests Identified

Test Name	Subtests/tasks	Task Type	Neglect type tested	Author (year)
Line Bisection (far)		Line Bisection task	Extrapersonal	Aimola (2012); Berti (2002)
Line Bisection (virtual, far)*		Line Bisection task	Extrapersonal	Van Der Stoep (2013)
Shape Cancellation (virtual, far)*		Cancellation task	Extrapersonal	Van Der Stoep (2013)
Letter Cancellation (virtual, far)*		Cancellation task	Extrapersonal	Van Der Stoep (2013)
Immersive VR-based task*		Cancellation task	Extrapersonal	Thomasson (2023)
Bells Test (far)		Cancellation task	Extrapersonal	Aimola (2012)
Halifax Visual Scanning Test (HVST)	Wall Subtest Table Subtest Shirt Subtest	Cancellation task Cancellation task Cancellation task	Extrapersonal Peripersonal Personal	Whitehouse (2019)
Three-Dimensional Virtual Street Assessment*		Detection task	Extrapersonal	Kim (2010)
Virtual Reality Street Crossing Test (VRSCT)*		Navigation task	Extrapersonal	Mesa-Gresa (2011)
Virtual Reality Lateralized Attention Test (VRLAT)*		Navigation/ Cancellation task	Extrapersonal	Buxbaum (2008); Buxbaum (2012); Dawson (2008)
VR-DiSTRO*	VR-Star Cancellation Test (VR-SCT); VR-Line Bisection (VR-LB) VR-Visual Extinction (VR-EXT) VR-Baking Tray Task (VR-BTT)	Cancellation task, Line Bisection task Extinction task Functional task	Extrapersonal Extrapersonal Hemianopia Peripersonal	Fordell (2011)
Ecological VR-based Evaluation of Neglect Symptoms (EVENS)*	Goal-Directed Navigation task Detection task	Navigation task Detection task	Extrapersonal Extrapersonal	Ogourtsova (2018a); Ogourtsova (2018b)
Simulated Driving Task*	Computerised Visual Reaction Time Task (CVRT) Lane Tracking Task Dual (CVRT-D) Task	Detection/ Cancellation task Navigation task Detection/ Cancellation/ Navigation task	Extrapersonal Extrapersonal Extrapersonal	Van Kessel (2010); Van Kessel (2013); Spreij (2020)
Virtual Reality-Based Navigation Task*	Obstacle Detection Task Obstacle Avoidance Task	Cancellation/ Detection task Navigation task	Extrapersonal Extrapersonal	Aravind (2015)
Door bisection (walking task)		Functional/ Navigational/ Line Bisection task	Extrapersonal	Berti (2002)
Wheelchair Collision Test (WCT)		Functional task	Extrapersonal	Qiang (2005)
Catherine Bergego Scale (CBS)	Grooming Dressing Eating Mouth Cleaning Gaze Orientation Knowledge of left limbs Auditory attention Moving (collisions) Spatial orientation Finding personal belongings	Functional task Functional task Functional task Functional task Functional task Functional task Functional task Navigation task Functional task Functional task	Personal Personal Personal Personal Peri/ Extrapersonal Personal Auditory Extrapersonal Extrapersonal Extrapersonal	Azouvi (2003)
Kessler Foundation Neglect Assessment Process – Japanese (KF-NAP-J) (New	Grooming Dressing Eating Mouth Cleaning Gaze Orientation	Functional task Functional task Functional task Functional task Functional task	Personal Personal Personal Personal Peri/Extrapersonal	Nishida (2021)

Test Name	Subtests/tasks	Task Type	Neglect type tested	Author (year)
scoring method for CBS)	Knowledge of left limbs	Functional task	Personal	
	Auditory attention	Functional task	Auditory	
	Moving (collisions)	Navigation task	Extrapersonal	
	Spatial orientation	Functional task	Extrapersonal	
	Finding personal belongings	Functional task	Extrapersonal	
Semi-structured extrapersonal evaluation scale	Serving Tea	Functional task	Peripersonal	Zoccolotti (1991); Zoccolotti (1992)
	Card Dealing	Functional task	Peripersonal	
	Picture Description	Cancellation task	Peripersonal	
	Description of environment	Cancellation task	Extrapersonal	

*Computerised test.

4. Synthesis

4.1. Types of Diagnostic Test

The 22 studies used 19 diagnostic tests and observational scales to detect extrapersonal neglect. Just over half of index tests were computerised (n = 11, 57.9%) and the rest were non-computerised (n = 8, 42.11%). Three tests were observational diagnostic scales (15.79%) involving a series of functional tasks where performance was observed and rated on a scale by a clinician, and 16 were diagnostic tests (84.21%). These diagnostic tests and scales in total consisted of 49 individual tasks: 28 extrapersonal neglect tasks, 57.14%; 11 personal neglect tasks, 22.45%; five peripersonal neglect tasks, 10.2%; two auditory neglect tasks 4.08%; one hemianopia task (which functioned as a screening task, 2.04%); and two peri/extrapersonal neglect tasks where it was not clear (4.08%).

Most index tests comprised of a single task (n = 14, 73.68%), while a minority involved multiple tasks (n = 5, 26.32%). The most common type of tasks were functional tasks (n = 22, 44.9%), followed by cancellation tasks (n = 10, 20.41%), navigation tasks (n = 6, 12.24%), line bisection tasks (n = 3, 6.12%), detection tasks (n = 2, 4.08%) and an extinction task (n = 1, 2.04%). The five remaining tasks (10.2%) involved a mixture of task types (e.g. Virtual Reality Lateralized Attention Test, in which the task involved simultaneous navigation and cancellation elements). The psychometric properties of five diagnostic tests (26.32%) were investigated by more than one study (Line bisection [far]; VRLAT; EVENS; Simulated Driving Task; and Semi-structured extrapersonal evaluation scale), and 14 tests were evaluated by a single study (73.68%). A summary of individual test and subtests can be found in table 9.

4.2. Psychometric properties

4.2.1. Diagnostic Accuracy

Two studies reported statistics pertaining to diagnostic accuracy (9.09%; Fordell, Bodin, Bucht & Malm, 2011; Spreij, Ten Brink, Visser-Meily & Nijboer, 2020). Half of the studies did not report appropriate information relating to diagnostic accuracy and did not provide sufficient information (i.e. individual patient scores) to calculate specificity and sensitivity (n = 11, 50%), with many reporting "specificity" as simply the percentage detected by the index test, not considering important factors such as false-positives. The remaining studies (n = 9, 40.9%) provided sufficient information, and we were able to calculate sensitivity and specificity estimates. Only one of these studies (Van Der Stoep et al., 2013) featured a 2×2 table reporting cross-classification of participants by index and reference test result (Eusebi, 2013).

Spreij et al. (2020) was the only study that reported a ROC analysis to inform specificity and sensitivity and appropriate cut-off estimates. They provided separate ROC values for lateralised performance on the Simulated Driving Task: left-sided (0.844) and right-sided spatial neglect (0.429). They also provided PPV and NPV scores for both left (PPV = 85%; NPV = 75.8%) and right-sided spatial neglect (PPV = 40%; NPV = 90.9%). These findings indicate that the Simulated Driving Task is better at detecting left-sided spatial neglect than right. While the test appears to be relatively effective in ruling out neglect when the test result is negative in left and right-sided neglect, positive test results may be less reliable in accurately identifying the presence of neglect (particularly right sided neglect). Prior to this, Van Kessel, Van Nes, Brouwer, Geurts & Fasotti (2010) reported notably poorer diagnostic accuracy during their development of the Simulated Driving Task (sensitivity = 63.6%, specificity = 92.3%).

Fordell et al. (2011), provided VR-DiSTRO total sensitivity (100%, CI 72-100) and specificity (82%, CI 62-94) percentages with their confidence intervals, along with a likelihood ratio. A likelihood ratio of 5.5 (2.3-13.4) suggests individuals with spatial neglect are 5.5 times more likely to have a positive test result compared to individuals without spatial neglect. Furthermore, it appears this VR test demonstrates excellent sensitivity and moderate specificity when compared with the BIT. However, participants were sat with a screen in their peripersonal space and wore stereoscopic vision glasses to render the image 3D. Although the authors report it as a test for extrapersonal neglect, it could be argued that the high sensitivity and specificity with peripersonal reference tasks could be due to the participants proximity to the screen, ultimately rendering it a peripersonal neglect test.

The nine studies providing enough information to perform the necessary calculations showed variable sensitivity and specificity. Other than Fordell et al. (2011), no studies demonstrated both sensitivity and specificity percentages between 80–100%. The four studies that had both sensitivity and specificity of above 70% were the Line Bisection in far space (Aimola, Schindler, Simone & Venneri 2012); the Immersive VR-based task (Thomasson, Perez-Marcos, Crottaz-Herbette, Brenet, Saj, Bernati, Serino, Tadi, Blanke & Ronchi, 2023); the HVST (Whitehouse, Green, Giles, Rahman, Coolican, & Eskes, 2019) and the Shape Cancellation (virtual, far space; Van Der Stoep et al., 2013).

The remaining studies had a sensitivity or specificity percentage below 70% indicating poor diagnostic accuracy. These included the Bells test in far space (Aimola et al., 2012); the VRLAT (Buxbaum, Dawson & Linsley, 2012; Dawson, Buxbaum & Rizzo, 2008); the EVENS (Ogourtsova, Archambault & Lamontagne, 2018b); the Letter Cancellation (virtual, far) (Van Der Stoep et al., 2013); and the Line Bisection (virtual, far; Van Der Stoep et al., 2013).

Overall, the diagnostic tests currently available to detect extrapersonal spatial neglect demonstrate poor diagnostic accuracy, apart from the VR-DiSTRO, although the VR-DiSTRO could be argued is not an extrapersonal neglect test due to the participant’s proximity to the screen.

4.2.2. Content (Face) Validity

Only one study mentioned content validity. Buxbaum et al. (2012) mentioned the content validity of the VRLAT, stating that the task itself bears a “transparent relationship” with tasks patients often need to perform and thus could be considered to have content validity. However, they did not report on the process of selecting an expert panel to formally evaluate content validity, or their qualifications.

4.2.3. Criterion Validity

A total of 18 studies reported aspects of criterion validity (81.82%), for 14 distinct tests (28%). All of these studies provided estimated concurrent validity, with none reporting predictive validity.

4.2.3.1. Concurrent Validity

Regarding reference tests, the most used reference test battery was the Behavioural Inattention Test (BIT) with five studies using the full version (22.73%). Four studies administered the full CBS (18.18%). In terms of individual spatial neglect reference tasks from test batteries, the most used task was the Line Bisection (pen-and-paper version from BIT; n = 16, 72.73%), followed by the Letter Cancellation Task (BIT; n = 8, 36.36%), Bells test (n = 7, 31.82%), and Laser Line Bisection task (n = 5, 22.72%). Most studies used multiple reference tests (n = 19, 86.36%), but some used a single reference test (n = 2, 9.1%) and one did not use a reference test (Berti et al., 2002) for analysis. See table 6 for the comparator tasks used in each study.

The studies reporting concurrent validity investigated correlations between their index test and reference tests complete at the same time-point. Strong correlations have values between ±0.7-1, moderate correlations ±0.3-0.7 and weak correlations are ±0-0.3 (Akoglu, 2018). In terms of computerised tests that investigated concurrent validity, the Immersive VR-Based Task (Thomasson et al., 2023) demonstrated significant moderate correlations between the exploration time at level 4 and the reading test (number of omissions total: r = -0.51; and omissions left minus right: r = -0.56). No other correlations survived multiple comparison corrections.

The 3D Virtual Street Assessment (Kim et al., 2010) had a significant moderate correlation with the Line Bisection test (r = 0.633). The VRLAT (Buxbaum, Palermo, Mastrogiovanni, Read, Rosenberg-Pitonyak, Rizzo & Coslett, 2008; Buxbaum et al., 2012; Dawson et al., 2008) was correlated strongly with the Bell Cancellation test (r = 0.87; 0.83; Left only, r = 0.43), Letter Cancellation Test (r = 0.95; 0.83; Left, 0.59), Line Bisection (r = -0.87; -0.5), Laser Line Bisection (r = -0.85), Picture Copy (r = 0.91) and Menu task (r = 0.91), and moderately with Fluff test (left, r = 0.41). The VR-DiSTRO (Fordell et al., 2011) demonstrated significant correlations between the Virtual Reality subtask and its corresponding reference test for the Baking Tray task (k = 0.85), Line Bisection task (k = 0.47), Star Cancellation task (k = 0.56) and extinction task (k = 0.65).

The EVENS (Ogourtsova, Archambault & Lamontagne, 2018a; Ogourtsova et al. 2018b) revealed significant but moderate to weak correlations between the heading error outcome of the EVENS and Line Bisection (r = 0.42) and Star Cancellation in near space (total, r = -0.34; time, r = 0.28), and Star Cancellation in far space (total, r = -0.30; time, r = 0.26) performance. Moreover, this was replicated with slightly stronger correlations when looking at navigation time. The EVENS correlated significantly with Line Bisection in near space (r = 0.43) and far space (r = 0.40), as well as Star cancellation in near space (total, r = -0.40; time, r = 0.43).

The CVRT and CVRT-D subtasks of the Simulated Driving Task (Van Kessel et al., 2010; Van Kessel, Van Nes, Geurts, Brouwer & Fasotti, 2013) demonstrated significant moderate correlations with total BIT scores in a group of patients with right hemisphere lesions (CVRT, r = -0.54; CVR-D, r = -0.62). For the left hemisphere lesion patients, only the correlation between total BIT and CVRT-D was significant and strong (r = -0.72). Spreij et al. (2020) also explored concurrent validity in the Simulated Driving Task, and found it had a significant moderate correlation with the Star Cancellation test (r = 0.47) and CBS (r = 0.53).

The Virtual Reality-Based Navigation Task (Aravind, Darekar, Fung & Lamontagne, 2015) did not correlate significantly with any of the reference tests. Similarly, the Virtual Reality Street Crossing Test (VRSCT; Mesa-Gresa et al., 2011) had no significant correlations between any of the VRSCT measures and BIT scores in the overall sample.

In terms of non-computerised tests that investigated concurrent validity, the HVST wall subtest (Whitehouse et al., 2019) demonstrated a significant moderate correlation with Star Cancellation (r = 0.61, α = 0.01), a significant moderate correlation with the Line Crossing task (r = 0.42, α > 0.05) and a significant weak correlation with the Letter Cancellation task (r = 0.33; α > 0.05). The Wheelchair Collision Test (Qiang et al., 2005) showed significant strong correlations with the CBS in the 120cm condition (r = 0.72) and 140cm condition (r = 0.75). The CBS (Azouvi et al., 2005) demonstrated highly significant strong correlations with the Bells test (r = 0.76), figure copy (r = 0.70), and a moderate correlation with a reading task (r = 0.54). The Kessler Foundation Neglect Assessment (Japanese Version; Nishida et al., 2021) was found to be significantly moderately correlated with the BIT total (r = 0.41, R^2= 0.59). Lastly, the Semi-Structured Extrapersonal Evaluation Scale (Zoccolotti & Judica, 1991; Zoccolotti & Antonucci, 1992) presented significant correlations with the Line Cancellation task (Tau = -0.52; -0.60), Letter Cancellation task (Tau = -0.51; -0.52), the sentence reading task (Tau = 0.41), and Wundt-Jastrow Illusions task (Tau = 0.29; 0.20).

Overall, there were variable correlations between index and reference tests. The computerised simulated driving task stood out as strongly correlated with total BIT. For non-computerised tests, the Wheelchair Collision Test was strongly correlated with the CBS, and the CBS was strongly correlated with the Bells test and Figure Copy test.

4.2.4. Construct Validity

Several studies analysed construct validity (n = 8, 36.36%). Four studies (18.18%) reported discriminant validity and five studies (22.73%) reported convergent validity correlates with theoretically similar or dissimilar constructs. One study reported both convergent and discriminant validity (Dawson et al., 2008).

4.2.4.1. Convergent Validity

Anosognosia is a neurological symptom often associated with more severe spatial neglect (Azouvi et al., 2003). Azouvi et al. (2003) hypothesised that anosognosia plays a significant part in the presentation of spatial neglect and asked participants to rate their own performance on CBS tasks. The difference between their self-assessment score and the observer rated score was operationalised as their anosognosia score. They found, not only a highly significant correlation between anosognosia score and neglect severity as assessed by CBS (r = 0.79***), but also between anosognosia score and other pen-and-paper reference tests (r range = 0.43-0.72**).

Buxbaum et al. (2008) explored correlations between their Virtual Reality Lateralised Attention Test (VRLAT) tasks that required similar physical and attentional demands. VRLAT scores were compared with a modified version of the Moss-Magee Wheelchair Navigation Test (MMWNT) as a real world parallel to their test, as well as VRLAT correlations with a computerised version of the Dual Task test. The VRLAT mean score correlated highly with the different tasks of the dual task (Base L, r = -0.97**; Dual L, r = -0.93**; Interference, r = 0.82**). Correlations between VRLAT mean score and MMWNT were also high (r = -0.85**). Dawson et al. (2008) explored correlations between the VRLAT and dual task, and found similar significant correlations (Dual L, r = -0.86***; Interference, r = -0.88***).

Given that both the CBS and KF-NAP tasks evaluate the extent to which individuals struggle with everyday situations due to spatial neglect, Nishida et al. (2021) hypothesised that scores on the KF-NAP would correlate with a measure of functional independence (FIM). The KF-NAP had significant correlations with the FIM total score as expected (r = -0.521*, R^2= 0.266).

Lastly, Whitehouse et al. (2019) investigated whether their Halifax Visual Scanning Test (HVST) Wall subtest was correlated with performance on an existing functional task involving a wheelchair and found their wall subtest was significantly correlated with direct hits on the wheelchair task (r = -0.67**). Considering both tests aim to detect extrapersonal neglect, correlations between them inform convergent validity as they appear to be measuring the same underlying construct.

Overall, while the KF-NAP, CBS and the HVST also showed significant correlations with theoretically similar constructs, the VRLAT demonstrated more substantial and replicable correlations with theoretically similar constructs, demonstrating good convergent validity.

4.2.4.2. Discriminant Validity

Aravind et al. (2015) explored whether results on the Virtual Reality Based Navigation Task - a computerised test consisting of two subtasks, the obstacle detection task (cancellation/detection task) and the obstacle avoidance task (navigation task) - were correlated with the Trail Making Task, a test of processing speed and executive functioning. The Trail Making B test was significantly correlated with the obstacle avoidance task variable ‘distance at onset of strategy’ when the obstacles approached from the participant’s contralesional side (r = -0.63**). The Trail Making B test was also correlated with the distance at detection when obstacles approached head on (r = -0.70**), from the contralesional side (r = -0.55*) and from the ipsilesional side (r = -0.60*). The sample only consisted of 12 stroke patients, and at baseline, all but one had Trail Making B test durations higher than their corresponding age and education related normative values. Given the limited sample size, the observed correlations may be influenced by the variability inherent in smaller sample sizes.

Buxbaum et al. (2012) investigated firstly whether the VRLAT was able to discriminate between visual field deficit and spatial neglect. They found that while the pen-and-paper reference tests were significantly more likely to capture individuals with visual field deficits, the VRLAT was no more likely to identify individuals with or without visual field deficits. This is a particularly interesting finding, as spatial neglect diagnostic tests historically have found it difficult to distinguish neglect from visual field deficits like hemianopia (Ting, Pollock, Dutton, Doubal, Ting, Thompson & Dhillon, 2011). Moreover, Buxbaum et al. (2012) completed a multiple regression to explore whether the VRLAT was influenced by other deficits and found it was not influenced by non-lateralised attentional deficits, further contributing to its discriminant validity. These findings were also demonstrated in Dawson et al. (2008) examination of the VRLAT, in which they too found the VRLAT was not influenced by visual field deficits or generalised attentional deficits.

Mesa-Gresa et al. (2011) tested whether the Virtual Reality Street Crossing Test (VRSCT) was influenced by non-spatial attention, using conventional attentional tests (CTT and CPT-II). They found the VRSCT total duration was significantly correlated with CTT-A ($r^2 = 0.802^{**}$), CTT-B ($r^2 = 0.506^{*}$) and one variable on the CPT ($r^2 = 0.613^{**}$) but only in the non-neglect group, implying that it may be effective in differentiating between neglect and attentional deficits in non-neglect patients, but not in neglect patients. It is worth noting that Mesa-Gresa et al. (2011) did not have an exclusively stroke sample, including patients with tumours also.

Overall, the VRSCT and Virtual Reality Based Navigation Task were found to be correlated with theoretically separate cognitive abilities such as non-spatial attention and executive functioning, however due to limitations in sampling, such as small sample size and the inclusion of other neurological conditions, it is difficult to conclude whether other confounding variables influenced this. The VRLAT on the other hand, demonstrated good and replicable discriminant validity, as it appeared it was not influenced by visual field deficits or generalised attentional deficits.

4.2.5. Internal Consistency

A total of five studies investigated internal consistency within four distinct tests. One test was a computerised navigation/cancellation task (VRLAT; Buxbaum et al., 2012). The remaining three tests were observational functional task batteries: the Catherine Bergego Scale (CBS) - consisting of nine functional tasks (two of which are conducted in the extrapersonal space) and one extrapersonal space navigation task (Azouvi et al., 2003); the Kessler Foundation Neglect Assessment Process (Japanese version; KF-NAP-J; Nishida et al., 2021) - a new scoring method for the CBS so has identical tasks; and the Semi-Structured Extrapersonal Neglect Scale – comprising of four tasks, two of which are functional peripersonal neglect tasks, one peripersonal cancellation task and one extrapersonal cancellation task (Zoccolotti & Judica, 1991; Zoccolotti & Antonucci, 1992).

Zoccolotti & Judica (1991), noted there may be good internal consistency on the semi-structured extrapersonal neglect scale following an analysis of agglomeration coefficients. They reported small differences between agglomeration coefficients on the peripersonal/extrapersonal scale, indicating a degree of similarity. Zoccolotti & Antonucci (1992) investigated this further when they found the spatial neglect group scores on the individual tasks of the Semi-Structured Extrapersonal Neglect Scale were correlated with the total score of the scale using Kendall's tau, demonstrating good internal consistency (0.44-0.71*** in all subtests).

Nishida et al. (2021) investigated the internal consistency of the KF-NAP-J by calculating the Cronbach's alpha of KF-NAP-J group's scores on subtests ($\alpha = 0.97$), indicating excellent internal consistency. Excellent internal consistency was also found when Buxbaum et al. (2012) analysed the internal consistency of the VRLAT and reported both high Cronbach's Alpha ($\alpha = 0.97$) across the simple, enhanced and complex versions of the test, and high corrected item-total correlations (all $\geq$ 0.92) indicating that each version is highly correlated with the overall score on the VRLAT.

Azouvi et al. (2003) conducted a principal component analysis, which revealed that all 10 items of the CBS were significantly correlated with each other, with correlation coefficients ranging from 0.48 to 0.73, all of which were highly significant. This consistent degree of significant correlation amongst the items suggests strong internal consistency within the scale.

Overall, the CBS, KF-NAP-J and Semi-Structured Extrapersonal Neglect Scale all demonstrated good internal consistency.

4.2.6. Test-Retest Reliability

One study, Qiang et al. (2005) evaluated test-retest reliability of the Wheelchair Collision Test (WCT). The WCT is a functional extrapersonal neglect task. They asked participants to complete two tasks, one where they had to manoeuvre between chairs positioned 120cm apart, and the other with chairs positioned 140cm apart. They completed each task twice and reported the intraclass correlation coefficients (ICC) for each (120cm: left direction ICC = 0.69, CI = 0.36-0.87; right direction ICC = 0.97, CI = 0.95-0.99; 140cm: left direction ICC = 0.87, CI = 0.69-0.95; right direction ICC = 0.68, CI = 0.36-0.86), indicating substantial or almost perfect agreement.

4.2.7. Interrater Reliability

A total of four studies (18.18%) investigated the interrater reliability of three distinct tests. Two of these tests were functional batteries including some extrapersonal neglect tasks (Nishida et al., 2021; Zoccolotti & Judica, 1991; Zoccolotti & Antonucci, 1992), and one was a functional extrapersonal neglect task (Qiang et al., 2005). Two studies reported the interrater reliability between ratings on their test, and their ratings on the Catherine Bergego Scale (CBS), while two studies reported interrater reliability between two independent judges rating their functional battery. Qiang et al. (2005) and Nishida et al. (2021) reported Cohen's Kappa Coefficients between their ratings of the CBS and their ratings of their own tests. Qiang et al. (2005) reported higher Kappa coefficients when the WCT distance between chairs was 120cm instead of 140cm (0.68 vs 0.58, considered moderate and substantial respectively; Lyden & Lau, 1991). Nishida et al. (2021) reported Kappa coefficients were higher for the Kessler Foundation Neglect Assessment Process Japanese version (KF-NAP-J; 0.92), than for the CBS (0.85) indicating almost perfect and substantial interrater reliability respectively. Zoccolotti & Judica (1991) and Zoccolotti & Antonucci (1992) indicated high interrater reliability using Kendall's tau (Zoccolotti & Judica 1991: median = 0.92, range = 0.71-1.00; Zoccolotti & Antonucci, 1992: range = 0.92-0.97, total score = 0.96) for each sub-task with high significance in all cases. Overall, these three tests demonstrated high interrater reliability.

4.3. Computerised versus Non-Computerised Tests

4.3.1 Computerised Tests

Approximately half of the tests identified were not computerised (n = 8, 42.11%); the rest were computerised, either by the task being displayed on a screen (n = 7, 36.84%), or involving a full head-mounted virtual reality display (n = 5, 26.32%). For the computerised tests displayed on a screen, three were virtual versions of commonly used pen-and-paper tests for peripersonal neglect, that were projected into a screen in the far space (120cm), requiring the participant to either cancel stimuli (Shape Cancellation or Letter Cancellation) or bisect a line (Line Bisection) using a computer mouse (Van Der Stoep et al., 2013). Similarly, the VR-DiSTRO (Fordell et al., 2011) involved computerised versions of commonly used pen-and-paper tasks (VR-Star Cancellation, VR-Line Bisection, VR-Visual Extinction) and a computerised functional task (VR-Baking Tray Task) displayed on a screen. However, this test also requires other equipment, for example it requires eye shutter stereoscopic glasses and the use of a robotic pen.

The rest of the computerised diagnostic extrapersonal neglect tests that are displayed on a screen consist of tasks that have a navigation, cancellation and/or detection component. The Simulated Driving Task (Spreij et al., 2020; Van Kessel et al., 2010; 2013) involved a task where participants were seated 90cm away from a large 2.13m x 3.18m projection. They used a steering wheel to navigate and detect stimuli throughout their virtual environment. The VRLAT (Buxbaum et al., 2008; 2012; Dawson et al., 2008), was similar in that participants travelled along a virtual path (either propelling themselves using a computer joystick or controlled by the examiner moving at a constant rate) and had to identify virtual obstacles and avoid coming off the path.

One test, the Virtual Reality Street Crossing Test (VRSCT, Mesa-Gresa et al., 2011) involved a computer screen to display the virtual test, but also involved two other wireless devices in order to interact with the virtual environment. Participants used a wireless joystick for navigation and an optical tracking system, attached to a hat, that enabled the programme to track the participant's head movements without the need for a full head-mounted display. This was seen as a less invasive and more intuitive way of interacting with a virtual environment. During the test, participants had to cross virtual streets with traffic to get to a supermarket and return as quickly and as safely as possible. The trial was stopped and marked with a car horn sound, if the participant collided with a virtual car.

For the computerised tests requiring head-mounted displays, they also consisted mainly of navigation, detection and/or cancellations tasks. For example, for the Immersive VR-based task (Thomasson et al., 2023), participants found themselves immersed in a 360-degree virtual forest environment, accompanied by the sounds of wind, moving leaves and a central fire. The task consisted of different levels (Level 1-2: Static targets; Level 3-4: dynamic targets, moving animals), where participants had to press a button to indicate target detection.

For the Virtual Reality-Based Navigation Task (Aravind et al., 2015), participants were seated in a comfortable chair and immersed in a virtual room (12x8m) where they were asked to reach a blue circular target 11m away. Along their path were three red cylinders that acted as obstacles. When the task begins, the participant automatically begins moving at a constant rate (0.75m/s) and the participant must use a joystick to navigate around the task, or simply press a button if they perceive any of the obstacles moving, depending on whether it was the detection or avoidance condition. Each condition has 8 trials.

Participants completing the EVENS (Ogourtsova et al., 2018a; 2018b) found themselves in a similar test. Having had reflective markers attached to their bodies, participants were immersed in a closed virtual room (9x15m), and a red ball appeared 7m away, either to their left, right or perfectly in the centre of their midline. They completed 45 walking trials (15 for each location of red ball, randomly ordered) where they had to walk to the red ball.

For the Three-Dimensional virtual street crossing test (Kim et al., 2010), the participant found themselves immersed in a virtual street crossing environment, with a large road in front of them. There were traffic lights and cars in this environment and participants could see an avatar on the other side of the road. In the different trials, participants were instructed to keep the virtual avatar safe by observing both directions of traffic and clicking the mouse button as soon as they observe an incoming car to stop it. The cars varied in speeds across 16 trials and if it went unnoticed, an alarm sound would be heard, and if still unnoticed, the trial was deemed a failure.

4.3.2. Non-computerised tests

Some non-computerised tests replicated conventional pen-and-paper tests but in far space. For example, for Line Bisection in far space (Aimola et al., 2012; Berti et al., 2002), participants were asked to indicate with a laser pen, the midpoint of horizontal lines on a wall (1.5m and 3m away, Berti et al., 2002; 3.2m away, Aimola et al., 2012). The lines also varied in length according to distance at which they were presented. However, one significant limitation of this approach was that participant's scores were recorded by the clinician replicating the laser location on an acetate spreadsheet. Minor deviations between the participant's estimation of midpoint, and the examiner's estimation of the participants estimation of the midline, could pose significant confounding variables.

Much like the Line Bisection test, Berti et al. (2002) devised the Door Bisection Test, in which participants were required to walk with open eyes as close to the centre of a doorway as possible (width 148cm). 10 trials were completed in each condition. It is worth noting that this study only had 13 participants, so more investigation is needed.

For the Bells Test in far space (Aimola et al., 2012), participants had to cancel stimuli (Bells) projected on the wall 3.2m away using a laser pointer. For this test, an acetate spreadsheet was also used to record correctly identified stimuli.

For the Wheelchair Collision Test (WCT; Qiang et al., 2005), participants sat in a wheelchair 2m away from a pattern of chairs. Four chairs were arranged in two staggered parallel lines. In one condition the chairs were 1.2m apart, and in the other they were 1.4m apart. The chairs were staggered in a way, that upon passing between the first two chairs, the participant would have to move left or right to go between the next two chairs in the back row. The participant's aim was to navigate through the chairs without colliding with them.

The Halifax Visual Scanning Test (Whitehouse et al., 2019) consists of three subtests: the shirt subtest (personal neglect), table subtest (peripersonal neglect) and wall subtest (extrapersonal neglect). All three tasks involved identifying and reading out words amongst various distractors in different areas of space. For the wall subtest, the words were presented on a board mounted on a wall 2.5m away.

The remaining three tests are functional observational scales. The CBS (Azouvi et al., 2003) and the KF-NAP-J (Nishida et al., 2021) consist of the same functional tasks, but raters use separate rating scales. The tasks pertaining to extrapersonal neglect, are the moving (collisions) item, the spatial orientation item and the finding personal belongings item. The moving (collisions) item requires the participant to navigate their environment without colliding with anything. The spatial orientation item requires the participant to find their way around their environment remaining orientated. The finding personal belongings item requires the participant to locate their possessions in a room or bathroom. One task could be a peri-personal or extrapersonal measure, however the description of the item does not provide sufficient information about the distance at which the stimuli are presented.

The Semi-Structured Extrapersonal Evaluation Scale comprises of four tasks, one of which could be considered extrapersonal – the Description of an Environment Task. In this task, participants enter a room containing a range of different stimuli. The participant is simply asked "will you describe everything you see in this room?" and the participant's answers are recorded.

4.4. Practical Considerations

It is important for clinicians to consider practical considerations when using novel diagnostic tests in clinical settings. In addition to psychometric properties, the amount of equipment needed to administer the diagnostic test and amount of space required must also be considered. As these diagnostic tests measure extrapersonal neglect, they are likely to require a considerable amount of space since stimuli must be presented outside of arms reach. An example of this the WCT test (Qiang et al., 2005), which involves enough space to set out a pattern of chairs for the participant to navigate in a wheelchair.

Computerised tests, although still requiring some space, allow for the mapping of much larger virtual space over relatively smaller physical space, thus increasing their utility and practicality in clinical settings. However, this often comes at the cost of requiring significant investment in expensive VR equipment, including high-quality headsets (e.g. Oculus Rift DK2 head-mounted display for the Immersive VR-based task; Thomasson et al., 2023), motion tracking systems (e.g. 12-camera Vicon 512 motion capture system in the EVENS, Ogourtsova, 2018a), and computer hardware capable of rendering complex virtual environments (e.g. PC with Intel Core 2 Duo processor at 1.86 GHz with 2 GB RAM and a NVidia GeForce 7950 GX2 dual video card with 512MB RAM, VRLAT; Dawson et al., 2008).

Clinicians should also consider the time required to set up and administer the test, as well as the ease of interpretation of the results. Just under half of the studies provided estimates of test duration (n = 9, 40.91%). The durations provided ranged from just three minutes (including a one-minute practice trial in the Simulated Driving Task; Spreij et al., 2020) to 30 minutes (EVENS; Ogourtsova et al., 2018b). The type of test and whether it is computerised has little impact on test duration, as the tasks with the shortest and longest duration are both computerised navigation tasks.

5. Discussion

This systematic review is, to the best of our knowledge, the first to appraise and synthesise research validating diagnostic assessments of extrapersonal spatial neglect, summarising the psychometric properties and clinical utility of available extrapersonal spatial neglect tests to enable clinicians to make educated decisions when selecting diagnostic tools for their service context. In addition, this systematic review identifies new gaps of knowledge that inform avenues of future research.

The narrative synthesis covered 22 validation studies of stroke survivors and 19 individual diagnostic tests of extrapersonal neglect. The mean average quality appraisal score on the QAVALS for these studies was 13.91 out of 24, indicating that the quality of diagnostic validation studies in this area is generally quite poor. Measures of diagnostic accuracy are extremely sensitive to study design (Eusebi, 2013), and if studies fail to adopt rigorous methodological standards, they may significantly overestimate or underestimate their findings and by extension, the overall accuracy of the tests proposed. In studies of diagnostic accuracy, it is considered best practice to report 2x2 tables for others to clearly see information pertaining to sensitivity and specificity (Eusebi, 2013). Only one study reported this. Furthermore, studies often reported sensitivity as the percentage of participants that their index test identified as having extrapersonal neglect, without reporting on efforts to check for the possibility of type one error. The use of terms such as sensitivity and specificity without the use of their associated formula could potentially be misleading to clinicians attempting to select between two seemingly sensitive tools.

Moreover, typically when evaluating the sensitivity and specificity of a novel diagnostic test, the reference standard is assumed to have perfect sensitivity and specificity (100%). However, in the absence of this (as seen in tests of spatial neglect), reliable classification of participants becomes conceptually challenging. Since all index tests reportedly focus on extrapersonal spatial neglect and all the reference tests target peripersonal neglect, reported false-positive and false-negative rates could either indicate a lack of accuracy, or suggest the index tests actually excel in diagnosing extrapersonal spatial neglect compared to peripersonal reference tests. This ambiguity highlights the necessity for rigorously designed validation studies and high-quality reporting of results.

Of the eight types of validity and reliability considered within the scope of this review, the average study reported less than two. The most common form of validity evidence analysed and reported in these studies was Concurrent Validity, followed by Convergent Validity and Discriminant Validity. The most common form of reliability was internal consistency. Overall, the Criterion and Content Validity of the studies was quite variable and these extrapersonal diagnostic tests could really benefit from further empirical investigations.

The sample demographics of the studies were generally representative of stroke survivor populations. Every study included stroke survivors, however, some studies also included patients with tumours, which could be problematic for clinicians evaluating the usefulness of these tools in a stroke-survivor clinical population. Moreover, some of the sample sizes of these validation studies were very small (e.g. n = 13, Berti et al., 2002; n = 13, Buxbaum et al., 2008). This is particularly important when conducting research on stroke survivors, because stroke can impact people in many ways, and individuals often present with a wide range of symptom variability. Large samples help account for these differences and allow for strong statistical analyses. Furthermore, many of these studies did not include healthy controls (n = 12). Healthy controls provide a crucial baseline against which the performance of individuals with spatial neglect is compared. Including healthy controls can not only facilitate in the establishing of normative values, but it is crucial in determining specificity.

A considerable number of novel diagnostic tests were computerised in some way. Some were simply projected onto a screen that users interacted with, while others involved a fully immersive virtual reality experience requiring participants to wear VR-head mounted displays. While these fully immersive VR experiences facilitate the exploration of interesting new types of diagnostic test, for example tasks that include navigation, cancellation, and functional elements, they do have associated technological and financial limitations that services may find difficult to secure funding and tech support for. While computerisation has some substantial diagnostic benefits, such as allowing for rapid scoring of test results with minimal human error or standardisation of elements of testing procedure, future test developers should find a balance between complex computerisation requiring very specific equipment, and simple computerisation which allows for the mass application of the diagnostic test in a range of settings and service contexts.

Some of these tests hold promise, especially as they continue to develop. For example, initially the VRLAT required considerable specialist equipment such as a wheelchair treadmill when first tested on stroke survivors (Buxbaum et al., 2008). As the diagnostic test has developed over the years, a better balance has been found between, now requiring only a computer, a joystick and the VRLAT programme (Buxbaum et al., 2012).

Some of the studies included in this systematic review were observation-based functional scales (CBS, Azouvi et al., 2023; KF-NAP-J, Nishida et al., 2021; Semi-structured Extrapersonal Evaluation Scale, Zoccolotti & Judica, 1991; Zoccolotti & Antonucci, 1992). The use of observational scales of structured functional tasks can be problematic, as scoring may vary among clinicians for several reasons (Chen et al., 2012). In some instances, this may be due to observer interpretation of scoring or where they are physically positioned in the room. Moreover, it may be due to a general lack of understanding or training around spatial neglect, potentially combined with expectation bias (Colwell, Demeyere & Vancleef, 2022; Moore, Vancleef, Shalev, Husain & Demeyere, 2019).

Consistency in terminology was another issue raised by the studies included. Certain studies (Zoccolotti & Judica 1991; Zoccolotti & Antonucci, 1992) use the broad definition for extrapersonal neglect - i.e. both peripersonal and extrapersonal. We decided to include this study as one of the subtests (Description of an environment task) appears to be a subtest that could be considered extrapersonal as it involves stimuli outside of arms reach. They cluster peri-personal and extrapersonal tasks in their analysis of the extrapersonal test battery, however, which makes it difficult to separate, thus limiting our ability to evaluate this test's overall ability to detect neglect in the far space.

The QAVALS was selected as a quality appraisal tool, since it covers a broader range of validity than other popular measures for appraising validation studies (such as the QUADAS-2, Whiting et al., 2014) and has strong psychometric properties (Gore, Goldberg, Huang, Shoemaker & Blackwood, 2017). Although the QAVALS covered areas of validity such as criterion, content, and construct validity, it does not include criteria concerning other aspects explored in this systematic review, however, such as diagnostic accuracy or reliability.

Although this systematic review does cover a range of psychometric properties, one limitation is that this systematic review did not cover certain aspects of validity, for example ecological validity. Validity and reliability are broad constructs with significant overlap, especially in the absence of a clear gold-standard assessment (Rutjes, Reitsma, Coomaransamy, Khan & Bossuyt 2007). It could be argued that ecological validity, is an important aspect to be evaluated, especially considering the use of virtual reality and immersive experiences, and the lack of ecological validity that is associated with standard pen-and-paper diagnostic testing.

One further limitation of this systematic review is that we restricted our search to studies that validated on stroke survivor populations. By restricting our inclusion criteria in this way, we did not incorporate some promising tools in early development (e.g. Borsotti, Mosca, Di Lauro, Pancani, Bracali, Dore, Macchi & Cecchi, 2020; Cunningham, O'Rourke, Finlay & Gallagher, 2017; Perez-Marcos, Ronchi, Giroux, Brenet, Serino, Tadi & Blanke, 2023), that have yet to be validated on stroke survivor populations.

Future research should continue validating and establishing the psychometric properties of these and novel extrapersonal diagnostic tests, as currently no extrapersonal neglect test has a comprehensive, robust evaluation of psychometric properties. This is crucial to guide clinical decision-making regarding selection of tests appropriate to service context. Furthermore, studies should ensure they adopt large stroke samples and healthy age-matched controls to strengthen the generalisability of study findings by increasing statistical power for analyses and minimising confounding variables such as age-related cognitive decline in a diagnostic population with large variability in symptoms.

6. Conclusions

There are currently no well-established, diagnostically accurate tests for extrapersonal spatial neglect. Robust validation studies on clinical populations are urgently needed with careful consideration of study methodology and reporting, along with the clinical test's utility and practicality. Stroke survivors who experience extrapersonal spatial neglect may currently be being underdiagnosed and undertreated. More large-scale validation studies are needed to establish diagnostically accurate tools suitable for regular clinical practice.

7. Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

8. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. At the point of conducting this systematic review, the authors are developing a new open-source diagnostic test for extrapersonal neglect.

9. Availability of data

All data extracted for this systematic review are reported in tables 6, 7, 8 and 9.

10. References

Aimola, L., Schindler, I., Simone, A. M., & Venneri, A. (2012). Near and far space neglect: Task sensitivity and anatomical substrates. Neuropsychologia, 50(6), 1115–1123. https://doi.org/10.1016/j.neuropsychologia.2012.01.022

Akoglu, H. (2018). User's guide to correlation coefficients. In Turkish Journal of Emergency Medicine (Vol. 18, Issue 3, pp. 91–93). Emergency Medicine Association of Turkey. https://doi.org/10.1016/j.tjem.2018.08.001

Appelros, P., Nydevik, I., Karlsson, G. M., Thorwalls, A., & Seiger, Å. (2004). Recovery from unilateral neglect after right-hemisphere stroke. Disability and Rehabilitation, 26(8), 471–477. https://doi.org/10.1080/09638280410001663058

Aravind, G., Darekar, A., Fung, J., & Lamontagne, A. (2015). Virtual Reality-Based Navigation Task to Reveal Obstacle Avoidance Performance in Individuals with Visuospatial Neglect. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 23(2), 179–188. https://doi.org/10.1109/TNSRE.2014.2369812

Aravind, G., & Lamontagne, A. (2014). Perceptual and locomotor factors affect obstacle avoidance in persons with visuospatial neglect. Journal of NeuroEngineering and Rehabilitation, 11(1). https://doi.org/10.1186/1743-0003-11-38

Azouvi, P., Bartolomeo, P., Beis, J.-M., Perennou, D., Pradat-Diehl, P., & Rousseaux, M. (2006). A battery of tests for the quantitative assessment of unilateral neglect 1. In Restorative Neurology and Neuroscience, 24, IOS Press.

Azouvi, P., Samuel, C., Louis-Dreyfus, A., Bernati, T., Bartolomeo, P., Beis, J. M., Chokron, S., Leclercq, M., Marchal, F., Martin, Y., De Montety, G., Olivier, S., Perennou, D., Pradat-Diehl, P., Prairial, C., Rode, G., Siéroff, E., Wiart, L., & Rousseaux, M. (2002). Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke. Journal of Neurology Neurosurgery and Psychiatry, 73(2), 160–166. https://doi.org/10.1136/jnnp.73.2.160

Bailey, M. J., Riddoch, M. J., & Crome, P. (2000). Evaluation of a test battery for hemineglect in elderly stroke patients for use by therapists in clinical practice. Neuro Rehabilitation, 14, 139–150.

Berti, A., Smania, N., Rabuffetti, M., Ferrarin, M., Spinazzola, L., D'Amico, A., Ongaro, E., & Allport, A. (2002). Coding of far and near space during walking in neglect patients. Neuropsychology, 16(3), 390–399. https://doi.org/10.1037/0894-4105.16.3.390

Beschin, N., Basso, A., & Sala, S. Della. (2000). Perceiving Left and imagining Right: Dissociation in Neglect. Cortex, 36, 401–414.

Bonato, M. (2012). Neglect and extinction depend greatly on task demands: A review. In Frontiers in Human Neuroscience (Issue JUNE 2012). Frontiers Media S. A. https://doi.org/10.3389/fnhum.2012.00195

Bonato, M. (2015). Unveiling residual, spontaneous recovery from subtle hemispatial neglect three years after stroke. Frontiers in Human Neuroscience, 9, 1–9. https://doi.org/10.3389/fnhum.2015.00413

Borsotti, M., Mosca, I. E., Di Lauro, F., Pancani, S., Bracali, C., Dore, T., Macchi, C., & Cecchi, F. (2020). The Visual Scanning Test: a newly developed neuropsychological tool to assess and target rehabilitation of extrapersonal visual unilateral spatial neglect. Neurological Sciences, 41(5), 1145–1152. https://doi.org/10.1007/s10072-019-04218-2

Buxbaum, L. J., Dawson, A. M., & Linsley, D. (2012). Reliability and validity of the virtual reality lateralized attention test in assessing hemispatial neglect in right-hemisphere stroke. Neuropsychology, 26(4), 430–441. https://doi.org/10.1037/a0028674

Buxbaum, L. J., Ferraro, M. K., Veramonti, T., Farne, A., Whyte, J., Ladavas, E., Frassinetti, F., & Coslett, H. B. (2004). Hemispatial Neglect. Neurology, 62(5), 749–756.

Buxbaum, L. J., Palermo, M. A., Mastrogiovanni, D., Read, M. S., Rosenberg-Pitonyak, E., Rizzo, A. A., & Coslett, H. B. (2008). Assessment of spatial attention and neglect with a virtual wheelchair navigation task. Journal of Clinical and Experimental Neuropsychology, 30(6), 650–660. https://doi.org/10.1080/13803390701625821

Cavedoni, S., Cipresso, P., Mancuso, V., Bruni, F., & Pedroli, E. (2022). Virtual reality for the assessment and rehabilitation of neglect: where are we now? A 6-year review update. Virtual Reality, 26(4), 1663–1704. https://doi.org/10.1007/s10055-022-00648-0

Checketts, M., Mancuso, M., Fordell, H., Chen, P., Hreha, K., Eskes, G. A., Vuilleumier, P., Vail, A., & Bowen, A. (2020). Current clinical practice in the screening and diagnosis of spatial neglect post-stroke: Findings from a multidisciplinary international survey. Neuropsychological Rehabilitation, 1–32. https://doi.org/10.1080/09602011.2020.1782946

Chen, P., Fyffe, D. C., & Hreha, K. (2017). Informal caregivers' burden and stress in caring for stroke survivors with spatial neglect: An exploratory mixed-method study. Topics in Stroke Rehabilitation, 24(1), 24–33. https://doi.org/10.1080/10749357.2016.1186373

Chen, P., Hreha, K., Fortis, P., Goedert, K., & Barrett, A. (2012). Functional assessment of spatial neglect: A review of the catherine bergego scale and an introduction of the kessler foundation neglect assessment process. In Topics in Stroke Rehabilitation (Vol. 19, Issue 5, pp. 423–435). https://doi.org/10.1310/tsr1905-423

Chen, P., Hreha, K., Kong, Y., & Barrett, A. M. (2015). Impact of Spatial Neglect on Stroke Rehabilitation: Evidence from the Setting of an Inpatient Rehabilitation Facility. Archives of Physical Medicine and Rehabilitation, 96(8), 1458–1466. https://doi.org/10.1016/j.apmr.2015.03.019

Cohen, J. F., Korevaar, D. A., Altman, D. G., Bruns, D. E., Gatsonis, C. A., Hooft, L., ... & Bossuyt, P. M. (2016). STARD 2015 guidelines for reporting diagnostic accuracy studies: explanation and elaboration. *BMJ open*, *6*, 11, e012799.

Colwell, M. J., Demeyere, N., & Vancleef, K. (2022). Visual perceptual deficit screening in stroke survivors: evaluation of current practice in the United Kingdom and Republic of Ireland. Disability and Rehabilitation, 44(22), 6620–6632. https://doi.org/10.1080/09638288.2021.1970246

Committeri, G., Pitzalis, S., Galati, G., Patria, F., Pelle, G., Sabatini, U., Castriota-Scanderbeg, A., Piccardi, L., Guariglia, C., & Pizzamiglio, L. (2007). Neural bases of personal and extrapersonal neglect in humans. Brain, 130(2), 431–441. https://doi.org/10.1093/brain/awl265

Corbetta, M., Kincade, M. J., Lewis, C., Snyder, A. Z., & Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. Nature Neuroscience, 8(11), 1603–1610. https://doi.org/10.1038/nn1574

Cunningham, L. J., O'Rourke, K., Finlay, C., & Gallagher, M. B. (2017). A preliminary investigation into the psychometric properties of the Dublin Extrapersonal Neglect Assessment (DENA): A novel screening tool for extrapersonal neglect. Neuropsychological Rehabilitation, 27(3), 349–368. https://doi.org/10.1080/09602011.2015.1084334

Dalmaijer, E. S., Van der Stigchel, S., Nijboer, T. C., Cornelissen, T. H., & Husain, M. (2015). Cancellation Tools: All-in-one software for administration and analysis of cancellation tasks. Behavior Research Methods, 47(4), 1065–1075.

Dawson, A., Buxbaum, L., & Rizzo, A. (2008). The Virtual Reality Lateralized Attention Test: Sensitivity and validity of a new clinical tool for assessing hemispatial neglect. Virtual Rehabilitation, 77–82.

Demeyere, N., Riddoch, M. J., Slavkova, E. D., Bickerton, W. L., & Humphreys, G. W. (2015). The Oxford Cognitive Screen (OCS): validation of a stroke-specific short cognitive screening tool. Psychological Assessment, 27(3), 883.

Esposito, E., Shekhtman, G., & Chen, P. (2021). Prevalence of spatial neglect post-stroke: A systematic review. In Annals of Physical and Rehabilitation Medicine (Vol. 64, Issue 5). Elsevier Masson s.r.l. https://doi.org/10.1016/j.rehab.2020.10.010

Eusebi, P. (2013). Diagnostic accuracy measures. Cerebrovascular Diseases, 36(4), 267–272. https://doi.org/10.1159/000353863

Evald, L., Wilms, I., & Nordfang, M. (2021). Assessment of spatial neglect in clinical practice: A nationwide survey. Neuropsychological Rehabilitation, 31(9), 1374–1389. https://doi.org/10.1080/09602011.2020.1778490

Farnè, A., Buxbaum, L. J., Ferraro, M., Frassinetti, F., Whyte, J., Veramonti, T., Angeli, V., Coslett, H. B., & Làdavas, E. (2004). Patterns of spontaneous recovery of neglect and associated disorders in acute right brain-damaged patients. Journal of Neurology, Neurosurgery and Psychiatry, 75(10), 1401–1410. https://doi.org/10.1136/jnnp.2002.003095

Feigin, V. L., Brainin, M., Norrving, B., Martins, S., Sacco, R. L., Hacke, W., Fisher, M., Pandian, J., & Lindsay, P. (2022). World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. In International Journal of Stroke (Vol. 17, Issue 1, pp. 18–29). SAGE Publications Inc. https://doi.org/10.1177/17474930211065917

Fordell, H., Bodin, K., Bucht, G., & Malm, J. (2011). A virtual reality test battery for assessment and screening of spatial neglect. Acta Neurologica Scandinavica, 123(3), 167–174. https://doi.org/10.1111/j.1600-0404.2010.01390.x

Friedman P. J. (1991). Clock Drawing in Acute Stroke. Age Ageing, 20, 140–145.

Gauthier, L., Dehaut, F., & Joanette, Y. (1989). The Bells Test: A Quantitative and Qualitative Test for Visual Neglect. International Journal of Clinical Neuropsychology, 11, 49–54.

Giannakou, I., Lin, D., & Punt, D. (2022). Computer-based assessment of unilateral spatial neglect: A systematic review. Frontiers in Neuroscience, 16, 1–14. http://clinicaltrials.gov/

Gore, S. (2017). Subjective Assessment of Physical Activity in Chronic Obstructive Pulmonary Disease. Doctoral Dissertation, University of Michigan-Flint, 1–195.

Gore, S., Goldberg, A., Huang, M. H., Shoemaker, M., & Blackwood, J. (2021). Development and validation of a quality appraisal tool for validity studies (QAVALS). Physiotherapy Theory and Practice, 37(5), 646–654. https://doi.org/10.1080/09593985.2019.1636435

Grattan, E. S., & Woodbury, M. L. (2017). Do neglect assessments detect neglect differently? American Journal of Occupational Therapy, 71(3). https://doi.org/10.5014/ajot.2017.025015

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. British Medical Journal, 331, 1064–1067.

Guariglia, P., Matano, A., & Piccardi, L. (2014). Bisecting or not bisecting: This is the neglect question. Line bisection performance in the diagnosis of neglect in right brain-damaged patients. PLoS ONE, 9(6). https://doi.org/10.1371/journal.pone.0099700

Guilbert, A. (2022). Clinical Assessment of Unilateral Spatial Neglect Dissociations and Heterogeneities: A Narrative Synthesis. Neuropsychology, 37(4), 450–462. https://doi.org/10.1037/neu0000841

Hajian-Tilaki, K. (2013). Receiver Operating Characteristic (ROC) Curve Analysis for Medical Diagnostic Test Evaluation. In Caspian J Intern Med (Vol. 4, Issue 2).

Halligan, P. W., Marshall, J. C., & Wade, D. T. (1989). Visuospatial neglect: underlying factors and test sensitivity. Lancet, 2, 908–911.

Halligan, P. W., Fink, G. R., Marshall, J. C., & Vallar, G. (2003). Spatial cognition: Evidence from visual neglect. In Trends in Cognitive Sciences (Vol. 7, Issue 3, pp. 125–133). Elsevier Ltd. https://doi.org/10.1016/S1364-6613(03)00032-9

Hannaford S, Gower G, Potter JM, Guest RM, & Fairhurst MC. (2003). Assessing visual inattention: study of interrater reliability. Br. J. Therapy Rehabilitation, 10(2), 72–75.

Kim, D. Y., Ku, J., Chang, W. H., Park, T. H., Lim, J. Y., Han, K., Kim, I. Y., & Kim, S. I. (2010). Assessment of post-stroke extrapersonal neglect using a three-dimensional immersive virtual street crossing program. Acta Neurologica Scandinavica, 121(3), 171–177. https://doi.org/10.1111/j.1600-0404.2009.01194.x

Lane, A. R., Ball, K., Smith, D. T., Schenk, T., & Ellison, A. (2013). Near and far space: Understanding the neural mechanisms of spatial attention. Human Brain Mapping, 34(2), 356–366. https://doi.org/10.1002/hbm.21433

Li, K., & Malhotra, P. A. (2015). Spatial neglect. In Practical Neurology (Vol. 15, Issue 5, pp. 333–339). BMJ Publishing Group. https://doi.org/10.1136/practneurol-2015-001115

Liang, Y., Fairhurst, M. C., Guest, R. M., & Potter, J. M. (2010). A learning model for the automated assessment of hand-drawn images for visuo-spatial neglect rehabilitation. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 18(5), 560–570. https://doi.org/10.1109/TNSRE.2010.2047605

Lieberman, D., Galinsky, D., & Fried, V. (1999). Factors affecting the results of the clock drawing test in the elderly patients hospitalized for physical rehabilitation. International Journal of Geriatric Psychiatry, 14, 325–330.

Linden, A. (2006). Measuring diagnostic and predictive accuracy in disease management: An introduction to receiver operating characteristic (ROC) analysis. Journal of Evaluation in Clinical Practice, 12(2), 132–139. https://doi.org/10.1111/j.1365-2753.2005.00598.x

Lyden, P. D., & Lau, G. T. (1991). A Critical Appraisal of Stroke Evaluation and Rating Scales. Stroke, 22(11), 1345–1352. http://ahajournals.org

Menon-Nair, A., Korner-Bitensky, N., & Ogourtsova, T. (2007). Occupational therapists' identification, assessment, and treatment of unilateral spatial neglect during stroke rehabilitation in Canada. Stroke, 38(9), 2556–2562. https://doi.org/10.1161/STROKEAHA.107.484857

Mesa-Gresa, P., Lozano, J. A., Llórens, R., Alcañiz, M., Navarro, D., Noé, E., & Navarro, M. D. (2011). Clinical Validation of a Virtual Environment Test for Safe Street Crossing in the Assessment of Acquired Brain Injury Patients with and without Neglect. Human- Computer Interaction - INTERACT 2011: 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part II, 13, 44–51. https://doi.org/10.1007/978-3-642-23771

Moher, D. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews, 4, 1–9.

Moore, M. J., Milosevich, E., Mattingley, J., Demeyere, N., & Au, M. M. E. (2023). The neuroanatomy of visuospatial neglect: A systematic review and analysis of lesion-mapping methodology. Neuropsychologia, 108–470.

Moore, M. J., Vancleef, K., Shalev, N., Husain, M., & Demeyere, N. (2019). When neglect is neglected: NIHSS observational measure lacks sensitivity in identifying post-stroke unilateral neglect. In Journal of Neurology, Neurosurgery and Psychiatry (Vol. 90, Issue 9, pp. 1070–1071). BMJ Publishing Group. https://doi.org/10.1136/jnnp-2018-319668

Moore, M., Milosevich, E., Beisteiner, R., Bowen, A., Checketts, M., Demeyere, N., Fordell, H., Godefroy, O., Laczó, J., Rich, T., Williams, L., Woodward-Nutt, K., & Husain, M. (2022). Rapid screening for neglect following stroke: A systematic search and European Academy of Neurology recommendations. European Journal of Neurology, 29(9), 2596–2606. https://doi.org/10.1111/ene.15381

Munn, Z., Moola, S., Riitano, D., & Lisy, K. (2014). The development of a critical appraisal tool for use in systematic reviews addressing questions of prevalence. International Journal of Health Policy and Management, 3(3), 123–128. https://doi.org/10.15171/ijhpm.2014.71

NICE Guideline. (2023, October 18). Stroke rehabilitation in adults NG236. National Institute of Clinical Excellence.

Nijboer, T. C. W., Kollen, B. J., & Kwakkel, G. (2013). Time course of visuospatial neglect early after stroke: A longitudinal cohort study. Cortex, 49(8), 2021–2027. https://doi.org/10.1016/j.cortex.2012.11.006

Nishida, D., Mizuno, K., Tahara, M., Shindo, S., Watanabe, Y., Ebata, H., & Tsuji, T. (2021). Behavioral assessment of unilateral spatial neglect with the catherine bergego scale (CBS) using the kessler foundation neglect assessment process (KF-NAP) in patients with subacute stroke during rehabilitation in Japan. Behavioural Neurology. https://doi.org/10.1155/2021/8825192

Ogourtsova, T., Archambault, P. S., & Lamontagne, A. (2018a). Post-stroke visual neglect affects goal-directed locomotion in different perceptuo-cognitive conditions and on a wide visual spectrum. Restorative Neurology and Neuroscience, 36(3), 313–331. https://doi.org/10.3233/RNN170766

Ogourtsova, T., Archambault, P., Sangani, S., & Lamontagne, A. (2018b). Ecological Virtual Reality Evaluation of Neglect Symptoms (EVENS): Effects of Virtual Scene Complexity in the Assessment of Poststroke Unilateral Spatial Neglect. Neurorehabilitation and Neural Repair, 32(1), 46–61. https://doi.org/10.1177/1545968317751677

Ortigue, S., Mégevand, P., Perren, F., Landis, T., & Blanke, O. (2006). Double dissociation between representational personal and extrapersonal neglect. www.neurology.org

Pedroli, E., Serino, S., Cipresso, P., Pallavicini, F., & Riva, G. (2015). Assessment and rehabilitation of neglect using virtual reality: A systematic review. Frontiers in Behavioral Neuroscience, 9 (August). https://doi.org/10.3389/fnbeh.2015.00226

Perez-Marcos, D., Ronchi, R., Giroux, A., Brenet, F., Serino, A., Tadi, T., & Blanke, O. (2023). An immersive virtual reality system for ecological assessment of peripersonal and extrapersonal unilateral spatial neglect. Journal of NeuroEngineering and Rehabilitation, 20(1). https://doi.org/10.1186/s12984-023-01156-1

Plummer, P., Morris, M. E., & Dunai, J. (2003). Assessment of Unilateral Neglect. In Physical Therapy, 83(8). https://academic.oup.com/ptj/article/83/8/732/2805294

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., Britten, N., Roen, K., & Duffy, S. (2006). Guidance on the Conduct of Narrative Synthesis in Systematic Reviews A Product from the ESRC Methods Programme Peninsula Medical School, Universities of Exeter and Plymouth. Product from the ESRC Methods Programme, 1–92.

Qiang, W., Sonoda, S., Suzuki, M., Okamoto, S., & Saitoh, E. (2005). Reliability and validity of a wheelchair collision test for screening behavioral assessment of unilateral neglect after stroke. American Journal of Physical Medicine and Rehabilitation, 84(3), 161–166. https://doi.org/10.1097/01.PHM.0000154902.79990.12

Rode, G., Fourtassi, M., Pagliari, C., Pisella, L., & Rossetti, Y. (2017). Complexity vs. unity in unilateral spatial neglect. In Revue Neurologique (Vol. 173, Issues 7–8, pp. 440–450). Elsevier Masson SAS. https://doi.org/10.1016/j.neurol.2017.07.010

Rutjes, A. W. S. Reitsma, J. B., Coomarasamy, A., Khan, K. S., & Bossuyt, P. M. M. (2007). Evaluation of diagnostic tests when there is no gold standard: A review of methods. . Health Technology Assessment, 11(50).

Serino, A., Bonifazi, S., Pierfederici, L., & Làdavas, E. (2007). Neglect treatment by prism adaptation: What recovers and for how long. Neuropsychological Rehabilitation, 17(6), 657–687. https://doi.org/10.1080/09602010601052006

Souza, A. C. de, Alexandre, N. M. C., & Guirardello, E. de B. (2017). Propriedades psicométricas na avaliação de instrumentos: avaliação da confiabilidade e da validade. Epidemiologia e Servicos de Saude: Revista Do Sistema Unico de Saude Do Brasil, 26(3), 649–659. https://doi.org/10.5123/S1679-49742017000300022

Spaccavento, S., Cellamare, F., Falcone, R., Loverre, A., & Nardulli, R. (2017). Effect of subtypes of neglect on functional outcome in stroke patients. Annals of Physical and Rehabilitation Medicine, 60(6), 376–381. https://doi.org/10.1016/j.rehab.2017.07.245

Spreij, L. A., Ten Brink, A. F., Visser-Meily, J. M. A., & Nijboer, T. C. W. (2020). Simulated driving: The added value of dynamic testing in the assessment of visuo-spatial neglect after stroke. Journal of Neuropsychology, 14(1), 28–45. https://doi.org/10.1111/jnp.12172

Stone, S. P., Wilson, B., Wroot, A., Halligan, P. W., Lange, L. S., Marshall, J. C., Greenwood, R. J., & Bartholomew, S. (1991). The assessment of visuo-spatial neglect after acute stroke. In Neurosurgery, and Psychiatry (Vol. 54).

Thomasson, M., Perez-Marcos, D., Crottaz-Herbette, S., Brenet, F., Saj, A., Bernati, T., Serino, A., Tadi, T., Blanke, O., & Ronchi, R. (2023). An immersive virtual reality tool for assessing left and right unilateral spatial neglect. Journal of Neuropsychology. https://doi.org/10.1111/jnp.12361

Ting, D. S. J., Pollock, A., Dutton, G. N., Doubal, F. N., Ting, D. S. W., Thompson, M., & Dhillon, B. (2011). Visual Neglect Following Stroke: Current Concepts and Future Focus. In Survey of Ophthalmology, 56(2)114–134. https://doi.org/10.1016/j.survophthal.2010.08.001

Van Der Stoep, N., Visser-Meily, J. M. A., Kappelle, L. J., De Kort, P. L. M., Huisman, K. D., Eijsackers, A. L. H., Kouwenhoven, M., Van Der Stigchel, S., & Nijboer, T. C. W. (2013). Exploring near and far regions of space: Distance-specific visuospatial neglect after stroke. Journal of Clinical and Experimental Neuropsychology, 35(8), 799–811. https://doi.org/10.1080/13803395.2013.824555

Van Kessel, M. E., Van Nes, I. J., Brouwer, W. H., Geurts, A. C., & Fasotti, L. (2010). Visuospatial asymmetry and non-spatial attention in subacute stroke patients with and without neglect. Cortex, 46(6), 602–612.

Van Kessel, M. E., van Nes, I. J., Geurts, A. C., Brouwer, W. H., & Fasotti, L. (2013). Visuospatial asymmetry in dual-task performance after subacute stroke. Journal of Neuropsychology, 7(1), 72–90.

Villarreal, S., Linnavuo, M., Sepponen, R., Vuori, O., Bonato, M., Jokinen, H., & Hietanen, M. (2021). Unilateral stroke: Computer-based assessment uncovers non-lateralized and contralesional visuoattentive deficits. Journal of the International Neuropsychological Society, 27(10), 959–969. https://doi.org/10.1017/S1355617720001393

Villarreal, S., Linnavuo, M., Sepponen, R., Vuori, O., Jokinen, H., & Hietanen, M. (2020). Dual-Task in Large Perceptual Space Reveals Subclinical Hemispatial Neglect. Journal of the International Neuropsychological Society, 26(10), 993–1005. https://doi.org/10.1017/S1355617720000508

Whitehouse, C. E., Green, J., Giles, S. M., Rahman, R., Coolican, J., & Eskes, G. A. (2019). Development of the Halifax Visual Scanning Test: A New Measure of Visual-Spatial Neglect for Personal, Peripersonal, and Extrapersonal Space. Journal of the International Neuropsychological Society, 25(5), 490–500. https://doi.org/10.1017/S135561771900002X

Whiting, P., Rutjes, A., Westwood, M., Mallett, S., Leeflang, M., Reitsma, H., Deeks, J., Sterne, J., & Bossuyt, P. (2014). Updating QUADAS: Evidence to inform the development of QUADAS-2. http:// www.bristol.ac.uk/quadas/resources/quadas2report v4.pdf.

Williams, L. J., Kernot, J., Hillier, S. L., & Loetscher, T. (2021). Spatial Neglect Subtypes, Definitions and Assessment Tools: A Scoping Review. Frontiers in Neurology, 12. https://doi.org/10.3389/fneur.2021.742365

Zoccolotti, P., & Antonucci, G. (1992). Psychometric Characteristics of Two Semi-Structured Scales for the Functional Evaluation of Hemi-inattention in Extrapersonal and Personal Space. Neuropsychological Rehabilitation, 2(3), 179–191.

Zoccolotti, P., & Judica, A. (1991). Functional Evaluation of Hemineglect by Means of a Semistructured Scale: Personal Extrapersonal Differentiation. Neuropsychological Rehabilitation, 1(1), 33–44. https://doi.org/10.1080/09602019108401378

Chapter 3: Bridging Chapter

The systematic review outlined in Chapter 2, highlights the need for more robust, diagnostic validation studies for extrapersonal spatial neglect tools. It noted the need and clinical utility of future validation studies in this area evaluating multiple psychometric properties, to give clinicians a holistic understanding of a diagnostic test's psychometric properties. The Neurolab team have been developing a novel Computerised Extrapersonal Neglect Test (CENT), and the empirical paper that follows in Chapter 4 investigates a range of psychometric properties for the CENT to further progress and give a meaningful addition to this field of clinical research.

Chapter 4: Empirical Paper

Diagnostic Validation of the Computerised Extrapersonal Neglect Test (CENT) in Stroke Survivors

Petar Stermsek[1], Helen Morse[2], Catherine E. L. Ford[1], Andreas Michaelides[1], Stephanie Rossit[2]

[1]Faculty of Medical and Health Sciences, University of East Anglia, UK

[2]Faculty of Psychology, University of East Anglia, UK

Abstract word count: 213

Manuscript word count: 8,387

This work was supported by the Stroke Association.

Disclaimer: this manuscript has been formatted for submission to Cortex. In accordance with this guidance, there is no defined word limit. Please see the publication guidance: https://www.sciencedirect.com/journal/cortex/publish/guide-for-authors.

Abstract

Background: Emerging research has identified Extrapersonal spatial neglect as one of the subtypes of spatial neglect syndrome. Current widely used formal diagnostic tests for spatial neglect generally focus on spatial neglect in the peripersonal space. This may be leaving individuals with extrapersonal spatial neglect undiagnosed. The diagnostic validation of novel extrapersonal spatial neglect tests may help bridge this gap.

Aims: To explore the psychometric properties of the Computerised Extrapersonal Neglect Test (CENT) - a novel spatial neglect diagnostic test assessing spatial neglect outside of arm's reach, using a laptop and a television screen.

Methods: A sample consisting of 73 stroke survivors (29 with spatial neglect and 44 without spatial neglect) completed the CENT, as well as a series of comparator tests and self-report measures (e.g. BIT cancellation subtest, Oxford Cognitive Scale, Stroke Impact Scale) to evaluate the psychometric properties of the CENT.

Results: The CENT cancellation subtest demonstrated excellent diagnostic accuracy and high concurrent validity, discriminant validity, ecological validity, and internal consistency. This study found 11% of stroke survivors as having extrapersonal neglect only.

Conclusion: This study concludes that the CENT appears to have promising psychometric properties. Moreover, this study underscores the importance of formal extrapersonal spatial neglect testing, as potentially one in ten stroke survivors may be being overlooked without proper diagnosis.

Keywords: Stroke; Validation; Diagnostic Accuracy; Extrapersonal Spatial Neglect; Computerized.

Highlights:

- CENT Cancellation task demonstrated excellent diagnostic accuracy.
- CENT demonstrated a wide range of promising psychometric properties
- 11% of stroke survivors demonstrated extrapersonal spatial neglect only.
- Clinicians relying on pen-and-paper tests may not be capturing extrapersonal spatial neglect
- CENT can be administered effectively within service users' homes.

1. Introduction

Stroke, a cerebrovascular event characterised by the sudden disruption of blood flow to the brain, is the third leading cause of disability worldwide (Feigin, Brainin, Norrving, Martins, Sacco, Hacke, Fisher, Pandian & Lindsay, 2022). Approximately 20% of strokes are caused by a cerebral haemorrhage, and 80% are ischaemic events (Markus, 2008). Following a stroke, individuals are often left grappling with an array of cognitive and perceptual challenges, with approximately half of stroke survivors being left with impairments in 6-10 separate domains of disability (Lawrence, Coshall, Dundas, Stewart, Rudd, Howard, Charles & Wolfe, 2001). Spatial neglect is a common consequence of stroke in both acute and long-term stages of stroke recovery (Farne, Buxbaum, Ferraro, Frassinetti, Whyte, Veramonti, Angeli, Coslett & Ladavas, 2004), with approximately 30% of individuals meeting diagnostic criteria (Esposito, Shekhtman & Chen, 2021). Spatial neglect is defined as a diminished ability to attend to and respond to stimuli presented in an individual's contralesional side (Corbetta, Kincade, Lewis, Snyder & Sapir, 2005). Spatial neglect most commonly occurs in individuals who have experienced strokes in the right hemisphere, but it can also occur in individuals with left hemisphere lesions (Bowen, Mckenna & Tallis, 1999; Beis, Keller, Morin, Bartolomeo, Bernati, Chokron, Leclercq, Louis-Dreyfus, Marchal, Martin, Perennou, Pradat-Diehl, Prairial, Rode, Rousseaux Samuel, Sieroff, Wiart & Azouvi, 2004).

Spatial neglect is also associated with a range of poor prognostic factors when compared with stroke survivors without spatial neglect, such as greater risk of falling (Ugur, Gücüyener, Uzuner, Özkan & Özdemir, 2000; Wee & Hopman, 2008; Chen, Hreha, Kong & Barrett, 2015), longer lengths of stay in hospital (Hammerbeck, Gittins, Vail, Paley, Tyson & Bowen, 2019) and an increased likelihood to be discharged to a nursing setting rather than be discharged home (Wee & Hopman, 2008). Moreover, spatial neglect is associated with increased carer burden (Bosma, Nijboer, Caljouw, Achterberg, 2020; Chen, Fyffe & Hreha, 2017) and the severity of neglect symptoms predicts scores on the family burden questionnaire more accurately than the number of lesioned cerebral regions did (Buxbaum, Ferraro, Veramonti, Farne, Whyte, Ladavas, Frassinetti & Coslett, 2004).

As research on spatial neglect has developed, so has our understanding of its diagnostic features and different presentations. Spatial neglect can occur for different types of stimuli, including visual, auditory, tactile, or mental representation (Rode, Pagliari, Huchon, Rossetti & Pisella, 2017). Many stroke-survivors experience deficits in more than one of these areas (Demeyere & Gillebert, 2019). It is now generally accepted that there are multiple subtypes of spatial neglect. Within the visual domain, these including allocentric, egocentric, personal, peripersonal and extrapersonal neglect (Rode, 2017).

Certain individuals may exhibit more pronounced neglect in far-space (extrapersonal neglect) compared to near-space, as some studies have highlighted (Cowey, Small & Ellis, 1998; Pitzalis, Russo, Spinelli & Zoccolotti, 2001; Butler, Eskes & Vandorpe, 2004; Keller, Schindler, Kerkhoff, Rosen & Golz, 2005). Conversely, some studies present contrasting findings (Halligan & Marshall, 1991; Berti & Frassinetti, 2000; Butler et al., 2004; Aimola, Shindler, Simone & Venneri, 2012). This underscores the importance of the separate clinical screening of spatial neglect in near-space and far-space.

Spatial neglect is thought to be associated with multiple neuroanatomical areas. A recent systematic review of 34 lesion-symptom mapping studies found very few studies (n = 2) have pinpointed neuroanatomical areas associated with peripersonal and extrapersonal neglect and further investigation is required (Moore, Milosevich, Mattingley, Demeyere & Au, 2023). Several studies have found separate and distinct cerebral areas associated with egocentric and allocentric neglect. One of the leading theories regarding the neuroanatomical areas thought to be associated with spatial neglect is the two-stream hypothesis (Goodale & Milner, 1992). This posits that the dorsal stream has a preferential bias for processing of near space visual information for action guidance and the ventral stream has a preferential bias for processing of far space visual information for object identification and interaction (Lane, Ball, Smith, Schenk & Ellison, 2013). Therefore, allocentric attention may be associated with the ventral stream, considering it relates to the object frame of reference and egocentric neglect may be associated with the dorsal stream, as it relates to action guidance in the near space (Possin, 2010).

In terms of subtype prevalence, Spaccavento, Cellamare, Falcone, Loverre and Nardulli (2017) found 69% of stroke survivors exhibited extrapersonal neglect, frequently alongside other neglect types, while 11% displayed only extrapersonal neglect. Similarly, Aimola et al., (2012) and Van der Stoep, Visser-Meily, Kappelle, De Kort, Huisman, Eijsackers, Kouwenhoven, Van Der Stigchel and Nijboer (2013) observed that as many as 25% of stroke survivors tested exhibited exclusively extrapersonal neglect. Moreover, Demeyere & Gillebert (2019) found 50% of neglect patients had egocentric neglect only and 25% had allocentric neglect only.

Given the prevalence and impact of spatial neglect on daily living post-stroke, clinicians and academics have been developing diagnostic tests for measuring spatial neglect for many years. However, as our understanding of this enigmatic condition has broadened into multiple subtypes, so too has our realisation that many of our most popular tests are only measuring some aspects of spatial neglect, and certain forms of spatial neglect are not effectively detected. A recent international multidisciplinary survey reported that 82% of clinicians use cognitive tests (i.e., cancellation and drawing tasks) to detect spatial neglect (Checketts, Mancuso, Fordell, Chen, Hreha, Eskes, Vuilleumier, Vail & Bowen, 2020). However, standardised pen-and-paper tests (and even tablet-based tasks; Demeyere, Haupt, Webb, Strobel, Milosevich, Moore, Wright, Finke & Duta, 2021), by virtue of them being conducted within arm's-reach, do not effectively capture extrapersonal spatial neglect deficits (Appelros, Nydevik, Karlsson, Thorwalls & Seiger, 2003), leading to extrapersonal neglect rarely being assessed in current clinical practice (Guilbert, 2022).

Two very common types of spatial neglect test are Cancellation tasks and Line Bisection tasks. Cancellation tasks require individuals to identify targets presented among a series of distractor stimuli, which increases attentional demand and consequently test sensitivity (Ferber & Karnath, 2001; Husain, Shapiro, Martin & Kennard, 1997; Kartsounis & Findley, 1994). Another common type of spatial neglect test are Line Bisection tasks - requiring individuals to judge the midpoint of horizontal lines presented in either to their left, in the centre or to the right with respect to their body midline. Cancellation tasks are considered the most sensitive (Ferber & Karnath, 2001) type of cognitive spatial neglect test, and have good test-retest reliability (Bailey, Riddoch & Crome, 2004).

Several researchers have suggested that variations in performance on diagnostic tests may be due to differing task requirements (allocentric versus egocentric tasks) rather than only the distance involved (Berti & Frassinetti, 2000; Ackroyd, Riddoch, Humphreys, Nightingale & Townsend, 2002; Aimola et al., 2012; Lane, Ball & Ellison, 2015). It is argued that Line Bisection tasks necessitate an allocentric frame of reference because they entail judging the distance from one half of a line to the other (Rorden, Berger & Karnath, 2006; Chechlacz, Rotshein, Bickerton, Hansen, Deb & Humphreys, 2010; Karnath & Rorden, 2012). On the other hand, Cancellation tasks require an egocentric frame of reference as they involve locating objects relative to the person performing the task (Rorden et al., 2006; Chechlacz et al., 2010; Karnath & Rorden, 2012). Consequently, spatial neglect is typically assessed within either allocentric or egocentric frameworks and only within near space, potentially leading to significant underdiagnosis (Puig-Pijoan, Giralt-Steinhauer, Zabalza de Torres, Manero Borras, Sanchez-Benavides, Garcia Escobar, Perez Enriquez, Gomez-Gonzalez, Ois, Rodriguez-Campello, Cuadrado-Godia, Jimenez-Conde, Pena-Casanova & Roquer, 2018; Van Den Stoep et al., 2013).

To bridge the gap in our ability to measure neglect effectively, experts have been increasingly utilising technology such as projectors, virtual reality, and computer programmes in their development. This is particularly seen in novel extrapersonal spatial neglect diagnostic tests (Kim, Ku, Chang, Park, Lim, Han, Kim & Kim, 2010; Mesa-Gresa, Lozano, Llorens, Alcaniz, Navarro, Noe & Navarro, 2011; Buxbaum, Dawson & Linsley, 2012; Aravind, Darekar, Fung & Lamontagne, 2015; Ogourtsova, Archambault, Sangani & Lamontagne, 2018; Spreij, Ten Brink, Visser-Meily & Nijboer, 2020). Aside from permitting individuals to interact with stimuli in the far-space, computerised tests can have a range of additional benefits when it comes to diagnostic testing. For example, automatic scoring and millisecond precision could reduce the chance of human error and clinical resource consumption (Liang, Fairhurst, Guest & Potter, 2010; Hannaford, Gower, Potter, Guest & Fairhurst, 2003; Gauthier, Dehaut, & Joanette, 1989; Stone, Wilson, Wroot, Halligan, Lange, Marshall, Greenwood & Bartholomew, 1991). Furthermore, currently, in the UK, computer equipment is easily accessible in most settings and computerised testing may limit the extent to which individuals can use compensatory strategies (Giannakou, Lin & Punt, 2022), as for example, it is more difficult for a participant to move a monitor or projection than it is a piece of paper placed in front of them.

However, overall, these novel tests of extrapersonal spatial neglect had notable limitations in terms of methodology and reporting (Stermsek et al., unpublished manuscript). Aravind et al. (2015) for example had a stroke survivor sample of 12, all with spatial neglect, which is a substantial limitation given the large amount of symptom variability found among stroke-survivors. Mesa-Gresa et al.'s (2011) sample of 25 included other neurological conditions such as brain tumours. Moreover, there needs to be more consistency in how validation studies analyse and report diagnostic accuracy as very few of these novel tests analyse and report their findings in way that clinicians can easily compare them with each other. There is a need therefore for novel tests of extrapersonal spatial neglect to produce high quality, methodologically rigorous diagnostic validation studies moving forward.

The Neurolab team at the University of East Anglia have developed the Computerised Extrapersonal Neglect Test (CENT). This test can be conducted at home or within a clinical setting. It comprises of a cancellation task, and line bisection task, presented in the far-space (extrapersonal space). Given its design, it may be able to detect multiple forms of neglect (allocentric, egocentric and extrapersonal). Research has yet to explore how this approach to testing compares to the currently used pen-and-paper diagnostic reference tests such as the Behavioural Inattention Test (BIT). Morse, Jolly, Browning, Clark, Pomeroy and Rossit (2023) have explored performance on the CENT across different age ranges among healthy adults, but CENT has yet to be tested and validated on stroke-survivor populations.

This study aims to evaluate the psychometric properties of CENT, namely, its diagnostic accuracy, concurrent validity, discriminant validity, internal consistency and ecological validity when administered to stroke-survivors in their homes.

2. Methodology

2.1. Design

A cross-sectional diagnostic validation study design was used to validate the CENT with stroke survivors as part of a wider Stroke Association funded multi-centre, mixed-methods two-arm feasibility randomised controlled trial (RCT), named the C-Sight trial.

2.2 Participants

A sample of 93 stroke survivors (46 with spatial neglect and 46 without spatial neglect) were recruited from the following National Health Service (NHS) Trusts: Norfolk Community Health and Care NHS Trust, Norwich (Lead site); Norfolk and Norwich University Hospitals NHS Foundation trust, Norwich; East Coast Community Healthcare, Lowestoft; Cambridge University Hospitals NHS Foundation Trust, Cambridge. A total sample of 73 participants completed this validation study, with

20 participants not included in the analysis as they were unable to complete the CENT. See figure 1 for sample flow chart.

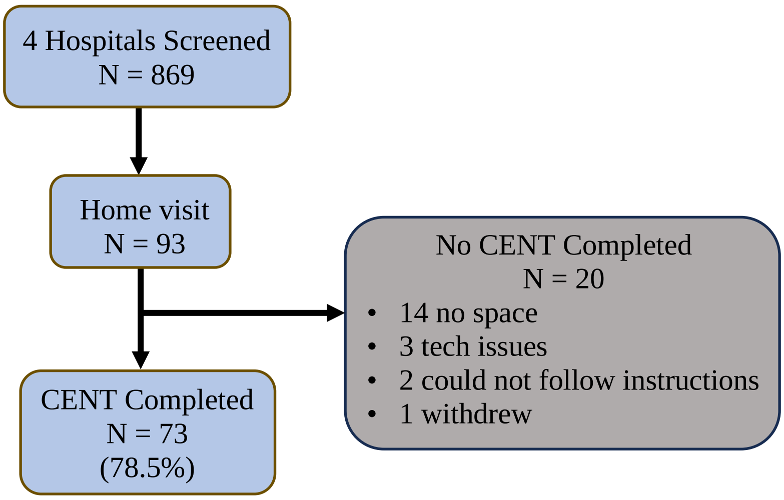


Figure 1. CENT Validation Sample Flow Chart

Stroke survivors taking part in this project met all eligibility criteria required for the wider trial to participate in the study (see table 1 for inclusion and exclusion criteria)

Table 1. Inclusion and exclusion criteria for C-Sight Trial

Inclusion Criteria	Exclusion Criteria
18 years and older	History of other neurological conditions
Stroke confirmed using clinical neuroimaging	Bilateral impairment in arms
Medically stable (as confirmed by the stroke service medical team responsible for the individual's stroke care)	Taking part in another stroke rehabilitation intervention trial
Capacity to give informed consent to participate with no concerns about this raised by the stroke team involved	
Able to follow and execute a two-step command (e.g. "lift and balance this pen/pencil")	
Live within 70 miles of the University of East Anglia	

After identified as eligible by NHS staff in recruiting sites, participants were invited to take part in the trial and given information sheets and consent forms (see Appendix E and F). As this research was part of a larger clinical trial, the consent forms and information sheets cover more than is required for the current study which concerned only the assessment stage of the trial.

If eligible participants had been discharged home before the team was able to approach them to take part, a home invitation letter with an information sheet and notification of interest was sent to them. If they return a signed notification of interested (in the pre-paid envelope), they were included. If no response was received within two weeks, the team attempted to contact the participant once to check interest and answer any pending questions. A planned recruitment rate of four stroke survivors per month over 24 months was estimated. The recruitment phase of the study was between February 2021 and August 2023.

The target sample size for this study was 92 stroke survivors. This number was determined for the intervention part of the wider feasibility study. Originally the sample size was determined based on Rossit, Benwell, Szymanek, Learmonth, McKernan-Ward, Corrigan, Muir, Reeves, Duncan, Birschel, Roberts, Livingstone, Jackson, Castle & Harvey (2019), suggesting a small to moderate effect size. However, the methodology in the aforementioned paper was not computerised, so it was difficult to estimate the sample size required. Upon reflection, the research team agreed to aim for 92 stroke survivors, but not have a formal sample size calculation as this is not recommended for feasibility studies (Lancaster, Dodd & Williamson, 2004) due to their focus on retention rates and adherence which inform future full trials. A sample size of 92 is above what is typical of validation studies in this field, as the combined mean sample size of a recent systematic review on validation studies for extrapersonal spatial neglect was 50.82 (Stermsek et al., unpublished manuscript). Inclusion criteria for the c-sight trial (ClinicalTrials.gov Identifier: NCT04752982) required stroke survivors in the spatial neglect group to show impairment on at least one of the following tests for neglect:

- BIT Star cancellation (cut off < 51; Wilson, Cockburn & Halligan, 1987)
- OCS Broken Hearts overall accuracy (cut-off < 42; Demeyere, Riddoch, Slavkova, Bickerton & Humphreys, 2015)
- OCS Egocentric neglect score (cut-off < -2, > 3; Demeyere et al., 2015)
- OCS Allocentric neglect score (cut-off < -1, > 1; Demeyere et al., 2015)
- Line bisection deviation (cut off > 6mm average)

2.3. Apparatus

2.3.1. CENT

The CENT (programmed by Unity Technologies and developed in collaboration with Evolv Rehabilitation Technologies) was run on a laptop (OMEN by HP 15-dc0003) and connected to the participant's home television. The participants were given a wireless HTC Vive controller to interact with the programme (a computer mouse is also compatible). The responses were recorded using a HTC Vive Base Station placed underneath the television and in line with the centre of the participants body. The Controller and base station were both connected to the laptop using a Steam wireless dongle. An A4 sheet of paper was used to calibrate the size of the test stimuli to ensure stimuli size consistency across screens. In instances where participants did not have a television measuring 40" or larger, a projector accompanied by a projector screen and mount was assembled in the participant's home. A tripod was used to mount the base station in front of the TV/Screen, should there not be room on the participant's TV stand.

2.3.2. Pen-and-Paper Tests

Printed and laminated administration materials for the Oxford Cognitive Screen (OCS) were used. All other pen-and-paper tests were printed on A4 paper for participants to complete.

2.4. Measures

2.4.1. Computerised Extrapersonal Neglect Test (CENT)

The Computerised Extrapersonal Neglect Test (CENT) is the primary measure for this validation study. It is projected onto a wall or TV out of reach (Morse, Jolly, Pomeroy, Biggart & Rossit, 2019a; 2019b). It comprises two tasks: a cancellation task where participants look for images of mugs amongst different distractor images; and a line bisection task where participants must indicate the exact midpoint of different lines (presented individually) using a handheld controller/mouse. Test duration is approximately 10 minutes.

The three comparator measures were widely used pen-and-paper clinical diagnostic tests for spatial neglect. These have been selected as they are the most commonly used measures for spatial neglect utilised by stroke services in the UK (Checketts et al., 2020). In addition, the Stroke Impact Scale, One-Item Extended Test, and remaining subtests of the Oxford Cognitive Scale were administered as a self-report measure of activities of daily living, measure of personal neglect, and measure of other cognitive domains and visual field deficit, respectively. The following measures were collected:

2.4.2. Star Cancellation Test (Behavioural Inattention Test - BIT)

A pen and paper assessment task taken from the BIT battery, used for measuring spatial neglect (Wilson, Cockburn & Halligan, 1981). Participants look for images of stars amongst different distractor images. The test duration is approximately 5 minutes and has good reliability (interrater, parallel form and test-retest reliability; $r = 0.99, 0.91, 0.99$, respectively, $p < 0.001$) and validity (concurrent, $r = 0.92$, $p < 0.001$; predictive validity, $r = 0.67$, $p < 0.001$; Wilson et al., 1987; Halligan, Cockburn & Wilson, 1991) in stroke. It is also reported to have a relative sensitivity of 76.4% in elderly stroke patients (Bailey, Riddoch & Crome, 2000)

2.3.3. Line Bisection Task

A pen and paper assessment used for measuring spatial neglect (Rossit, et al., 2019). Participants must determine and mark the exact mid-point of different lines. Test duration is approximately two minutes. It was reported to have a sensitivity of 76.4% in elderly stroke patients

(Bailey et al., 2000). It was also reported to have excellent test-retest reliability in elderly stroke patients, ranging from r = 0.84 to r = 0.93 (Schenkenberg, Bradford & Ajax, 1980; Sea & Henderson, 1994).

2.4.4. Oxford Cognitive Screen (OCS)

A short cognitive battery used to assess spatial neglect, as well as the following broader cognitive domains: Memory, Language, Number, Praxis, Executive Functioning, Attention and Vision (Demeyere et al., 2015). The OCS was designed to be aphasia-friendly and neglect-friendly (minimising the extent to which these specific difficulties confound the measurement of other cognitive functions) and can differentiate between allocentric and egocentric neglect (Demeyere et al., 2015). It also contains a visual field deficit subtest. Test duration is approximately 15 to 20 minutes. The broken hearts subtest of the OCS was reported to have high sensitivity – 94.12% and good test-retest reliability (Intraclass Correlation = 0.73; Positive Predictive Value 75%; Negative Predictive Value 77.78%; Demeyere et al., 2015).

2.4.5. Spatial Neglect Visual Analogue Rating Scale

A single question self-rated scale where participants are asked to mark on a vertical line their perceived severity of spatial neglect. Test duration is less than 2 minutes. This was used as a self-report measure of neglect severity and anosognosia and is based on a similar scale by Ronchi, Bassolino, Viceic, Bellmann, Vuadens, Blanke and Vallar (2020).

2.4.6. Stroke Impact Scale

A self-report questionnaire covering eight unique domains of post-stroke functioning, quality of life and recovery (Strength, Hand Function, Activities of Daily Living, Mobility, Communication, Emotion, Memory and Thinking and Participation). Originally developed by Duncan, Lai, Bode, Perera, & DeRosa (2003), it has also demonstrated excellent internal consistency and test-retest reliability ranging between 0.79 and 0.98 (Vellone, Savini, Fida, Dickson, Melkus, Carod-Artal, Rocco & Alvaro, 2015).

2.4.7. One-item Extended Test

The One-item Extended Test is a measure of personal neglect (Fortis, Maravita, Gallucci, Ronchi, Grassi, Senna, Olgiati, Perucca, Banco, Posteraro, Tesio & Vallar, 2010). Participants are asked to reach six left-sided body parts (ear, shoulder, elbow, wrist, waist, knee), using their right hand. Points are given for immediate reaching, with hesitation scoring less points. This was selected as it was quick to administer and did not involve physical contact, so was appropriate for a trial conducted during COVID-19.

2.5. Procedure

Following recruitment and the consenting process, participants were asked to complete the Star Cancellation Task (BIT) by the clinical research team/local staff immediately prior to discharge. Following this, they were allocated into groups (stroke survivors with spatial neglect and stroke survivors without spatial neglect). The researcher then organised to visit the participants in their homes for approximately 1.5hrs (participants had the option of splitting this into shorter sessions if required). During the visit, all participants completed an assessment battery of tests outlined in the measures section. Excluding the CENT, these tests were all pen-and-paper assessments/questionnaires. All testing was completed under test conditions (minimal sound and distractions and no support from others) in the participant's home. A fold out table was made available for pen-and-paper test completion should the participant not have a table.

For the CENT, participants were seated in their homes, at least 170cm away from their television, positioned so their midsagittal line was aligned with the television. Participants were given a wireless HTC Vive controller to complete the computerised tasks.

During the cancellation task, participants were instructed to locate and click on 50 targets (complete mugs; figure 2a) both small (220mm x 220mm) and large (280mm x 280mm), amongst 100 distractor stimuli (50 mugs are incomplete on left side; 50 mugs are incomplete on right side; figure 2b). The cancellation targets were all presented simultaneously on the same screen (figure 2c). The stimuli were evenly distributed within a grid of ten cells (figure 2d; each cell contained five target stimuli, five left side incomplete, five right side incomplete). The cursor in this task resembled a blue "bullseye" symbol. Participants heard a "popping" sound, and a short diagonal line covered the target upon clicking to indicate a registered response. Prior to the test beginning, participants completed a simplified practice cancellation trial (12 targets and 12 distractors) to ensure they understood the task and how to use the equipment.

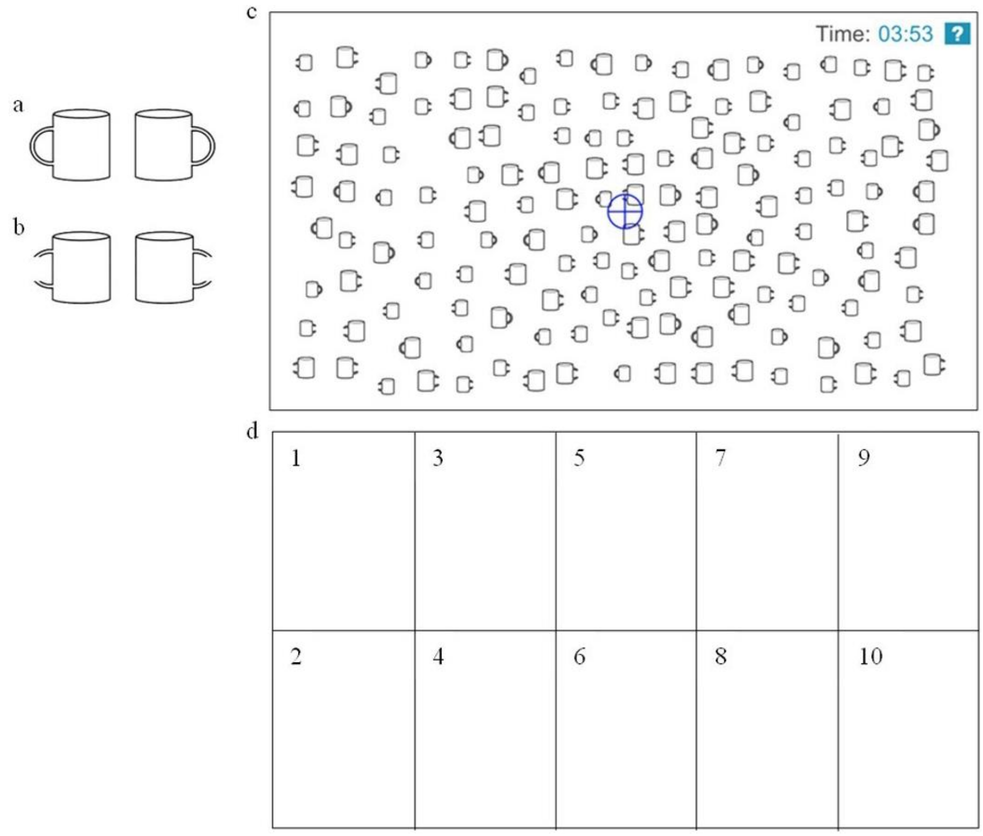


Figure 2. CENT broken mugs cancellation task example. a. Cancellation task target stimuli; b. distractor stimuli; c. task display; d. grid used to position stimuli (boxes 1-4 indicate left; 5-6 middle; 7-10 right side of the display.

During the line bisection task, participants were instructed to locate and click on the centre point on ten lines (604mm length x 50mm thickness), presented one at a time (figure 3). Throughout the exercise, two lines were positioned in the middle of the screen, four on the left-hand side of the midline and four on the right. Given the complexity of the task, the line bisection task had no practice trial, in common with many neuropsychological assessments (Ferber & Karnath, 2001; Lezak, 2004; Wilson et al., 1987)

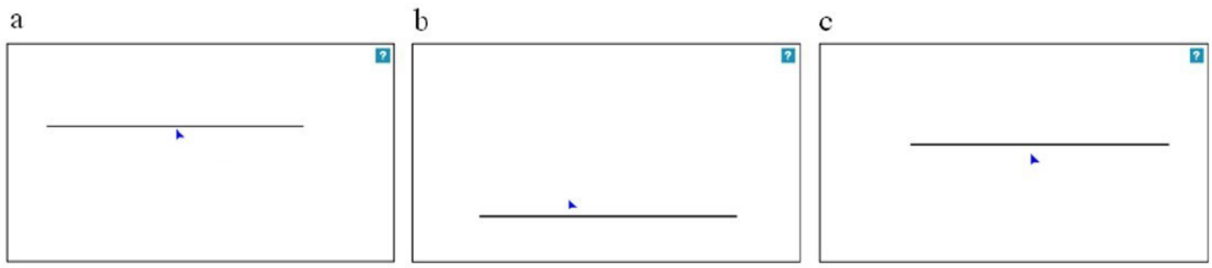


Figure 3. CENT Line Bisection task example (Lines presented on a. left; b. middle; c. right)

Before both tasks and the cancellation trial, participants received written instructions on the screen accompanied by a voice reading the instructions. The instructions were the same for the cancellation task and practice trial. Neither task had a time limit, and participants were instructed to inform the experimenter when the cancellation task was finished. The line bisection task was programmed to finish after a response is registered for the final line.

Following the completion of all the tests, depending on test performance, the participants were grouped into either the “spatial neglect” or “no spatial neglect” group. Those that gave consent to take part in the wider trial, were then randomised and entered the intervention stage of the wider clinical trial (testing a novel spatial neglect intervention). When participants finished their participation in the wider trial, they were debriefed and had an opportunity to ask any questions.

The following variables were recorded and extracted during the pen-and-paper assessment: accuracy (total number of targets cancelled), line bisection error (% left/right deviation from true centre), egocentric score (asymmetry score between the number of targets found on left versus right side of the screen) and allocentric score (asymmetry score between left-gap and right-gap distractors cancelled). The variables that were recorded and extracted from the CENT can be seen in table 2 (variables from Morse et al., 2023). One of the benefits of the CENT is that it progresses data collection and scoring when compared to pen-and-paper assessments, as it automatically provides quantitative outputs, and where a given participant scores in relation to the clinical thresholds of the test. These outputs and automatic scoring reduce clinical time spent on scoring and aide interpretation. Moreover, the programme also calculates a heatmap of the participants cursor activity, which is also clinically useful when feeding back test results to service users.

Table 2. CENT Variables

Variable	Description
Accuracy	Total number of targets cancelled. Max score 50
Errors	Total number of distractors cancelled. Max score 100.
Intersections	Number of times cancellation path crosses over itself
Re-cancellations	Cancellation of target already cancelled (e.g. perseverations)
Search duration	Total time (secs) taken in cancellation task
Quality of search	Search speed and accuracy summarised as a single score (Q score) using number of targets cancelled, total number of targets and total task duration. High scores indicate high number of targets detected and high cancellation speed. Formula available in CancellationTools (Dalmaijer et al., 2015).
Egocentric score	Measure of bias in finding targets across the screen (space neglect). Calculated by subtracting number of targets cancelled on left of the screen from number of targets cancelled on right. Positive value represents more targets cancelled on left side, indicating right egocentric neglect. Negative value represents more targets cancelled on right side, indicating left egocentric neglect.
Allocentric score	Bias in cancelling distractors with a gap on left or right side (object neglect). Calculated by subtracting number of left-gap distractors by number of right-gap distractors. Positive value represents more right-gap distractors cancelled, indicating right object centred neglect. Negative value represents more left-gap distractors cancelled, indicating left object centred neglect.
Line bisection error	Deviation (%) from true centre when judging the middle of ten lines on screen.
Total line bisection duration	Total response time (secs) taken in line bisection task (10 lines)

Regarding my unique contribution to this project, I organised and completed the pre, post, and follow up visits for eight participants whose data was used in the final analysis. Other trial responsibilities included liaising with participating hospitals, administration tasks for the trial, inputting and analysing the data and disseminating this work at the annual UK Stroke Forum.

2.6. Analysis

Differences between the three groups (with spatial neglect, without spatial neglect, and healthy controls) on demographic variables (age, gender, years of education etc) were statistically evaluated using a one-way analysis of variance (ANOVA). Bonferroni post-hoc corrections were applied to account for multiple comparisons. Then, CENT variables as well as comparator test variables were statistically evaluated using a non-parametric Spearman's rank correlations. Non-parametric tests were used as several variables were not normally distributed. Bonferroni post-hoc correlations were again applied to account for multiple comparisons. Strong correlations have values between ±0.7-1, moderate correlations ±0.3-0.7 and weak correlations are ±0-0.3 (Akoglu, 2018)

The diagnostic accuracy of the CENT in correctly classifying individuals with extrapersonal, allocentric and egocentric spatial neglect was investigated using receiver-operating characteristic (ROC) curve analysis. Diagnostic test accuracy is determined by the sensitivity and specificity it has at a chosen point that identifies a 'case' or a 'non-case'. Specificity is the proportion of true negatives (non-cases) correctly detected by the test and sensitivity is the proportion of true positives (cases) correctly detected by the test. ROC analyses facilitate the plotting of sensitivity and specificity and help inform possible cut-offs and visualise a test's ability to detect a condition. An ROC analysis was chosen for this study as it plots the test's accuracy for different thresholds and provides a clear, interpretable graphical visualisation of all the different cutoffs and their corresponding accuracy (Akobeng, 2006). ROC analyses therefore facilitate a more holistic understanding of a given test's overall diagnostic sensitivity and specificity, reducing the influence of chance that may occur when focusing on a single threshold (Eusebi, 2013). In addition to the ROC, an Area Under the Curve (AUC) statistic can be computed. The AUC serves as a single measure, that summarises the discriminative ability of the test across the cutoffs and presenting both the AUC and ROC together is considered best practice and the most informative (Eusebi, 2013). Simundic (2012) suggests the following AUC classifications: Test not useful (AUC < 0.5), Bad (0.5 - 0.6), Sufficient (0.6 - 0.7), Good (0.7 - 0.8), Very good (0.8 - 0.9), Excellent (0.9 - 1).

2.7. Participant and public involvement

The CENT was developed in collaboration with end-users, as reported in Morse et al. (2023). Study design involved consultation with a study-specific patient and public involvement group of stroke survivors, their unpaid carers and clinicians before study start and midway through recruitment. The PPI partners (n = 6) reviewed patient facing materials including information sheets and consent forms. The CENT instructions, sounds and symbols used in the test were also reviewed by PPI partners. The mug symbols used in the CENT cancellation task for example were specifically suggested by a PPI member during one of these consultations.

2.8. Ethical Approval

This clinical trial is registered on ClinicalTrials.gov (NCT04752982). The full protocol is available (https://osf.io/x2jg9/). Ethical approval was authorized by the Health Research Authority (HRA) East of England Cambridge South Research Ethics Committee (reference: 22/EE/0107) on 05/06/2020. See appendix G for documentation pertaining to ethical approval.

3. Results

3.1. Screening

A total of four hospitals screened 869 stroke survivors and 93 met eligibility criteria and were recruited for the c-SIGHT trial. They were each visited at home approximately three months post-stroke. The CENT was completed with 73 stroke-survivors (78.49%). 20 stroke survivors did not complete the CENT for the following reasons: no space (n = 14); technical difficulties (n = 3); difficulties following the instructions (n = 2) and study withdrawal (n = 1). Additionally, a total of 57 age-matched healthy controls from Morse et al. (2023) normative sample were included who had completed the CENT and comparator tests.

3.2. Sample Characteristics

A total of 29 stroke survivors with spatial neglect and 44 stroke survivors without spatial neglect (determined by performance on three spatial neglect comparator tests) participated. The additional 57 healthy age-matched controls from Morse et al. (2023) were included for the analysis of internal consistency. The spatial neglect group had a mean age of 69.31 years, the no spatial neglect group on average aged 68.89 years and the control group were on average 69.0 years old. The spatial neglect group were 59% male, the no spatial neglect group were 48% male, and the age-matched control group was 57% male. The average years of education for the spatial neglect group was 7.5 years, the no spatial neglect group was 7.41 years, and the age-matched control group was 11.46 years. The average length of hospital stay for the spatial neglect and no spatial neglect groups was 27.37 days and 15.14 days respectively. The average number of days post-stroke was 113.72 days for the spatial neglect group and 102.75 days for the no spatial neglect group. Regarding types of strokes, 58.6% of the spatial neglect group and 63.6% of the no spatial neglect group experience right hemisphere strokes, and 82.8% of the spatial neglect group and 90.9% of the no spatial neglect group experienced ischaemic strokes. See table 3 for sample characteristics.

A one-way, within subjects, repeated measures ANOVA was conducted to compare sample characteristics between groups (neglect, no neglect and healthy control). Due to the number of comparisons, a Bonferroni correction was calculated and used to adjust the p values in all post-hoc analyses. The participants did not significantly differ in terms of age ($F(2, 127) = 0.01$, $p = 0.99$), years of education ($F(2, 127) = 1.21$, $p = 0.3$), length of hospital stay ($F(1, 67) = 2.95$, $p = 0.09$), days post-stroke ($F(1, 71) = 0.22$, $p = 0.64$), TV size ($F(1, 70) = 0.48$, $p = 0.49$), and space in front of TV ($F(1, 70) = 1.33$, $p = 0.25$).

Within the stroke survivor sample (n = 73), half of the stroke survivors met criteria for either extrapersonal neglect, peripersonal neglect, or both (50.58%). Over a third of stroke survivors met threshold for peripersonal neglect in pen-and-paper diagnostic tests (39.73%). Approximately one third of stroke survivors met threshold for extrapersonal neglect in the CENT (34.25%). Roughly a quarter of stroke survivors met threshold for both extrapersonal and peripersonal neglect (23.29%).

16.33% had only peripersonal neglect and 10.96% had only extrapersonal neglect. Pen-and-paper tests identified allocentric neglect in 15.07% and egocentric neglect in 13.7% of stroke survivors, with 6.85% identified as having both. The CENT identified allocentric neglect in 13.7% and egocentric neglect in 16.44% of stroke survivors, with 5.48% identified as having both. See table 4 for spatial neglect subtype rates in the stroke survivor sample.

Table 3. Sample characteristics.
SD = Standard Deviation

	Spatial Neglect (n=29)	**No Spatial Neglect (n=44)**	**Age-matched controls (n=57)**
Mean age in years (SD)	69.31 (13.03)	68.89 (13.49)	69.0 (7.26)
Female %	41%	52%	44%
Male %	59%	48%	57%
Mean years of education (SD)	7.5 (3.67)	7.41 (3.64)	11.46 (21.59)
Right Hemisphere stroke %	58.6%	63.6%	
Left Hemisphere stroke %	27.6%	31.8%	
Bilateral stroke %	13.8%	4.5%	
Ischaemic %	82.8%	90.9%	
Haemorrhagic %	17.2%	9.1%	
Mean days in hospital (SD)	27.37 (33.54)	15.14 (25.44)	
Mean days post-stroke (SD)	113.72 (62.30)	102.75 (115.62)	
Mean Star Cancellation Score (SD)	47.55 (9.52)	53.32 (1.03)	
Mean Hearts Cancellation Score (SD)	39.76 (7.98)	48.34 (1.75)	
Mean Line Bisection Deviation (SD)	5.14 (9.87)	-1.08 (4.35)	

Table 4. Spatial Neglect Subtype Rates in Stroke Survivor Sample

Subtype	% (n = 73)
Peripersonal	39.73% (n = 29)
Extrapersonal	34.25% (n = 25)
Peripersonal and Extrapersonal	23.29% (n = 17)
Peripersonal Only	16.33% (n = 12)
Extrapersonal Only	10.96% (n = 8)
Peripersonal Allocentric	15.07% (n = 11)
Peripersonal Egocentric	13.7% (n = 10)
Peripersonal Allocentric and Egocentric	6.85% (n = 5)
Extrapersonal Allocentric	13.7% (n = 10)
Extrapersonal Egocentric	16.44% (n = 12)
Extrapersonal Allocentric and Egocentric	5.48% (n = 4)

3.3. Psychometric Properties

3.3.1. Concurrent Validity

To examine the Concurrent Validity of the CENT, non-parametric Spearman correlation coefficients were computed between the 10 variables of the CENT (index test), and performance on the star cancellation, OCS hearts cancellation, One-item extended test, Visual Analogue Scale and line bisection tests (comparator tests). A Bonferroni correction (probability value of 0.05 divided by the number of correlations) was applied to counteract the issue of multiple comparisons ($p \leq 0.000075$).

CENT Cancellation Accuracy had moderate significant correlations with Star Cancellation Test ($r = 0.689$, $p \leq .000075$), and OCS Hearts Cancellation Test ($r = 0.63$, $p \leq 0.000075$), demonstrating good concurrent validity. The CENT Cancellation Accuracy did not correlate significantly with the Line Bisection Test ($r = 0.05$, $p = 0.70$), One Item Extended Test ($r = 0.27$, $p = 0.02$), or Visual Analogue Scale ($r = -0.36$, $p = 0.00$). See table 5 for correlation coefficients between CENT Cancellation Accuracy and comparator tests.

Similarly, CENT Quality of Search also showed significant moderate correlations with Star Cancellation ($r = 0.54$, $p \leq 0.000075$) and OCS Hearts Cancellation ($r = 0.54$, $p \leq 0.000075$), but not with Line Bisection ($r = -0.17$, $p = 0.15$). The remaining CENT variables did not correlate significantly with comparator tests. Furthermore, the CENT Line Bisection deviation and CENT Line Bisection duration did not correlate significantly with any reference tests.

Table 5. Spearman Correlations: CENT Cancellation Accuracy and conventional tests

Test Variables	**Spearman Correlation Coefficient**
Star Cancellation Score	r = 0.69*
OCS Hearts Cancellation Score	r = 0.63*
Line Bisection Error	r = 0.05, p = 0.70
One Item Extended Test	r = 0.27, p = 0.02
Visual Analogue Scale	r = -0.36, p = 0.00

*p ≤ 0.000075

3.3.2. Discriminant Validity

To investigate the Discriminant Validity of the CENT, correlation coefficients were calculated with the other subtests of the OCS which measure other cognitive functions, theoretically distinct from spatial neglect. Non-parametric Spearman correlations were calculated between test outputs, namely, the ten CENT outputs and OCS subtests relating to theoretically separate cognitive domains. A Bonferroni correction was applied to counteract the issue of multiple comparisons ($p \leq 0.000075$). OCS Visual Field Subtest demonstrated a moderate significant correlation with CENT Cancellation Accuracy ($r = 0.46$, $p \leq 0.000075$). All other subtests pertaining to cognitive domains theoretically distinct from spatial neglect did not correlate significantly with any of the remaining CENT variables, indicating that the CENT has good discriminant validity. See table 6 for CENT Cancellation Accuracy Correlations with non-spatial neglect OCS domains.

Table 6. Spearman Correlations: CENT Cancellation Accuracy and OCS domains

Test Variables	**Spearman Correlation Coefficient**
OCS Picture Naming	r = 0.29, p = 0.01
OCS Orientation	r = 0.10, p = 0.42
OCS Visual Field	r = 0.46*
OCS Reading	r = 0.01, p = 0.11
OCS Number	r = 0.37, p = 0.00
OCS Calculation	r = 0.30, p = 0.01
OCS Imitation	r = -0.02, p = 0.90
OCS Recall	r = 0.02, p = 0.85
OCS Episodic Recognition	r = 0.24, p = 0.04
OCS Executive Functioning	r = -0.31, p = 0.01

*p ≤ 0.000075

3.3.3. Ecological Validity

To ascertain a quantitative understanding of the CENT's ecological validity, non-parametric Spearman correlation coefficients were computed between the 10 CENT variables and a self-report measure of post-stroke quality of life, physical functioning, and activities of daily living – the Stroke Impact Scale (SIS) – consisting of 9 variables. A Bonferroni correction was applied to counteract the issue of multiple comparisons ($p \leq 0.000075$). The CENT demonstrated good ecological validity as CENT Cancellation Accuracy was moderately correlated with SIS Activities of Daily Living ($r = 0.45$, $p \leq 0.000075$). Notably, CENT Cancellation Accuracy also correlated moderately with SIS domains pertaining to physical functioning and quality of life such as SIS recovery scale ($r = 0.49$, $p \leq 0.000075$), SIS Social ($r = 0.48$, $p \leq 0.000075$), SIS Mood ($r = 0.47$, $p \leq 0.000075$), SIS Physical ($r = 0.47$, $p \leq 0.000075$), SIS mobility ($r = 0.51$, $p \leq 0.000075$), and SIS Hand Function ($r = 0.49$, $p \leq 0.000075$). However, CENT Cancellation Accuracy did not correlate significantly with the self-reported domains of SIS Cognition and SIS Communication. See table 7 for CENT Cancellation Accuracy correlations with SIS domains. CENT Quality of Search also correlated with SIS Activities of Daily Living and Hand Function. The remaining CENT variables did not correlate significantly with the SIS domains.

Table 7. Spearman Correlations: CENT Cancellation Accuracy and SIS domains

Test Variables	**Spearman Correlation Coefficient**
SIS Physical	r = 0.49*
SIS Cognition	r = 0.29, p = 0.01
SIS Mood	r = 0.47*
SIS Communication	r = 0.28, p = 0.02
SIS Activities of Daily Living	r = 0.45*
SIS Mobility	r = 0.51*
SIS Hand Function	r = 0.49*
SIS Social	r = 0.48*
SIS Recovery Scale	r = 0.49*

*p ≤ 0.000075

3.3.4. Internal Consistency

To ascertain the internal consistency of the CENT, non-parametric Spearman correlation coefficients were computed between the 10 CENT variables. A Bonferroni correction was applied to counteract the issue of multiple comparisons ($p \leq 0.000075$). Healthy age matched controls were used for this section of the analysis as the CENT variables were being compared with each other. While for other psychometric properties, the analysis required exclusively stroke survivor participants (e.g.

ecological validity), using matched controls from Morse et al. (2024) in the analysis of internal consistency sought to strengthen this analysis by increasing the sample size with other participants who had completed the CENT. CENT variables that depend on time correlated with each other across subtests – Search Duration and Bisection Duration ($r = 0.70$, $p \leq 0.000075$). The CENT variables that depend on factors associated with the strategy participants implemented when completing the test correlated with each other - Quality of Search and Intersections ($r = -0.36$, $p \leq 0.000075$). Interestingly, these variables also demonstrated significant correlations with duration and across tests - Quality of Search and Bisection Duration ($r = -0.74$, $p \leq 0.000075$), Search Duration and Intersections ($r = 0.36$, $p \leq .000075$), Search Duration and Quality of Search ($r = -0.94$, $p \leq 0.000075$). The CENT variables that depend on precision also correlated with each other - CENT Accuracy and Quality of Search ($r = 0.44$, $p \leq 0.000075$). Overall, these correlations indicate that the CENT demonstrated good internal consistency.

Figure 4 provides a visual representation of all Spearman Correlations described in sections 3.3.1 to 3.3.4. Moreover, full correlation coefficients and significance values of all computed Spearman correlations can be found in Chapter six.

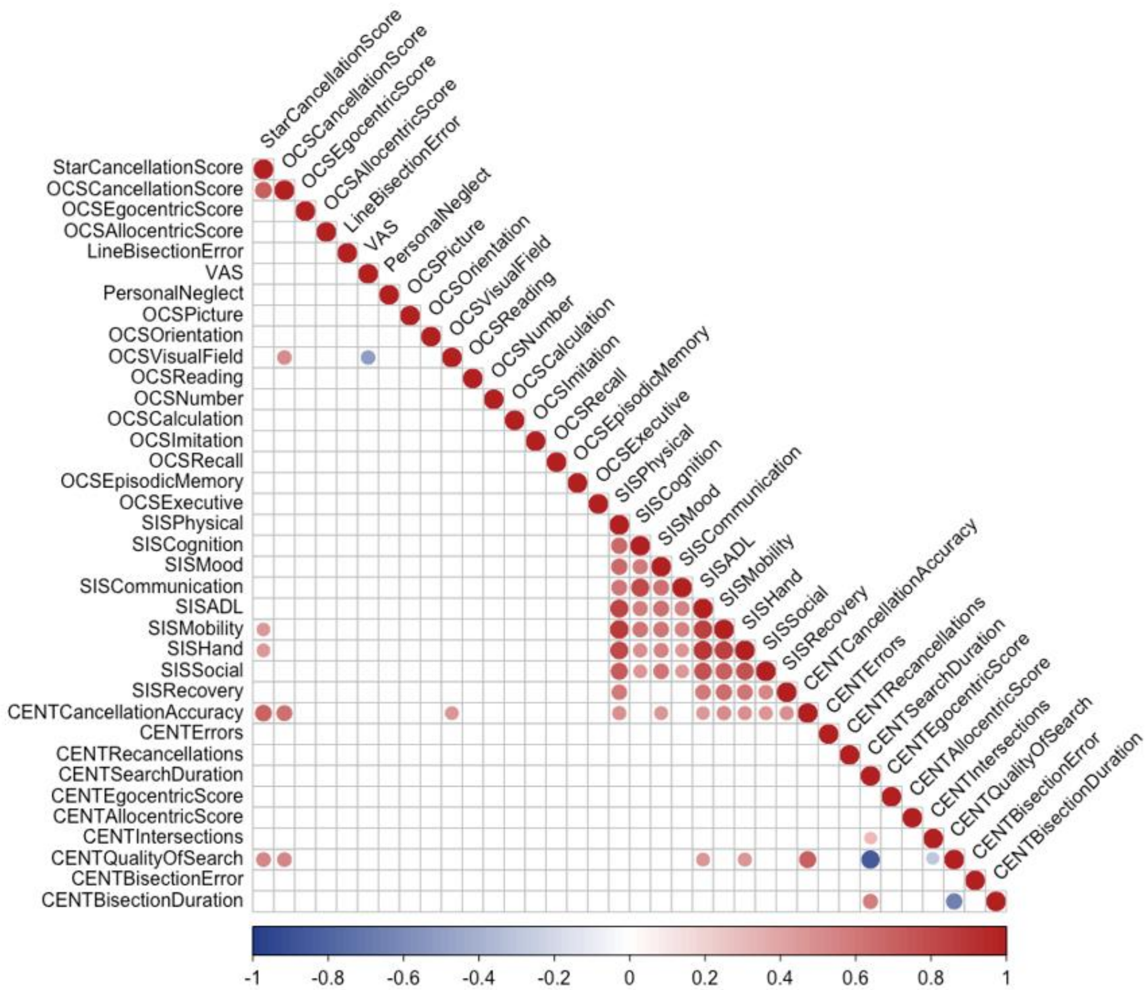


Figure 4. Spearman Correlation Plots (Bonferroni Corrected). SIS = Stroke Impact Scale; ADL = Activities of Daily Living; VAS = Visual Analogue Scale; OCS = Oxford Cognitive Scale.

3.3.5. Diagnostic Accuracy

The initial raw findings of our study are presented in a 2x2 table as seen in table 8.

Table 8. 2x2 table reporting cross-classification of subjects and combined reference tests.

	Reference tests		
	Subjects with Spatial Neglect	**Subjects without Spatial Neglect**	
Index test			**Total**
Positive	17	8	25
Negative	12	36	48
Total	29	44	73

The normal range of CENT performance and age-related diagnostic cut-offs for spatial neglect were established in a previous study, Morse et al. (2023), based on the performance of 179 healthy control participants. A standard deviation of 2 above or below the average for the participant's age group was used to establish a diagnostic cut-off (5th percentile).

3.3.4.1. CENT Cancellation and Star Cancellation

The first ROC analysis assessed the ability of the CENT to correctly identify patients with spatial neglect (as determined by external criteria, Star Cancellation) from a total sample which included stroke survivor controls without spatial neglect. This analysis demonstrated a ROC curve for the CENT (AUC = 0.91, 95% CI 0.83-0.91), is significantly better than chance in correctly identifying individuals with spatial neglect versus controls (see figure 5). This analysis demonstrates excellent classification accuracy (Simundic, 2012).

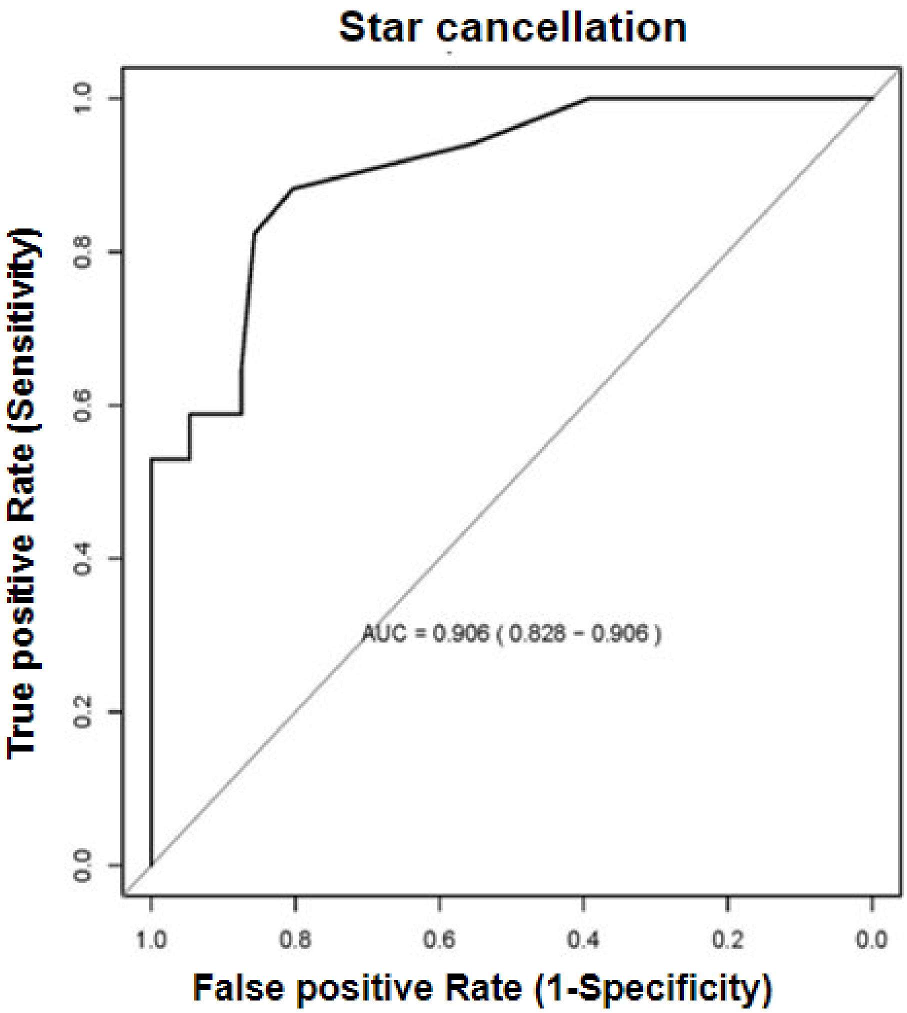


Figure 5. AUC graphs for CENT compared with the Star Cancellation test.

3.3.4.2. CENT Cancellation and OCS Cancellation

The second ROC analysis assessed the ability of the CENT to identify patients with spatial neglect (as determined by OCS cancellation) from a total sample which included stroke survivor controls without spatial neglect. This analysis demonstrated an excellent ROC curve for the CENT (AUC = 0.94, 95% CI 0.87-0.94), is significantly better than chance in correctly detecting individuals with spatial neglect versus controls (see figure 6). This analysis also demonstrates excellent classification accuracy (Simundic, 2012).

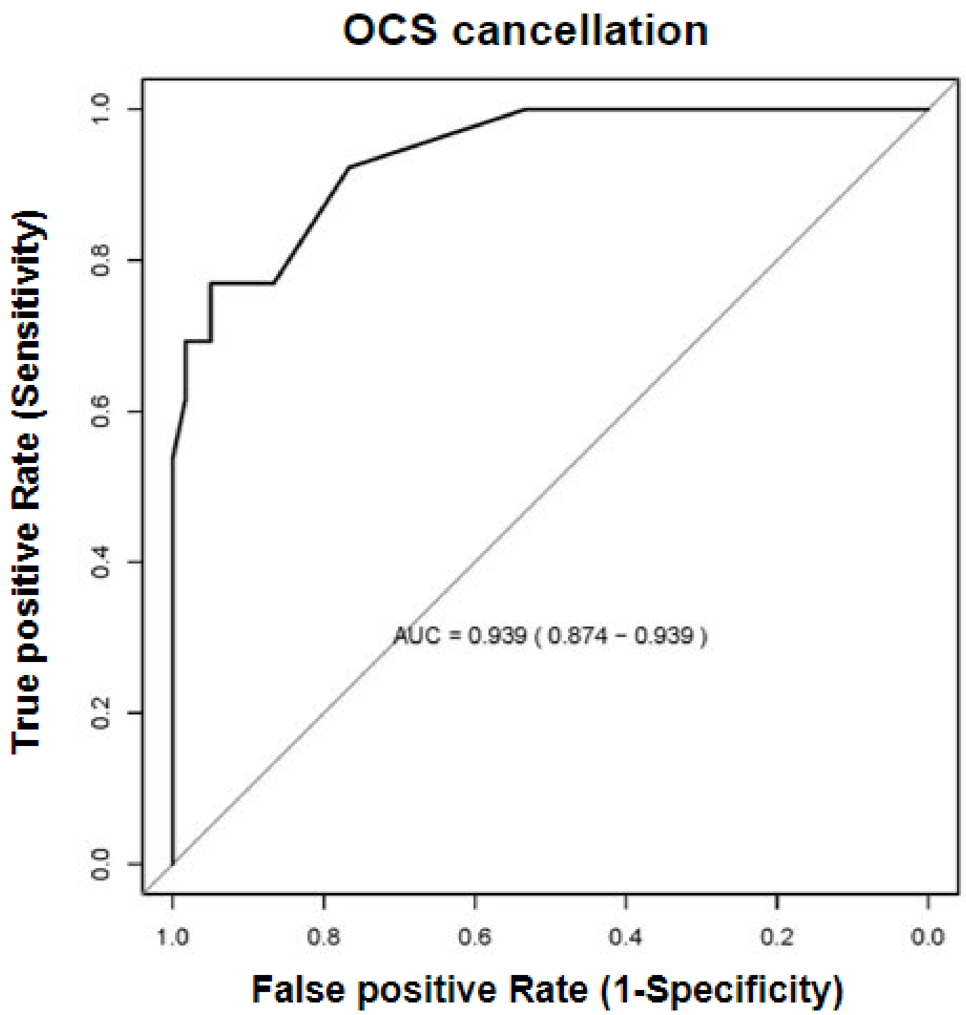


Figure 6. AUC graph for CENT compared with OCS Broken Hearts Cancellation Subtest

3.3.4.3. CENT Cancellation and Line Bisection

The third ROC analysis assessed the ability of the CENT to identify patients with spatial neglect (as determined by the Line Bisection Test) from a total sample including stroke survivor controls without spatial neglect. This analysis demonstrated a ROC curve for CENT (AUC = 0.59, 95% CI 0.39-0.59), is no better than chance in correctly identifying individuals with spatial neglect versus controls. This analysis demonstrates bad classification accuracy (Simundic, 2012).

3.3.4.4. CENT Allocentric Score and Line Bisection

The fourth ROC analysis assessed the ability of the CENT to identify patients with Allocentric Neglect (as determined by the Line Bisection Test) from a total sample including stroke survivor controls without spatial neglect. This analysis demonstrated a ROC curve for CENT (AUC = 0.53, 95% CI 0.43-0.53), is no better than chance in correctly identifying individuals with allocentric neglect verses controls. This analysis demonstrates bad classification accuracy (Simundic, 2012).

3.3.4.5. CENT Allocentric Score and OCS Allocentric Score

The fourth ROC analysis assessed the ability of the CENT to identify patients with Allocentric Neglect (as determined by the OCS Allocentric Score) from a total sample including stroke survivor controls without spatial neglect. This analysis demonstrated a ROC curve for CENT (AUC = 0.59, 95% CI 0.42-0.58), is no better than chance in correctly identifying individuals with allocentric neglect verses controls. This analysis demonstrates bad classification accuracy (Simundic, 2012).

3.3.4.6. CENT Egocentric Score and OCS Egocentric Score

The fourth ROC analysis assessed the ability of the CENT to identify patients with Egocentric Neglect (as determined by the OCS Egocentric Score) from a total sample including stroke survivor controls without spatial neglect. This analysis demonstrated a ROC curve for CENT (AUC = 0.67, 95% CI 0.42-0.67), is no better than chance in correctly identifying individuals with egocentric neglect versus controls. This analysis demonstrates sufficient classification accuracy (Simundic, 2012).

Overall, the CENT demonstrated an excellent ability to capture whether a stroke survivor has or does not have spatial neglect. However, it was not as accurate in its ability to determine whether someone had allocentric or egocentric spatial neglect. All ROC curves figures can be found in the additional results chapter, chapter six.

4. Discussion

This study assessed the psychometric properties of the CENT, a novel portable computerised test of extrapersonal neglect in stroke survivors. This study confirms and expands on previous findings (Morse et al., 2023), finding that the CENT has excellent diagnostic accuracy and good internal consistency, ecological validity, discriminant validity and concurrent validity. Moreover, this study demonstrated that the CENT can be used to assess extrapersonal spatial neglect in stroke patients when administered in their own homes.

The CENT cancellation subtask showed excellent diagnostic accuracy following a ROC analysis, demonstrating higher diagnostic accuracy than the only other diagnostic test for extrapersonal spatial neglect analysed using a ROC analysis the Simulated Driving Task (AUC = 0.84; Spreij et al., 2020). Both studies used cancellation task as the reference standard. Usually, when sensitivity and specificity are calculated for a new diagnostic test, the reference test has a sensitivity and specificity of 100%. In the absence of a gold standard, arguably, it becomes conceptually impossible to classify participants reliably. As there is currently no gold standard for spatial neglect tests (Moore, Milosevich, Beisteiner, Bowen, Checketts, Demeyere, Fordell, Godefroy, Laczo, Rich, Williams, Woodward-Nutt & Husain, 2022), as is common with many neuropsychological diagnostic tests compared with medical diagnostic tests, we referenced the closest widely used, and most similar tests currently available (Behavioural Inattention Test, OCS, Line Bisection). By virtue of the CENT being an extrapersonal spatial neglect test and our reference tests being peripersonal spatial neglect tests, the false-positive and false-negative rates of the CENT may be either a sign of diagnostic inaccuracy, or evidence that the CENT is better able to diagnose individuals with extrapersonal neglect than peripersonal reference tests. It could also be both. Theoretically, there is considerable evidence that extrapersonal neglect is a distinct subtype of spatial neglect (Rode et al., 2017). Considering the CENT comprises of two well-established subtests that are known to measure peripersonal spatial neglect accurately (Cancellation and Line Bisection task), with one key difference being that the CENT is administered far away in the extrapersonal space, it could be argued the CENT should theoretically be measuring extrapersonal spatial neglect. It is also important to acknowledge that another key difference between the CENT and pen-and-paper tests, is that the CENT is computerised. It is unclear currently to what extent, if any, this has on the CENT's accuracy.

The CENT Line Bisection task and CENT Allocentric and Egocentric variables did not demonstrate good diagnostic accuracy following ROC analyses with different reference tests. This is somewhat surprising as there is theoretical support that Allocentric neglect is associated with the same attentional stream (ventral) as extrapersonal neglect (Chen, Weidner, Weiss, Marhsall & Fink, 2012) and it has also been argued that Line Bisection requires an allocentric frame of reference (Rorden et al., 2006; Chechlacz et al., 2010; Karnath & Rorden, 2012). At first glance, the rates of allocentric and egocentric neglect in extrapersonal and peripersonal space appear quite similar, however, only four of eleven (36%) stroke survivors identified as having allocentric neglect on the OCS showed allocentric neglect on the CENT. Moreover, half of stroke survivors identified as having egocentric neglect on the OCS showed egocentric neglect on the CENT (five of ten). Two participants demonstrated both allocentric and egocentric neglect at both distances. Our findings suggest that many of the individuals who showed impaired allocentric or egocentric performance on the OCS did not perform in the impaired allocentric or egocentric range on the CENT. It is believed that egocentric and peripersonal judgements draw upon the dorsal action-related stream, while both allocentric and extrapersonal judgements draw upon the ventral perception-related stream (Chen et al., 2012). The little overlap of performance on the OCS compared to the CENT regarding allocentric may be due to them being part of two dissociable streams. This is further supported in a study by Keller (2005), in which they found evidence to support the notion that distance impacts perception for the allocentric frame of reference but does not impact the perception of the egocentric frame of reference. Considering Keller's (2005) findings, it is currently unclear why some stroke survivors performed in the egocentric neglect range in only the extrapersonal space. Matching performance on these tests with lesion mapping data would allow us to explore whether these individuals have impairment in regions associated with the communication between the ventral and dorsal streams, which might explain such findings. These preliminary findings warrant further investigation into extrapersonal allocentric and egocentric neglect.

A further strength of the CENT is that performance on the CENT Cancellation correlates significantly with activities of daily living, indicating good ecological validity. These correlations with a self-report scale indicate that the CENT is a meaningful measure, able to predict stroke recovery and post-stroke quality of life. To our knowledge, no other validation studies for extrapersonal spatial neglect tests evaluated ecological validity using quantitative measures (Stermsek et al., unpublished manuscript). Moreover, pen-and-paper tests are often believed to lack ecological validity (Azouvi, Samuel, Louis-Dreyfus, Bernati, Bartolomeo, Beis, Chokron, Leclercq, Marchal, Martin, Montety, Oliver, Perennou, Pradat-Diehl, Prairial, Rode, Sieroff, Wiart, & Rousseaux, 2002), and this is supported by our findings, as none of the pen-and-paper reference test correlated significantly with multiple domains of the SIS.

The CENT Cancellation task also demonstrated good concurrent validity, correlating significantly with other commonly used tests for spatial neglect. Other extrapersonal neglect tests that explored concurrent validity reported similar moderate correlations (Whitehouse, Green, Giles, Rahman, Coolican & Eskes, 2019; Spreij et al., 2020). The CENT Line Bisection task however did not correlate with comparator tests indicating that this subtest alone has low concurrent validity.

The CENT also demonstrated strong internal consistency, showing significant moderate to strong correlations across tests and in expected directions. Most tests of extrapersonal spatial neglect that reported internal consistency were functional observation task batteries, such as the Catherine Bergego Scale (Azouvi et al., 2002), Kessler Foundation Neglect Assessment Process (Japanese version; KF-NAP-J; Nishida, Mizuno, Tahara, Shindo, Watanabe, Ebata & Tsuji, 2021) and Semi-Structured Extrapersonal Neglect Scale (Zoccolotti & Antonucci, 1991; Zoccolotti & Judica, 1992). They all reported good internal consistency. The VRLAT (Buxbaum et al., 2012), also demonstrated excellent internal consistency ($\alpha = 0.97$).

The CENT also demonstrated strong discriminant validity as it did not correlate significantly with other theoretically separate cognitive domains, however the CENT did correlate with the OCS Visual Field subtest. This is not surprising, as historically, spatial neglect diagnostic tests have found it difficult to distinguish neglect from visual field deficits (Ting, Pollock, Dutton, Doubal, Ting, Thompson & Dhillon, 2011). Other extrapersonal neglect tests that explored discriminant validity found that they correlated with other cognitive domains such as executive functioning and non-lateralised attention (Mesa-Gresa et al., 2011; Aravind et al., 2015). One extrapersonal spatial neglect test, the Virtual Reality Lateralised Attention Test (VRLAT), however was found to be markedly less likely to identify individuals with visual field deficits than pen-and-paper spatial neglect tests, indicating good discriminant validity (Buxbaum et al., 2012).

When administering pen-and-paper tests, the research team noticed participants naturally used a range of compensatory techniques to improve their test ability. For example, individuals shifted their midline, used their hands to manipulate the paper, or pinpoint the ends of the line in the line-bisection test. Researchers watched attentively to ensure participants did not utilise these compensatory strategies, so as to not influence the results. The research team noticed however, that participants were not able to use such strategies in the CENT test (due in part to the screen's distance from them). A reduction in compensatory strategies has been theorised as a potential benefit of computerised tests for spatial neglect (Giannakou et al., 2022). One strength of the CENT therefore is that its design minimises the use of subtle compensatory strategies that left unnoticed might reduce the validity of such measures.

One limitation of this study is that we did not formally test for the presence of hemianopia. Hemianopia is the very common visual field deficit post-stroke (Rowe, Wright, Brand, Jackson, Harrison, Maan, Scott, Vogwell, Peel, Akerman, Dodridge, Howard, Shipman, Sperring, MacDiarmid, & Freeman, 2013), causing individuals to experience a loss of vision in half of their visual field. To ascertain hemianopia, we included the visual field deficit subtest of the OCS. Our participants did not however complete formal visual field testing, such as the Humphreys perimetry test administered by a certified ophthalmologist. To compensate for their visual field deficit individuals with Hemianopia are likely to turn their head to compensate to their blind field, this is a behaviour less frequent in neglect patients (Walker, Findlay, Young & Welch, 1991) unless they have had an intervention (Liu, Hanly, Fahey, Fong & Bye, 2019). This is potentially a consequence of a common symptom of neglect being a lack of insight or anosognosia (Takamura, Imanishi, Osaka, Ohmatsu, Tominaga, Yamanaka, Morioka & Kawashima, 2016; Grattan, Skidmore & Woodbury, 2018; Vossel, Weiss, Eschenbeck, Saliger, Karbe & Fink, 2012). In this study, CENT Cancellation Accuracy had a significant moderate correlation with the OCS visual field subtest. Although the OCS can detect a visual field deficit in the absence of neglect (impaired visual field subtest and unimpaired cancellation task), if both are impaired, it can be difficult to separate (Moore, Shalev, Gillebert, Demeyere, 2020). Upon further inspection, not a single participant had impairment on the visual field subtest and was unimpaired on a cancellation task.

Future research should investigate the psychometric properties of the CENT that have not yet been assessed, such as test-retest reliability. This study administered the CENT within stroke-survivor's homes. It was important to gather valuable insights into the feasibility and applicability of the CENT in different settings as community neurorehabilitation is provided in people's homes. Moreover, an important step would be to test CENT in acute settings to evaluate its usefulness in tracking recovery compared with other tests. Future research should also explore the feasibility within clinical hospital settings, to give a more holistic view of the test's overall clinical usefulness, applicability, and feasibility.

It would have been interesting to compute ROC analyses of other variables such as quality of search or search speed. For the purpose of this study, we decided to use the outputs most commonly used by traditional standardised diagnostic tests, such as cancellation accuracy (total cancellation score), Allocentric and Egocentric score and Line Bisection mean deviation, as these facilitate the most direct comparisons. Moreover, considering tracking stroke recovery is a crucially important element of clinical practice, future research should explore the utility of CENT in acute settings to evaluate its usefulness in tracking recovery compared with other tests. Future research should also consider exploring the diagnostic accuracy of quality of search and search speed of the CENT.

5. Conclusions

This validation study aimed to evaluate the psychometric properties of the CENT, a novel computerised diagnostic test for extrapersonal spatial neglect that can be completed in stroke-survivor's homes. The findings indicate that the CENT has promising psychometric properties, namely, good concurrent validity, discriminant validity, ecological validity, internal consistency, and excellent diagnostic accuracy. The CENT found 34% of stroke survivors experience extrapersonal spatial neglect, with 11% of stroke-survivors demonstrating extrapersonal spatial neglect without the presence of peripersonal spatial neglect. This study stresses how important it is for clinicians to consider the presence of extrapersonal spatial neglect, as it could inform rehabilitation and safety planning.

6. References

Ackroyd, K., Riddoch, J. M., Humphreys, G. W., Nightingale, S., & Townsend, S. (2010). Widening the Sphere of Influence: Using a Tool to Extend Extrapersonal Visual Space in a Patient with Severe Neglect. Behaviour, Cognition and Neuroscience, 8(1), 1–12.

Aimola, L., Schindler, I., Simone, A. M., & Venneri, A. (2012). Near and far space neglect: Task sensitivity and anatomical substrates. Neuropsychologia, 50(6), 1115–1123. https://doi.org/10.1016/j.neuropsychologia.2012.01.022

Akobeng, A. (2006). Understanding diagnostic tests 3: receiver operating characteristic curves. Acta Paediatrica. 96, 644-647.

Akoglu, H. (2018). User's guide to correlation coefficients. Turkish Journal of Emergency Medicine. 18(3) 91–93. https://doi.org/10.1016/j.tjem.2018.08.001

Appelros, P., Nydevik, I., Karlsson, G. M., Thorwalls, A., & Seiger, Å. (2003). Assessing unilateral neglect: Shortcomings of standard test methods. Disability and Rehabilitation, 25(9), 473–479. https://doi.org/10.1080/0963828031000071714

Aravind, G., Darekar, A., Fung, J., & Lamontagne, A. (2015). Virtual Reality-Based Navigation Task to Reveal Obstacle Avoidance Performance in Individuals with Visuospatial Neglect. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 23(2), 179–188. https://doi.org/10.1109/TNSRE.2014.2369812

Azouvi, P., Samuel, C., Louis-Dreyfus, A., Bernati, T., Bartolomeo, P., Beis, J. M., Chokron, S., Leclercq, M., Marchal, F., Martin, Y., De Montety, G., Olivier, S., Perennou, D., Pradat-Diehl, P., Prairial, C., Rode, G., Siéroff, E., Wiart, L., & Rousseaux, M. (2002). Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke. Journal of Neurology Neurosurgery and Psychiatry, 73(2), 160–166. https://doi.org/10.1136/jnnp.73.2.160

Bailey, M. J., Riddoch, M. J., & Crome, P. (2000). Evaluation of a test battery for hemineglect in elderly stroke patients for use by therapists in clinical practice. Neuro Rehabilitation, 14, 139–150.

Bailey, M. J., Riddoch, M. J., & Crome, P. (2004). Test-retest stability of three tests for unilateral visual neglect in patients with stroke: Star Cancellation, Line Bisection, and the Baking Tray Task. Neuropsychological Rehabilitation, 14(4), 403–419. https://doi.org/10.1080/09602010343000282

Beis, J. M., Keller, C., Morin, N., Bartolomeo, P., Bernati, T., Chokron, S., Leclercq, M., Louis-Dreyfus, A., Marchal, F., Martin, Y., Perennou, D., Pradat-Diehl, P., Prairial, C., Rode, G., Rousseaux, M., Samuel, C., Sieroff, E., Wiart, L., & Azouvi, P. (2004). Right spatial neglect after left hemisphere stroke: Qualitative and quantitative study. Neurology, 63(9), 1600–1605. https://doi.org/10.1212/01.WNL.0000142967.60579.32

Berti, A., & Frassinetti, F. (2000). When Far Becomes Near: Remapping of Space by Tool Use. Journal of Cognitive Neuroscience, 12(3), 415-420.

Bosma, M. S., Nijboer, T. C. W., Caljouw, M. A. A., & Achterberg, W. P. (2020). Impact of visuospatial neglect post-stroke on daily activities, participation and informal caregiver burden: A systematic review. In Annals of Physical and Rehabilitation Medicine (Vol. 63, Issue 4, pp. 344–358). Elsevier Masson SAS. https://doi.org/10.1016/j.rehab.2019.05.006

Bowen, A., Mckenna, K., & Tallis, R. C. (1999). Reasons for Variability in the Reported Rate of Occurrence of Unilateral Spatial Neglect After Stroke. http://ahajournals.org

Butler, B. C., Eskes, G. A., & Vandorpe, R. A. (2004). Gradients of detection in neglect: comparison of peripersonal and extrapersonal space. Neuropsychologia, 42(3), 346–358.

Buxbaum, L. J., Dawson, A. M., & Linsley, D. (2012). Reliability and validity of the virtual reality lateralized attention test in assessing hemispatial neglect in right-hemisphere stroke. Neuropsychology, 26(4), 430–441. https://doi.org/10.1037/a0028674

Buxbaum, L. J., Ferraro, M. K., Veramonti, T., Farne, A., Whyte, J., Ladavas, E., Frassinetti, F., & Coslett, H. B. (2004). Hemispatial Neglect. Neurology, 62(5), 749–756.

Chechlacz, M., Rotshtein, P., Bickerton, W. L., Hansen, P. C., Deb, S., & Humphreys, G. W. (2010). Separating neural correlates of allocentric and egocentric neglect: Distinct cortical sites and common white matter disconnections. Cognitive Neuropsychology, 27(3), 277–303. https://doi.org/10.1080/02643294.2010.519699

Checketts, M., Mancuso, M., Fordell, H., Chen, P., Hreha, K., Eskes, G. A., Vuilleumier, P., Vail, A., & Bowen, A. (2020). Current clinical practice in the screening and diagnosis of spatial neglect post-stroke: Findings from a multidisciplinary international survey. Neuropsychological Rehabilitation, 1–32. https://doi.org/10.1080/09602011.2020.1782946

Chen, P., Fyffe, D. C., & Hreha, K. (2017). Informal caregivers’ burden and stress in caring for stroke survivors with spatial neglect: An exploratory mixed-method study. Topics in Stroke Rehabilitation, 24(1), 24–33. https://doi.org/10.1080/10749357.2016.1186373

Chen, P., Hreha, K., Kong, Y., & Barrett, A. M. (2015). Impact of Spatial Neglect on Stroke Rehabilitation: Evidence from the Setting of an Inpatient Rehabilitation Facility. Archives of Physical Medicine and Rehabilitation, 96(8), 1458–1466. https://doi.org/10.1016/j.apmr.2015.03.019

Chen, Q., Weidner, R., Weiss, P. H., Marshall, J. C., & Fink, G. R. (2012). Neural Interaction between Spatial Domain and Spatial Reference Frame in Parietal–Occipital Junction. Journal of Cognitive Neuroscience, 24(11), 2223–2236.

Corbetta, M., Kincade, M. J., Lewis, C., Snyder, A. Z., & Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. Nature Neuroscience, 8(11), 1603–1610. https://doi.org/10.1038/nn1574

Cowey, A., Small, M., & Ellis, S. (1998). No abrupt change in visual hemineglect from near to far space. Neuropsychologia, 37(1), 1–6.

Demeyere, N., Riddoch, M. J., Slavkova, E. D., Bickerton, W. L., & Humphreys, G. W. (2015). The Oxford Cognitive Screen (OCS): validation of a stroke-specific short cognitive screening tool. Psychological Assessment, 27(3), 883.

Demeyere, N., & Gillebert, C. R. (2019). Supplemental Material for Ego- and Allocentric Visuospatial Neglect: Dissociations, Prevalence, and Laterality in Acute Stroke. Neuropsychology. https://doi.org/10.1037/neu0000527.supp

Demeyere, N., Haupt, M., Webb, S. S., Strobel, L., Milosevich, E. T., Moore, M. J., Wright, H., Finke, K., & Duta, M. D. (2021). Introducing the tablet-based Oxford Cognitive Screen-Plus (OCS-Plus) as an assessment tool for subtle cognitive impairments. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-87287-8

Duncan, P. W., Lai, S. M., Bode, R. K., Perera, S., DeRosa, J., & GAIN Americas Investigators. (2003). Stroke Impact Scale-16: A brief assessment of physical function. Neurology, 60(2), 291–296.

Esposito, E., Shekhtman, G., & Chen, P. (2021). Prevalence of spatial neglect post-stroke: A systematic review. In Annals of Physical and Rehabilitation Medicine (Vol. 64, Issue 5). Elsevier Masson s.r.l. https://doi.org/10.1016/j.rehab.2020.10.010

Eusebi, P. (2013). Diagnostic Accuracy Measures. Cerebrovascular Diseases, 36, 267-272.

Farnè, A., Buxbaum, L. J., Ferraro, M., Frassinetti, F., Whyte, J., Veramonti, T., Angeli, V., Coslett, H. B., & Làdavas, E. (2004). Patterns of spontaneous recovery of neglect and associated disorders in acute right brain-damaged patients. Journal of Neurology, Neurosurgery and Psychiatry, 75(10), 1401–1410. https://doi.org/10.1136/jnnp.2002.003095

Feigin, V. L., Brainin, M., Norrving, B., Martins, S., Sacco, R. L., Hacke, W., Fisher, M., Pandian, J., & Lindsay, P. (2022). World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. In International Journal of Stroke (Vol. 17, Issue 1, pp. 18–29). SAGE Publications Inc. https://doi.org/10.1177/17474930211065917

Ferber, S., & Karnath, H. O. (2001). How to assess spatial neglect - Line bisection or cancellation tasks? Journal of Clinical and Experimental Neuropsychology, 23(5), 599–607. https://doi.org/10.1076/jcen.23.5.599.1243

Fortis, P., Maravita, A., Gallucci, M., Ronchi, R., Grassi, E., Senna, I., Olgiati, E., Perucca, L., Banco, E., Posteraro, L., Tesio, L., & Vallar, G. (2010). Rehabilitating Patients with Left Spatial Neglect by Prism Exposure During a Visuomotor Activity. Neuropsychology, 24(6), 681–697. https://doi.org/10.1037/a0019476

Gauthier, L., Dehaut, F., & Joanette, Y. (1989). The Bells Test: A Quantitative and Qualitative Test for Visual Neglect. International Journal of Clinical Neuropsychology, 11, 49–54.

Giannakou, I., Lin, D., & Punt, D. (2022). Computer-based assessment of unilateral spatial neglect: A systematic review. Frontiers in Neuroscience, 16, 1–14. http://clinicaltrials.gov/

Goodale, M. A., & Milner, D. A. (1992). Separate visual pathways for perception. TINS, 15(1), 20–26.

Grattan, E. S., Skidmore, E. R., & Woodbury, M. L. (2018). Examining anosognosia of neglect. OTJR Occupation, Participation and Health, 38(2), 113–120. https://doi.org/10.1177/1539449217747586

Guilbert, A. (2022). Clinical Assessment of Unilateral Spatial Neglect Dissociations and Heterogeneities: A Narrative Synthesis. Neuropsychology, 37(4), 450–462. https://doi.org/10.1037/neu0000841

Halligan, P. W., Cockburn, J., & Wilson, B. A. (1991). The behavioural assessment of visual neglect. Neuropsychological Rehabilitation, 1, 5–32.

Halligan, P. W., & Marshall, J. C. (1991). Left neglect for near but not far space in man. . Nature, 350(6318), 498–500.

Hammerbeck, U., Gittins, M., Vail, A., Paley, L., Tyson, S. F., & Bowen, A. (2019). Spatial neglect in stroke: Identification, disease process and association with outcome during inpatient rehabilitation. Brain Sciences, 9(12). https://doi.org/10.3390/brainsci9120374

Hannaford S, Gower G, Potter JM, Guest RM, & Fairhurst MC. (2003). Assessing visual inattention: study of interrater reliability. Br. J. Therapy Rehabil, 10(2), 72–75.

Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. Nature, 385, 154–156.

Karnath, H. O., & Rorden, C. (2012). The anatomy of spatial neglect. In Neuropsychologia (Vol. 50, Issue 6, pp. 1010–1017). https://doi.org/10.1016/j.neuropsychologia.2011.06.027

Kartsounis, L. D., & Findley, L. J. (1994). Task specific visuospatial neglect related to density and salience of stimuli. Cortex, 30, 647–659.

Keller, I., Schindler, I., Kerkhoff, G., Rosen, F. Von, & Golz, D. (2005). Visuospatial neglect in near and far space: Dissociation between line bisection and letter cancellation. Neuropsychologia, 43(5), 724–731. https://doi.org/10.1016/j.neuropsychologia.2004.08.003

Kim, D. Y., Ku, J., Chang, W. H., Park, T. H., Lim, J. Y., Han, K., Kim, I. Y., & Kim, S. I. (2010). Assessment of post-stroke extrapersonal neglect using a three-dimensional immersive virtual street crossing program. Acta Neurologica Scandinavica, 121(3), 171–177. https://doi.org/10.1111/j.1600-0404.2009.01194.x

Lancaster, G. A., Dodd, S., & Williamson, P. R. (2004). Correspondence Design and analysis of pilot studies: recommendations for good practice. In Journal of Evaluation in Clinical Practice (Vol. 10).

Lane, A. R., Ball, K., & Ellison, A. (2015). Dissociating the neural mechanisms of distance and spatial reference frames. Neuropsychologia, 74, 42–49. https://doi.org/10.1016/j.neuropsychologia.2014.12.019

Lane, A. R., Ball, K., Smith, D. T., Schenk, T., & Ellison, A. (2013). Near and far space: Understanding the neural mechanisms of spatial attention. Human Brain Mapping, 34(2), 356–366. https://doi.org/10.1002/hbm.21433

Lawrence, E. S., Coshall, C., Dundas, R., Stewart, J., Rudd, A. G., Howard, R., Charles, ;, & Wolfe, D. A. (2001). Estimates of the Prevalence of Acute Stroke Impairments and Disability in a Multiethnic Population. http://ahajournals.org

Lezak, M. D. (2004). Neuropsychological assessment. Oxford University Press.

Liang, Y., Fairhurst, M. C., Guest, R. M., & Potter, J. M. (2010). A learning model for the automated assessment of hand-drawn images for visuo-spatial neglect rehabilitation. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 18(5), 560–570. https://doi.org/10.1109/TNSRE.2010.2047605

Liu, K. P. Y., Hanly, J., Fahey, P., Fong, S. S. M., & Bye, R. (2019). A Systematic Review and Meta-Analysis of Rehabilitative Interventions for Unilateral Spatial Neglect and Hemianopia Poststroke From 2006 Through 2016. In Archives of Physical Medicine and Rehabilitation (Vol. 100, Issue 5, pp. 956–979). W.B. Saunders. https://doi.org/10.1016/j.apmr.2018.05.037

Markus, H. (2008). Stroke: causes and clinical features. Medicine, 36(11), 586–591. https://doi.org/10.1016/j.mpmed.2008.08.009

Mesa-Gresa, P., Lozano, J. A., Llórens, R., Alcañiz, M., Navarro, D., Noé, E., & Navarro, M. D. (2011). Clinical Validation of a Virtual Environment Test for Safe Street Crossing in the Assessment of Acquired Brain Injury Patients with and without Neglect. Human- Computer Interaction - INTERACT 2011: 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part II, 13, 44–51. https://doi.org/10.1007/978-3-642-23771

Moore, M. J., Milosevich, E., Mattingley, J., Demeyere, N., & Au, M. M. E. (2023). The neuroanatomy of visuospatial neglect: A systematic review and analysis of lesion-mapping methodology. Neuropsychologia, 108–470.

Moore, M. J., Shalev, N., Gillebert, C. R., & Demeyere, N. (2020). Dissociations within neglect-related reading impairments: Egocentric and allocentric neglect dyslexia. Journal of Clinical and Experimental Neuropsychology, 42(4), 352–362. https://doi.org/10.1080/13803395.2020.1715926

Moore, M., Milosevich, E., Beisteiner, R., Bowen, A., Checketts, M., Demeyere, N., Fordell, H., Godefroy, O., Laczó, J., Rich, T., Williams, L., Woodward-Nutt, K., & Husain, M. (2022). Rapid screening for neglect following stroke: A systematic search and European Academy of

Neurology recommendations. European Journal of Neurology, 29(9), 2596–2606. https://doi.org/10.1111/ene.15381

Morse, H., Jolly, A. A., Browning, H., Clark, A., Pomeroy, V., & Rossit, S. (2023). Aging effects on extrapersonal (far-space) attention: cancellation and line bisection performance from 179 healthy adults. Aging, Neuropsychology, and Cognition. https://doi.org/10.1080/13825585.2023.2223903

Morse, H., Jolly, A., Pomeroy, V., Biggart, L., & Rossit, S. (2019a). A portable and self-administered computerised therapy for spatial neglect post-stroke (c-SIGHT): preliminary findings of a multiple baseline pilot study. British Neurospychological Society, London.

Morse, H., Jolly, A., Pomeroy, V., Biggart, L., & Rossit, S. (2019b). Investigating a home-based self-administered computerised therapy and assessment for spatial neglect post-stroke (c-SIGHT): preliminary findings of a usability study. UK Stroke Forum, Telford.

Nishida, D., Mizuno, K., Tahara, M., Shindo, S., Watanabe, Y., Ebata, H., & Tsuji, T. (2021). Behavioral assessment of unilateral spatial neglect with the catherine bergego scale (CBS) using the kessler foundation neglect assessment process (KF-NAP) in patients with subacute stroke during rehabilitation in Japan. Behavioural Neurology, 2021. https://doi.org/10.1155/2021/8825192

Ogourtsova, T., Archambault, P., Sangani, S., & Lamontagne, A. (2018). Ecological Virtual Reality Evaluation of Neglect Symptoms (EVENS): Effects of Virtual Scene Complexity in the Assessment of Poststroke Unilateral Spatial Neglect. Neurorehabilitation and Neural Repair, 32(1), 46–61. https://doi.org/10.1177/1545968317751677

Pitzalis, S., Di Russo, F., Spinelli, D., & Zoccolotti, P. (2001). Influence of the radial and vertical dimensions on lateral neglect. Experimental Brain Research, 136(3), 281–294. https://doi.org/10.1007/s002210000580

Possin, K. L. (2010). Visual spatial cognition in neurodegenerative disease. In Neurocase (Vol. 16, Issue 6, pp. 466–487). https://doi.org/10.1080/13554791003730600

Puig-Pijoan, A., Giralt-Steinhauer, E., Zabalza de Torres, A., Manero Borràs, R. M., Sánchez-Benavides, G., García Escobar, G., Pérez Enríquez, C., Gómez-González, A., Ois, Á., Rodríguez-Campello, A., Cuadrado-Godía, E., Jiménez-Conde, J., Peña-Casanova, J., & Roquer, J. (2018). Underdiagnosis of Unilateral Spatial Neglect in stroke unit. Acta Neurologica Scandinavica, 138(5), 441–446. https://doi.org/10.1111/ane.12998

Rode, G., Pagliari, C., Huchon, L., Rossetti, Y., & Pisella, L. (2017). Semiology of neglect: An update. In Annals of Physical and Rehabilitation Medicine (Vol. 60, Issue 3, pp. 177–185). Elsevier Masson SAS. https://doi.org/10.1016/j.rehab.2016.03.003

Ronchi, R., Bassolino, M., Viceic, D., Bellmann, A., Vuadens, P., Blanke, O., & Vallar, G. (2020). Disownership of body parts as revealed by a visual scale evaluation. An observational study. Neuropsychologia, 138. https://doi.org/10.1016/j.neuropsychologia.2020.107337

Rorden, C., Fruhmann Berger, M., & Karnath, H. O. (2006). Disturbed line bisection is associated with posterior brain lesions. Brain Research, 1080(1), 17–25. https://doi.org/10.1016/j.brainres.2004.10.071

Rossit, S., Benwell, C. S. Y., Szymanek, L., Learmonth, G., McKernan-Ward, L., Corrigan, E., Muir, K., Reeves, I., Duncan, G., Birschel, P., Roberts, M., Livingstone, K., Jackson, H., Castle, P., & Harvey, M. (2019). Efficacy of home-based visuomotor feedback training in stroke patients with chronic hemispatial neglect. Neuropsychological Rehabilitation, 29(2), 251–272. https://doi.org/10.1080/09602011.2016.1273119

Rowe, F. J., Wright, D., Brand, D., Jackson, C., Harrison, S., Maan, T., Scott, C., Vogwell, L., Peel, S., Akerman, N., Dodridge, C., Howard, C., Shipman, T., Sperring, U., MacDiarmid, S., & Freeman, C. (2013). A prospective profile of visual field loss following stroke: Prevalence, type, rehabilitation, and outcome. BioMed Research International, 2013. https://doi.org/10.1155/2013/719096

Schenkenberg, T., Bradford, D. C., & Ajax, E. T. (1980). Line bisection and unilateral visual neglect in patients with neurologic impairment. Neurology, 30(5), 509–509.

Sea, M. J. C., & Henderson, A. (1994). The reliability and validity of visuospatial inattention tests with stroke patients. Occupational Therapy International, 1(1), 36–48.

Simundic, A.-M. (2012). Article in Point of Care the Journal of Near-Patient Testing & Technology. Point of Care, 11(1), 1–8. www.acutecaretesting.org

Spaccavento, S., Cellamare, F., Falcone, R., Loverre, A., & Nardulli, R. (2017). Effect of subtypes of neglect on functional outcome in stroke patients. Annals of Physical and Rehabilitation Medicine, 60(6), 376–381. https://doi.org/10.1016/j.rehab.2017.07.245

Spreij, L. A., Ten Brink, A. F., Visser-Meily, J. M. A., & Nijboer, T. C. W. (2020). Simulated driving: The added value of dynamic testing in the assessment of visuo-spatial neglect after stroke. Journal of Neuropsychology, 14(1), 28–45. https://doi.org/10.1111/jnp.12172

Stone, S. P., Wilson, B., Wroot, A., Halligan, P. W., Lange, L. S., Marshall, J. C., Greenwood, R. J., & Bartholomew, S. (1991). The assessment of visuo-spatial neglect after acute stroke. In Neurosurgery, and Psychiatry (Vol. 54).

Takamura, Y., Imanishi, M., Osaka, M., Ohmatsu, S., Tominaga, T., Yamanaka, K., Morioka, S., & Kawashima, N. (2016). Intentional gaze shift to neglected space: a compensatory strategy during recovery after unilateral spatial neglect. Brain, 139(11), 2970–2982. https://doi.org/10.1093/brain/aww226

Ting, D. S. J., Pollock, A., Dutton, G. N., Doubal, F. N., Ting, D. S. W., Thompson, M., & Dhillon, B. (2011). Visual Neglect Following Stroke: Current Concepts and Future Focus. In Survey of Ophthalmology (Vol. 56, Issue 2, pp. 114–134). https://doi.org/10.1016/j.survophthal.2010.08.001

Ugur, C., Gücüyener, D., Uzuner, N., Özkan, S., & Özdemir, G. (2000). Characteristics of falling in patients with stroke. In J Neurol Neurosurg Psychiatry (Vol. 69). www.jnnp.com

Van Der Stoep, N., Visser-Meily, J. M. A., Kappelle, L. J., De Kort, P. L. M., Huisman, K. D., Eijsackers, A. L. H., Kouwenhoven, M., Van Der Stigchel, S., & Nijboer, T. C. W. (2013). Exploring near and far regions of space: Distance-specific visuospatial neglect after stroke. Journal of Clinical and Experimental Neuropsychology, 35(8), 799–811. https://doi.org/10.1080/13803395.2013.824555

Vellone, E., Savini, S., Fida, R., Dickson, V. V., Melkus, G. D. E., Carod-Artal, F. J., Rocco, G., & Alvaro, R. (2015). Psychometric evaluation of the stroke impact scale 3.0. Journal of Cardiovascular Nursing, 30(3), 229–241. https://doi.org/10.1097/JCN.0000000000000145

Vossel, S., Weiss, P. H., Eschenbeck, P., Saliger, J., Karbe, H., & Fink, G. R. (2012). The Neural Basis of Anosognosia for Spatial Neglect After Stroke. Stroke, 43, 1954–1956. https://doi.org/10.1161/STROKEAHA.112

Walker, R., Findlay, J. M., Young, A. W., & Welch, J. (1991). Disentangling Neglect and Hemianopia. Neuropsychologia, 29(10), 1019–1027.

Wee, J., & Hopman, W. (2008). Comparing Consequences of Right and Left Unilateral Neglect in a Stroke Rehabilitation Population. American Journal of Physical Medicine & Rehabilitation, 87(11), 910–920.

Whitehouse, C. E., Green, J., Giles, S. M., Rahman, R., Coolican, J., & Eskes, G. A. (2019). Development of the Halifax Visual Scanning Test: A New Measure of Visual-Spatial Neglect for Personal, Peripersonal, and Extrapersonal Space. Journal of the International Neuropsychological Society, 25(5), 490–500. https://doi.org/10.1017/S135561771900002X

Wilson, B. , Cockburn, J., & Halligan, P. (1987). Development of a Behavioural test of visuospatial neglect. Archives of Physical Medicine and Rehabilitation, 68, 98–102.

Wilson, B. A. , Cockburn, J. , & Halligan, P. W. (1981). Behavioural Inattention Test Manual.

Zoccolotti, P., & Antonucci, G. (1992). Psychometric Characteristics of Two Semi-Structured Scales for the Functional Evaluation of Hemi-inattention in Extrapersonal and Personal Space. Neuropsychological Rehabilitation, 2(3), 179–191.

Zoccolotti, P., & Judica, A. (1991). Functional Evaluation of Hemineglect by Means of a Semistructured Scale: Personal Extrapersonal Differentiation. Neuropsychological Rehabilitation, 1(1), 33–44. https://doi.org/10.1080/09602019108401378

Chapter 5: Critical Appraisal and Discussion

The overall aims of this thesis were to systematically review studies validating the psychometric properties of extrapersonal spatial neglect tests before exploring the psychometric properties of the newly developed CENT. The systematic review of 2522 published articles (Chapter 2) demonstrated that validation studies exploring extrapersonal neglect tests show limited psychometric properties, varying definitions of validity (and extrapersonal neglect) and variable consistency in their methodological approach and reporting. In the diagnostic validation study that follows (Chapter 4), the CENT is proposed along with an evaluation of its psychometric properties and diagnostic accuracy.

Main Findings

Systematic Review

The systematic review reviewed 22 validation studies for extrapersonal neglect and highlighted that there are currently no extrapersonal spatial neglect tests with excellent diagnostic accuracy and the studies reporting on their psychometric properties had notable limitations in their methodological approach. In particular, limitations were found in sample sizes, sample size calculations and sample inclusion criteria, as well as substantial gaps in the reporting of pertinent information. Of the eight types of validity and reliability considered within the scope of this review, the average study reported less than two.

The theoretical and clinical implications of this systematic review are that while novel extrapersonal neglect tests show promise compared to widely used peripersonal spatial neglect comparators, inconsistencies in the reporting of these studies of diagnostic validation limit their overall utility and comparability. This limits the ability of clinicians who acknowledge the need for extrapersonal diagnostic tools to compare them and select the test that is most appropriate for their service context.

Empirical Paper

This validation study demonstrates that the CENT appears to have high diagnostic accuracy, concurrent validity, ecological validity, internal consistency, and discriminant validity. To our knowledge the CENT demonstrates higher diagnostic accuracy than other extrapersonal neglect tests (Stermsek et al., unpublished manuscript). In this study, the CENT also identified 10.96% of the stroke-survivors in our sample as having extrapersonal neglect without peripersonal neglect, demonstrating a potential dissociation. A similar extrapersonal neglect prevalence has been echoed in other studies (7%-11%, Van Den Stoep, Visser-Meily, Kappelle, De Kort, Huisman, Eijsackers, Kouwenhoven, Van Der Stigchel & Nijboer, 2013; 21%, Thomasson, Perez-Marcos, Crottaz-Herbette, Brenet, Saj, Bernati, Serino, Tadi, Blanke & Ronchi, 2023; 11-25%, Aimola, Schindler, Simone & Venneri, 2012). Moreover, our sample presented with similar rates of peripersonal neglect (39.73%), as seen in other literature (Bowen, McKenna & Tallis, 1999; Hammerbeck et al., 2019; Puig-Pijoan, Giralt-Steinhauer, Zabalza de Torres, Manero Borras, Sanchez-Benavides, Garcia-Escobar, Perez-Enriquez, Gomez-Gonzalez, Ois, Rodriguez-Campello, Cuadrado-Godia, Jimenez-Conde, Pena-Casanova & Roquer, 2018).

In addition, our findings demonstrate a dissociation between allocentric and egocentric neglect, with 15.07% (n = 11) participants demonstrating peripersonal allocentric neglect, 13.7% (n = 10) peripersonal egocentric neglect, with only 6.85% (n = 5) participants demonstrated both forms of neglect in the peripersonal space. Similar findings were replicated by Demeyere & Gillebert (2019) when exploring the allocentric and egocentric variables of the OCS cancellation task. However, their sample tested stroke survivors within three weeks of their stroke, while this study consists of discharged stroke survivors in the community. The low rates of allocentric and egocentric neglect in our sample, may be due to high recovery rates (reported as 74% and 81% respectively; Demeyere & Gillebert, 2019). In terms of allocentric and egocentric neglect in the extrapersonal space, 13.7% (n = 10) participants met threshold for allocentric, 16.44% (n = 12) participants showed egocentric, and 5.48% (n = 4) showed both forms of neglect in the extrapersonal space.

There was little overlap between participants identified as allocentric in the peripersonal space and those identified as allocentric in the extrapersonal space (36%, n = 4). Approximately 50% (n=5) overlap was found for egocentric neglect in peripersonal and extrapersonal space. These preliminary findings arguably provide support for the theory that these subtypes of neglect are dissociable, and that peripersonal and egocentric attention are linked to the dorsal steam and extrapersonal and allocentric attention are linked to the ventral stream. Furthermore, the overlap between neglect subtypes in these findings might suggest that neglect symptoms are not solely determined by damage to specific areas (ventral stream; Utz, Hesse, Hintz, Gruneberg, Kulke, Roth, Klos, Kromichal, Melms, Schupp, Kohl & Schenk, 2018), but rather, determined by disruption to the cortical networks impacting communication between these two visual steams (Rossit, McIntosh, Malhotra, Butler, Muir & Harvey, 2012). To our knowledge, apart from the previously published preliminary results of the CENT (Morse et al., 2023) there are no other studies that investigated allocentric and egocentric neglect in the extrapersonal space.

The strong diagnostic accuracy and psychometric properties demonstrated by the CENT Cancellation subtask were not found in the CENT Line Bisection subtest. Previous literature has demonstrated that extrapersonal line bisection performance was less sensitive when compared to extrapersonal cancellation performance (Van Den Stoep et al., 2013). Moreover, the CENT Line Bisection variables (Line Bisection Duration and Line Bisection Deviation) did not correlate significantly with the peripersonal Line Bisection reference test. These findings are echoed in previous literature and could potentially be due to extrapersonal and peripersonal neglect being associated with different attentional streams, the ventral and dorsal streams respectively (Aimola et al., 2012; Van Den Stoep et al., 2013). Given these results, the CENT may benefit from removing the Line Bisection subtask, as it provides limited psychometric benefit.

Strengths and Limitations

Systematic Review

This systematic review has several strengths, making it a valuable and rigorous contribution to stroke research. In terms of rigor, the review closely followed the PRISMA guidelines (Moher, 2015) and throughout the process of study selection and appraisal, an independent second reviewer was utilised to ensure accuracy and consistency in decision making. Moreover, a validated quality assessment tool, the QAVALS was used. Given the stark lack of consistency in the terms used for extrapersonal spatial neglect, the search strategy was directly informed by a recent scoping review which found 17 different terms for extrapersonal spatial neglect currently being used (Williams, Kernot, Hillier & Loetscher, 2021). This field of extrapersonal spatial neglect research may benefit greatly from a Delphi study aiming to achieve international consensus in terms of extrapersonal spatial neglect nomenclature. More consensus in terminology would allow for better communication and collaboration amongst both researchers and clinicians, as well as making it easier to aggregate data from different studies, conduct meta-analyses and draw more robust conclusions.

In terms of value, a critical strength of this systematic review is that it provides a thorough overview of extrapersonal spatial neglect tests, presenting and critically appraising their findings in a way that allows clinicians to easily make evidence-based decisions that can directly inform assessment. Moreover, it highlights the importance and value of computerisation while also acknowledging that a balance must be found as expensive equipment can make it difficult for services to secure funding.

Empirical Paper

This empirical paper also has notable strengths, making it a valuable and rigorous contribution to stroke research. In terms of rigor, this validation study meets all applicable QAVALS criteria, demonstrating high quality reporting and a robust methodology for validation studies. This study also provides a wider range of psychometric properties than any other extrapersonal diagnostic test currently validated on stroke survivors, increasing its ability to be compared with future validation studies.

Pertaining to value, the clinical implications of this research are firstly, that it offers evidence that extrapersonal spatial neglect is currently eluding detection by widely used pen-and-paper diagnostic tests for spatial neglect, emphasising the clinical need for validated diagnostic tests for extrapersonal spatial neglect. The clinical implications of this are that one in ten stroke survivors with extrapersonal spatial neglect remain undiagnosed and therefore may not be being taken into consideration for their rehabilitation, risk, and discharge planning. Moreover, this study provides evidence that extrapersonal neglect is a dissociable condition requiring clinical consideration. It also provides some preliminary evidence that for some stroke survivors egocentric and allocentric neglect may present in the extrapersonal space only, however this requires further investigation, potentially on an acute stroke survivor population, as high rates of recovery have been reported in the literature (Demeyere & Gillebert, 2019), or in combination with lesion mapping data to better understand the neuroanatomical areas involved. Another clinical implication is that this research highlights the applicability of a computerised format of diagnostic testing. It demonstrates how even partial computerisation can allow for swift delivery, automatic scoring and paves the way for formulation (and feedback) assisting outputs, like a visual field heatmap that the Neurolab team are currently developing.

A limitation of this empirical paper is that lesion-symptom analysis was not computed due to time constraints. Implementing this analysis into our findings would have further broadened our understanding of the enigmatic neuroanatomical regions associated with the subtypes of neglect, but also added to the very limited number of studies in this area (Moore et al., 2023).

Another limitation of this empirical paper related to our assessment of personal neglect. Due to the COVID-19 pandemic and in an attempt to reduce test burden, the One-Item Extended task was used. In practice, this test was not sensitive, as all but three participants scored full marks, indicating a ceiling effect. This is vastly different from the literature, reporting comorbid personal and extrapersonal neglect rates of as high as 85% (Caggiano & Jehkonen, 2018). Using a functional diagnostic battery such as the Catherine Bergego Scale (Azouvi, Marchal, Samuel, Morin, Renard, Louis-Dreyfus, Jokic, Wiart, Pradat-Diehl, Deloche & Bergego, 1996) would have not only allowed for a more accurate assessment of personal neglect, but due to its true to real life subtasks in the peripersonal and extrapersonal space, it would have also allowed for additional reference test comparisons. Furthermore, it would also allow for additional comparisons for ecological validity as the tasks involve activities of daily living. Although beneficial, it was felt this would have substantially increased test burden.

Moreover, a limitation of this empirical paper relates to the potential presence of hemianopia. Hemianopia and spatial neglect, while having distinct and separate anatomical and medical causes, present very similarly and both can be persisting conditions experienced by stroke survivors. To capture participants who may have hemianopia in our sample, we included the Visual Field Deficit Subtest of the OCS. Although the OCS subtest can detect a visual field deficit in the absence of neglect (impaired visual field subtest and unimpaired cancellation task), if both are impaired, it can be difficult to separate. Upon closer inspection of the dataset, not a single participant scored in the impaired range on the Visual Field Deficit Subtest that did not also score in the impaired range on tests of spatial neglect. Future trials exploring spatial neglect may benefit from including a formal ophthalmology assessment for participants, such as the Humphreys Perimetry test, as this may help distinguish these two similarly presenting conditions. While we have attempted to screen and mitigate the presence of hemianopia in this study, we cannot be certain that some participants did not have both spatial neglect and hemianopia.

Another limitation of this empirical study is that due to a lack of established reference standard to compare to, there is an inherent challenge in ascertaining the diagnostic accuracy of the CENT. Usually when sensitivity and specificity are computed for a new diagnostic test, the reference standard has a sensitivity and specificity of 100%. In the absence of a gold standard, as is common with many neuropsychological diagnostic tests (compared to medical diagnostic tests), we referenced the closest widely used and most similar tests. By virtue of the CENT being an extrapersonal spatial neglect test and our reference standards being peripersonal spatial neglect tests, the false-positive and false-negative rates of the CENT may be either a sign of diagnostic inaccuracy, or evidence that the CENT is better able to diagnose individuals with extrapersonal spatial neglect than peripersonal reference tests. Given the similarity between the CENT subtests and our reference tests (line bisection and cancellation) with the main difference being that it is administered in the near or far space, it could be argued that the CENT should be measuring extrapersonal spatial neglect. Another important difference worth acknowledging is that the CENT is computerised, and the reference tests were not. This is important as it is currently unclear to what extent, if any, this has on CENT's accuracy.

Future research should continue to develop and establish the psychometric properties of diagnostic tests for extrapersonal neglect as clinicians currently have little choice. Given how promising the CENT has shown to be in this initial validation study, future research should continue to explore the test's usefulness in tracking recovery compared with other widely used tests. A next step would be for future research to explore the feasibility within clinical hospital settings, to give a more holistic view of the test's overall clinical usefulness, applicability, and feasibility.

Conclusions

This thesis set out to systematically review the current landscape of validated diagnostic tests for extrapersonal spatial neglect before conducting a large validation study of a novel test currently being developed in stroke survivor's homes. While the quality of currently available validated tests for extrapersonal spatial neglect generally appear to be limited in their psychometric properties and methodological rigor, the preliminary psychometric properties of the CENT appear promising and worthy of further investigation. Clinical settings currently not utilising formal extrapersonal neglect testing may not be identifying one in ten stroke survivors who have extrapersonal spatial neglect. Identifying these individuals would inform treatment and safety planning. Clinicians reading this thesis portfolio may therefore benefit from evaluating the evidence presented and seeing which extrapersonal spatial neglect test would be most appropriate and best fit for their service context.

Chapter 6: Additional Results

This chapter presents all ROC analyses and Spearman Correlations completed for the empirical paper. Figures 3, 4, 5 and 6 illustrate the ROC analyses that did not demonstrate high diagnostic accuracy. Tables 3, 4, 5 and 6 report all computed Spearman Correlations with significant results (Bonferroni Corrected), highlighted in green.

Additional ROC Results

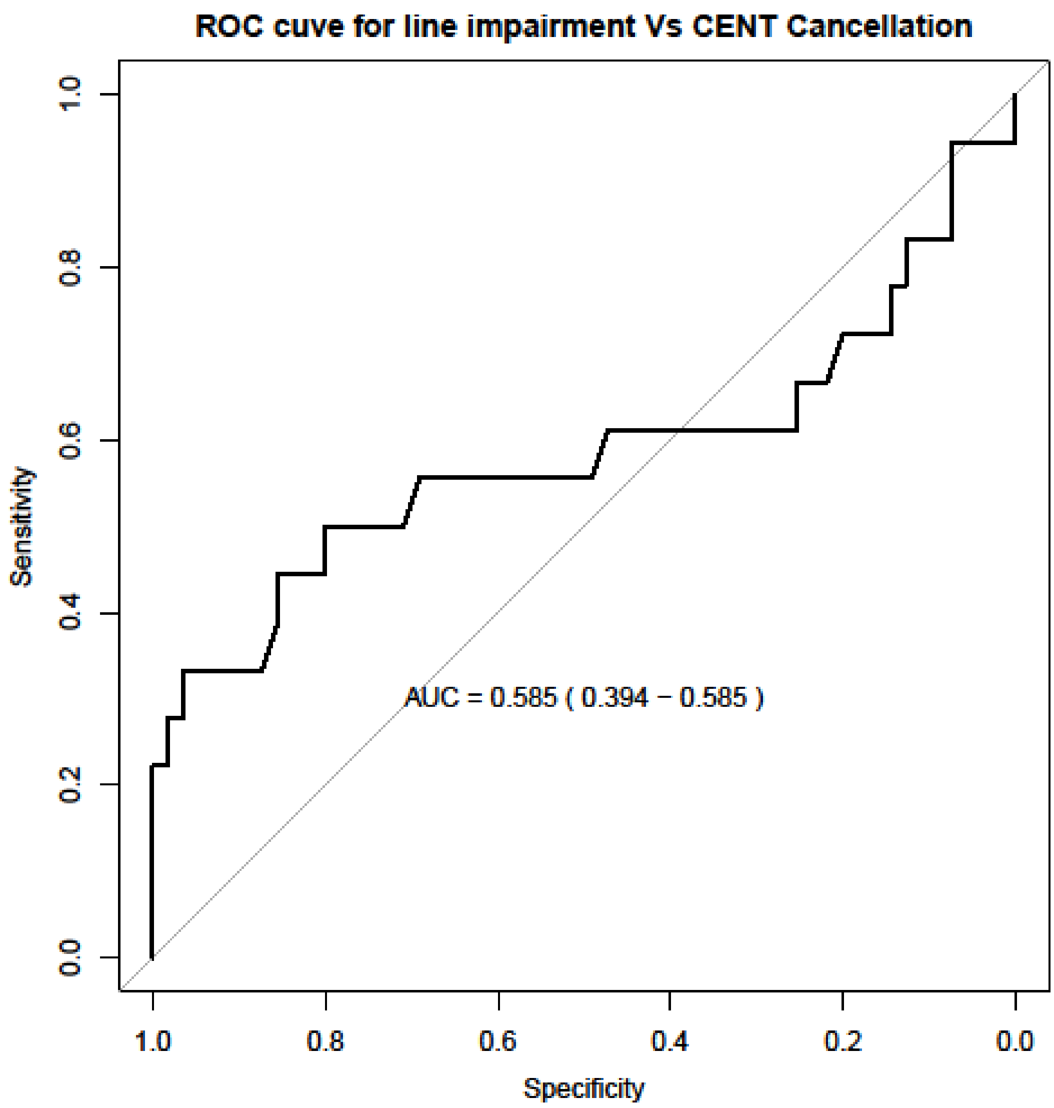


Figure 3. CENT Cancellation and Line Bisection.

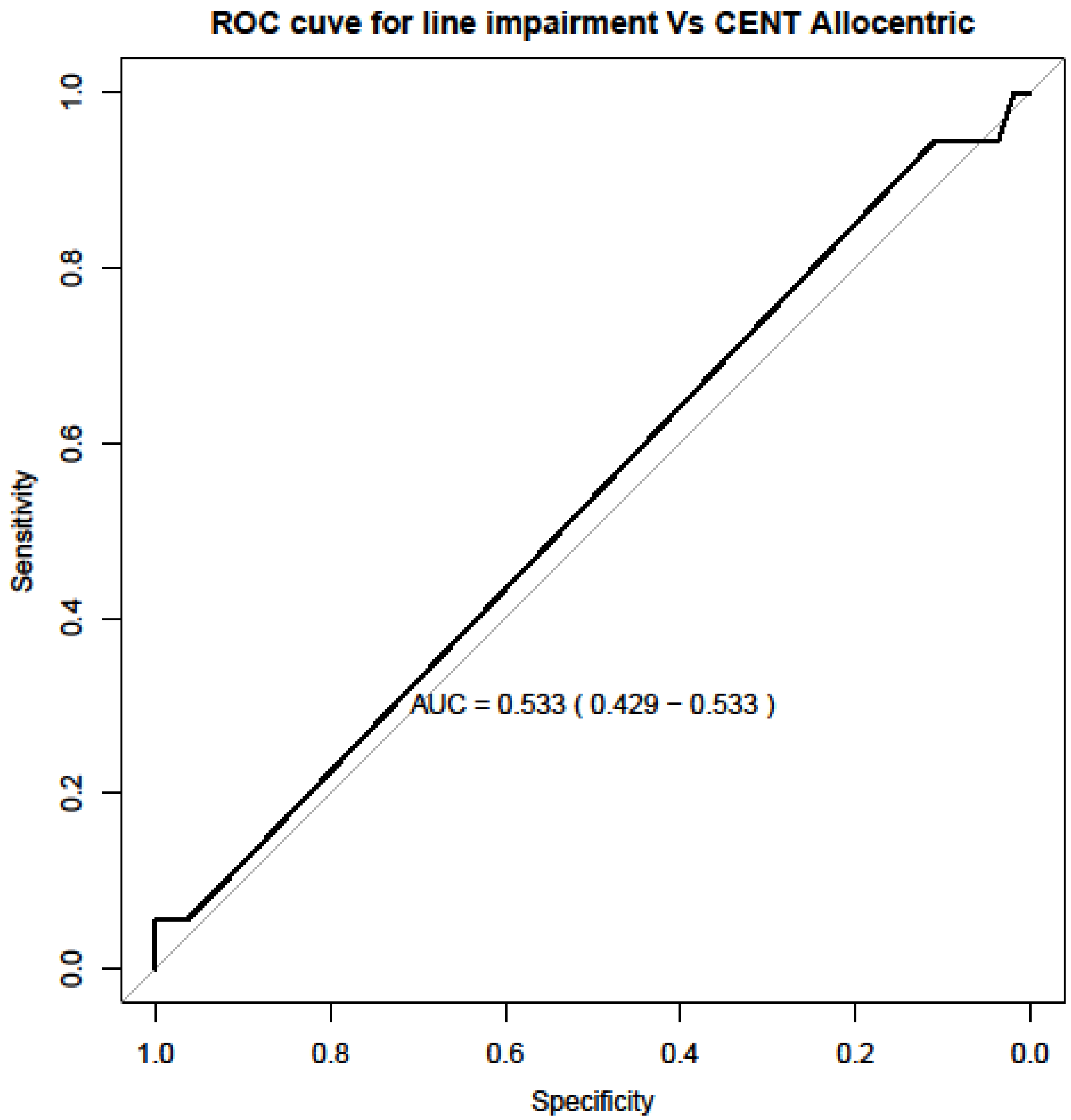


Figure 4. CENT Allocentric Score and Line Bisection.

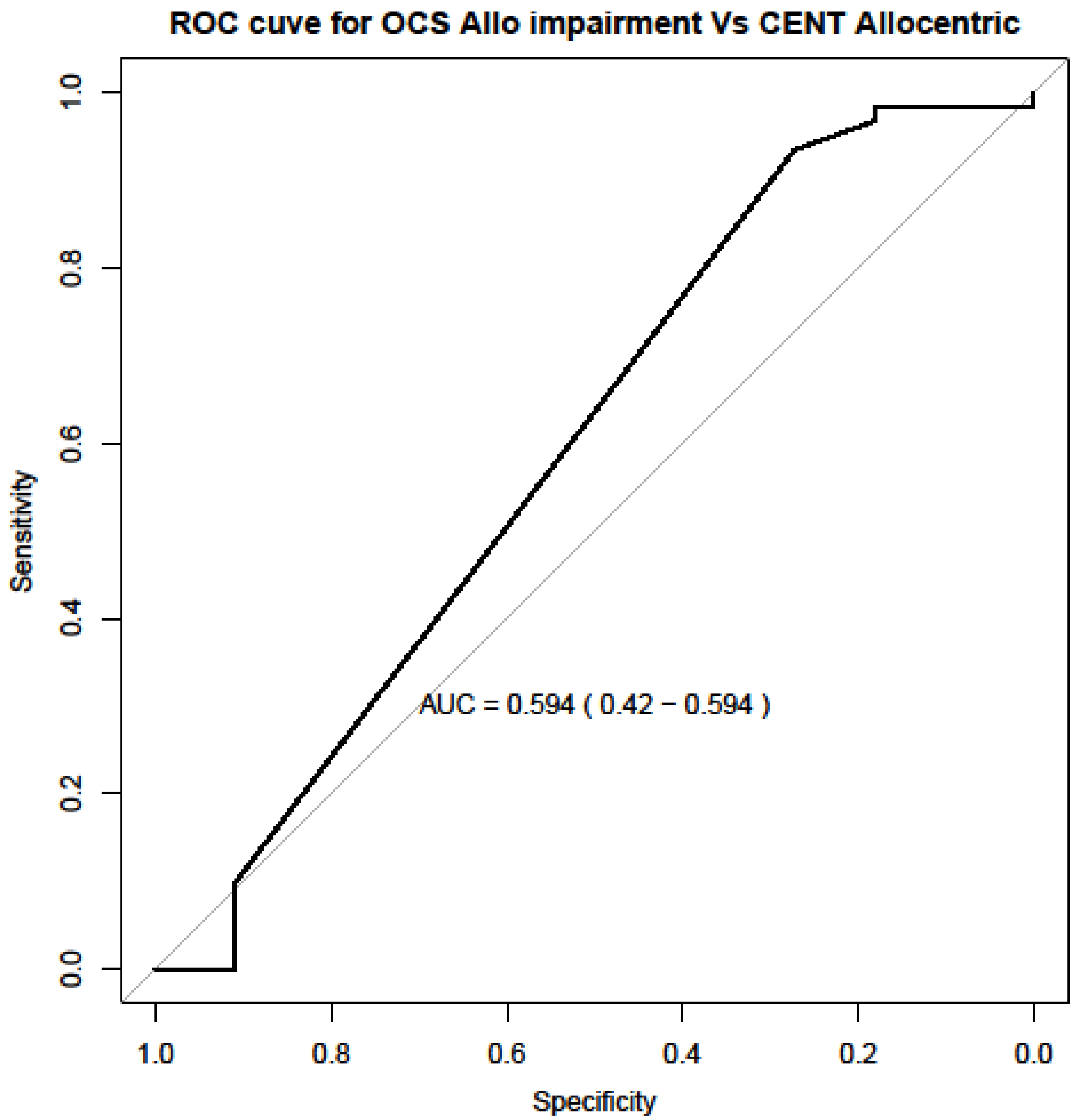


Figure 5. CENT Allocentric Score and OCS Allocentric Score**.**

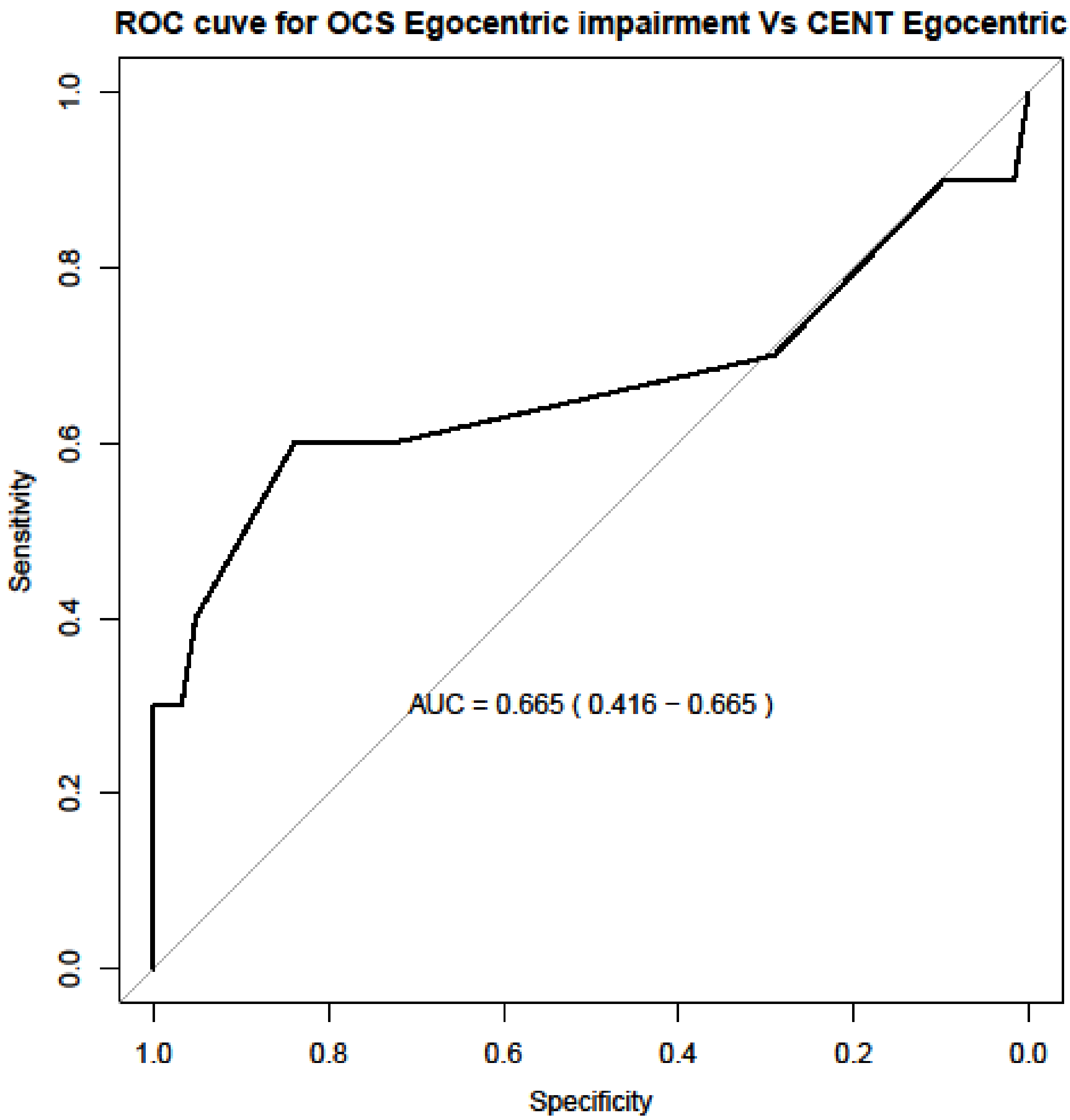


Figure 6. CENT Egocentric Score and OCS Egocentric Score

Additional Spearman correlation results

Table 3. All computed Spearman correlations for Oxford Cognitive Scale variables.

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
Star Cancellation Test	r =	0.200	0.199	.379	0.229	.379	.355	-0.035	0.133	.231	-0.180
	p =	0.089736257558861	0.090856656345856	0.000946162002232	0.051039479290707	0.000929030014540	0.002052597959461	0.769254956390673	0.262859729458560	0.049378912215909	0.132060068314266
	n =	73	73	73	73	73	73	73	73	73	71
OCS Hearts Cancellation	r =	0.182	0.227	.519	.283	.338	.258	0.226	0.220	0.223	-.317
	p =	0.122681021659626	0.053201501798718	0.000002605785990	0.015108584196074	0.003414924169659	0.027343531402538	0.054383982809287	0.061672808862411	0.057394924843553	0.007140414523196
	n =	73	73	73	73	73	73	73	73	73	71
OCS Allocentric	r =	0.045	-0.125	-.329	-0.102	-0.174	-0.122	-0.063	.243	-0.175	0.189
	p =	0.708918231585634	0.293828163645098	0.004801416210169	0.393573784358328	0.143221562046871	0.308556785350466	0.601918919883087	0.039613041386442	0.142531024542320	0.116753434996937
	n =	72	72	72	72	72	72	72	72	72	70
OCS Egocentric	r =	0.075	-0.011	-0.215	0.190	0.083	0.037	-0.068	.245	-0.072	-0.043
	p =	0.529107250048933	0.930159744805062	0.070100452367409	0.110706439663316	0.488902034284306	0.756626584406108	0.567862394613176	0.038134579352464	0.549242020132463	0.721330979734283
	n =	72	72	72	72	72	72	72	72	72	70
Line Bisection Error	r =	-0.007	-.259	-0.186	0.085	-0.155	0.004	0.066	-0.080	-0.042	0.097
	p =	0.950405747893971	0.026993528465153	0.115132113965569	0.473539046734631	0.191340321360373	0.973422507410123	0.581297448643287	0.499253789394804	0.726570072718224	0.419923260997217
	n =	73	73	73	73	73	73	73	73	73	71
VAS	r =	-0.124	-0.147	-.507	-0.033	-0.011	-0.067	-0.057	-0.034	-0.153	0.118

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
	p =	0.300831170036035	0.218202091100943	0.000005448431068	0.783212981033485	0.929598517409243	0.575108150526508	0.635099373696736	0.778007943386765	0.198129369651773	0.330570176453227
	n =	72	72	72	72	72	72	72	72	72	70
Personal neglect	r =	0.102	-0.035	0.092	.314	.332	0.172	-0.065	.236	-0.074	-.262
	p =	0.393285853760497	0.768861132193587	0.441203654400462	0.007163712756241	0.004386015378900	0.148295687919292	0.589463203643393	0.045952707096297	0.538659490034977	0.028606271886717
	n =	72	72	72	72	72	72	72	72	72	70
OCS Picture	r =	1.000	-0.078	0.143	.274	0.021	0.019	-0.032	.233	0.156	-0.048
	p =		0.512930974415702	0.228932035718566	0.019139200605384	0.860213776794576	0.875670386974014	0.785931153329555	0.047327706751980	0.186127386039881	0.693390909115420
	n =	73	73	73	73	73	73	73	73	73	71
OCS Orientation	r =	-0.078	1.000	0.180	-0.081	0.167	0.077	0.167	0.141	-0.063	-0.206
	p =	0.512930974415702		0.127287757408280	0.494787873763733	0.158437355605215	0.518287959692629	0.156879255281032	0.235077549837175	0.597361367058847	0.084938015592136
	n =	73	73	73	73	73	73	73	73	73	71
OCS Visual Field	r =	0.143	0.180	1.000	0.038	0.053	0.105	0.160	-0.042	.328	-.315
	p =	0.228932035718566	0.127287757408280		0.750327017030366	0.658551889916561	0.375111663784292	0.175352616423810	0.721885537968943	0.004631613201650	0.007415519448333
	n =	73	73	73	73	73	73	73	73	73	71
OCS Reading	r =	.274	-0.081	0.038	1.000	.438	.246	-0.094	0.178	0.066	-0.064
	p =	0.019139200605384	0.494787873763733	0.750327017030366		0.000105124226015	0.035972501997847	0.428132557818160	0.132639530948405	0.577928385911706	0.595712234904340
	n =	73	73	73	73	73	73	73	73	73	71

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
OCS Number	r =	0.021	0.167	0.053	.438	1.000	.389	-0.069	-0.105	-0.036	-0.084
	p =	0.860213776794576	0.158437355605215	0.658551889916561	0.000105124226015		0.000675188100329	0.559988775603425	0.376253144420243	0.760783190999664	0.485725537507137
	n =	73	73	73	73	73	73	73	73	73	71
OCS Calculation	r =	0.019	0.077	0.105	.246	.389	1.000	-0.053	0.032	0.128	-0.073
	p =	0.875670386974014	0.518287959692629	0.375111663784292	0.035972501997847	0.000675188100329		0.655975396590236	0.787982363138970	0.279852743018488	0.542903451771222
	n =	73	73	73	73	73	73	73	73	73	71
OCS Imitation	r =	-0.032	0.167	0.160	-0.094	-0.069	-0.053	1.000	0.218	-0.025	-0.096
	p =	0.785931153329555	0.156879255281032	0.175352616423810	0.428132557818160	0.559988775603425	0.655975396590236		0.063568114274983	0.833996621807208	0.426448004845553
	n =	73	73	73	73	73	73	73	73	73	71
OCS Recall	r =	.233	0.141	-0.042	0.178	-0.105	0.032	0.218	1.000	0.114	-0.119
	p =	0.047327706751980	0.235077549837175	0.721885537968943	0.132639530948405	0.376253144420243	0.787982363138970	0.063568114274983		0.335533001956765	0.323915744788875
	n =	73	73	73	73	73	73	73	73	73	71
OCS Episodic Memory	r =	0.156	-0.063	.328	0.066	-0.036	0.128	-0.025	0.114	1.000	-.331
	p =	0.186127386039881	0.597361367058847	0.004631613201650	0.577928385911706	0.760783190999664	0.279852743018488	0.833996621807208	0.335533001956765		0.004859087629161
	n =	73	73	73	73	73	73	73	73	73	71
OCS Executive	r =	-0.048	-0.206	-.315	-0.064	-0.084	-0.073	-0.096	-0.119	-.331	1.000
	p =	0.693390909115420	0.084938015592136	0.007415519448333	0.595712234904340	0.485725537507137	0.542903451771222	0.426448004845553	0.323915744788875	0.004859087629161	
	n =	71	71	71	71	71	71	71	71	71	71

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
SIS Physical	r =	0.063	0.035	.263	0.111	.235	0.107	-.326	-0.008	0.116	-0.193
	p =	0.603404485928659	0.768856749546210	0.026452611709816	0.358418084602862	0.048247689966002	0.372926486844604	0.005573400728663	0.948433170496684	0.335646498343809	0.111913635993049
	n =	71	71	71	71	71	71	71	71	71	69
SIS Cognition	r =	0.117	0.146	0.225	0.122	0.146	-0.092	-.421	-0.055	0.226	-0.141
	p =	0.331519498662431	0.224195400481698	0.059537528879621	0.311673994488570	0.224663963283412	0.445494353257429	0.000257904668793	0.646126609806244	0.058207516096700	0.248545567179458
	n =	71	71	71	71	71	71	71	71	71	69
SIS Mood	r =	0.033	-0.083	.276	0.054	0.177	0.008	-.405	-0.099	0.159	-0.066
	p =	0.784582003282304	0.485753084406801	0.019097169380774	0.653632502012824	0.137014437140103	0.943943343100769	0.000420836531000	0.408528464698655	0.181279583001976	0.588954447296307
	n =	72	72	72	72	72	72	72	72	72	70
SIS Communication	r =	0.086	0.115	0.218	0.196	0.222	-0.044	-.377	-0.037	0.170	-0.098
	p =	0.472501520355069	0.334741117853849	0.065258169485579	0.098545275526902	0.060574705300064	0.712159005306502	0.001098993673623	0.758889765404879	0.153516347123083	0.417609393976512
	n =	72	72	72	72	72	72	72	72	72	70
SIS ADL	r =	0.130	0.106	.347	0.008	.242	0.112	-.239	0.012	0.218	-0.115
	p =	0.277540013207452	0.374889971460788	0.002855566007679	0.949511490307616	0.040414459731892	0.350856717473213	0.042751553109391	0.920983853794077	0.066282558556758	0.342708298714486
	n =	72	72	72	72	72	72	72	72	72	70
SIS Mobility	r =	0.097	0.075	.284	-0.005	0.219	0.191	-.279	0.061	0.158	-0.121
	p =	0.417386424424117	0.529159676357094	0.015584349426661	0.963572278079922	0.064273555406474	0.107310786486129	0.017425111496304	0.608659025889013	0.184242032049657	0.319782012608398
	n =	72	72	72	72	72	72	72	72	72	70

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
SIS Hand	r =	0.083	0.098	.354	0.051	.342	0.212	-0.189	0.100	0.160	-0.197
	p =	0.487222523518118	0.412068480010041	0.002270144319744	0.669938773666201	0.003245357797864	0.073786580022245	0.111177282690178	0.403848198690277	0.178472335665722	0.101403658683972
	n =	72	72	72	72	72	72	72	72	72	70
SIS Social	r =	-0.001	0.071	.322	0.012	.271	0.041	-0.206	0.024	0.092	-0.188
	p =	0.992513073226075	0.558108499200962	0.006200304462262	0.920494115353779	0.022025904373855	0.733536869480638	0.085222137942498	0.839566687528503	0.447350458582246	0.121052522292636
	n =	71	71	71	71	71	71	71	71	71	69
SIS Recovery	r =	.325	0.178	.332	0.011	0.109	0.094	-0.053	0.120	0.105	-0.145
	p =	0.005354653651114	0.135328818121607	0.004332105434449	0.927185523658438	0.360670734407368	0.432899734615720	0.657822880609993	0.317339670381323	0.379066342232119	0.231973435879145
	n =	72	72	72	72	72	72	72	72	72	70
CENT Cancellation Accuracy	r =	.289	0.095	.463	0.191	.366	.300	-0.016	0.022	.238	-.313
	p =	0.013066548947493	0.421742207009962	0.000037188824489	0.105196673801802	0.001456848094814	0.009819940147408	0.894501675002563	0.854017997392550	0.042334132026966	0.007779588414974
	n =	73	73	73	73	73	73	73	73	73	71
CENT Errors	r =	-0.198	0.088	-0.080	-0.042	-0.194	-.263	0.029	-0.071	-0.096	0.096
	p =	0.092684955960726	0.458512885297952	0.502009146011764	0.725282255483940	0.100623860205336	0.024847122868729	0.805395769007617	0.550942163240758	0.421453783289858	0.428191288345942
	n =	73	73	73	73	73	73	73	73	73	71
CENT Recancellations	r =	-.249	-0.209	-.334	-0.044	-0.214	-0.221	-0.024	-0.109	-0.114	0.204
	p =	0.033900351677363	0.075435437327851	0.003864362404406	0.714606075287956	0.068793450457477	0.060755186196891	0.842089551157670	0.360480344233307	0.337109298102515	0.087402646404795
	n =	73	73	73	73	73	73	73	73	73	71

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
CENT Search duration	r =	-.395	-0.122	-0.050	-0.143	-0.160	-.231	0.044	-.263	-0.158	.270
	p =	0.000544088714245	0.305839502440048	0.671711921322318	0.228750921198977	0.175598417284259	0.049294389692649	0.713606367075801	0.024750751147153	0.181822535617487	0.022599245019671
	n =	73	73	73	73	73	73	73	73	73	71
CENT Egocentric	r =	0.109	0.218	0.119	0.001	0.003	-0.026	0.139	-0.113	-0.196	0.105
	p =	0.358262377342055	0.063371992239152	0.316153995273340	0.992526119747949	0.981189727504933	0.825345508797237	0.240310942169302	0.340293968735941	0.096851600177435	0.385334931693070
	n =	73	73	73	73	73	73	73	73	73	71
CENT Allocentric	r =	0.080	0.000	-0.069	0.095	0.012	-0.157	-0.079	-0.068	0.087	-0.063
	p =	0.498446374978965	1.000000000000000	0.563751014546405	0.425715097246865	0.916976076249874	0.185615452741107	0.503800173426151	0.567562635232156	0.465972319883662	0.603591272987416
	n =	73	73	73	73	73	73	73	73	73	71
CENT Intersections	r =	-0.147	-0.174	-0.216	0.157	-0.097	0.075	0.080	0.014	-0.024	.289
	p =	0.215092104664625	0.141559476972171	0.067056896209114	0.184260829719843	0.414007066013458	0.531017688149416	0.500625166946029	0.906295689627711	0.841037313834603	0.014599056096799
	n =	72	73	73	73	73	73	73	73	73	73
CENT Quality of Search	r =	.381	0.166	.339	0.136	.232	.317	0.048	0.197	0.187	-.304
	p =	0.000875165805762	0.161683001625123	0.003375393437558	0.251089865786055	0.048513605898851	0.006342178857159	0.687856071768706	0.095664002306396	0.113706612373271	0.009841896371695
	n =	72	73	73	73	73	73	73	73	73	73
CENT Bisection Error	r =	-0.199	-0.131	-0.009	-0.162	-0.164	-0.025	-0.084	0.007	-0.124	-0.042
	p =	0.090702074280478	0.267644378956119	0.940579233441457	0.170154566542511	0.165293959580542	0.831763953704063	0.478337872246500	0.951622600144651	0.295909139653986	0.730538950929476
	n =	72	73	73	73	73	73	73	73	73	73

		OCS Picture	OCS Orientation	OCS Visual Field	OCS Reading	OCS Number	OCS Calculation	OCS Imitation	OCS Recall	OCS Episodic Memory	OCS Executive
CENT Bisection Duration	r =	-.280	-0.185	-.341	-0.173	-.270	-0.139	-0.116	-0.200	-0.120	0.190
	p =	0.016380283334684	0.1166483574862 72	0.0031711563858 83	0.143854688845157	0.020755684844376	0.239172578298347	0.328388149103497	0.090308457735315	0.313267653218557	0.112129021167820
	n =	72	73	73	73	73	73	73	73	73	73

*Green indicates significance (p ≤ 0.000075)

Table 4. All computed Spearman correlations for spatial neglect comparator tests

		Star Cancellation	**OCS Hearts Cancellation**	**OCS Allocentric**	**OCS Egocentric**	**Line Bisection Error**	**Visual Analogue Scale**	**Personal Neglect**
Star Cancellation Test	r =	1.000	.701	-.321	0.050	-.255	-.314	.267
	p =		0.000000000005167	0.006035073492402	0.675925502485686	0.029668512853694	0.007160600278759	0.023493947674081
	n =	73	73	72	72	73	72	72
OCS Hearts Cancellation	r =	.701	1.000	-.329	-0.063	-.289	-.435	.273
	p =	0.000000000005167		0.004779664635908	0.601362453730833	0.013103233739290	0.000134146263012	0.020531505068839
	n =	73	73	72	72	73	72	72
OCS Allocentric	r =	-.321	-.329	1.000	0.176	.312	0.193	0.153
	p =	0.006035073492402	0.004779664635908		0.140229357653919	0.007533133681625	0.106010457620404	0.203546258235479
	n =	72	72	72	72	72	71	71
OCS Egocentric	r =	0.050	-0.063	0.176	1.000	-0.102	0.102	0.233
	p =	0.675925502485686	0.601362453730833	0.140229357653919		0.395459653281880	0.399143156100423	0.050756434290924
	n =	72	72	72	72	72	71	71
Line Bisection Error	r =	-.255	-.289	.312	-0.102	1.000	0.215	-0.025
	p =	0.029668512853694	0.013103233739290	0.007533133681625	0.395459653281880		0.070011476029932	0.834507843098433
	n =	73	73	72	72	73	72	72
Visual Analogue Scale	r =	-.314	-.435	0.193	0.102	0.215	1.000	0.101
	p =	0.007160600278759	0.000134146263012	0.106010457620404	0.399143156100423	0.070011476029932		0.396789050229773
	n =	72	72	71	71	72	72	72
Personal neglect	r =	.267	.273	0.153	0.233	-0.025	0.101	1.000
	p =	0.023493947674081	0.020531505068839	0.203546258235479	0.050756434290924	0.834507843098433	0.396789050229773	
	n =	72	72	71	71	72	72	72

		Star Cancellation	OCS Hearts Cancellation	OCS Allocentric	OCS Egocentric	Line Bisection Error	Visual Analogue Scale	Personal Neglect
OCS Picture	r =	0.200	0.182	0.045	0.075	-0.007	-0.124	0.102
	p =	0.089736257558861	0.122681021659626	0.708918231585634	0.529107250048933	0.950405747893971	0.300831170036035	0.393285853760497
	n =	73	73	72	72	73	72	72
OCS Orientation	r =	0.199	0.227	-0.125	-0.011	-.259	-0.147	-0.035
	p =	0.090856656345856	0.053201501798718	0.293828163645098	0.930159744805062	0.026993528465153	0.218202091100943	0.768861132193587
	n =	73	73	72	72	73	72	72
OCS Visual Field	r =	.379	.519	-.329	-0.215	-0.186	-.507	0.092
	p =	0.000946162002232	0.000002605785990	0.004801416210169	0.070100452367409	0.115132113965569	0.000005448431068	0.441203654400462
	n =	73	73	72	72	73	72	72
OCS Reading	r =	0.229	.283	-0.102	0.190	0.085	-0.033	.314
	p =	0.051039479290707	0.015108584196074	0.393573784358328	0.110706439663316	0.473539046734631	0.783212981033485	0.007163712756241
	n =	73	73	72	72	73	72	72
OCS Number	r =	.379	.338	-0.174	0.083	-0.155	-0.011	.332
	p =	0.000929030014540	0.003414924169659	0.143221562046871	0.488902034284306	0.191340321360373	0.929598517409243	0.004386015378900
	n =	73	73	72	72	73	72	72
OCS Calculation	r =	.355	.258	-0.122	0.037	0.004	-0.067	0.172
	p =	0.002052597959461	0.027343531402538	0.308556785350466	0.756626584406108	0.973422507410123	0.575108150526508	0.148295687919292
	n =	73	73	72	72	73	72	72
OCS Imitation	r =	-0.035	0.226	-0.063	-0.068	0.066	-0.057	-0.065
	p =	0.769254956390673	0.054383982809287	0.601918919883087	0.567862394613176	0.581297448643287	0.635099373696736	0.589463203643393
	n =	73	73	72	72	73	72	72
OCS Recall	r =	0.133	0.220	.243	.245	-0.080	-0.034	.236
	p =	0.262859729458560	0.061672808862411	0.039613041386442	0.038134579352464	0.499253789394804	0.778007943386765	0.045952707096297

		Star Cancellation	OCS Hearts Cancellation	OCS Allocentric	OCS Egocentric	Line Bisection Error	Visual Analogue Scale	Personal Neglect
	n =	73	73	72	72	73	72	72
OCS Episodic Memory	r =	.231	0.223	-0.175	-0.072	-0.042	-0.153	-0.074
	p =	0.049378912215909	0.057394924843553	0.142531024542320	0.549242020132463	0.726570072718224	0.198129369651773	0.538659490034977
	n =	73	73	72	72	73	72	72
OCS Executive	r =	-0.180	-.317	0.189	-0.043	0.097	0.118	-.262
	p =	0.132060068314266	0.007140414523196	0.116753434996937	0.721330979734283	0.419923260997217	0.330570176453227	0.028606271886717
	n =	71	71	70	70	71	70	70
SIS Physical	r =	.375	.295	-0.027	0.007	-0.131	-0.145	0.202
	p =	0.001280444168433	0.012435766838005	0.826774880907027	0.956453932114610	0.275416053999787	0.227243436223088	0.091681204947708
	n =	71	71	70	70	71	71	71
SIS Cognition	r =	.322	0.151	0.132	0.135	-0.151	-0.147	0.120
	p =	0.006235464807833	0.207680742157355	0.275838181485014	0.264097771262797	0.208792582981997	0.220488139829774	0.320184082024275
	n =	71	71	70	70	71	71	71
SIS Mood	r =	.406	0.215	-0.086	0.069	-0.147	-0.103	.259
	p =	0.000409686685100	0.069680508442490	0.477767434377374	0.567274717843616	0.216411939955514	0.389756503706092	0.027861401332425
	n =	72	72	71	71	72	72	72
SIS Communication	r =	.327	.243	0.126	0.138	-0.115	-0.145	.233
	p =	0.004989447634816	0.040048125928794	0.294016415853702	0.250651491895469	0.338045391487139	0.223410798814933	0.048409002951079
	n =	72	72	71	71	72	72	72
SIS ADL	r =	.414	.316	-0.076	-0.103	-0.180	-0.072	0.184
	p =	0.000301195727865	0.006864951639077	0.528325765525488	0.393836694447022	0.130988135842337	0.550248368680612	0.120804726982938
	n =	72	72	71	71	72	72	72
SIS Mobility	r =	.453	.312	-0.039	-0.042	-0.138	-0.074	0.220

		Star Cancellation	OCS Hearts Cancellation	OCS Allocentric	OCS Egocentric	Line Bisection Error	Visual Analogue Scale	Personal Neglect
	p =	0.000065866416131	0.007563649352927	0.749858750407784	0.730631365465022	0.246981894000389	0.536029153243833	0.062739734269881
	n =	72	72	71	71	72	72	72
SIS Hand	r =	.457	.319	-0.083	-0.067	-0.202	-0.107	0.136
	p =	0.000054635923378	0.006252546734183	0.488907294334089	0.576604781808185	0.088704004156347	0.373081701602517	0.255977821869420
	n =	72	72	71	71	72	72	72
SIS Social	r =	.395	.331	-0.083	-0.012	-.314	-0.158	.242
	p =	0.000642199540459	0.004794965409063	0.495338669799286	0.922370450742044	0.007756827074764	0.188939215558527	0.042056743277871
	n =	71	71	70	70	71	71	71
SIS Recovery	r =	.291	0.215	-0.197	-0.041	-.249	-0.219	0.046
	p =	0.013295060049730	0.069271981502295	0.100193318982445	0.731792371809392	0.034819893633346	0.064537369860729	0.701931750214361
	n =	72	72	71	71	72	72	72
CENT Cancellation Accuracy	r =	.689	.627	-.258	-0.109	-.237	-.356	.267
	p =	0.000000000016102	0.000000002879944	0.028589812243793	0.362288192679140	0.043255701980768	0.002152162615210	0.023355493089539
	n =	73	73	72	72	73	72	72
CENT Errors	r =	-.247	-0.137	-0.064	-0.072	-0.100	-0.005	-.350
	p =	0.035231899628735	0.248136355487450	0.591653720010114	0.548747610278413	0.401435401840770	0.965737831578432	0.002558905362772
	n =	73	73	72	72	73	72	72
CENT Recancellations	r =	-0.199	-0.159	-0.042	-0.094	0.171	0.063	-.318
	p =	0.091168217268230	0.179928523401736	0.726401293632452	0.431251780162590	0.147904847965623	0.596829824195163	0.006541273976439
	n =	73	73	72	72	73	72	72
CENT Search duration	r =	-.284	-.283	-0.083	-0.014	0.031	0.129	-0.148
	p =	0.014992263022820	0.015080077853179	0.488983847266068	0.908548215558046	0.795424670714700	0.280161580289473	0.214949017120857
	n =	73	73	72	72	73	72	72

		Star Cancellation	OCS Hearts Cancellation	OCS Allocentric	OCS Egocentric	Line Bisection Error	Visual Analogue Scale	Personal Neglect
CENT Egocentric	r =	0.139	0.132	-0.008	-0.195	0.046	-0.146	0.124
	p =	0.241033682924594	0.263888016765862	0.946751028211594	0.101215621454506	0.698645139028636	0.219759391114234	0.298870513726756
	n =	73	73	72	72	73	72	72
CENT Allocentric	r =	0.061	0.038	-.282	-0.034	0.070	0.035	-0.134
	p =	0.607425476144572	0.751704848882686	0.016301079195105	0.779002948402175	0.556183819822384	0.772407945694157	0.260799390108564
	n =	73	73	72	72	73	72	72
CENT Intersections	r =	-0.091	-0.083	-0.010	-0.027	0.173	0.157	-0.018
	p =	0.443601211028987	0.483317865589201	0.933649312931163	0.822056833232346	0.144147131743314	0.187681681714219	0.879182900432459
	n =	73	73	72	72	73	72	72
CENT Quality of Search	r =	.540	.536	-0.117	-0.087	-0.170	-.338	0.206
	p =	0.000000799665057	0.000001033036890	0.325719526446641	0.464942309913223	0.150643846113448	0.003734052759711	0.082820214980507
	n =	73	73	72	72	73	72	72
CENT Bisection Error	r =	-.339	-.250	0.186	-0.226	.418	-0.061	-0.105
	p =	0.003396565308253	0.032816935886465	0.116995250402357	0.055848847782503	0.000229140431292	0.612222306880740	0.381458124738898
	n =	73	73	72	72	73	72	72
CENT Bisection Duration	r =	-.370	-.437	-0.069	0.065	0.156	.285	-.240
	p =	0.001264848620806	0.000112294750247	0.564091126997635	0.586404254570220	0.188827031134255	0.015288061911725	0.042477122656537
	n =	73	73	72	72	73	72	72

*Green indicates significance ($p \leq 0.000075$)

Table 5. All computed Spearman correlations for Stroke Impact Scale

		SIS Physical	SIS Cognition	SIS Mood	SIS Communication	SIS ADL	SIS Mobility	SIS Hand	SIS Social	SIS Recovery
Star Cancellation Test	r =	.375	.322	.406	.327	.414	.453	.457	.395	.291
	p =	0.001280444168433	0.006235464807833	0.000409686685100	0.004989447634816	0.000301195727865	0.000065866416131	0.000054635923378	0.000642199540459	0.013295060049730
	n =	71	71	72	72	72	72	72	71	72
OCS Hearts Cancellation	r =	.295	0.151	0.215	.243	.316	.312	.319	.331	0.215
	p =	0.012435766838005	0.207680742157355	0.069680508442490	0.040048125928794	0.006864951639077	0.007563649352927	0.006252546734183	0.004794965409063	0.069271981502295
	n =	71	71	72	72	72	72	72	71	72
OCS Allocentric	r =	-0.027	0.132	-0.086	0.126	-0.076	-0.039	-0.083	-0.083	-0.197
	p =	0.826774880907027	0.275838181485014	0.477767434377374	0.294016415853702	0.528325765525488	0.749858750407784	0.488907294334089	0.495338669799286	0.100193318982445
	n =	70	70	71	71	71	71	71	70	71
OCS Egocentric	r =	0.007	0.135	0.069	0.138	-0.103	-0.042	-0.067	-0.012	-0.041
	p =	0.956453932114610	0.264097771262797	0.567274717843616	0.250651491895469	0.393836694447022	0.730631365465022	0.576604781808185	0.922370450742044	0.731792371809392
	n =	70	70	71	71	71	71	71	70	71
Line Bisection Error	r =	-0.131	-0.151	-0.147	-0.115	-0.180	-0.138	-0.202	-.314	-.249
	p =	0.275416053999787	0.208792582981997	0.216411939955514	0.338045391487139	0.130988135842337	0.246981894000389	0.088704004156347	0.007756827074764	0.034819893633346
	n =	71	71	72	72	72	72	72	71	72
Visual Analogue Scale	r =	-0.145	-0.147	-0.103	-0.145	-0.072	-0.074	-0.107	-0.158	-0.219
	p =	0.227243436223088	0.220488139829774	0.389756503706092	0.223410798814933	0.550248368680612	0.536029153243833	0.373081701602517	0.188939215558527	0.064537369860729
	n =	71	71	72	72	72	72	72	71	72
Personal neglect	r =	0.202	0.120	.259	.233	0.184	0.220	0.136	.242	0.046
	p =	0.091681204947708	0.320184082024275	0.027861401332425	0.048409002951079	0.120804726982938	0.062739734269881	0.255977821869420	0.042056743277871	0.701931750214361
	n =	71	71	72	72	72	72	72	71	72

		SIS Physical	SIS Cognition	SIS Mood	SIS Communication	SIS ADL	SIS Mobility	SIS Hand	SIS Social	SIS Recovery
OCS Picture	r =	0.063	0.117	0.033	0.086	0.130	0.097	0.083	-0.001	.325
	p =	0.603404485928659	0.331519498662431	0.784582003282304	0.472501520355069	0.277540013207452	0.417386424424117	0.487222523518118	0.992513073226075	0.005354653651114
	n =	71	71	72	72	72	72	72	71	72
OCS Orientation	r =	0.035	0.146	-0.083	0.115	0.106	0.075	0.098	0.071	0.178
	p =	0.768856749546210	0.224195400481698	0.485753084406801	0.334741117853849	0.374889971460788	0.529159676357094	0.412068480010041	0.558108499200962	0.135328818121607
	n =	71	71	72	72	72	72	72	71	72
OCS Visual Field	r =	.263	0.225	.276	0.218	.347	.284	.354	.322	.332
	p =	0.026452611709816	0.059537528879621	0.019097169380774	0.065258169485579	0.002855566007679	0.015584349426661	0.002270144319744	0.006200304462262	0.004332105434449
	n =	71	71	72	72	72	72	72	71	72
OCS Reading	r =	0.111	0.122	0.054	0.196	0.008	-0.005	0.051	0.012	0.011
	p =	0.358418084602862	0.311673994488570	0.653632502012824	0.098545275526902	0.949511490307616	0.963572278079922	0.669938773666201	0.920494115353779	0.927185523658438
	n =	71	71	72	72	72	72	72	71	72
OCS Number	r =	.235	0.146	0.177	0.222	.242	0.219	.342	.271	0.109
	p =	0.048247689966002	0.224663963283412	0.137014437140103	0.060574705300064	0.040414459731892	0.064273555406474	0.003245357797864	0.022025904373855	0.360670734407368
	n =	71	71	72	72	72	72	72	71	72
OCS Calculation	r =	0.107	-0.092	0.008	-0.044	0.112	0.191	0.212	0.041	0.094
	p =	0.372926486844604	0.445494353257429	0.943943343100769	0.712159005306502	0.350856717473213	0.107310786486129	0.073786580022245	0.733536869480638	0.432899734615720
	n =	71	71	72	72	72	72	72	71	72
OCS Imitation	r =	-.326	-.421	-.405	-.377	-.239	-.279	-0.189	-0.206	-0.053
	p =	0.005573400728663	0.000257904668793	0.000420836531000	0.001098993673623	0.042751553109391	0.017425111496304	0.111177282690178	0.085222137942498	0.657822880609993
	n =	71	71	72	72	72	72	72	71	72
OCS Recall	r =	-0.008	-0.055	-0.099	-0.037	0.012	0.061	0.100	0.024	0.120

		SIS Physical	SIS Cognition	SIS Mood	SIS Communication	SIS ADL	SIS Mobility	SIS Hand	SIS Social	SIS Recovery
	p =	0.948433170496684	0.646126609806244	0.408528464698655	0.758889765404879	0.920983853794077	0.608659025889013	0.403848198690277	0.839566687528503	0.317339670381323
	n =	71	71	72	72	72	72	72	71	72
OCS Episodic Memory	r =	0.116	0.226	0.159	0.170	0.218	0.158	0.160	0.092	0.105
	p =	0.335646498343809	0.058207516096700	0.181279583001976	0.153516347123083	0.066282558556758	0.184242032049657	0.178472335665722	0.447350458582246	0.379066342232119
	n =	71	71	72	72	72	72	72	71	72
OCS Executive	r =	-0.193	-0.141	-0.066	-0.098	-0.115	-0.121	-0.197	-0.188	-0.145
	p =	0.111913635993049	0.248545567179458	0.588954447296307	0.417609393976512	0.342708298714486	0.319782012608398	0.101403658683972	0.121052522292636	0.231973435879145
	n =	69	69	70	70	70	70	70	69	70
SIS Physical	r =	1.000	.666	.664	.617	.824	.879	.808	.732	.592
	p =		0.000000000231549	0.000000000278622	0.000000009935442	0.000000000000000	0.000000000000000	0.000000000000000	0.000000000000584	0.000000053518246
	n =	71	71	71	71	71	71	71	70	71
SIS Cognition	r =	.666	1.000	.583	.817	.572	.609	.500	.461	.308
	p =	0.000000000231549		0.000000098341452	0.000000000000000	0.000000190649916	0.000000017553452	0.000009134878229	0.000058143772942	0.008885434793972
	n =	71	71	71	71	71	71	71	70	71
SIS Mood	r =	.664	.583	1.000	.628	.639	.606	.550	.603	.243
	p =	0.000000000278622	0.000000098341452		0.000000003451880	0.000000001508007	0.000000017129077	0.000000560309343	0.000000025857810	0.040013411155557
	n =	71	71	72	72	72	72	72	71	72
SIS Communication	r =	.617	.817	.628	1.000	.559	.548	.464	.458	0.157
	p =	0.000000009935442	0.000000000000000	0.000000003451880		0.000000338668394	0.000000622390909	0.000040541618645	0.000058088845261	0.188189869861481
	n =	71	71	72	72	72	72	72	71	72
SIS ADL	r =	.824	.572	.639	.559	1.000	.860	.892	.761	.596
	p =	0.000000000000000	0.000000190649916	0.000000001508007	0.000000338668394		0.000000000000000	0.000000000000000	0.000000000000014	0.000000033814540

		SIS Physical	SIS Cognition	SIS Mood	SIS Communication	SIS ADL	SIS Mobility	SIS Hand	SIS Social	SIS Recovery
	n =	71	71	72	72	72	72	72	71	72
SIS Mobility	r =	.879	.609	.606	.548	.860	1.000	.851	.716	.645
	p =	0.000000000000000	0.000000017553452	0.000000017129077	0.000000622390909	0.000000000000000		0.000000000000000	0.000000000002261	0.000000000953735
	n =	71	71	72	72	72	72	72	71	72
SIS Hand	r =	.808	.500	.550	.464	.892	.851	1.000	.767	.611
	p =	0.000000000000000	0.000009134878229	0.000000560309343	0.000040541618645	0.000000000000000	0.000000000000000		0.000000000000006	0.000000012220207
	n =	71	71	72	72	72	72	72	71	72
SIS Social	r =	.732	.461	.603	.458	.761	.716	.767	1.000	.531
	p =	0.000000000000584	0.000058143772942	0.000000025857810	0.000058088845261	0.000000000000014	0.000000000002261	0.000000000000006		0.000001868642422
	n =	70	70	71	71	71	71	71	71	71
SIS Recovery	r =	.592	.308	.243	0.157	.596	.645	.611	.531	1.000
	p =	0.000000053518246	0.008885434793972	0.040013411155557	0.188189869861481	0.000000033814540	0.000000000953735	0.000000012220207	0.000001868642422	
	n =	71	71	72	72	72	72	72	71	72
CENT Cancellation Accuracy	r =	.490	.290	.469	.279	.450	.513	.486	.475	.490
	p =	0.000014711129861	0.014291277744140	0.000031878256712	0.017557734579043	0.000072309712667	0.000004036218070	0.000014976583387	0.000027927680884	0.000012394570208
	n =	71	71	72	72	72	72	72	71	72
CENT Errors	r =	-.274	-.239	-.249	-0.193	-.294	-.319	-.254	-0.208	-0.178
	p =	0.020654359931573	0.045040283169001	0.034834878884842	0.104963667521608	0.012288784705368	0.006289435181859	0.031261333247036	0.081494350452516	0.133887094975338
	n =	71	71	72	72	72	72	72	71	72
CENT Recancellations	r =	-0.163	-0.129	-0.219	-0.182	-0.224	-0.204	-.304	-.304	-0.145
	p =	0.175353778063322	0.282219690852992	0.064794269012945	0.125078839619336	0.059128463679111	0.085679350295749	0.009316330271578	0.009935589983353	0.224313284611585
	n =	71	71	72	72	72	72	72	71	72

		SIS Physical	SIS Cognition	SIS Mood	SIS Communication	SIS ADL	SIS Mobility	SIS Hand	SIS Social	SIS Recovery
CENT Search duration	r =	-.281	-0.210	-0.159	-0.138	-.343	-.277	-.356	-.306	-.300
	p =	0.017731883239440	0.078789978715387	0.180798359502376	0.247266484168693	0.003148954792526	0.018619414761682	0.002170492970876	0.009401010059421	0.010542177471341
	n =	71	71	72	72	72	72	72	71	72
CENT Egocentric	r =	0.035	-0.024	0.043	-0.038	0.053	0.037	-0.056	-0.134	0.087
	p =	0.770081895594849	0.843599276260944	0.718331567769677	0.749545415409841	0.659430629520915	0.755580060130242	0.641320196715419	0.266347552584082	0.464876238997405
	n =	71	71	72	72	72	72	72	71	72
CENT Allocentric	r =	-0.031	0.023	0.003	-0.066	-0.025	-0.061	-0.080	-0.101	0.089
	p =	0.797652131508641	0.851953490531491	0.982870084204616	0.581688569130221	0.836073295070618	0.611762587399974	0.505477474834249	0.403593616816500	0.458565300925401
	n =	71	71	72	72	72	72	72	71	72
CENT Intersections	r =	-0.187	-0.190	-0.131	-0.125	-0.096	-0.154	-0.147	-0.176	-.274
	p =	0.117627797567957	0.112689217985881	0.272780001529272	0.293874564609825	0.424546037029260	0.196509585857221	0.217447020731252	0.142227141897423	0.019642137037435
	n =	71	71	72	72	72	72	72	71	72
CENT Quality of Search	r =	.394	.237	.285	0.167	.456	.445	.469	.389	.446
	p =	0.000686247615965	0.046911325536257	0.015421188361307	0.161265006685569	0.000057950347366	0.000088598013591	0.000032078951045	0.000800955202326	0.000087279503212
	n =	71	71	72	72	72	72	72	71	72
CENT Bisection Error	r =	-0.042	-0.066	-0.035	0.009	-0.074	-0.039	-0.010	0.048	-0.043
	p =	0.731074540804528	0.583627986893053	0.770414995284125	0.940688442274364	0.537505613596773	0.747851977973982	0.931505294433028	0.693033806556423	0.717272010048004
	n =	71	71	72	72	72	72	72	71	72
CENT Bisection Duration	r =	-0.228	-.283	-0.231	-.329	-.387	-.308	-.353	-.343	-0.198
	p =	0.056077969257615	0.016859263343417	0.050770400099007	0.004804886001987	0.000772152350587	0.008588906091846	0.002334339574935	0.003385891780014	0.095476378021373
	n =	71	71	72	72	72	72	72	71	72

*Green indicates significance ($p \leq 0.000075$)

Table 6. All computed Spearman correlations for CENT variables

		CENT Cancellation Accuracy	**CENT Errors**	**CENT Recancellations**	**CENT Search duration**	**CENT Egocentric**	**CENT Allocentric**	**CENT Intersections**	**CENT Quality of Search**	**CENT Bisection Error**	**CENT Bisection Duration**
Star Cancellation Test	r =	.689	-.247	-0.199	-.284	0.139	0.061	-0.091	.540	-.339	-.370
	p =	0.000000000016102	0.035231899628735	0.091168217268230	0.014992263022820	0.241033682924594	0.607425476144572	0.443601211028987	0.000000799665057	0.003396565308253	0.001264848620806
	n =	73	73	73	73	73	73	73	73	73	73
OCS Hearts Cancellation	r =	.627	-0.137	-0.159	-.283	0.132	0.038	-0.083	.536	-.250	-.437
	p =	0.000000002879944	0.248136355487450	0.179928523401736	0.015080077853179	0.263888016765862	0.751704848882686	0.483317865589201	0.000001033036890	0.032816935886465	0.000112294750247
	n =	73	73	73	73	73	73	73	73	73	73
OCS Allocentric	r =	-.258	-0.064	-0.042	-0.083	-0.008	-.282	-0.010	-0.117	0.186	-0.069
	p =	0.028589812243793	0.591653720010114	0.726401293632452	0.488983847266068	0.946751028211594	0.016301079195105	0.933649312931163	0.325719526446641	0.116995250402357	0.564091126997635
	n =	72	72	72	72	72	72	72	72	72	72
OCS Egocentric	r =	-0.109	-0.072	-0.094	-0.014	-0.195	-0.034	-0.027	-0.087	-0.226	0.065
	p =	0.362288192679140	0.548747610278413	0.431251780162590	0.908548215558046	0.101215621454506	0.779002948402175	0.822056833232346	0.464942309913223	0.055848847782503	0.586404254570220
	n =	72	72	72	72	72	72	72	72	72	72
Line Bisection Error	r =	-.237	-0.100	0.171	0.031	0.046	0.070	0.173	-0.170	.418	0.156
	p =	0.043255701980768	0.401435401840770	0.147904847965623	0.795424670714700	0.698645139028636	0.556183819822384	0.144147131743314	0.150643846113448	0.000229140431292	0.188827031134255
	n =	73	73	73	73	73	73	73	73	73	73
	r =	-.356	-0.005	0.063	0.129	-0.146	0.035	0.157	-.338	-0.061	.285

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
Visual Analogue Scale	p =	0.002152162615210	0.965737831578432	0.596829824195163	0.280161580289473	0.219759391114234	0.772407945694157	0.187681681714219	0.003734052759711	0.612222306880740	0.015288061911725
	n =	72	72	72	72	72	72	72	72	72	72
Personal neglect	r =	.267	-.350	-.318	-0.148	0.124	-0.134	-0.018	0.206	-0.105	-.240
	p =	0.023355493089539	0.002558905362772	0.006541273976439	0.214949017120857	0.298870513726756	0.260799390108564	0.879182900432459	0.082820214980507	0.381458124738898	0.042477122656537
	n =	72	72	72	72	72	72	72	72	72	72
OCS Picture	r =	.289	-0.198	-.249	-.395	0.109	0.080	-0.147	.381	-0.199	-.280
	p =	0.013066548947493	0.092684955960726	0.033900351677363	0.000544088714245	0.358262377342055	0.498446374978965	0.215092104664625	0.000875165805762	0.090702074280478	0.016380283334684
	n =	73	73	73	73	73	73	73	73	73	73
OCS Orientation	r =	0.095	0.088	-0.209	-0.122	0.218	0.000	-0.174	0.166	-0.131	-0.185
	p =	0.421742207009962	0.458512885297952	0.075435437327851	0.305839502440048	0.063371992239152	1.000000000000000	0.141559476972171	0.161683001625123	0.267644378956119	0.116648357486272
	n =	73	73	73	73	73	73	73	73	73	73
OCS Visual Field	r =	.463	-0.080	-.334	-0.050	0.119	-0.069	-0.216	.339	-0.009	-.341
	p =	0.000037188824489	0.502009146011764	0.003864362404406	0.671711921322318	0.316153995273340	0.563751014546405	0.067056896209114	0.003375393437558	0.940579233441457	0.003171156385883
	n =	73	73	73	73	73	73	73	73	73	73
OCS Reading	r =	0.191	-0.042	-0.044	-0.143	0.001	0.095	0.157	0.136	-0.162	-0.173
	p =	0.105196673801802	0.725282255483940	0.714606075287956	0.228750921198977	0.992526119747949	0.425715097246865	0.184260829719843	0.251089865786055	0.170154566542511	0.143854688845157
	n =	73	73	73	73	73	73	73	73	73	73

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
OCS Number	r =	.366	-0.194	-0.214	-0.160	0.003	0.012	-0.097	.232	-0.164	-.270
	p =	0.001456848094814	0.100623860205336	0.068793450457477	0.175598417284259	0.981189727504933	0.916976076249874	0.414007066013458	0.048513605898851	0.165293959580542	0.020755684844376
	n =	73	73	73	73	73	73	73	73	73	73
OCS Calculation	r =	.300	-.263	-0.221	-.231	-0.026	-0.157	0.075	.317	-0.025	-0.139
	p =	0.009819940147408	0.024847122868729	0.060755186196891	0.049294389692649	0.825345508797237	0.185615452741107	0.531017688149416	0.006342178857159	0.831763953704063	0.239172578298347
	n =	73	73	73	73	73	73	73	73	73	73
OCS Imitation	r =	-0.016	0.029	-0.024	0.044	0.139	-0.079	0.080	0.048	-0.084	-0.116
	p =	0.894501675002563	0.805395769007617	0.842089551157670	0.713606367075801	0.240310942169302	0.503800173426151	0.500625166946029	0.687856071768706	0.478337872246500	0.328388149103497
	n =	73	73	73	73	73	73	73	73	73	73
OCS Recall	r =	0.022	-0.071	-0.109	-.263	-0.113	-0.068	0.014	0.197	0.007	-0.200
	p =	0.854017997392550	0.550942163240758	0.360480344233307	0.024750751147153	0.340293968735941	0.567562635232156	0.906295689627711	0.095664002306396	0.951622600144651	0.090308457735315
	n =	73	73	73	73	73	73	73	73	73	73
OCS Episodic Memory	r =	.238	-0.096	-0.114	-0.158	-0.196	0.087	-0.024	0.187	-0.124	-0.120
	p =	0.042334132026966	0.421453783289858	0.337109298102515	0.181822535617487	0.096851600177435	0.465972319883662	0.841037313834603	0.113706612373271	0.295909139653986	0.313267653218557
	n =	73	73	73	73	73	73	73	73	73	73
OCS Executive	r =	-.313	0.096	0.204	.270	0.105	-0.063	.289	-.304	-0.042	0.190
	p =	0.007779588414974	0.428191288345942	0.087402646404795	0.022599245019671	0.385334931693070	0.603591272987416	0.014599056096799	0.009841896371695	0.730538950929476	0.112129021167820

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
	n =	71	71	71	71	71	71	71	71	71	71
SIS Physical	r =	.490	-.274	-0.163	-.281	0.035	-0.031	-0.187	.394	-0.042	-0.228
	p =	0.000014711129861	0.020654359931573	0.175353778063322	0.017731883239440	0.770081895594849	0.797652131508641	0.117627797567957	0.000686247615965	0.731074540804528	0.056077969257615
	n =	71	71	71	71	71	71	71	71	71	71
SIS Cognition	r =	.290	-.239	-0.129	-0.210	-0.024	0.023	-0.190	.237	-0.066	-.283
	p =	0.014291277744140	0.045040283169001	0.282219690852992	0.078789978715387	0.843599276260944	0.851953490531491	0.112689217985881	0.046911325536257	0.583627986893053	0.016859263343417
	n =	71	71	71	71	71	71	71	71	71	71
SIS Mood	r =	.469	-.249	-0.219	-0.159	0.043	0.003	-0.131	.285	-0.035	-0.231
	p =	0.000031878256712	0.034834878884842	0.064794269012945	0.180798359502376	0.718331567769677	0.982870084204616	0.272780001529272	0.015421188361307	0.770414995284125	0.050770400099007
	n =	72	72	72	72	72	72	72	72	72	72
SIS Communication	r =	.279	-0.193	-0.182	-0.138	-0.038	-0.066	-0.125	0.167	0.009	-.329
	p =	0.017557734579043	0.104963667521608	0.125078839619336	0.247266484168693	0.749545415409841	0.581688569130221	0.293874564609825	0.161265006685569	0.940688442274364	0.004804886001987
	n =	72	72	72	72	72	72	72	72	72	72
SIS ADL	r =	.450	-.294	-0.224	-.343	0.053	-0.025	-0.096	.456	-0.074	-.387
	p =	0.000072309712667	0.012288784705368	0.059128463679111	0.003148954792526	0.659430629520915	0.836073295070618	0.424546037029260	0.000057950347366	0.537505613596773	0.000772152350587
	n =	72	72	72	72	72	72	72	72	72	72
	r =	.513	-.319	-0.204	-.277	0.037	-0.061	-0.154	.445	-0.039	-.308

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
SIS Mobility	p =	0.000004036218070	0.006289435181859	0.085679350295749	0.018619414761682	0.755580060130242	0.611762587399974	0.196509585857221	0.000088598013591	0.747851977973982	0.008588906091846
	n =	72	72	72	72	72	72	72	72	72	72
SIS Hand	r =	.486	-.254	-.304	-.356	-0.056	-0.080	-0.147	.469	-0.010	-.353
	p =	0.000014976583387	0.031261333247036	0.009316330271578	0.002170492970876	0.641320196715419	0.505477474834249	0.217447020731252	0.000032078951045	0.931505294433028	0.002334339574935
	n =	72	72	72	72	72	72	72	72	72	72
SIS Social	r =	.475	-0.208	-.304	-.306	-0.134	-0.101	-0.176	.389	0.048	-.343
	p =	0.000027927680884	0.081494350452516	0.009935589983353	0.009401010059421	0.266347552584082	0.403593616816500	0.142227141897423	0.000800955202326	0.693033806556423	0.003385891780014
	n =	71	71	71	71	71	71	71	71	71	71
SIS Recovery	r =	.490	-0.178	-0.145	-.300	0.087	0.089	-.274	.446	-0.043	-0.198
	p =	0.000012394570208	0.133887094975338	0.224313284611585	0.010542177471341	0.464876238997405	0.458565300925401	0.019642137037435	0.000087279503212	0.717272010048004	0.095476378021373
	n =	72	72	72	72	72	72	72	72	72	72
CENT Cancellation Accuracy	r =	1.000	-.280	-.212	-.237	0.081	0.055	-0.109	.440	-0.063	-.324
	p =		0.001273088488767	0.015374682355680	0.006667118241084	0.359369821468830	0.537716230936912	0.218625812457617	0.000000160129203	0.478107917484935	0.000166207578014
	n =	130	130	130	130	130	130	130	130	130	130
CENT Errors	r =	-.280	1.000	.237	.307	-0.020	-0.018	0.096	-.327	-0.043	.299
	p =	0.001273088488767		0.006672806369184	0.000389031324357	0.821497314129584	0.835959363532884	0.277823671048074	0.000147766007261	0.624475166291717	0.000537860888322
	n =	130	130	130	130	130	130	130	130	130	130

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
CENT Recancellations	r =	-.212	.237	1.000	.204	0.002	.229	0.039	-.213	0.054	.216
	p =	0.015374682355680	0.006672806369184		0.019650553620550	0.979558683873827	0.008867955756623	0.660948838568652	0.015138843141439	0.542185441432075	0.013586828075675
	n =	130	130	130	130	130	130	130	130	130	130
CENT Search duration	r =	-.237	.307	.204	1.000	-0.101	-0.107	.357	-.938	0.108	.695
	p =	0.006667118241084	0.000389031324357	0.019650553620550		0.251265105841624	0.227172873773490	0.000029826015875	0.000000000000000	0.223072726447676	0.000000000000000
	n =	130	130	130	130	130	130	130	130	130	130
CENT Egocentric	r =	0.081	-0.020	0.002	-0.101	1.000	0.164	0.040	0.138	-.208	-0.013
	p =	0.359369821468830	0.821497314129584	0.979558683873827	0.251265105841624		0.062689065935980	0.650562002170388	0.116455339703676	0.017498665415907	0.883015838455949
	n =	130	130	130	130	130	130	130	130	130	130
CENT Allocentric	r =	0.055	-0.018	.229	-0.107	0.164	1.000	-0.036	0.079	-0.119	0.024
	p =	0.537716230936912	0.835959363532884	0.008867955756623	0.227172873773490	0.062689065935980		0.681684933201298	0.371912917128842	0.175941706752509	0.783771262799714
	n =	130	130	130	130	130	130	130	130	130	130
CENT Intersections	r =	-0.109	0.096	0.039	.357	0.040	-0.036	1.000	-.358	-0.139	.180
	p =	0.218625812457617	0.277823671048074	0.660948838568652	0.000029826015875	0.650562002170388	0.681684933201298		0.000028953924441	0.115174403300870	0.040134492454169
	n =	130	130	130	130	130	130	130	130	130	130
CENT Quality of Search	r =	.440	-.327	-.213	-.938	0.138	0.079	-.358	1.000	-0.122	-.740
	p =	0.000000160129203	0.000147766007261	0.015138843141439	0.000000000000000	0.116455339703676	0.371912917128842	0.000028953924441		0.167909884156392	0.000000000000000

		CENT Cancellation Accuracy	CENT Errors	CENT Recancellations	CENT Search duration	CENT Egocentric	CENT Allocentric	CENT Intersections	CENT Quality of Search	CENT Bisection Error	CENT Bisection Duration
	n =	130	130	130	130	130	130	130	130	130	130
CENT Bisection Error	r =	-0.063	-0.043	0.054	0.108	-.208*	-0.119	-0.139	-0.122	1.000	0.154
	p =	0.4781079174849 35	0.624475166291 717	0.542185441432075	0.223072726447676	0.017498665415907	0.175941706752509	0.115174403300870	0.167909884156392		0.07974621398137 6
	n =	130	130	130	130	130	130	130	130	130	130
CENT Bisection Duration	r =	-.324	.299	.216	.695	-0.013	0.024	.180	-.740	0.154	1.000
	p =	0.00016620757801 4	0.000537860888 322	0.013586828075675	0.000000000000000	0.883015838455949	0.783771262799714	0.040134492454169	0.000000000000000	0.079746213981376	
	n =	130	130	130	130	130	130	130	130	130	130

*Green indicates significance ($p \leq 0.000075$).

Portfolio References

Aimola, L., Schindler, I., Simone, A. M., & Venneri, A. (2012). Near and far space neglect: Task sensitivity and anatomical substrates. Neuropsychologia, 50(6), 1115–1123. https://doi.org/10.1016/j.neuropsychologia.2012.01.022

Azouvi, P., Marchal, F., Samuel, C., Morin, L., Renard, C., Louis-Dreyfus, A., Jokic, C., Wiart, L., Pradat-Diehl, P., Deloche, G., & Bergego, C. (1996). Functional consequences and awareness of unilateral neglect: Study of an evaluation scale. Neuropsychological Rehabilitation, 6(2), 133–150. https://doi.org/10.1080/713755501

Barton, J. J. S., & Black, S. E. (1998). Line bisection in hemianopia. In J Neurol Neurosurg Psychiatry, 64.

Bisiach, E., & Luzzatti, C. (1978). Unilateral Neglect of Representational Space. Cortex, 14, 129–133.

Bowen, A., Mckenna, K., & Tallis, R. C. (1999). Reasons for Variability in the Reported Rate of Occurrence of Unilateral Spatial Neglect After Stroke. http://ahajournals.org

Brain, R. (1941). Section of Neurology A Form of Visual Disorientation Resulting from Lesions of the Right Cerebral Hemisphere. Brain: A Journal of Neurology, 27–32.

Butler, B. C., Eskes, G. A., & Vandorpe, R. A. (2004). Gradients of detection in neglect: Comparison of peripersonal and extrapersonal space. Neuropsychologia, 42(3), 346–358. https://doi.org/10.1016/j.neuropsychologia.2003.08.008

Caggiano, P., & Jehkonen, M. (2018). The 'Neglected' Personal Neglect. In Neuropsychology Review, 28(4), 417–435. Springer New York LLC. https://doi.org/10.1007/s11065-018-9394-4

Camargo, S. L., Herrera, A. N., & Traynor, A. (2018). Looking for a Consensus in the Discussion about the Concept of Validity: A Delphi Study. Methodology, 14(4), 146–155. https://doi.org/10.1027/1614-2241/a000157

Chechlacz, M., Rotshtein, P., Bickerton, W. L., Hansen, P. C., Deb, S., & Humphreys, G. W. (2010). Separating neural correlates of allocentric and egocentric neglect: Distinct cortical sites and common white matter disconnections. Cognitive Neuropsychology, 27(3), 277–303. https://doi.org/10.1080/02643294.2010.519699

Checketts, M., Mancuso, M., Fordell, H., Chen, P., Hreha, K., Eskes, G. A., Vuilleumier, P., Vail, A., & Bowen, A. (2020). Current clinical practice in the screening and diagnosis of spatial neglect post-stroke: Findings from a multidisciplinary international survey. Neuropsychological Rehabilitation, 1–32. https://doi.org/10.1080/09602011.2020.1782946

Chen, P., Hreha, K., Kong, Y., & Barrett, A. M. (2015). Impact of Spatial Neglect on Stroke Rehabilitation: Evidence from the Setting of an Inpatient Rehabilitation Facility. Archives of Physical Medicine and Rehabilitation, 96(8), 1458–1466. https://doi.org/10.1016/j.apmr.2015.03.019

Committeri, G., Pitzalis, S., Galati, G., Patria, F., Pelle, G., Sabatini, U., Castriota-Scanderbeg, A., Piccardi, L., Guariglia, C., & Pizzamiglio, L. (2007). Neural bases of personal and extrapersonal neglect in humans. Brain, 130(2), 431–441. https://doi.org/10.1093/brain/awl265

Demeyere, N., & Gillebert, C. R. (2019). Supplemental Material for Ego- and Allocentric Visuospatial Neglect: Dissociations, Prevalence, and Laterality in Acute Stroke. Neuropsychology, 33(4), 490–498. https://doi.org/10.1037/neu0000527.supp

Diller, L., Ben-Yishay, Y., Gerstman, L. J., Goodkin, R., Gordon, W., & Weinberg, J. (1974). Studies in cognition and rehabilitation in hemiplegia.

Esposito, E., Shekhtman, G., & Chen, P. (2021). Prevalence of spatial neglect post-stroke: A systematic review. In Annals of Physical and Rehabilitation Medicine, 64(5). Elsevier Masson s.r.l. https://doi.org/10.1016/j.rehab.2020.10.010

Eusebi, P. (2013). Diagnostic accuracy measures. Cerebrovascular Diseases, 36(4), 267–272. https://doi.org/10.1159/000353863

Feigin, V. L., Brainin, M., Norrving, B., Martins, S., Sacco, R. L., Hacke, W., Fisher, M., Pandian, J., & Lindsay, P. (2022). World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. In International Journal of Stroke, 17(1), 18–29). SAGE Publications Inc. https://doi.org/10.1177/17474930211065917

Ferber, S., & Karnath, H. O. (2001). How to assess spatial neglect - Line bisection or cancellation tasks? Journal of Clinical and Experimental Neuropsychology, 23(5), 599–607. https://doi.org/10.1076/jcen.23.5.599.1243

Gainotti, G., & Tiacci, C. (1970). Patterns of Drawing Disability in Right and Left Hemispheric Patients. In Neuropsychologia, 8. Pergamon Press.

Gauthier, L., Dehaut. Framcois, & Yves Joanette. (1989). The Bells Test: A Quantitative and Qualitative Test for Visual Neglect. International Journal of Clinical Neuropsychology, 11(2), 49–54.

Giannakou, I., Punt, D., & Lin, D. (2022). Computer-based assessment of unilateral spatial neglect: A systematic review. Frontiers in Neuroscience, 16, 1–14. http://clinicaltrials.gov/

Goodale, M. A., & Milner, D. A. (1992). Separate visual pathways for perception. TINS, 15(1), 20–26.

Gottesman, R. F., Kleinman, J. T., Davis, B. C., Heidler-Gary, B. J., Newhart, M., Kannan, B. V, & Hillis, B. A. E. (2008). Unilateral neglect is more severe and common in older patients with right hemispheric stroke. Neurology, 71, 1439–1444. www.neurology.org

Halligan, P. W., & Marshall, J. C. (1993). Unilateral Neglect: Clinical and Experimental Studies.

Halsband, U., Gruhn, S., & Ettlinger, G. (1985). Unilateral spatial neglect and defective performance in one half of space. International Journal of Neuroscience, 28(3), 173–195.

Hammerbeck, U., Gittins, M., Vail, A., Paley, L., Tyson, S. F., & Bowen, A. (2019). Spatial neglect in stroke: Identification, disease process and association with outcome during inpatient rehabilitation. Brain Sciences, 9(12). https://doi.org/10.3390/brainsci9120374

Kerkhoff, G., Rode, G., & Clarke, S. (2021). Clinical Pathways in Stroke Rehabilitation. In T. Platz (Ed.), Clinical Pathways in Stroke Rehabilitation: Evidence-based Clinical Practice Recommendations, 191–217. Springer.

Klatzky, R. L., Loomis, J. M., Beall, A. C., Chance, S. S., & Golledge, R. G. (1998). Updating Spatial Representations. Psychological Science, 9(4), 293–298.

Kleinman, J. T., Gottesman, R. F., Davis, C., Newhart, M., Heidler-Gary, J., & Hillis, A. E. (2008). Gender differences in unilateral spatial neglect within 24 hours of ischemic stroke. Brain and Cognition, 68(1), 49–52. https://doi.org/10.1016/j.bandc.2008.02.122

Lane, A. R., Ball, K., Smith, D. T., Schenk, T., & Ellison, A. (2013). Near and far space: Understanding the neural mechanisms of spatial attention. Human Brain Mapping, 34(2), 356–366. https://doi.org/10.1002/hbm.21433

Lezak, M. D. (2004). Neuropsychological assessment. Oxford University Press.

Lindell, A. B. , Jalas M.J., Tenovuo, O. , Brunila, T. , Voeten, M. J. , & Hämäläinen, H. (2007). Clinical assessment of hemispatial neglect: evaluation of different measures and dimensions. The Clinical Neuropsychologist, 21(3), 479–497.

Longley, V., Woodward-Nutt, K., Turton, A. J., Stocking, K., Checketts, M., Bamford, A., Douglass, E., Taylor, J., Woodley, J., Moule, P., Vail, A., & Bowen, A. (2023). A study of prisms and therapy in attention loss after stroke (SPATIAL): A feasibility randomised controlled trial. Clinical Rehabilitation, 37(3), 381–393. https://doi.org/10.1177/02692155221134060

Meador, K. J., Loring, D. W., Bowers, D., & Heilman, K. M. (1987). Remote memory and neglect syndrome. Neurology, 37(3), 522–522.

Moher, D. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews, 4, 1–9.

Moore, M. J., Milosevich, E., Mattingley, J., Demeyere, N., & Au, M. M. E. (2023). The neuroanatomy of visuospatial neglect: A systematic review and analysis of lesion-mapping methodology. Neuropsychologia, 108–470.

Moore, M., Milosevich, E., Beisteiner, R., Bowen, A., Checketts, M., Demeyere, N., Fordell, H., Godefroy, O., Laczó, J., Rich, T., Williams, L., Woodward-Nutt, K., & Husain, M. (2022). Rapid screening for neglect following stroke: A systematic search and European Academy of Neurology recommendations. European Journal of Neurology, 29(9), 2596–2606. https://doi.org/10.1111/ene.15381

Morse, H. (2023). Using Technology in the Assessment and Rehabilitation of Spatial Neglect (Vol. 63) [Dissertation]. University of East Anglia.

Morse, H., Jolly, A. A., Browning, H., Clark, A., Pomeroy, V., & Rossit, S. (2023). Aging effects on extrapersonal (far-space) attention: cancellation and line bisection performance from 179 healthy adults. Aging, Neuropsychology, and Cognition. https://doi.org/10.1080/13825585.2023.2223903

Newton, P. E. (2012). Clarifying the Consensus Definition of Validity. Measurement, 10(1–2), 1–29. https://doi.org/10.1080/15366367.2012.669666

NICE Guideline. (2023, October 18). Stroke rehabilitation in adults NG236. National Institute of Clinical Excellence.

Parsey, C. M., & Schmitter-Edgecombe, M. (2013). Applications of technology in neuropsychological assessment. Clinical Neuropsychologist, 27(8), 1328–1361. https://doi.org/10.1080/13854046.2013.834971

Poppeireuter, W. (1917). Die Psychischen Schaedungen durch Kopfschuss in Kriege 1914-1916. In Leipzig: Voss.

Portegies, M. L. P., Koudstaal, P. J., & Ikram, M. A. (2016). Cerebrovascular disease. In Handbook of Clinical Neurology, 138, 239–261. Elsevier B.V. https://doi.org/10.1016/B978-0-12-802973-2.00014-8

Puig-Pijoan, A., Giralt-Steinhauer, E., Zabalza de Torres, A., Manero Borràs, R. M., Sánchez-Benavides, G., García Escobar, G., Pérez Enríquez, C., Gómez-González, A., Ois, Á., Rodríguez-Campello, A., Cuadrado-Godía, E., Jiménez-Conde, J., Peña-Casanova, J., & Roquer, J. (2018). Underdiagnosis of Unilateral Spatial Neglect in stroke unit. Acta Neurologica Scandinavica, 138(5), 441–446. https://doi.org/10.1111/ane.12998

Rossit, S., McIntosh, R. D., Malhotra, P., Butler, S. H., Muir, K., & Harvey, M. (2012). Attention in action: Evidence from on-line corrections in left visual neglect. Neuropsychologia, 50(6), 1124–1135. https://doi.org/10.1016/j.neuropsychologia.2011.10.004

Sachdev, P., Brodaty, H., Valenzuela, M., Lorentz, L., & Koschera, A. (2004). Progression of cognitive impairment in stroke patients. Neurology, 63.

Schenkenberg, T., Bradford, D. C., & Ajax, E. T. (1980). Line bisection and unilateral visual neglect in patients with neurologic impairment. Neurology, 30(5), 509.

Souza, A. C. de, Alexandre, N. M. C., & Guirardello, E. de B. (2017). Propriedades psicométricas na avaliação de instrumentos: avaliação da confiabilidade e da validade. Epidemiologia e Servicos de Saude: Revista Do Sistema Unico de Saude Do Brasil, 26(3), 649–659. https://doi.org/10.5123/S1679-49742017000300022

Ten Brink, A. F., Biesbroek, J. M., Oort, Q., Visser-Meily, J. M. A., & Nijboer, T. C. W. (2019). Peripersonal and extrapersonal visuospatial neglect in different frames of reference: A brain lesion-symptom mapping study. Behavioural Brain Research, 356, 504–515. https://doi.org/10.1016/j.bbr.2018.06.010

Thomasson, M., Perez-Marcos, D., Crottaz-Herbette, S., Brenet, F., Saj, A., Bernati, T., Serino, A., Tadi, T., Blanke, O., & Ronchi, R. (2023). An immersive virtual reality tool for assessing left and right unilateral spatial neglect. Journal of Neuropsychology. https://doi.org/10.1111/jnp.12361

Utz, K., Hesse, C., Hintz, A., Gruneberger, D., Kulke, H., Klos, T., Kromichal, V., Melms, A., Schupp, W., Kohl, D., & Schenk, T. (2018). Visual feedback explains why propointing is better than antipointing in spatial neglect. Brain, 136, 3, 751-760.

Van Der Stoep, N., Visser-Meily, J. M. A., Kappelle, L. J., De Kort, P. L. M., Huisman, K. D., Eijsackers, A. L. H., Kouwenhoven, M., Van Der Stigchel, S., & Nijboer, T. C. W. (2013). Exploring near and far regions of space: Distance-specific visuospatial neglect after stroke. Journal of Clinical and Experimental Neuropsychology, 35(8), 799–811. https://doi.org/10.1080/13803395.2013.824555

Wee, J., & Hopman, W. (2008). Comparing Consequences of Right and Left Unilateral Neglect in a Stroke Rehabilitation Population. American Journal of Physical Medicine & Rehabilitation, 87(11), 910–920.

Williams, L. J., Kernot, J., Hillier, S. L., & Loetscher, T. (2021). Spatial Neglect Subtypes, Definitions and Assessment Tools: A Scoping Review. Frontiers in Neurology, 12. https://doi.org/10.3389/fneur.2021.742365

Wilson, B., Cockburn, J., & Halligan, P. (1987). Development of a Behavioural test of visuospatial neglect. Archives of Physical Medicine and Rehabilitation, 68, 98–102.

Appendices

Appendix A. Submission Guidelines for Neuropsychologia

(https://www.sciencedirect.com/journal/neuropsychologia/publish/guide-for-authors)

Preparation

The following article types are accepted:

(b) Reviews and Perspectives

(up to 30 printed journal pages or 26,000 words). These should also provide critical accounts and comprehensive surveys of topics of major current interest within the scope of the journal.

NEW SUBMISSIONS

Submission to this journal proceeds totally online and you will be guided stepwise through the creation and uploading of your files. The system automatically converts your files to a single PDF file, which is used in the peer-review process.

As part of the Your Paper Your Way service, you may choose to submit your manuscript as a single file to be used in the refereeing process. This can be a PDF file or a Word document, in any format or lay-out that can be used by referees to evaluate your manuscript. It should contain high enough quality figures for refereeing. If you prefer to do so, you may still provide all or some of the source files at the initial submission. Please note that individual figure files larger than 10 MB must be uploaded separately.

References

There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent. Where applicable, author(s) name(s), journal title/book title, chapter title/article title, year of publication, volume number/book chapter and the article number or pagination must be present. Use of DOI is highly encouraged. The reference style used by the journal will be applied to the accepted article by Elsevier at the proof stage. Note that missing data will be highlighted at proof stage for the author to correct.

Formatting requirements

There are no strict formatting requirements but all manuscripts must contain the essential elements needed to convey your manuscript, for example Abstract, Keywords, Introduction, Materials and Methods, Results, Conclusions, Artwork and Tables with Captions.

If your article includes any Videos and/or other Supplementary material, this should be included in your initial submission for peer review purposes.

Divide the article into clearly defined sections.

Figures and tables embedded in text

Please ensure the figures and the tables included in the single file are placed next to the relevant text in the manuscript, rather than at the bottom or the top of the file. The corresponding caption should be placed directly below the figure or table.

Peer review

This journal operates a single anonymized review process. All contributions will be initially assessed by the editor for suitability for the journal. Papers deemed suitable are then typically sent to a minimum of two independent expert reviewers to assess the scientific quality of the paper. The Editor is responsible for the final decision regarding acceptance or rejection of articles. The Editor's decision is final. Editors are not involved in decisions about papers which they have written themselves or have been written by family members or colleagues or which relate to products or services in which the editor has an interest. Any such submission is subject to all of the journal's usual procedures, with peer review handled independently of the relevant editor and their research groups. More information on types of peer review.

REVISED SUBMISSIONS

Use of word processing software

Regardless of the file format of the original submission, at revision you must provide us with an editable file of the entire article. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier). See also the section on Electronic artwork.

To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

LaTeX

You are recommended to use the latest Elsevier article class to prepare your manuscript and BibTeX to generate your bibliography.

Our Guidelines has full details.

Article structure

Subdivision - numbered sections

Divide your article into clearly defined and numbered sections. Subsections should be numbered 1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line.

Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Material and methods

Provide sufficient details to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized, and indicated by a reference. If quoting directly from a previously published method, use quotation marks and also cite the source. Any modifications to existing methods should also be described.

Results

Results should be clear and concise.

Discussion

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

Appendices

If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Essential title page information

• **Title.** Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.

• **Author names and affiliations**. Please clearly indicate the given name(s) and family name(s) of each author and check that all names are accurately spelled. You can add your name between parentheses in your own script behind the English transliteration. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.

• **Corresponding author**. Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. This responsibility includes answering any future queries about Methodology and Materials. Ensure that the e-mail address is given and that contact details are kept up to date by the corresponding author.

• **Present/permanent address**. If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

Highlights

Highlights are mandatory for this journal as they help increase the discoverability of your article via search engines. They consist of a short collection of bullet points that capture the novel results of your research as well as new methods that were used during the study (if any). Please have a look at the example Highlights.

Highlights should be submitted in a separate editable file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point).

Abstract

A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.

Graphical abstract

Although a graphical abstract is optional, its use is encouraged as it draws more attention to the online article. The graphical abstract should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 × 1328 pixels (h × w) or proportionally more. The image should be readable at a size of 5 × 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. You can view Example Graphical Abstracts on our information site.

Keywords

Immediately after the abstract, provide a maximum of 6 keywords, using British spelling and avoiding general and plural terms and multiple concepts (avoid, for example, 'and', 'of'). Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

Formatting of funding sources

List funding sources in this standard way to facilitate compliance to funder's requirements:

Funding: This work was supported by the National Institutes of Health [grant numbers xxxx, yyyy]; the Bill & Melinda Gates Foundation, Seattle, WA [grant number zzzz]; and the United States Institutes of Peace [grant number aaaa].

It is not necessary to include detailed descriptions on the program or type of grants and awards. When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding.

If no funding has been provided for the research, it is recommended to include the following sentence:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Footnotes

Footnotes should be used sparingly. Number them consecutively throughout the article. Many word processors build footnotes into the text, and this feature may be used. Should this not be the case, indicate the position of footnotes in the text and present the footnotes themselves separately at the end of the article.

Artwork

Electronic artwork

General points

• Make sure you use uniform lettering and sizing of your original artwork.

• Preferred fonts: Arial (or Helvetica), Times New Roman (or Times), Symbol, Courier.

• Number the illustrations according to their sequence in the text.

• Use a logical naming convention for your artwork files.

• Indicate per figure if it is a single, 1.5 or 2-column fitting image.

• For Word submissions only, you may still provide figures and their captions, and tables within a single file at the revision stage.

• Please note that individual figure files larger than 10 MB must be provided in separate source files.

A detailed guide on electronic artwork is available.

You are urged to visit this site; some excerpts from the detailed information are given here.

Formats

Regardless of the application used, when your electronic artwork is finalized, please 'save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):

EPS (or PDF): Vector drawings. Embed the font or save the text as 'graphics'.

TIFF (or JPG): Color or grayscale photographs (halftones): always use a minimum of 300 dpi.

TIFF (or JPG): Bitmapped line drawings: use a minimum of 1000 dpi.

TIFF (or JPG): Combinations bitmapped line/half-tone (color or grayscale): a minimum of 500 dpi is required.

Please do not:

• Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); the resolution is too low.

• Supply files that are too low in resolution.

• Submit graphics that are disproportionately large for the content.

Color artwork

Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color online (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article. Please indicate your preference for color: in print or online only. Further information on the preparation of electronic artwork.

Figure captions

Ensure that each illustration has a caption. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

Tables

Please submit tables as editable text and not as images. Tables can be placed either next to the relevant text in the article, or on separate page(s) at the end. Number tables consecutively in accordance with their appearance in the text and place any table notes below the table body. Be sparing in the use of tables and ensure that the data presented in them do not duplicate results described elsewhere in the article. Please avoid using vertical rules and shading in table cells.

References

Citation in text

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Web references

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

Data references

This journal encourages you to cite underlying or relevant datasets in your manuscript by citing them in your text and including a data reference in your Reference List. Data references should include the following elements: author name(s), dataset title, data repository, version (where available), year, and global persistent identifier. Add [dataset] immediately before the reference so we can properly identify it as a data reference. The [dataset] identifier will not appear in your published article.

Preprint references

Where a preprint has subsequently become available as a peer-reviewed publication, the formal publication should be used as the reference. If there are preprints that are central to your work or that cover crucial developments in the topic, but are not yet formally published, these may be referenced. Preprints should be clearly marked as such, for example by including the word preprint, or the name of the preprint server, as part of the reference. The preprint DOI should also be provided.

References in a special issue

Please ensure that the words 'this issue' are added to any references in the list (and any citations in the text) to other articles in the same Special Issue.

Reference management software

Most Elsevier journals have their reference template available in many of the most popular reference management software products. These include all products that support Citation Style Language styles, such as Mendeley. Using citation plug-ins from these products, authors only need to select the appropriate journal template when preparing their article, after which citations and bibliographies will be automatically formatted in the journal's style. If no template is yet available for this journal, please follow the format of the sample references and citations as shown in this Guide. If you use reference management software, please ensure that you remove all field codes before submitting the electronic manuscript. More information on how to remove field codes from different reference management software.

Reference formatting

There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent. Where applicable, author(s) name(s), journal title/book title, chapter title/article title, year of publication, volume number/book chapter and the article number or pagination must be present. Use of DOI is highly encouraged. The reference style used by the journal will be applied to the accepted article by Elsevier at the proof stage. Note that missing data will be highlighted at proof stage for the author to correct. If you do wish to format the references yourself they should be arranged according to the following examples:

Reference style

Text: All citations in the text should refer to:

1. Single author: the author's name (without initials, unless there is ambiguity) and the year of publication;

2. Two authors: both authors' names and the year of publication;

3. Three or more authors: first author's name followed by 'et al.' and the year of publication.

Citations may be made directly (or parenthetically). Groups of references can be listed either first alphabetically, then chronologically, or vice versa.

Examples: 'as demonstrated (Allan, 2000a, 2000b, 1999; Allan and Jones, 1999)…. Or, as demonstrated (Jones, 1999; Allan, 2000)… Kramer et al. (2010) have recently shown …'

List: References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.

Examples:

Reference to a journal publication:

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2010. The art of writing a scientific article. J. Sci. Commun. 163, 51–59. https://doi.org/10.1016/j.Sc.2010.00372.

Reference to a journal publication with an article number:

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2018. The art of writing a scientific article. Heliyon. 19, e00205. https://doi.org/10.1016/j.heliyon.2018.e00205.

Reference to a book:

Strunk Jr., W., White, E.B., 2000. The Elements of Style, fourth ed. Longman, New York.

Reference to a chapter in an edited book:

Mettam, G.R., Adams, L.B., 2009. How to prepare an electronic version of your article, in: Jones, B.S., Smith , R.Z. (Eds.), Introduction to the Electronic Age. E-Publishing Inc., New York, pp. 281–304.

Reference to a website:

Cancer Research UK, 1975. Cancer statistics reports for the UK. http://www.cancerresearchuk.org/aboutcancer/statistics/cancerstatsreport/ (accessed 13 March 2003).

Reference to a dataset:

[dataset] Oguro, M., Imahiro, S., Saito, S., Nakashizuka, T., 2015. Mortality data for Japanese oak wilt disease and surrounding forest compositions. Mendeley Data, v1. https://doi.org/10.17632/xwj98nb39r.1.

Reference to software:

Coon, E., Berndt, M., Jan, A., Svyatsky, D., Atchley, A., Kikinzon, E., Harp, D., Manzini, G., Shelef, E., Lipnikov, K., Garimella, R., Xu, C., Moulton, D., Karra, S., Painter, S., Jafarov, E., & Molins, S., 2020. Advanced Terrestrial Simulator (ATS) v0.88 (Version 0.88). Zenodo. https://doi.org/10.5281/zenodo.3727209.

Video

Elsevier accepts video material and animation sequences to support and enhance your scientific research. Authors who have video or animation files that they wish to submit with their article are strongly encouraged to include links to these within the body of the article. This can be done in the same way as a figure or table by referring to the video or animation content and noting in the body text where it should be placed. All submitted files should be properly labeled so that they directly relate to the video file's content. In order to ensure that your video or animation material is directly usable, please provide the file in one of our recommended file formats with a preferred maximum size of 150 MB per file, 1 GB in total. Video and animation files supplied will be published online in the electronic version of your article in Elsevier Web products, including ScienceDirect. Please supply 'stills' with your files: you can choose any frame from the video or animation or make a separate image. These will be used instead of standard icons and will personalize the link to your video data. For more detailed instructions please visit our video instruction pages. Note: since video and animation cannot be embedded in the print version of the journal, please provide text for both the electronic and the print version for the portions of the article that refer to this content.

Data visualization

Include interactive data visualizations in your publication and let your readers interact and engage more closely with your research. Follow the instructions here to find out about available data visualization options and how to include them with your article.

Supplementary material

Supplementary material such as applications, images and sound clips, can be published with your article to enhance it. Submitted supplementary items are published exactly as they are received (Excel or PowerPoint files will appear as such online). Please submit your material together with the article and supply a concise, descriptive caption for each supplementary file. If you wish to make changes to supplementary material during any stage of the process, please make sure to provide an updated file. Do not annotate any corrections on a previous version. Please switch off the 'Track Changes' option in Microsoft Office files as these will appear in the published version.

Research data

This journal requires and enables you to share data that supports your research publication where appropriate, and enables you to interlink the data with your published articles. Research data refers to the results of observations or experimentation that validate research findings, which may also include software, code, models, algorithms, protocols, methods and other useful materials related to the project.

Below are a number of ways in which you can associate data with your article or make a statement about the availability of your data when submitting your manuscript. When sharing data in one of these ways, you are expected to cite the data in your manuscript and reference list. Please refer to the "References" section for more information about data citation. For more information on depositing, sharing and using research data and other relevant research materials, visit the research data page.

Data linking

If you have made your research data available in a data repository, you can link your article directly to the dataset. Elsevier collaborates with a number of repositories to link articles on ScienceDirect with relevant repositories, giving readers access to underlying data that gives them a better understanding of the research described.

There are different ways to link your datasets to your article. When available, you can directly link your dataset to your article by providing the relevant information in the submission system. For more information, visit the database linking page.

For supported data repositories a repository banner will automatically appear next to your published article on ScienceDirect.

In addition, you can link to relevant data or entities through identifiers within the text of your manuscript, using the following format: Database: xxxx (e.g., TAIR: AT1G01020; CCDC: 734053; PDB: 1XFN).

Data statement

To foster transparency, we require you to state the availability of your data in your submission if your data is unavailable to access or unsuitable to post. This may also be a requirement of your funding body or institution. You will have the opportunity to provide a data statement during the submission process. The statement will appear with your published article on ScienceDirect. For more information, visit the Data Statement page..

After acceptance

Online proof correction

To ensure a fast publication process of the article, we kindly ask authors to provide us with their proof corrections within two days. Corresponding authors will receive an e-mail with a link to our online proofing system, allowing annotation and correction of proofs online. The environment is similar to MS Word: in addition to editing text, you can also comment on figures/tables and answer questions from the Copy Editor. Web-based proofing provides a faster and less error-prone process by allowing you to directly type your corrections, eliminating the potential introduction of errors.

If preferred, you can still choose to annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors, including alternative methods to the online version and PDF.

We will do everything possible to get your article published quickly and accurately. Please use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor. It is important to ensure that all corrections are sent back to us in one communication. Please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely your responsibility.

Offprints

The corresponding author will, at no cost, receive 25 free paper offprints, or alternatively a customized Share Link providing 50 days free access to the final published version of the article on ScienceDirect. The Share Link can be used for sharing the article via any communication channel, including email and social media. For an extra charge, paper offprints can be ordered via the offprint order form which is sent once the article is accepted for publication. Corresponding authors who have published their article gold open access do not receive a Share Link as their final published version of the article is available open access on ScienceDirect and can be shared through the article DOI link.

Appendix B. Prospero Registration (Registration ID: CRD42023491317)

Prospero registration:
https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023491317

Appendix C. PRISMA Checklist

Selection and Topic	Item #	Checklist Item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review	18
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist	19
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	23
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	23
METHODS			
Eligibility Criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses	25
Information Sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	29
Search Strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	24
Selection Process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	25
Data Collection Process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	26
Data Items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	26
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	27
Study Risk of Bias Assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	25

Effect Measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	N/A
Synthesis Methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5).	25
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	44
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	25
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	26
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	25
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting Bias Assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	26
Certainty Assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study Selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	26
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	58
Study Characteristics	17	Cite each included study and present its characteristics.	32
Risk of Bias in Studies	18	Present assessments of risk of bias for each included study.	30
Results of Individual Studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	37
Results of Syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	46
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	46
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	46

	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting Biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	31
Certainty of Evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	47
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	58
	23b	Discuss any limitations of the evidence included in the review.	59
	23c	Discuss any limitations of the review processes used.	59
	23d	Discuss implications of the results for practice, policy, and future research.	60
OTHER INFORMATION			
Registration and Protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	23
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	23
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	23
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	60
Competing Interests	26	Declare any competing interests of review authors.	60
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	60

Appendix D. Quality Assessment of Validity Studies (QAVALS) Form (Gore, 2017)

Gore, S. (2017). Subjective Assessment of Physical Activity in Chronic Obstructive Pulmonary Disease. Doctoral Dissertation, University of Michigan-Flint, 1–195.

Item	Item Criteria	Yes	No	NR
1	Was the study design reported?			
2	Did the study provide an accurate description of the type of validity tested?			
3	Was the study setting and time frame of participant recruitment clearly described?			
4	Were the criteria for participant selection clearly described?			
5	Were the participants in the study representative of the sample population from which they were recruited?			
6	Did the study clearly describe the outcome measures to be validated?			
7	Did the study provide a clear description of the procedures for testing validity?			
8	Was the testing procedure standardised for all participants?			
9	Was a priori sample size calculation performed to ensure that the study had sufficient power?			
10	Did the study describe and justify any attrition that may have occurred?			
11	Were statistical analyses used to test validity appropriate for the study?			
12	When multiple comparisons were performed, were appropriate statistical adjustments used to control for the likelihood of a type 1 error?			
13	Did the study identify potential confounding variables and if so, were measures taken to adjust for these confounders?			
14	Were primary findings of the study clearly described?			
15	Were validity coefficients reported for primary outcomes?			
16	For primary outcomes, did the study report standard deviations or confidence intervals for normally distributed data? If non-normally distributed data, did the study report inter-quartile ranges for the main outcomes?			
Face and Content Validity:				
17	Was the process of selecting expert panel and their qualifications described?			
Criterion Validity:				
18	Did the study provide a rationale for the selection of the reference standard?			
19	When the index test was assessed by more than one rater, were the raters blinded to the findings of the other raters?			
20	When the index test was assessed by more than one rater, was the inter-rater reliability between raters established and reported?			
21	Was the time interval used between administration of reference standard and the test measure appropriate?			
Construct Validity:				
22	Were subjects in different groups homogenous at baseline? If they weren't homogenous at baseline were differences between groups accounted for during the analysis?			
Construct Validity (convergent):				
23	Did the measures used for convergent validity represent a similar construct as the outcome measure of interest?			
Construct Validity (discriminant):				
24	Did the measures used for discriminant validity represent a construct different from the outcome measure of interest?			

*NR = not reported

Appendix E. C-Sight Study Information Sheet (Aphasia Friendly)

PARTICIPANT INFORMATION SHEET

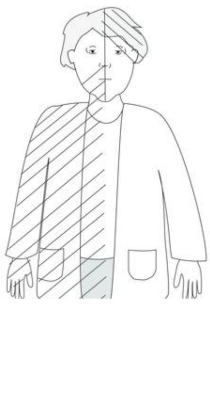
Title of project: Can we use c-SIGHT for spatial neglect in stroke survivors' homes? (All studies)

You are invited to take part in a **research** study.

Please **read** this sheet carefully. Please ask **questions**

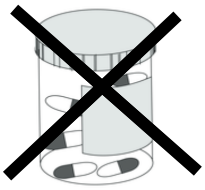
What is the research about?

Spatial neglect means a person **does not** notice things on **one side**.



It is **common** after **stroke**.

There is **no effective treatment**.



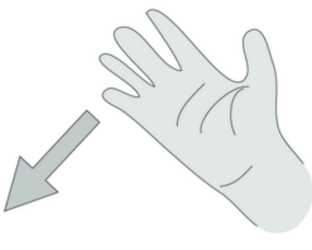
Some tests **do not detect** spatial neglect.

THE THERAPY

c-SIGHT is a **therapy** for spatial neglect and uses a **computer**

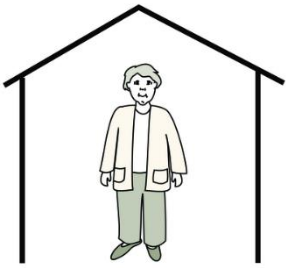
c-SIGHT involves **lifting wooden rods**

You use your **less impaired arm**



A computer tells you **what to do**

You do it **yourself**, without a therapist **at home**

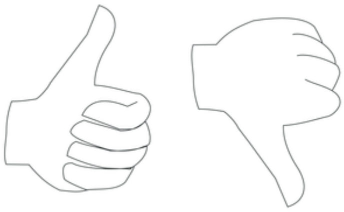


A motion **sensor** records how long you **use**

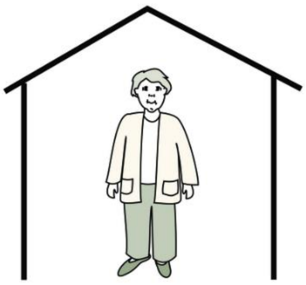
c-SIGHT

We want to see if spatial neglect **improves** after using **c-SIGHT 1**

or **c-SIGHT 2**



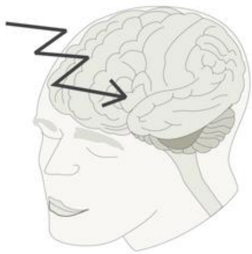
We want to see if we can **use c-SIGHT** at **home**



We want to see if a **computer test** can **detect** spatial neglect

Why me?

You are a **stroke survivor**



You might have **signs** of **spatial neglect**

Do I have to take part?

Taking part is **voluntary**

You can **decide**

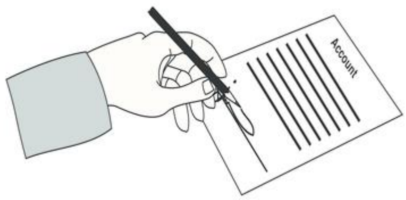
Please ask **questions**

You can **stop** at any time

If you stop, you **do not** have to **give a reason** and you will still **get your normal care**

What happens if I take part?

You will **sign** a consent form to show you **understand** the research and **want** to take part



You will complete a short visual **test**

The result from the **test** will tell us what **study** you can take part in

?

A **researcher** will **visit** you at **home**

You will do some **tests** and **questionnaires**

This will take between **2 and 2.5 hours**

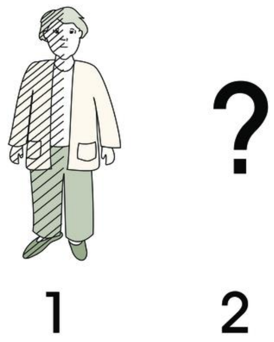
Your **carer** might do some **questionnaires**

If you **do not** show signs of **spatial neglect**

The study is **complete**

If you **do** show **signs** of **spatial neglect**

You might be put into **group 1 or 2**



A **computer** decides which **group you are in**

It is like **flipping** a **coin**

Each group will use the **same equipment**

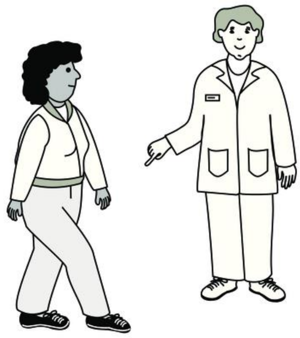
One group might **help** someone's spatial neglect

But we **do not think** one group will **change** someone's spatial neglect

We need this group so we can see if the **other group helps** people with spatial neglect

A **researcher** will **visit** you at **home**

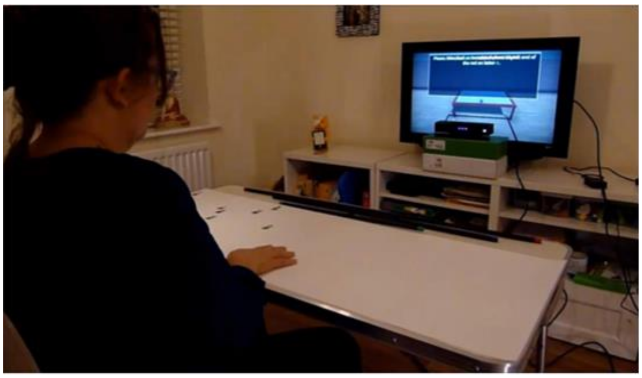
They will **show** you how to **use** c-SIGHT



They will **set-up** the **equipment**

This will take **2 hours**

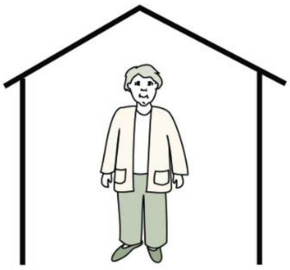
The **equipment** might look like this in your **home**



The **equipment** will be in your **home** for **10 days**

We will ask you to use c-SIGHT for **30 minutes two times a day**

You will use c-SIGHT **on your own** for **8 days**



Only use the equipment for **c-SIGHT**

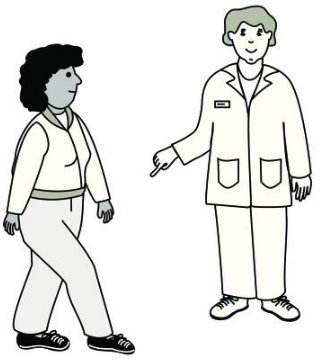
Only **you** should use the equipment

You will **not** pay for equipment that becomes damaged

A **researcher** will **call you** to check you are **using c-SIGHT**

A **researcher** will **visit** you on the **last day** of using c-SIGHT

You will **use c-SIGHT** for the **last time** with them



The **researcher** will **remove** the **equipment**

This will take **1 hour**

A **researcher** will **visit** you at **home**

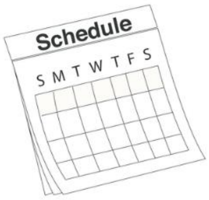
You will do some **tests** and **questionnaires**

The researcher will ask you some **questions** about **using c-SIGHT**

This will take between **2 and 2.5 hours**

Your **carer** might do some **questionnaires** and answer **questions** about **c-SIGHT**

A **researcher** will **visit** you at **home one month** later



You will do some **tests** and **questionnaires**

This will take between **2 and 2.5 hours**

Your **carer** might do some **questionnaires**

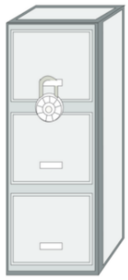
What information will be used?

Researchers at the **NHS** will **access** your **medical records**

Personal information (**name**, **contact information**)

Anonymous copies of your **brain scans**

All **data** will be kept **confidential**

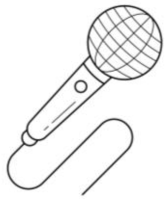


Recordings

With your **permission**:

- We will take **photographs**
- We will **video** you using the therapy

- We will **audio** record the interview



These will be **destroyed** at the **end** of the study

Your face will **not be shown**

The recordings will be **kept safe**

Only the **research team** will look at these recordings

We might use **anonymous quotations** in **presentations** and **reports**

What will happen to the results?

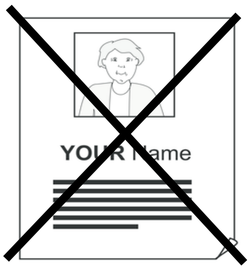
The results will be in a **PhD thesis**

The results may be **published** and **presented** to other researchers

The data will be **shared** with other researchers on an **online database**

Your **name** will **not** be shared

All data will be **anonymous**



You can **choose** to receive a **summary** of the **results** when the study ends

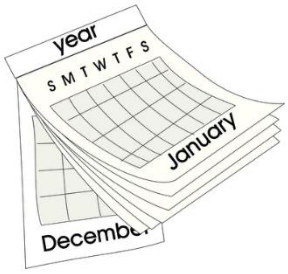
Is it confidential?

All data will be **anonymous**

An **anonymous number** will be used instead of your name

Your data will be **safely stored** on a password-protected computer

Identifiable data (your **name, address**) will be **destroyed 12 months** after the **study ends**



We can keep this **longer** if **you want us** to tell you about **future research** or hear about the **results** of the study

You can **leave** the study at **any time**

If you do, we will **destroy** your **identifiable data**

If you choose to **stop** taking part in the study, we would like to **continue collecting information** about your **health** from your hospital

If you **do not want** this to happen, tell us and we will **stop**

If your **carer** does not to take part or leaves the study, **you** can still carry on with the study

If we think you are in danger of **harm or find something** we did not expect, we have a **duty** to **tell your GP**

We will tell your **GP** you are taking part in this **study**

What if something goes wrong?

This is **unlikely**

Please **contact** the **research team**

Are there any problems with taking part?

There are **no** known **risks**

You might get **tired** but you can take **breaks**

Stop if you feel any **pain**

Will it help me if I take part?

We **cannot** promise it will **help you**

The study will **help** stroke survivors in **future**

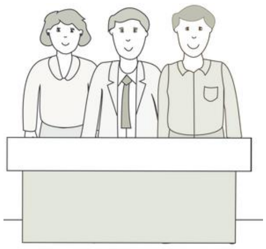
What happens when the study ends?

You will still get the **same routine care**

Contact your **GP** if you need to **talk** about your **care**

Is the research ethical?

An **ethics committee** looked at this research



Cambridge South Research Ethics Committee think the research is **ethical**

The research is funded by The Stroke Association

The study is run by the University of East Anglia

If you want to **talk** to a person **not** in the research team, please contact:

Professor Niall Broomfield
Email: **N.Broomfield@uea.ac.uk,** Phone: **01603591217**

If you want to **share** your **experience** of being in this research, please contact your local Patient Experience Team.

Patient Advice and Liaison Service (PALS):
Telephone 01603 289036 Email: **PALS@nnuh.nhs.uk**

Helen Morse (lead researcher)
Email: Helen.morse@uea.ac.uk
Phone: 07447479506

Dr Stephanie Rossit (principal investigator)
Email: S.rossit@uea.ac.uk
Phone: 01603591674

Thank you for reading this information sheet

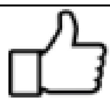
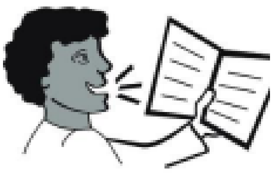
Appendix F. C-Sight Study Consent Form (Aphasia Friendly)

CONSENT FORM FOR STROKE SURVIVORS

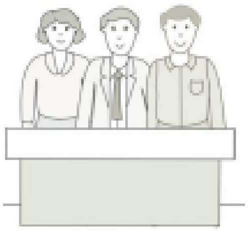
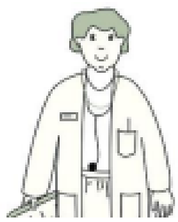
Title of project: Can we use c-SIGHT for spatial neglect in stroke survivors' homes? (Study 2)

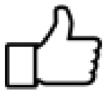
Researcher: Helen Morse (PhD student)
Supervisors: Dr. Stephanie Rossit, Professor Valerie Pomeroy & Dr. Allan Clark

Please **initial** each box if you agree:

	
I have **read** and I **understand** the **information sheet**  I have had the **chance** to **ask questions** about the research. I have had time to **think about** the research. 	

I understand that taking part is **voluntary.**  I can **stop** taking part in the research at any time. If I stop, **I do not** have to **give a reason** and I will still **get my normal care**.	
I agree to researchers at the [NHS trust] and University of East Anglia to **look at my medical records.** 	
I understand the information I give will be **anonymous. My name** will **never be used.**  I understand that the researchers might **share my information** and **results** with **other researchers**. This might be on a **public database**.	

 I understand my information will be kept **safe**. 	
I am happy for the researchers to **tell my GP** that I am taking part in this **research**. 	
I agree to take part in the research 	

Optional points	
I agree to the research team **contacting my GP** if they find something **unexpected**  I understand my **GP** will **decide** what to do about these results	
I want to know the **results** when the **research is complete**. 	

Signed (participant): ____________________________________

Print name (participant): ____________________________________

Date: (DD-MM-YYYY) ____________________________________

Signed (researcher): ______________________________

Print name (researcher): ______________________________

Date: (DD-MM-YYYY) ______________________________

When completed: 1 for participant; 1 for researcher site file; 1 to be kept in medical notes.

Appendix G. C-Sight Trial Ethical Approval

NHS
Health Research
Authority

East of England - Cambridge South Research Ethics Committee

Equinox House
City Link
Nottingham
NG2 4LA

Tel: 02071048227
Fax: N/A

<u>Please note: This is the favourable opinion of the REC only and does not allow</u> the amendment to be implemented at NHS sites in England until the outcome of the HRA assessment has been confirmed.

09 May 2023

Dr Stephanie Rossit
0.108a Lawrence Stenhouse Building
University of East Anglia
Norwich
NR4 7TJ

Dear Dr Rossit

Study title:	**A feasibility study of a computerised Spatial Inattention Grasping Home-based Therapy for stroke survivors (c-SIGHT)**
REC reference:	**20/EE/0107**
Protocol number:	**N/A**
Amendment number:	**R207146_A10**
Amendment date:	**20 April 2023**
IRAS project ID:	**275001**

The above amendment was reviewed by the Sub-Committee in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	*Version*	*Date*
Completed Amendment Tool [275001_R207146_SA10_20.04.23 Locked for submission]	1.6	20 April 2023
Other [IRAS form new CI]		20 April 2023
Summary CV for Chief Investigator (CI) [Rossit_R&D Ethics CV]		

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

Working with NHS Care Organisations

Sponsors should ensure that they notify the R&D office for the relevant NHS care organisation of this amendment in line with the terms detailed in the categorisation email issued by the lead nation for the study.

Amendments related to COVID-19

We will update your research summary for the above study on the research summaries section of our website. During this public health emergency, it is vital that everyone can promptly identify all relevant research related to COVID-19 that is taking place globally. If you have not already done so, please register your study on a public registry as soon as possible and provide the HRA with the registration detail, which will be posted alongside other information relating to your project.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

HRA Learning

We are pleased to welcome researchers and research staff to our HRA Learning Events and online learning opportunities– see details at: https://www.hra.nhs.uk/planning-and-improving-research/learning/

IRAS Project ID - 275001:	**Please quote this number on all correspondence**

Yours sincerely

PP
Mr Paul Smith
Chair

E-mail: cambridgesouth.rec@hra.nhs.uk

Enclosures: *List of names and professions of members who took part in the*

East of England - Cambridge South Research Ethics Committee

Attendance at Sub-Committee of the REC meeting on 09 May 2023

Committee Members:

Name	*Profession*	*Present*	*Notes*
Mr John Kirkpatrick	Statistician	Yes	
Mr Paul Smith (Chair)	Former Tumour Group Leader	Yes	

Also in attendance:

Name	*Position (or reason for attending)*
Ms Tracy Hamrang	Approvals Administrator