The QuickSort:

A brief screen for detecting cognitive impairment in older adults

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Declaration

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A M Foran: Date: 20/11/22

Dedication

To the memory of my father, Gerald Thomas Foran, *“kicking goals”.*

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1.1 Peer-reviewed journal articles

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Foran, A. M., Mathias, J. L., & Bowden, S. C. (2021). Development of a brief screen to detect cognitive impairment in older adults: The QuickSort. *Journal of the American Geriatrics* Society, 69(2), 441-449. DOI:10.1111/jgs.16898 IF: 7.54

Foran, A. M., Mathias, J. L., & Bowden, S. C. (In Press). Use of the QuickSort with older adults whose lifestyle decision-making capacity is being questioned. *Journal of the International Neuropsychology Society*. *Journal of the International Neuropsychology Society*, 1-12. DOI:10.1017/S1355617722000479 IF: 3.11

1.2 Test

Foran, A. M., Mathias, J. L., & Bowden, S. C. (2021). The QuickSort Manual, Record Form and Stimuli *Journal of the American Geriatrics Society*, published in the supplementary material. DOI:10.1111/jgs.16898 IF: 7.54

1.3 Software

Foran, A. M., Mathias, J. L., & Bowden, S. C. (2020). *The QuickSort-e*. iPad compatible version of the QuickSort. The prototype is available on TestFlight and approved users require a link and login password.

List of conference presentations

2019 Foran, A. M., Mathias, J. L., & Bowden, S. C. Sorting tests to detect cognitive decline: A meta-analysis. *Foley Conference,* Adelaide, SA, September

2019 Foran, A. M., Mathias, J. L., & Bowden, S. C. Effectiveness of sorting tests for detecting cognitive decline in older adults with dementia and other common neurodegenerative disorders: A meta-analysis. *APS College of Clinical Neuropsychologists National Conference,* Barossa, SA, November

2021 Foran, A. M, Mathias, J. L., & Bowden, S. C. The QuickSort: A briefer alternative cognitive screen for older adults. *6th Pacific Rim International Neuropsychological Society (INS), the Australasian Society for the Study of Brain Impairment (ASSBI), and the APS College of Clinical Neuropsychologists Hybrid Conference*, Melbourne, Vic, June

Award: Best student poster prize

2021 Foran, A. M., Mathias, J. L., & Bowden, S. C. The QuickSort: A brief new screen to detect cognitive impairment in older adults. *Alzheimer's Association International Conference*, Denver, USA, July

Abbreviations

ACE	Addenbrooke's Cognitive Exam
AD	Alzheimer's disease
APA	American Psychological Association
bvFTD	Behavioural-variant frontotemporal dementia
DASS-21	Depression Anxiety and Stress Scale-21
DMC	Decision-making capacity
FAB	Frontal Assessment Battery
FTD	Fronto-temporal dementia
ICC	Interclass correlation
LBD	Lewy body dementia
LR	Likelihood ratio
LR+	Positive likelihood ratio
LR-	Negative likelihood ratio
LS-DMC	Lifestyle decision-making capacity
MMSE	Mini-Mental State Examination
MND	Motor neuron disease
MoCA	Montreal Cognitive Assessment
RAH	Royal Adelaide Hospital
PD	Parkinson's disease
PDD	Parkinson's disease dementia
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
STROBE	Strengthening the reporting of observational studies in epidemiology
STARD	Standards for the reporting of diagnostic accuracy studies
VaD	Vascular dementia

Abstract

The prevalence of neurodegenerative disorders, especially dementia, is increasing as the population ages (Hou et al., 2019; World Health Organisation, 2021). There are currently no cures for dementia, but early treatments and interventions may slow disease progression and improve quality of life (Liss et al., 2021; Livingston et al., 2020). Despite early declines in memory and executive functioning (Erkkinen et al., 2018), dementia continues to be poorly detected (Amjad et al., 2018; Lang et al., 2017; Walker et al., 2017). The challenges in detecting dementia early are examined in Chapter 1, including reports of cognitive decline being unforthcoming or inaccurate and clinicians having limited time to conduct cognitive assessments (Olivari et al., 2020; Pink et al., 2018). Consequently, cognitive screens are recommended to detect cognitive decline quickly and objectively (Ismail Z et al., 2020; Pink et al., 2018). Chapter 1 examines how cognitive screens can expedite the assessments that are required to diagnose dementia (Roebuck-Spencer et al., 2017), facilitate access to interventions (Pink et al., 2018), and help identify older adults who are at risk of experiencing difficulties with independent functioning, decision-making, mental health and wellbeing (Ahlqvist et al., 2016).

Chapter 2 evaluates some of the most popular cognitive screens and recognises that they are less accurate for detecting cognitive decline than more time-intensive and comprehensive neuropsychological assessments (Summers et al., 2019). Neuropsychological assessments often examine executive functioning by administering tasks involving response inhibition, such as sorting tests (Wallace et al., 2022), which can detect dementia and MCI (Rabi et al., 2020). However, sorting tests are rarely used for screening purposes (Hobson, 2007). In reviewing the common cognitive screens, such as the Mini Mental Status Examination and Montreal Cognitive Assessment, Chapter 2 notes they do not include sorting tasks, and are limited by their administration and scoring time, user-friendliness, availability, reliability, and ability to detect cognitive decline (Hemmy et al., 2020; Larner, 2013). Although some sorting tests are quick to administer and provide a

promising alternative to common cognitive screens, they often use materials that are not readily available and there is limited information regarding their reliability (Beglinger et al., 2008; Hobson, 2007). Moreover, data relating to their effectiveness for detecting cognitive decline in older adults who have a neurodegenerative disorder had yet to be synthesized. The longstanding use of sorting tests in research and psychological practice suggested a meta-analysis would be useful to determine their effectiveness for detecting cognitive decline in older adults.

Study 1 (Chapter 3) involved a meta-analysis of 142 studies that used sorting tests in older adults (≥60 years of age) with and without a neurodegenerative disorder, including dementia and Parkinson's disease. This study found sorting tests were highly effectively for differentiating between those with and without a neurodegenerative disorder, especially dementia. In addition, their effectiveness seems to rival the Mini Mental Status Examination (MMSE; Mitchell, 2009), suggesting they may provide a viable alternative to this popular screen. Incidentally, the meta-analysis found sorting tests did not reliably differentiate between behavioural-variant fronto-temporal dementia and Alzheimer's dementia, which has significant clinical implications because they are often used for this purpose (American Psychiatric Association, 2013; Musa et al., 2020; Gustafson, et al., 1998; Possin et al., 2013). Of the different scores that sorting tests yield, the Category (grouping stimuli into categories) and Description (explaining the underlying categories) scores proved to be most effective for screening older adults for cognitive decline.

Study 2 (Chapter 4) introduced a newly developed cognitive screen – the QuickSort, which was designed to improve upon existing sorting tests (e.g.,Weigl). The QuickSort uses nine stimuli that need to be sorted by colour, shape and number, with the person additionally being required to explain/describe the basis for their correct sorts. It was designed to be quicker than existing sorting tests because it uses less stimuli and provides an early discontinuation rule for intact performance. The QuickSort also captures different levels of cognitive impairment through the use of additional trials and prompts. Designed for a wide

range of older adults, QuickSort scores can be computed even when an examinee finds it too difficult to complete or expressive language problems/low English proficiency prevent a person from explaining their sorts. The QuickSort stimuli, record form and manual are published online.

Study 3 (Chapter 5) involved the development of an iPad-compatible version of the QuickSort, called the QuickSort-e. This version of the test was specifically designed to improve the ease with which the test could be administered and scored in a standardized manner, reduce scoring errors and training requirements, and remove the need for physical stimuli and record forms. The QuickSort-e can share patients' records, which may assist in continuity of care, and store their information for clinical auditing (e.g., to determine patient characteristics) and research purposes.

Study 4 (Chapter 6) investigated the user-friendliness, and inter-rater and test-retest reliabilities of the QuickSort. It was administered to older (≥60 years) community-dwelling adults (*n* = 187) and inpatients referred for neuropsychological assessment (*n* = 78). The QuickSort was completed in less than two minutes by a cognitively-healthy subgroup (*n* = 115, defined using MMSE and FAB scores), confirming its brevity. QuickSort scores <2 and ≥17 increased and reduced the likelihood that an older adult was impaired on the MMSE or FAB or both of these screens by a factor of 9.26 (95% CI: 2.96 – 28.75) and 0.16 (95% CI: 0.06 – 0.41), respectively. Furthermore, the accuracy with which the QuickSort detected cognitive impairment improved when the prevalence of impairment on the MMSE and FAB in the specific healthcare setting was additionally considered. Overall, Study 4 found that the QuickSort is quick, easy, reliable, and a valid cognitive screen for detecting cognitive impairment in older adults.

Study 5 (Chapter 7) examined the QuickSort in relation to the complex clinical scenario of providing information regarding the lifestyle decision-making capacity of inpatients (LS-DMC; *n* = 124). In busy healthcare settings clinical interviews are used identify the inpatients needing comprehensive LS-DMC assessments in order to classify

them as lacking or not-lacking LS-DMC. Of the information available at the interview stage, which included cognitive screening performances on the MMSE and FAB, the QuickSort best differentiated between those who lacked LS-DMC and those who did not. Low (<2) and high (≥13) QuickSort scores increased or reduced the likelihood that a person lacked LS-DMC by a factor of 65.26 (95% CI: 2.91 – 1463.90) and 0.32 (95%CI: 0.18 – 0.57), respectively. In healthcare settings where many (58%) inpatients lack LS-DMC, the probability of inpatients lacking LS-DMC increased to 99% when their QuickSort scores were <2 and reduced to 30% with scores ≥13. Thus, the QuickSort appears to provide a viable alternative to other cognitive screens that are used at the initial clinical interview stage to provide information regarding inpatients' LS-DMC.

Overall, the rising prevalence of neurodegenerative disorders and associated cognitive decline is increasing the demand for cognitive screens (Connor, 2021), but existing measures are limited by the time they take to administer, their reliability and the accuracy with which they detect cognitive decline (Larner, 2016). Sorting tests are rarely used for screening (Hobson, 2007), but can effectively detect cognitive decline in older adults. The QuickSort is a new sorting test that provides a brief, reliable, and effective alternative to lengthier screens that are used for detecting cognitive impairment in older adults and appears to provide useful preliminary information regarding their LS-DMC.

Chapter 1

Neurodegenerative disorders and cognitive decline in older adults

1.1 Chapter overview

Chapter 1 examines how the prevalence of neurodegenerative disorders, especially dementia is increasing in the aging population, which is causing healthcare costs and disability to escalate (Hou et al., 2019; Parkinson's Foundation, 2021; Wimo et al., 2017; World Health Organisation, 2021). Although common, dementia often goes undetected (Lang et al., 2017; Liang et al., 2021a), reducing early access to medications, interventions and living supports, which are currently the only treatment options (Harrington et al., 2021; Lisko et al., 2021). Dementia typically presents with early decline in memory and executive functioning (Aarsland et al., 2017; Burrell et al., 2016; Mortamais et al., 2017), and is better detected using cognitive screens than clinical judgement or self-reports (Olivari et al., 2020; Pink et al., 2018; Roebuck-Spencer et al., 2017). Indeed, cognitive screens are widely used to identify those needing comprehensive and specialised investigations to diagnose dementia (Fink et al., 2020; National Institute of Health, 2020a; World Health Organisation, 2021). Beyond diagnosis and access to treatments, cognitive screens may help identify those at risk of experiencing issues with independent living, decision-making, mental health, and quality of life (Barry & Docherty, 2018; Leidi-Maimone et al., 2020; Regier, 2020).

1.2 Neurodegenerative disorders in older adults

People over 90 years of age are the fastest growing demographic group (Livingston et al., 2017) and those aged over 65 years will double by 2060 in the United States (US) and Australia (Mather et al., 2015; Australian Institute of Health and Welfare 2018). As the population ages, the prevalence of neurodegenerative disorders, such as dementia, will

increase (Hou et al., 2019). Neurodegenerative disorders progressively damage the brain and/or spinal cord (Marques-Aleixo et al., 2021; Sierra, 2020; Tanaka et al., 2020), resulting in a variety of cognitive, physical and behavioural symptoms that cause significant disability and reduce a person's quality of life (Risacher & Saykin, 2013).

There are currently over 60 million older adults living with a neurodegenerative disorder (Parkinson's Foundation, 2021; World Health Organisation, 2020), with many more family, friends and carers also being indirectly affected (de Wit et al., 2017; Page et al., 2017; Perneczky, 2019; Saunders, 2012). The annual healthcare expenditure for neurodegenerative disorders is very high, exceeding one trillion dollars in the US and 10 billion dollars in Australia (Brown et al., 2017; Economics, 2015; Wimo et al., 2017). Moreover, these costs are expected to surpass all other medical conditions by 2060 (Ecomonics, 2009). There are currently no cures for these disorders, only treatments and interventions that can slow disease-progression and improve quality of life, but their efficacy is reliant on early detection (Chaudhuri et al., 2006; Laske et al., 2015; Pagan, 2012; Sanford, 2017; von Arnim et al., 2019). In terms of prevalence, dementia of the Alzheimer's type (AD) is the most common neurodegenerative disorder in adults who are aged 65 years and over, followed by Parkinson's disease (PD), with other types of dementia and motor neuron disease (MND) being less prevalent (Hou et al., 2019; Liang et al., 2021). Indeed, dementia is by far the most common neurodegenerative disorder, although it remains poorly detected (Lang et al., 2017; Liang et al., 2021).

1.3 Dementia

Dementia refers to a range of neurodegenerative disorders that are characterized by progressive cognitive decline that is not attributable to reversible causes (Lisko et al., 2021). This decline can affect any cognitive domain, including memory, higher-level executive functioning (e.g., problem-solving, abstraction, reasoning, multitasking), speed of information processing, attention, perception and language (Guarino et al., 2019; Harrington et al., 2021;

Moreira et al., 2017). There are specific types of dementia (e.g., AD), and it is also associated with other neurodegenerative disorders, such as PD and MND (Erkkinen et al., 2018; Kovacs, 2017). Currently, there are an estimated 50 million people who are living with dementia, with this number expected to triple by 2050 (Rocca, 2018; World Health Organisation, 2021). Dementia is now the leading cause of disability and mortality in older adults (Connor, 2021).

Although prevalent, dementia goes undetected in more than 60% of affected individuals who are living in the community, even when they are admitted to hospital or are seen by general medical practitioners (Amjad et al., 2018; Lang et al., 2017; Walker et al., 2017). Furthermore, the failure to detect dementia is thought to be greater in lower income and developing countries (Lang et al; 2017). Consequently, its early detection is a public health priority for many countries (World Health Organisation, 2012, 2020).

Most older adults experience mild levels of cognitive decline in the early stages of dementia, with this condition being labelled ‘mild cognitive impairment’ (MCI) if it exceeds what is expected for a person’s age, but does not meet the diagnostic criteria for dementia (Hildreth & Church, 2015; Kasper et al., 2020; Petersen et al., 2001). The prevalence of MCI varies between 14% and 17% in community and clinical samples, respectively (Hu et al., 2017; Pessoa et al., 2019). However, not everyone with MCI will ‘convert’ to dementia, with a meta-analysis reporting an annual conversion rate of 9.6% and only 39% of people with MCI eventually being diagnosed with dementia (Mitchell & Shiri-Feshki, 2009). Nevertheless, MCI is considered to be a prodrome (symptom signalling the onset of a disease) for dementia and is also often seen in the early stages of a number of other neurodegenerative disorders, including PD and MND (Baiano et al., 2020; Chang et al., 2015; Koros et al., 2021; Litvan et al., 2011; Massman et al., 1996; Mortamais et al., 2017; Painous & Marti, 2020; Ringholz et al., 2005). It is thought that the most opportune time to commence interventions designed to delay or slow dementia is early, when MCI is present

(Adams et al., 2015; Han et al., 2019; Liss et al., 2021; Olivari et al., 2020; Robles Bayón, 2021).

1.4 Common types of dementia in older adults

AD is both the most common neurodegenerative disorder and the most common type of dementia in older adults (National Institute of Health, 2021). It accounts for approximately 80% of all cases of dementia and is present in 50% of people aged 95 years and over (Hou et al., 2019; Liang et al., 2021). AD is caused by the accumulation of extracellular amyloid plaques (amyloid-β: Aβ) and intracellular neurofibrillary tangles (tau) in the brain, which are primarily concentrated in the medial temporal lobe (Erkkinen et al., 2018; Weiner et al., 2015; Weller & Budson, 2018). Although a definitive diagnosis is not possible until an autopsy confirms the presence of plaques and tangles, a diagnosis of probable AD (amnesic or non-amnesic subtype) can be made using clinical information (Woodward et al., 2015). Amnesic AD requires a decline in short-term memory, whereas non-amnesic AD requires a decline in executive, visuospatial and/or language functioning (McKhann et al., 2011). Declining memory and executive functioning are thought to be the most disabling symptoms of AD and are often evident well before a diagnosis is made (Blenkinsop et al., 2020; Chang et al., 2015; Gaubert & Chainay, 2021; Guarino et al., 2019a; Mortamais et al., 2017). On average, the cognitive decline associated with AD becomes evident at 69 years of age, although people are typically diagnosed five years later, after which they only survive for another four years (Liang et al., 2021).

Vascular dementia (VaD) is the second most prevalent type of dementia (Liang et al., 2021) and is caused by multiple infarcts (localised damage of cardio-vascular origin) in the subcortical and frontostriatal circuits, which are visible on neuroimaging (Bir et al., 2021; Holmes et al., 1999; O'Brien & Thomas, 2015). The damage in VaD results in a ‘stepwise’ decline in cognitive functioning, often resulting in deficits in information processing, memory and executive functioning, which can appear similar to AD (Bir et al., 2021; Goodman et al.,

2017). Like AD, subtle cognitive changes are also often seen in the prodromal stages of VaD (Jaul & Meiron, 2017). The age at onset of VaD is normally around 68 years, although people are typically not diagnosed for another six years, after which they survive for an average of only three years (Liang et al., 2021). In addition, a mixed dementia – involving both AD and VaD pathologies – is common and is predicted to be the dementia-type that increases the most as the population ages (Langa et al., 2004; Livingston et al., 2020; Wolters & Ikram, 2019).

Lewy body dementia (LBD) is the third most prevalent type of dementia in older adults, although it accounts for only 5% of all dementia cases (Goodman et al., 2017). LBD is caused by an accumulation of lewy bodies (comprising misfolded α-synuclein & abnormal proteins), β-amyloid plaques and tau deposits, which are typically concentrated in brainstem, limbic and neocortical areas (Coughlin et al., 2020; Donaghy & McKeith, 2014; Jellinger, 2018; Kim et al., 2014; McKeith et al., 1996). LBD has more obvious physical symptoms, including rigidity, tremor and difficulties with mobility. In addition, there may also be visual hallucinations (often of people) and fluctuating mental status (including periods of confusion and reduced alertness; Donaghy & McKeith, 2014; Jellinger, 2018; McKeith et al., 1996; Taylor et al., 2020; Zaccai et al., 2005). Although non-cognitive symptoms are prominent, declining memory and executive functioning are amongst the most common and earliest symptoms of LBD (Erkkinen et al., 2018; Jellinger, 2018; Schumacher et al., 2019), and may be present in the prodromal stages (Tangalos & Petersen, 2018). The onset of LBD is around 72 years of age, with the pronounced physical symptoms likely contributing to a more timely diagnosis two years later, after which affected individuals live for approximately five more years (Liang et al., 2021).

Frontotemporal dementia (FTD) is a less common form of dementia, accounting for only 1% of all cases (Goodman et al., 2017). It primarily results from the accumulation of tau within the brain (Hogan et al., 2016; Li et al., 2020) and has two main subtypes: a behavioural variant and one involving primary progressive aphasia (Goodman et al., 2017;

Kirshner, 2014; Liang et al., 2021; Liu et al., 2019). The behavioural variant (bvFTD) is largely associated with atrophy (neuronal death) in the medial orbitofrontal regions, leading to changes in social behaviour, personality, empathy and insight (Rascovsky et al., 2007; Rascovsky et al., 2011). In contrast, primary progressive aphasia is normally associated with atrophy in the left frontal, temporal and parietal areas, resulting in problems with receptive and expressive language and speech (Kirshner, 2014; Roca et al., 2013). Despite these differences, executive dysfunction is reportedly a common feature of both FTD subtypes (Harciarek & Jodzio, 2005; Liu et al., 2019) and may be apparent in the prodromal stages, prior to receiving a diagnosis (Tangalos & Petersen, 2018). However, whether FTD can be distinguished from the other dementia types on the basis of executive impairment remains controversial (Hutchinson & Mathias, 2007; Musa et al., 2020; Roca et al., 2013). Although less prevalent than the other dementias, it is important to detect FTD early because it has a younger age of onset and an earlier mortality than the preceding dementias (Hogan et al., 2016). Symptoms typically start at around 59 years of age, but it takes an average of five years for people to receive a diagnosis, after which they are likely to live for only another four years (Liang, 2021).

1.5 Dementia caused by Parkinson's and motor neuron diseases

Dementia is also a common feature of several neurodegenerative disorders that have pronounced physical symptoms, with PD and MND being the most common of these (Logroscino et al., 2018; Parkinson's Foundation, 2021). PD is the second most prevalent neurodegenerative disorder in older adults and is more common in males (Parkinson's Foundation, 2021; Saeed et al., 2017). There are currently over 10 million people living with PD, although this figure is expected to double to 20 million by 2050 (Parkinson's Foundation, 2021; Rocca, 2018). PD is caused by Lewy bodies that accumulate in the brainstem, particularly the substantia nigra, which interfere with the production of dopamine and cause a range of physical symptoms (García-Sanz et al., 2021). These symptoms include resting

tremor (essential tremor), difficulties moving stiff limbs (rigidity), no or slowed movements (akinesia, bradykinesia), and postural problems (Parkinson's Foundation, 2021; Saeed et al., 2017). The average age of onset for PD is 64 years and there is a long period of significant disability before mortality at an average age of 78 years (Paul et al., 2019; Wong et al., 2014). Notably, the overt physical symptoms caused by PD result in a more timely diagnosis than dementia (Gillard et al., 2019), averaging two years after symptoms appear (Wong et al., 2014).

Cognitive symptoms are very common in PD, often affecting executive functioning as a consequence of disruptions to the dopaminergic pathways that project to the frontal lobes (Getz & Levin, 2017). Indeed, executive problems are often one of the earliest symptoms experienced by persons with PD and may be evident before a person is diagnosed (Fields, 2017; Jellinger, 2018; Pereira et al., 2019). The cognitive decline in PD is often severe enough to meet the criteria for dementia and is referred to as 'PD dementia' (PDD; Ascherio & Schwarzschild, 2016). PDD occurs in approximately 75% of people with PD and, as with LBD, it typically involves declining memory and executive functioning (Aarsland et al., 2003; Ascherio & Schwarzschild, 2016; Painous & Marti, 2020; Pennington et al., 2021; Saeed et al., 2017). Like other forms of dementia, PDD often goes undiagnosed (Ding et al., 2015; Lanskey et al., 2018), although it is typically preceded by MCI (De Roy et al., 2020). Importantly, persons with PD who experience cognitive decline have greater levels of disability and a shorter life expectancy, highlighting the need for early detection (Bäckström et al., 2018; Getz & Levin, 2017; Jellinger & Korczyn, 2018).

There are also atypical forms of PD, which are less prevalent, but have earlier and more marked cognitive decline and a shorter life expectancy, namely: multiple system atrophy, progressive supranuclear palsy and corticobasal degeneration (Bäckström et al., 2018; Grażyńska et al., 2020). The cognitive decline seen in these atypical forms of PD is thought to result from neuropathological changes that overlap with other types of dementia. Specifically, multiple system atrophy is associated with the α-synuclein pathology that occurs

in LBD, and both progressive supranuclear palsy and corticobasal degeneration feature the accumulation of tau, similar to FTD (Onyike & Diehl-Schmid, 2013; Saeed et al., 2017). Accordingly, executive functioning is considered to be an early and overlapping feature in PD and atypical PD because of the accompanying LBD and FTD features (Koros et al., 2021).

MND is another relatively uncommon neurodegenerative disorder, which occurs in six to eight people in every 100,000, with a higher prevalence in males (Smith et al., 2015). The pronounced physical symptoms in MND, including motor weakness and fatigue, are caused by a deterioration of the motor neurons in the precentral gyrus of the frontal lobe or in the ventral horn in the spinal cord (Foster & Salajegheh, 2019). The most common subtype of MND is amyotrophic lateral sclerosis (ALS), which is classified according to where the physical symptoms first appear (spinal, bulbar or respiratory; Ragagnin et al., 2019; Smith et al., 2015; Zarei et al., 2015). The age of onset of MND is early, ranging between 51 and 66 years of age (Longinetti & Fang, 2019). The overt physical symptoms contribute to more timely diagnoses, with people often being diagnosed shortly after the onset of their symptoms (time between symptom-onset and diagnosis: range = 9 to 24 months; Longinetti & Fang, 2019).

Cognitive decline is a common feature of MND (Borrego-Écija et al., 2021), occurring in up to 50% of people with ALS within two to five years after the onset of their physical symptoms (Crockford et al., 2018). Executive functioning, language, social cognition and empathy are commonly affected, resulting in 15% of persons with ALS being diagnosed with FTD (Crockford et al., 2018; Goldstein & Abrahams, 2013; Smith et al., 2015; Strong et al., 2017). Like PD, cognitive decline and dementia are less recognised aspects of MND, despite being associated with increased disability and a shorter life expectancy (Crockford et al., 2018; Massman et al., 1996; Nguyen et al., 2021; Pender et al., 2020).

Overall, PD and MND are less prevalent than dementia, but have distinct physical, and pathological features that typically result in more timely diagnoses (Erkkinen et al., 2018;

Kovacs, 2017). LBD and FTD frequently occur in PD and MND, respectively (Chang et al., 2015; Koros et al., 2021; Pereira et al., 2019; Tangalos & Petersen, 2018), but this is rarely recognised, particularly in the early stages (Borrego-Écija et al., 2021; Painous & Marti, 2020). Nevertheless, it is important to detect cognitive decline caused by PD and MND because it is associated with increased disability and shorter life expectancy (Bäckström et al., 2018; Nguyen et al., 2021).

1.6 Clinical stages in the diagnosis of dementia

In Australia and elsewhere, there are typically three stages of clinical investigation that can lead to a diagnosis of dementia (Pink et al., 2018). First, people with cognitive decline are often identified in healthcare settings (e.g., general medical practices and hospitals) during a face-to-face consultation with a clinician, which can involve a preliminary interview and cognitive screens (Porsteinsson & Clark, 2021; National Institute of Health, 2020b; Olivari et al., 2020). Next, these people may receive a diagnosis of dementia when more detailed clinical investigations confirm cognitive decline and exclude other conditions (Connor, 2021; Roebuck-Spencer et al., 2017). Third, a specific dementia-type may be diagnosed by specialists (e.g., neuropsychologists, geriatricians, etc.) after additional comprehensive investigations (Connor, 2021; Pink et al., 2018; Roebuck-Spencer et al., 2017).

1.6.1 The detection of cognitive decline in healthcare settings

Cognitive decline is often detected by clinicians working in healthcare settings, such as general medical practices or in tertiary health settings, including hospital outpatient clinics or inpatient units (Lam et al., 2019; Pendlebury et al., 2015; Roebuck-Spencer et al., 2017; Scott & Mayo, 2018; So et al., 2018). Time and clinical resources are usually very limited in these settings and consultations are generally quite brief (Pinsker et al., 2018). Older adults (or family members) may report difficulties with their thinking (e.g., forgetting birthdays or to

pay bills), behaviour (e.g., becoming socially inappropriate or disengaged) or functioning (e.g., not eating regularly, getting lost; Falk et al., 2021; Ismail et al., 2020; Liew, 2020; Perry-Young et al., 2018; Zhang et al., 2021), although there are often long delays between the onset of these problems and when they are discussed with a clinician (Perry-Young et al., 2018; Zhang et al., 2021).

In the absence of reports from older adults (or family), clinicians may also suspect cognitive decline if a person experiences problems recalling information during the clinical consultation or fails to attend appointments (Ismail et al., 2020). In addition, clinicians may be concerned about an older adult's cognition if there are changes in their health, independent functioning or behaviour, such as unexplained weight loss, declining ability to manage their health conditions and depressed mood (Ismail et al., 2020; World Health Organisation, 2019). Clinicians are usually also vigilant for signs of cognitive decline in older adults who have conditions that elevate their risk of dementia, such as sleep apnoea, a first episode of a major psychiatric illness or major depressive disorder, a neurodegenerative disease (e.g., Parkinson's disease), stroke, other vascular problems, or a recent episode of delirium (Ismail et al., 2020; Livingston et al., 2020; World Health Organisation, 2019). Most clinicians will initially seek to confirm or alleviate their concerns about the presence of cognitive decline by conducting an interview with the older adult and, ideally, someone who knows them well (e.g., a family member; Olivari et al., 2020)

Clinical interviews are being conducted with growing numbers of older adults who are experiencing cognitive decline because clinicians are aware of the benefits of detecting dementia early (Jacobson et al., 2020). These interviews are often conducted during a relatively brief clinical consultation and are used to determine if the older adult requires further investigations into their cognitive functioning (Hill et al., 2021; Lam et al., 2019; Olivari et al., 2020; Pink et al., 2018; Parker et al., 2020; Poole et al., 2020; Twomey et al., 2020). The interview can be particularly important for detecting cognitive decline in older adults who have limited access to transport and are unable to attend follow-up appointments (Corcoran

et al., 2012; Negrete-Najar et al., 2021), need assistance when getting ready (e.g., dressing) or experience problems remembering appointments and organising their attendance (Neal et al., 2005; Twomey et al., 2020).

Although useful, clinical interviews are limited when trying to detect cognitive decline in older adults (Ismail et al., 2020). Clinicians must be familiar with the older adult and their personal history in order to recognise changes in cognition or functioning, particularly when the changes are subtle (Borson, 2004; Burleigh et al., 2002; Parker et al., 2020). Additionally, affected older adults and their family members may not be forthcoming with reports of cognitive problems if they are fearful of dementia, despite public health campaigns aimed at addressing this issue (National Institute of Health, 2020b; Olivari et al., 2020; Phillipson et al., 2015). Older adults and their family may also misattribute cognitive decline to normal aging (Galvin, 2018). Lastly, persons with depression (Zlatar et al., 2017), limited insight (Fink et al., 2020; Galvin, 2018) or severe cognitive impairment (Edmonds et al., 2018) may provide inaccurate reports. Consequently, many clinicians now integrate more objective measures of cognitive decline into their consultations; usually in the form of cognitive screens (Fink et al., 2020; Galvin, 2018; Livingston et al., 2017; National Institute of Health, 2020b; Pendlebury et al., 2015).

There are several benefits of using cognitive screens for detecting cognitive decline in older adults during the clinical consultation (Pink et al., 2018). First, cognitive screening may expedite the additional investigations that are needed to formally diagnose dementia and thereby reduce delays in accessing pharmacological interventions, supports and services (Galvin, 2018; Laske et al., 2015; Liss et al., 2021; Tsoi et al., 2015). Second, cognitive screens may identify decline at an earlier stage, leading to timelier commencement of interventions that are designed to prevent or slow the progression of dementia (Livingston et al., 2020). These interventions include improving diet, cardiovascular health and social engagement (Ascherio & Schwarzschild, 2016; Bianchi et al., 2019; Heckman & McKelvie, 2008; Livingston et al., 2017; Marques-Aleixo et al., 2021; Martinez et al., 2010; Sanford,

2017). Currently, the most effective interventions for reducing the risk of dementia are being investigated through an international network of multidomain trials (see wwfingers.com; Kivipelto et al., 2020).

Third, cognitive screens may help to identify older adults who are having difficulties with independent living (Pink et al., 2018). Left undetected, cognitive impairment can lead to problems with managing health conditions, finances and driving, render a person susceptible to scams, and result in unnecessary hospitalisations and/or legal problems (Laske et al., 2015; Milne, 2010; Sanford, 2017).

Fourth, screens may help to identify older adults who are at risk of having their ability to make independent and informed decisions – known as 'decision-making capacity' – compromised by cognitive impairment (Moye et al., 2013). In tertiary (hospital) settings, older adults have longer and more complex admissions if their ability to make independent and informed lifestyle decisions is questioned (Chen et al., 2016; Miller et al., 1999; Torke et al., 2014). This is referred to as 'lifestyle decision making capacity' (LS-DMC) and includes decisions regarding where they live (independently or in care) and the supports they receive (Brindle & Holmes, 2005; Demakis, 2012; Shibu et al., 2020).

Fifth, cognitive screens may also assist in detecting the older adults who are at risk of mental health issues, because such issues are strongly correlated with the onset and severity of cognitive impairment in dementia, PD and MCI (Gallagher et al., 2017; Gustafsson et al., 2015; Hanganu & Monchi, 2018; Ismail et al., 2020; Kuring et al., 2018, 2020; Mirza et al., 2016). In particular, depression and anxiety are common in people with neurodegenerative disorders, occurring in 80% of people with dementia and 92% of people with late-stage PD (Hommel et al., 2020; Lyketsos et al., 2002; Pennington et al., 2021; Porsteinsson & Antonsdottir, 2015).

Lastly, cognitive screens may help identify older adults whose quality of life has been negatively impacted by cognitive decline (Crockford et al., 2018; Cui et al., 2015; Lawson et

al., 2017; Mosley et al., 2017; Page et al., 2017; Rose et al., 2021; Schrag et al., 2000; Yu et al., 2015) and who may be helped by accessing community supports, psychological interventions, carer education, support groups and/or respite (Anderson & Blair, 2020; Bouldin et al., 2021; Froggatt et al., 2020; Li et al., 2020; Seematter-Bagnoud & Büla, 2018; van Groenestijn et al., 2015; Vandepitte et al., 2019; Zarotti et al., 2021).

Issues with independent functioning, decision-making, mental health and quality of life can be improved through future-care planning, medication and supports (Barry & Docherty, 2018; Leidi-Maimone et al., 2020; Regier, 2020). Therefore, cognitive screens may not only improve the timeliness of diagnosis and access to interventions that help slow or prevent dementia, but they may also markedly improve the lives of persons with dementia (Brodaty & Arasaratnam, 2012; Gitlin et al., 2016; Kehagia, 2016; Leidi-Maimone et al., 2020; Lin et al., 2021; Moye et al., 2013; Regier, 2020).

1.6.2 The diagnosis of dementia and its types

After a person with cognitive decline has been detected, the clinician will usually recommend that they undergo a more detailed cognitive assessment and additional interviews to determine the severity, onset, progression and type of cognitive impairment, as well as its impact on everyday living (Ismail et al., 2020; Longinetti & Fang, 2019; Robinson et al., 2015; Robles Bayón, 2021; Seematter-Bagnoud & Büla, 2018). Additionally, laboratory and imaging investigations are used to rule out treatable causes for cognitive impairment, such as delirium, infections, raised intracranial pressure, bleeding in the brain, depression and vitamin deficiencies (Olivari et al., 2020). These investigations usually can't be accommodated in the initial clinical consultation because they are time-intensive (Roebuck-Spencer et al., 2017). The results of these investigations determine whether the diagnostic criteria for dementia is met, which is otherwise referred to as a 'neurocognitive disorder' in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013). Specifically, there must be evidence of progressive decline

in two or more cognitive domains that is having a negative impact on the person's everyday functioning (American Psychiatric Association, 2013). Other methods of diagnosing dementia, such as biomarkers (e.g., in cerebrospinal fluid, blood and urine) and molecular imaging (e.g., fluorinated molecular probes for detecting tau in AD), are too invasive, time consuming and expensive for routine use, and may not correlate with functional decline (Htike et al., 2019; National Institute on Aging, 2020; Verber et al., 2019; Yeo et al., 2020; Robles Bayon., 2021; Ismail et al., 2020).

Once a diagnosis of dementia has been made, a specific dementia-type may be investigated by conducting multiple comprehensive and time-intensive investigations, which are interpreted by specialists, such as geriatricians, neurologists, psychiatrists, neuropathologists and neuropsychologists (Brooks, 2021; Halliday et al., 2002; Nous et al., 2021; Robles Bayón, 2021; Villemagne et al., 2021). However, there is continuing controversy regarding the usefulness of diagnosing specific dementia types (Finucane, 2018a, 2018b; Robles Bayón, 2021). A diagnosis may assist in selecting medications (e.g., acetylcholinesterase inhibitors in early stages of AD) and treating co-morbid medical conditions (e.g., hypertension, in VaD; Teng & Mendez, 2018; Robinson, 2015). However, the management recommendations converge for most dementia's (e.g., management of vascular risk factors and advance care planning), the presenting symptoms worsen over-time (e.g., increasing memory difficulties), and they tend to progress like they start (e.g., a rapid onset of symptoms is associated with faster decline than those with slower onset; Finucane, 2018a; Robinson et al., 2015). In addition, the diagnosis of specific dementia types is challenging because symptoms often overlap, with declining memory and executive functioning being typical of multiple dementia types (Jiménez-Huete et al., 2014; Reul et al., 2017; Selvackadunco et al., 2019). Currently, the time-consuming investigations to diagnose dementia (and a specific type) cannot be expedited, so to improve the timeliness of diagnosis clinicians must detect older adults with cognitive decline early, typically in busy clinical settings where they use cognitive screens.

1.7 Summary

As the population ages, the number of older adults with neurodegenerative disorders – like dementia – is increasing, along with the associated levels of disability, premature deaths and healthcare expenditure (Connor, 2021; Parkinson's Foundation, 2021; World Health Organisation, 2021). Although prevalent, dementia often goes undetected, despite early declines in memory and/or executive functioning (Lang et al., 2017; Liang et al., 2021). This cognitive decline may not be detected during a routine clinical interview because complaints may not forthcoming or accurate (Fink et al., 2020; Ismail et al., 2020; Olivari et al., 2020). Hence, clinicians often use cognitive screens as a more objective way to detect cognitive decline (Pink et al., 2018). Cognitive screens help to identify those who are most in need of time-consuming specialist investigations to diagnose dementia (Roebuck-Spencer et al., 2017) and who would benefit from interventions and supports that may prolong and improve life (Lin et al., 2021; Liss et al., 2021; Livingston et al., 2020). Thus, as we face the challenges of an aging population, cognitive screens are likely to play an increasingly important role in healthcare.

Chapter 2

Cognitive screens for detecting cognitive impairment in older adults

2.1 Chapter overview

The demand for cognitive screens is increasing due to the rising prevalence of dementia and an emphasis on detecting decline early when interventions may prolong and improve life (Livingston et al., 2020; Pink et al., 2018). Although neuropsychological tests accurately detect cognitive decline, clinicians in many healthcare settings only have the time, expertise and resources to administer cognitive screens (Pinsker et al., 2018; Summers et al., 2019). This chapter critiques some of the most commonly-used cognitive screens in terms of the abilities they assess, their administration time, availability, reliability, and the accuracy with which they detect cognitive decline in older adults. The limitations of these cognitive screens are also examined, highlighting the need for alternative measures, such as sorting tests (Beglinger et al., 2008). Sorting tests are rarely used for screening purposes, despite the availability of brief and free versions that may detect declining memory and executive functioning, which occur in the most common neurodegenerative disorders in older adults, especially dementia (Goldstein & Scheerer, 1941; Rabi et al., 2020).

2.2 Neuropsychological tests

Neuropsychological tests are considered the 'gold standard' in cognitive testing (Ravdin et al., 2004) because they are able to accurately and objectively detect cognitive decline in dementia (Pinsker et al., 2018), PD (De Roy et al., 2020) and MND (Lillo & Hodges, 2010). They can also identify the people with MCI who are most likely to develop dementia, with some tests having over 90% accuracy (see Belleville et al., 2017 for meta-

analysis). Tests of executive functioning are especially effective, possibly because they assess multiple abilities that decline in dementia, including higher-order cognitive abilities and memory (Floyd et al., 2010; Jewsbury et al., 2016; Wallace et al., 2022). Indeed, multiple meta-analyses now confirm the accuracy of executive tests for detecting cognitive decline in older adults (Belleville et al., 2017; Henry et al., 2004; Pinsker et al., 2018; Prado et al., 2019). In particular, tests of executive functioning that involve response inhibition are very effective for detecting MCI and dementia (Kaiser et al., 2018; Wallace et al., 2022), with the Wisconsin Card Sorting Test amongst the most sensitive (Rabi et al., 2020). However, the Wisconsin Card Sorting Test is only one of a number of sorting tests and the usefulness of other sorting tests for detecting cognitive decline in older adults who have a neurodegenerative disorder has yet to be evaluated and compared to this test.

Although effective, neuropsychological tests (including sorting tests) are not often used to detect cognitive impairment in many healthcare settings because they take too long to administer, score and/or interpret (Laske et al., 2015; Summers et al., 2019). Instead, neuropsychological tests tend to be administered in subsequent appointments with a specialist (e.g., clinical neuropsychologists) in order to diagnose dementia and specific dementia types (Jacova et al., 2007). Additionally, clinicians may not have the expertise or funds to administer neuropsychological tests. For example the Wisconsin Card Sorting Test, which is the most popular sorting test, requires clinicians to have advanced training in psychological test administration and interpretation (e.g., a Masters degree in psychology), and costs $524 (US) for the test and over $3 (US) for each patient record form thereafter (see https://www.parinc.com).

2.3 Cognitive screens

Cognitive screens have been developed in response to the limited time and resources (e.g., expertise and funds) that are available in most healthcare settings and the increased demand for cognitive testing (Lam et al., 2019). While they are modelled on

neuropsychological and educational tests (Folstein et al., 1975), cognitive screens are generally designed to identify those who need more thorough diagnostic investigations in a quick and cost-effective way (Fink et al., 2020; Roebuck-Spencer et al., 2017). Like neuropsychological tests, cognitive screens can be used to detect dementia (Pink et al., 2018; Tsoi et al., 2015) and MCI (Breton et al., 2019b). When used in primary healthcare settings (e.g., by general medical practitioners), cognitive screens have been shown to improve the lives of older adults and reduce healthcare costs (Tong et al., 2017). Consequently, leading organisations – such as the National Institute for Health and Care Excellence (UK), the National Institute on Aging (US), the Royal Australian College of General Practitioners (AU), and the Alzheimer's Association – recommend the administration of cognitive screens to older adults who are at risk of dementia (Alzheimer's Association, 2021; Dyer et al., 2016; National Institute of Health, 2020b; Pink et al., 2018).

The most popular cognitive screens are 'multi-task' screens (e.g., Mini-Mental State Examination, Frontal Assessment Battery, Addenbrookes Cognitive Examination, Montreal Cognitive Assessment), which involve multiple subtests or tasks (e.g., picture naming, word recall, digit span) and assess a variety of different cognitive abilities (e.g., word finding, verbal memory, working memory; Possin et al., 2013; Strauss, 2006). A decline in two or more of these cognitive abilities may be indicative of dementia, although when screens are used for diagnostic purposes they result in a high error rate (Summers et al., 2019). Consequently, screens are only recommended to detect cognitive decline and not diagnose dementia (Pink et al., 2018), with the individual subtest scores often being summed into a Total score for this purpose (Carson et al., 2018). Of note, the Total Scores from single-task and multi-task screens can have comparable sensitivity for detecting cognitive decline (Brodaty & Moore, 1997; Bruijnen et al., 2020), possibly because some single-task screens also assess multiple cognitive domains (such as memory and higher-level abilities), especially those involving executive functioning (Floyd et al., 2010; Jewsbury et al., 2017).

Single-task screens often take less time to administer than multi-task screens (Larner, 2016; Menon & Larner, 2011; Tappen, 2019).

Cognitive screens that are quick to administer, score and interpret are preferred in settings where a clinician's time is very limited (De Roeck et al., 2019; Galvin, 2018; Scott & Mayo, 2018). Consistent with this, the National Institute for Health and Care Excellence (UK) considered administration time when recommending screens for detecting cognitive decline in older adults (Pink et al., 2018). Screens that require limited training are also popular (Scott & Mayo, 2018), as are ones that can be administered by nurse practitioners when medical practitioners are few and/or their time is limited (Scott & Mayo, 2018). Free cognitive screens, which use readily available materials (e.g., pen, downloadable record form, watch) are the most popular (Dubois et al., 2000; Folstein et al., 1975; Julayanont & Nasreddine, 2017; Mainland & Shulman, 2013; Scott & Mayo, 2018). However, the suitability of a screen for detecting cognitive decline in older adults does not just depend on the abilities they measure, how quickly they can be administered, the clinical expertise required to administer them and their cost/availability, but also how reliably and accurately they detect this decline.

The reliability of a cognitive screen is often determined on the basis of whether they produce stable scores when different clinicians (raters) administer and score the screen (inter-rater reliability) and whether people with stable conditions score comparably on repeated assessments (test-retest reliability; Bowden & Finch, 2017; Calamia et al., 2013; Lange, 2011). In the past, internal reliability was also considered, but the correlation between the items in a screen is no longer thought to be clinically relevant or helpful (Sijtsma, 2009). Although the inter-rater and test-retest reliabilities of many popular screens have frequently been examined, many only report the relationship between two sets of scores and fail to take into account any absolute differences between the scores (Bowden et al., 2021). For this purpose, the interclass correlation (ICC) using absolute agreement for single measures is recommended, with a satisfactory alternative being to report both the

standardized mean difference and a Pearson's *r* statistic (Bowden et al., 2021). Reliability coefficients of .8 are considered acceptable and .9 are considered good (Bowden & Finch, 2017; Bowden et al., 2021; Charter & Feldt, 2001). Unfortunately, it is often unclear whether the reported reliability coefficient assessed absolute agreement or not, in which case it should be assumed that it was *not* taken into consideration and that the reported statistic may overestimate the true reliability of a cognitive screen (Bowden et al., 2021).

The accuracy of a cognitive screen is determined by its ability to differentiate between adequately-sized and representative cognitively-healthy (e.g., no history of a neurological disorder) and cognitively-impaired (e.g., diagnosed with dementia) samples (Bowden, 2017). The cognitively-healthy sample provides a benchmark against which an individual's performance can be compared to in order to detect decline (Strauss, 2006). This comparison may need to consider factors that cause variations in performances (e.g., age, sex, education, previous level of functioning) to improve the accuracy of detecting cognitive decline (Bruijnen et al., 2020; Shulman, 2000; Strauss, 2006Summers et al., 2019). Differences between the cognitively-healthy and cognitively-impaired samples determine the sensitivity (ability to correctly identify someone with cognitive impairment) and specificity (ability to correctly identify someone who is not cognitively impaired) of a cognitive screen; also referred to as discriminant validity (Deeks, 2004; McGee, 2016; Straus., et al., 2019).

The two consecutive scores that optimise sensitivity and specificity are often used as a cut-score on a screen (Loring et al., 2009), enabling clinicians to quickly classify performances as 'impaired' or 'not-impaired' (Carson et al., 2018). Specifically, the score with greater sensitivity (usually the lower score) is used to classify people as impaired (Carson et al., 2018). Ideally, cut-scores should have high sensitivity and specificity (≥80%) for detecting cognitive decline, but this is often difficult to achieve even with comprehensive assessments (Summers et al., 2019). Therefore, sensitivity is often prioritised, particularly when the prevalence of cognitive impairment is low and clinicians want to avoid missing someone who may be experiencing decline (false-negatives; Hemmy et al., 2020; Larner,

2013). When sensitivity is prioritised over specificity, more cognitively-healthy people are likely to be misidentified as impaired (false-positives; Hemmy et al., 2020; Larner, 2013), but this should be apparent when additional investigations are undertaken following a positive screening result (Summer et al., 2019). One notable failing of cut-scores, however, is that scores in the middle range are often not very informative (poor discriminant validity; Loring et al., 2009; Pachet et al., 2010). Score categories are therefore recommended as an alternative because they group scores according to how useful they are at differentiating those with and without impairment (Loring et al., 2009).

Likelihood ratios (LR) provide a clinically-meaningful way to interpret screening scores (including cut-scores and score categories) because they combine a score's sensitivity and specificity in order to determine how much a given score increases (positive likelihood ratio; LR+) or decreases (negative likelihood ratio; LR-) the likelihood that a person is cognitively impaired (Loong, 2003; McGee, 2002). The likelihood of cognitive impairment increases when a LR is >1 and decreases when it is <1 (Deeks, 2004), with LRs >3 or <0.3 thought to indicate substantial changes in this likelihood (McGee, 2018). Moreover, LRs can be interpreted in combination with the local prevalence of cognitive impairment in order to determine a person's post-test probability of being impaired (McGee, 2018). For example, if 80% of patients referred to a memory clinic have cognitive impairment, and a patient's score has a LR of 2, his/her post-test probability of being cognitively impaired is 90%. Notably, calculating these probabilities for every person's score can be time-consuming, but clinical decision modelling can determine the score categories that substantially increase or decrease the probability of a person being cognitive impaired in certain settings (Bowden & Loring, 2009; Straus et al., 2019). These clinical decision models improve the accuracy of interpretation, so much so that they are promoted as part of evidence-based medicine (McGee, 2016; Centre for Evidence-Based Medicine, 2018; Straus et al., 2019).

In summary, the accuracy with which screening scores are interpreted can be improved by computing sensitivity, specificity, LRs, post-test probabilities and clinical

decision models, but the time this takes represents a significant obstacle for many clinicians (McGee, 2002). Although computerised cognitive screens can be programmed to instantly compare a person's score to their cognitively-healthy peers, calculate LRs and determine the probability that the person is cognitively-impaired, few such screens are currently available for clinical use (Roebuck-Spencer et al., 2017). The following screens are not often computerized, but are popular because of the cognitive abilities that they assess, the time they take to administer and their availability, with research additionally supporting their reliability and accuracy for detecting cognitive decline in older adults.

2.3.1 Mini-Mental Status Exam

The Mini-Mental State Examination (MMSE) was originally designed to measure cognitive impairment in psychiatric patients (Folstein et al., 1975) and is one of the most popular multi-task screens for detecting dementia (Sheehan, 2012; Tsoi et al., 2015). It has 11 tasks that assess orientation (time and place), verbal registration and recall, attention, object naming, word repetition, verbal comprehension, writing and construction, with a Total Score ranging between 0 and 30 (Folstein et al., 1975). Notably, the MMSE does not explicitly examine executive functioning, which is a key feature of many neurodegenerative disorders (Kim et al., 2013). Although not designed for diagnostic purposes (Folstein et al., 1975), the National Institute of Neurological and Communicative Disorders and Stroke and the AD and Related Disorders Association (NINCDS-ADRDA) recommended using the MMSE when diagnosing AD (McKhann et al., 2011).

The MMSE takes approximately 8 to 15 minutes to administer (Folstein et al., 1975), but there are no time limits (Molloy & Standish, 1997), which may prove too time-consuming for some healthcare settings (e.g., primary care and inpatient settings; Pink et al., 2018). One advantage of the MMSE is that it can be administered by a variety of clinicians, including nurses, and the test materials (pen, paper, watch) are readily available (Folstein et al., 2010). The updated MMSE (MMSE-2) has a more standardized administration, alternate

forms to lessen practice effects, a brief version for rapid screening, and an expanded version to reduce ceiling effects (Molloy & Standish, 1997). However, copyright restrictions and test costs (manual, record forms) may limit use of the MMSE (all versions) in clinical practice (Creavin. et al., 2016; Robinson et al., 2015).

The reliability of the MMSE is reported to be good to excellent because similar scores have been obtained by different clinicians (Kappa = 0.96; O'Connor et al., 1989 & concordance correlation coefficient = 0.87; Fabrigoule et al., 2003) and when older adults with/without cognitive impairment (Pearson's *r:* .8 to .95; Tombaugh & McIntyre, 1992) and mild to moderate AD (ICC & Pearson's *r:* >75; Kingery et al., 2011) were retested after a 2-month interval. These reliabilities may not, however, account for mean differences between the scores of different clinicians (inter-rater) and over time (test-retest). Additionally, there may be practice effects resulting from previous exposure to the MMSE, given its frequent use and availability on the internet (Tombaugh & McIntyre, 1992).

The original normative sample for the MMSE was small (*n* = 63; Folstein et al., 1975), but larger normative samples that are stratified by age and education are now available to assist in detecting cognitive decline (Crum, 1993; Li et al., 2016; Sakuma et al., 2017). The MMSE can also differentiate between persons with and without cognitive impairment, with a cut-score <24 having acceptable sensitivity (85%) and good specificity (90%) for detecting dementia in primary care settings (Creavin et al., 2016). McGee (2018) reported that the likelihood of dementia increases by a factor of 7.7 (LR+) for scores <24 and decreases by a factor of 0.2 (LR-) for scores ≥24. He also found that the accuracy of interpretation improved when three score categories (rather than a single cut-score) were used, with the likelihood of dementia increasing by a factor of 14.4 (LR+) for the lowest category (<20) and decreasing by a factor of 0.1 (LR-) for the highest category (≥26), but not changing substantially for scores in the middle range (20-25). The limited diagnostic information provided by scores in the middle category may explain why 8% of people with dementia go undetected in primary care and memory clinics (Mitchell, 2013), with high

functioning persons and those with executive problems being the most likely to be overlooked (O'Bryant et al., 2008).

Like many screens, the MMSE is less effective for detecting MCI, with a recent meta-analysis reporting low sensitivity (66%) and moderately-low specificity (77%; Breton et al., 2019), and another finding that the MMSE does not predict who will transition from MCI to dementia (Arevalo-Rodriguez et al., 2021). One explanation for these findings is that the MMSE doesn't overtly measure executive functioning, which may decline early in persons with MCI, especially in the prodromal stages of VaD, FTD, LBD and PDD (Kim et al., 2013). Consequently, screens that assess executive functioning (e.g., the Montreal Cognitive Assessment) are recommended for detecting MCI (Breton et al., 2019; Pinto et al., 2019). Alternatively, the MMSE can be supplemented with a test/screen of executive functioning, such as the Frontal Assessment Battery (Coen et al., 2016).

2.3.2 Frontal Assessment Battery

The Frontal Assessment Battery (FAB) was designed to provide a bedside test for detecting executive impairment caused by frontal lobe dysfunction, which is commonly seen in FTD, VaD and PD (Dubois et al., 2000). The FAB has six subtests that measure conceptualisation and abstract reasoning (Similarities), mental flexibility (Lexical Fluency), motor programming (Motor Series), sensitivity to interference (Conflicting Instructions), inhibitory control (Go-No-Go) and environmental autonomy (Prehension Behaviour; Dubois et al., 2000). Subtest scores are summed into a Total Score ranging between 0 and 18 (Dubois et al., 2000). The FAB takes 10 minutes to administer, is readily available on the internet, and does not require any special materials (Dubois et al., 2000). The FAB is commonly administered with the MMSE because it measures different cognitive abilities (Coen et al., 2016), thereby improving the likelihood of detecting dementia (Kim et al., 2013). However, administration time for the two screens often exceeds 20 minutes, which may be impractical for many healthcare settings (Pink et al., 2018).

The reliability of the FAB is reported to be excellent because similar scores have been obtained by different clinicians (Person's *r* = 0.96 & 0.90; Appollonio et al., 2005; Asaadi et al., 2016, respectively) and after 2- to 4-weeks in cognitively-healthy adults and persons with PD (Person's *r* = 0.89 & 0.85; Asaadi et al., 2016; Appollonio et al., 2005, respectively). While these correlations suggest FAB scores remain stable, there may be absolute differences between the scores obtained by different clinicians and over time.

The original normative sample for the FAB was small (*n*= 42; Dubois et al., 2000) but, as with the MMSE, recent studies have reported larger samples and stratified them by age and education in order to improve the detection of cognitive decline (Abrahámová et al., 2020; Appollonio et al., 2005; Asaadi et al., 2016; Paula et al., 2013; Wang et al., 2016). A cut-score of <12 on the FAB differentiated between cognitively-healthy adults and those with FTD, PD, multiple system atrophy and primary progressive supranuclear palsy with 89% accuracy (Dubois et al., 2000). Although scores <12 have been found to differentiate between persons with AD and FTD with acceptable sensitivity (81%) and moderately-low specificity (72%; Slachevsky et al., 2004), a later study failed to replicate this finding because both groups exhibit executive problems (Castiglioni et al., 2006). FAB scores <12 can also differentiate between people with PD and those with PDD, but only with low sensitivity (66%) and moderately-low specificity (72%; Kaszás et al., 2012).

The FAB has also been used to differentiate between those with and without MCI, with scores <13 having good sensitivity (92%) and moderate specificity (79%; Chong et al., 2011), although a recent study found that only the 'Similarities' and 'Fluency' subtests differentiate between these groups (Goh et al., 2019). Thus, the FAB assesses executive functioning which, when combined with the MMSE, can improve the detection of cognitive decline (Kim et al., 2013), however the combined administration time may exceed available resources (Pink et al., 2018). Subtests that involve executive functioning have therefore been integrated into multi-task screens, such as the Addenbrooke's Cognitive Examination

(Mathuranath et al., 2000) and the Montreal Cognitive Assessment (Galvin, 2018; Nasreddine et al., 2005).

2.3.3 Addenbrooke's Cognitive Examination

The Addenbrooke's Cognitive Examination (third version; ACE-III) is a multi-task screen that assesses memory, executive functioning (clock drawing and fluency), orientation, attention, language (naming, repetition, following commands, writing and reading) and visuospatial functioning (copying, dot-counting, and letter identification), with Total Scores ranging between 0 and 100 (Mathuranath et al., 2000). The fluency and clock drawing tasks were included to enable a comparison between memory and executive functioning to distinguish between AD and FTD (Mathuranath et al., 2000; Mirza et al., 2017). Earlier versions of the ACE allowed for the computation of a MMSE Total score, but involved copyright violations (Bruno et al., 2019; Hsieh et al., 2013). The ACE-III takes approximately 20 minutes to administer and an abbreviated version – the mini-ACE (M-ACE) – takes approximately 5 minutes (Total scores 0-30; Hsieh et al., 2015). The ACE-III and M-ACE are both free and only require a pen and stopwatch. Interestingly, there is also an iPad compatible version of the ACE-III that reduces administration and scoring errors, but does not calculate LRs or post-test probabilities (Newman et al., 2018).

Excellent reliability coefficients have been reported for the ACE-III due to very similar scores being obtained by different clinicians (ICC = 0.98 & 1.0) and after 3- to 8-weeks (ICC =.92 & 1.00) in mixed dementia, MCI and healthy samples (Matias-Guiu et al., 2015; Takenoshita et al., 2019). Once again, it is unclear whether these coefficients measure both relative and absolute consistency between raters and over time.

There are numerous ACE-III normative samples (Bruno et al., 2020; Kan et al., 2019; Kourtesis, 2016; Li et al., 2019; Matias-Guiu et al., 2015; Mirza et al., 2018; Qassem et al., 2020; Takenoshita et al., 2019; Wang et al., 2017), some of which stratify by age, but not

education. However, a recent review found some studies fail to provide adequate information about their sampling and inclusion criteria, making it difficult to determine if they provide a representative sample of cognitive-healthy adults (Habib & Stott, 2019). More recently, normative data, using adequate recruitment and inclusion criteria, have also been published for the M-ACE (Charernboon, 2019; Pan et al., 2022; Peixoto et al., 2021; Qassem et al., 2021).

The ACE-III can differentiate between those with and without cognitive impairment, with scores <89 having good sensitivity (92%), but poor specificity (50%) for detecting dementia (for review see Beishon et al., 2019). A recent large-scale memory clinic study additionally supported these findings, with ACE-III scores <89 having excellent sensitivity (99%), but very poor specificity (48%) for detecting dementia (Potts et al., 2021). M-ACE scores <26 also have excellent sensitivity (96% to 99%), but variable specificity (32% to 85%) for detecting dementia (for review see Beishon et al., 2019).

The ACE-III can also differentiate between those with and without MCI, with the Beishon et al. (2019) review finding scores <89 have moderately-low sensitivity (75% to 77%), but better specificity (89% to 92%). In contrast, a memory clinic study found ACE-III scores <85 detected MCI with good sensitivity (92%), but low specificity (63%; Potts et al., 2021). Smaller-scale studies have investigated the M-ACE for detecting MCI and proved promising, with scores <22 having good sensitivity (95% - 88%) and acceptable specificity (85%; Charernboon, 2019; Qassem et al., 2021).

Overall, it appears that some of the ACE-III normative samples may not be representative of cognitively-healthy older adults, but its scores can have acceptable reliability and good sensitivity for detecting dementia and MCI. Administration time for the ACE-III, however, may exceed what is available in many healthcare settings. The M-ACE is briefer, but test-retest reliability data and larger samples with and without MCI are required to determine its screening potential.

2.3.4 Montreal Cognitive Assessment

The Montreal Cognitive Assessment (MoCA) is another multitask screen that includes measures of executive functioning (trail making test, fluency, verbal abstraction and clock drawing) in order to detect cases of MCI (Nasreddine et al., 2005). In addition, it measures short term memory (learning and recall), visuospatial functions (cube copy), attention and working memory (target detection, serial subtraction, digits forwards and backwards), and language (naming and sentence repetition), with tasks combined into a Total score 0-30 (Nasreddine et al., 2005). The MoCA takes approximately 10 minutes to administer, although objectively recorded administration times have not been published (Roalf et al., 2016). No special materials are required for the MoCA (stopwatch is optional) and it is free (record forms are free on the internet), although many clinicians are now required to undergo certified training to use the MoCA (Nasreddine, 2019). Like the ACE-III, the MoCA has been computerised to reduce errors in administration and scoring, but it does not to generate LRs for scores (Yu et al., 2014).

The inter-rater reliability for the MoCA was reportedly excellent in a mixed dementia, MCI and cognitively-healthy sample (ICC = 1.00; Lee et al., 2018). The same-day test-retest reliability for the MoCA was also good in this same sample (ICC = 0.87; Lee et al., 2018), with comparable reliabilities seen after a 4-week interval (Pearson's r = 0.92, Nasreddine et al., 2005; ICC= .88, Tsai et al., 2012). Again, it is not known whether the reported coefficients assessed relative and absolute differences in the scores obtained by different clinicians and over time.

The MoCA has large and representative normative samples (see normative samples for different countries https://www.mocatest.org/reference/). Although stratification by demographic variables was not originally thought necessary, it is now recommended that scores be adjusted when people have a low level of education (Julayanont & Nasreddine, 2017). The MoCA can differentiate between people with and without cognitive impairment,

with a recent review finding scores <26 have good sensitivity (94%), but low specificity (60%) for detecting dementia (Davis et al., 2021). The MoCA was primarily developed to detect MCI and the original validation study found that scores <26 differentiated between those with and without MCI with good sensitivity (90%) and specificity (87%; Nasreddine et al., 2005). More recently, a review found scores <23 more accurately differentiate between those with and without MCI (compared to scores <26) because, although sensitivity was lower (83%, compared to 94%), specificity greatly improved (88% compared to 66%; Carson et al., 2018). The MoCA also detects persons with PD who have cognitive decline, with scores <27 having good sensitivity (90%), but low specificity (53%; Hoops et al., 2009).

Overall, like other multiple-task screens, the administration time for the MoCA is likely to exceed the time available in many healthcare settings. Consequently, it is recommended that briefer cognitive screens are initially administered in order to identify those who are in need of more comprehensive screening using the MoCA and ACE-III (Falk et al., 2021). Briefer screens could take the form of a single cognitive task, such as the Clock Drawing Test.

2.3.5 Clock Drawing Test

The Clock Drawing Test (CDT) is the most well-known single-task cognitive screen (Hazan et al., 2018). It involves drawing an analogue clock face (with numbers) and placing the hands at a specific time (Hazan et al., 2018). Multiple cognitive abilities are involved in the CDT, including attention, verbal comprehension, working memory, knowledge of numbers and time-telling, memory, visuospatial ability, praxis and executive functioning (Mainland & Shulman, 2013; Price et al., 2011). The executive aspects of this task include sequencing, abstraction, motor programming and planning the placement of numbers (Mainland & Shulman, 2013). Response inhibition is required when a person is asked to set the hands at 10 past 11 because an automatic response involves incorrectly placing the small hand on 10 (Mainland & Shulman, 2013). The CDT has long been used to detect

people with hemiplegia and visual neglect (Strauss, 2006), and similar tasks are included in the Boston Diagnostic Aphasia Battery (Goodglass et al., 2001), ACE-III (Mathuranath et al., 2000) and MoCA (Nasreddine et al., 2005).

The CDT is well-suited to most healthcare settings because it is very brief, taking approximately five minutes to administer and score, and only requires a pen and paper (Tappen, 2019). There are many different scoring systems for the CDT, although a simple scoring system is often used that awards five points for a perfect clock, four points for minor visuospatial errors, three points if hand placement is incorrect at 10 past 11, two points if numbers are disorganised, one point if the visuospatial organisation is very impaired, and no points if the person is unable to make a reasonable representation of a clock (Shulman, 2000). This simple scoring system can detect dementia (Shulman, 2000) and more complex scoring systems don't appear to enhance the detection of cognitive impairment (Mainland et al., 2014). Moreover, errors on clock drawing (missing, repeated or incorrectly orientated numbers, poor distancing between numbers, or extra marks) are one of the best methods for detecting cognitive impairment (Jouk & Tuokko, 2012).

The CDT reportedly has good inter-rater reliability (ICC ≥80), regardless of the scoring system, when assessing cognitively-healthy (Hubbard et al., 2008) and combined MCI and cognitively-healthy (Mazancova et al., 2017) samples. Test-retest reliability was also reportedly good after a 1- to 3-month interval in persons with and without AD (Person's r = 0.9; Lin et al 2003), although earlier studies suggested scores one week apart may vary in medically stable older patients (Spearman's p = 0.76; Watson et al., 1993) and after 12 and 24 weeks in persons with AD (Pearson's r = 0.76 and 0.70, respectively; Mendez et al., 1992). Additionally, these statistics may not account for absolute differences in CDT scores between clinicians and over time.

There are many published normative samples for the CDT, with most studies recommending that scores be stratified by age and education to improve the detection of cognitive decline (Crowe et al., 2010; Mazancova et al., 2017; Menon et al., 2012; Merims et

al., 2018; Nyborn et al., 2013; Santana et al., 2012; Shao et al., 2020; Storey et al., 2002). The accuracy of the CDT depends on the scoring system that is used, but a recent meta-analysis reported that the aforementioned simple 0-5 scoring system differentiates between those with and without AD with acceptable sensitivity (82%) and moderately-low specificity (76%), however the cut-score was not reported (Park et al., 2018). An early paper reported that the likelihood of dementia increases by a factor of 24 (LR+) when a clock is drawn abnormally and it decreases by a factor of 0.2 (LR-) when it is drawn correctly (Siu, 1991). Moreover, the CDT detected more patients with AD than the MMSE in a memory clinic sample (Brodaty & Moore, 1997). However, a recent review reported the diagnostic accuracy of the CDT for MCI remains unclear, because sensitivity values range from .58 to >.85 (Breton et al., 2019).

Overall, the CDT is an appealing cognitive screen because it is brief, has good inter-rater reliability, and very poor performance in older adults tends to be indicative of dementia (Mazancova et al., 2017; Brodaty & Moore, 1997). However, scores can vary over time and have variable sensitivity when used to detect MCI (Watson et al., 1993; Brenton et al., 2019). Importantly, the trend toward using digital, rather than analogue, clocks may soon render the CDT obsolete (Tappen, 2019).

2.3.6 Sorting Tests

Sorting tests involve grouping cards/stimuli into categories, such as colour and shape, and were originally based on the observation that individuals with a brain injury prefer to sort by colour and subsequently experience difficulty when required to sort by shape (Goldstein & Scheerer, 1941; Weigl, 1927; 1941). The Weigl Colour Form Sorting Test (Weigl) is the oldest sorting test and has 12 stimuli, which are grouped into three shapes (circle, square, triangle) and four colours (red, blue, yellow, green; Goldstien & Scheerer, 1941). Several other sorting tests are based on the Weigl, including the Weigl-revised, Wisconsin Card Sorting Test, and the sorting tests from the Halstead-Reitan

Neuropsychological Test Battery and the Delis-Kaplan Executive Functioning System (Beatty & Monson, 1990; Delis et al., 2001; Grant & Berg, 1948; Nelson, 1967; Reitan, 1993). Some of these sorting tests (e.g., Weigl-revised) additionally require the person to articulate the basis for their correct sort (Beglinger et al., 2008; Strauss, 2006).

Sorting tests assess executive functioning, which involves multiple cognitive abilities (Floyd et al., 2010; Schneider & McGrew, 2018). Specifically, shifting between the sorting categories requires response inhibition because of the tendency to repeat preferred categories (Byrne et al., 1998; Weigl, 1941). Shifting between the sorting categories also requires memory of the previous sorts, visual problem solving, abstraction and mental flexibility (Delis et al; 2001). In addition, praxis and motor programming are involved when manoeuvring the sorting cards/stimuli, and verbal comprehension is required to understand the instructions (Strauss, 2006). Verbal abstraction and expression are also needed for sorting tests that additionally require a person to explain the underlying category for their sort (Strauss, 2006).

The Wisconsin Card Sorting Test and the sorting tasks from the Halstead-Reitan Neuropsychological Test Battery and the Delis-Kaplan Executive Functioning System are considered to be amongst the most sensitive for detecting brain injury and are popular in medicolegal neuropsychological assessments (Delis et al., 1992; Demakis, 2003; Reitan, 1993; Strauss, 2006). A recent review also found the Wisconsin Card Sorting Test is one of the most sensitive neuropsychological tests for detecting dementia and MCI (Rabi et al., 2020). Sorting tests are often used to detect frontal lobe damage in persons with bv-FTD, PD and ALS (Barbagallo et al., 2014; Evans et al., 2015; Fine et al., 2009; Hobson et al., 2007; Paolo et al., 1996; Paolo et al., 1995) In particular, those with bvFTD have problems shifting between categories and tend to erroneously repeat (perseverate) sorts (Ames et al., 1994; Strauss, 2006). According to the DSM-5, people with bv-FTD have difficulties on tasks requiring response inhibition, such as sorting, and find memory tasks easier (American Psychiatric Association, 2013). Consequently, sorting tests have been used to differentiate

between bv-FTD and AD, although there is limited empirical evidence to support this practice (Hutchinson & Mathias, 2007; Roca et al., 2013).

The administration time for sorting tests vary, with the Weigl and Weigl-revised being the briefest, taking approximately five minutes to complete (Beglinger et al., 2008; Strauss, 2006). In contrast, the Wisconsin Card Sorting Test, and the sorting tests from the Halstead-Reitan Neuropsychological Test Battery and the Delis-Kaplan Executive Functioning System take approximately 20 minutes to complete, limiting their suitability as cognitive screens in settings where time and clinical resources are very limited (Beatty & Monson, 1990; Delis et al., 2001; Grant & Berg, 1948; Nelson, 1967; Reitan, 1993). Additionally, these lengthier sorting tests involve both an initial cost to purchase the test and ongoing costs for record forms. Thus, only the brief sorting tests (the Weigl and Weigl-revised) are likely to be viable for screening purposes. However, accessing the materials for these briefer tests can be problematic, with the 12 Weigl stimuli needing to be specific shapes and colours (Weiss, 1964) and 12 Weigl-revised stimuli also having grooves and symbols in order to provide two additional sorting categories (Beglinger et al., 2008). Moreover, although the sorting stimuli are specified in the published articles, they cannot be purchased through test publishers. Complex scoring procedures represent another shortcoming of these brief sorting tests, with different scores for sorts that are spontaneously correct, incorrect, correct after the examiner has provided a verbal clue, and correctly explained (either after the examinee has completed a correct sort or has seen the examiner sort the stimuli; Wardill, 2009; Berlinger et al., 2008). Consequently, many clinicians interpret brief sorting tests in a qualitative fashion (e.g., impaired vs non-impaired; Wardill, 2009).

Although the Weigl and Weigl-revised appear to be the most suitable sorting tests for screening purposes, there is a notable lack of inter-rater reliability data and a shortage of studies examining test-retest reliability. An early study reported unspecified improvements in sorting performances in people with dementia and healthy controls after a 20-minute interval,

but the usefulness of this test-retest reliability data is undermined because longer re-test intervals would typically occur in clinical practice (Grewal et al., 1985).

The earliest normative samples for the Weigl and Weigl-revised (Beglinger et al., 2008; Byrne et al., 1998; Grewal et al., 1985) were small (*n* = <35), but larger samples have since been published (*n* = 91; Hobson et al., 2007), including one comprising older Australian adults (*n* = 195; Wardill, 2009). However, it is not known whether these samples need to be stratified by age and/or education in order to improve the detection of cognitive decline.

When completing the Weigl, people with dementia (mean age = 76 years) have difficulty sorting without assistance and are easily differentiated from younger adults (mean age = 28 years) who achieve perfect scores (spontaneously sort by colour and shape; Grewal & Haward, 1984). However, older adults without dementia (mean age = 73 years) often require assistance with sorting, thus their performance should be considered intact if they need a verbal prompt from the examiner (Grewal & Haward, 1984). A cut-score that classifies those needing more than one prompt as impaired, differentiates between older adults with and without dementia with low sensitivity (61%), but excellent specificity (99%; values computed using the CAT-maker; Bachenoch, 2004; Grewal & Haward, 1984). Those with and without dementia also perform signficantly differently on the Weigl-revised, although small sample sizes have precluded sensitivity and specificity analyses (Beglinger et al., 2008). In addition, people with and without PD can be differentiated on the Weigl using the cut-score that classifies those needing more than one prompt as impaired, with moderate sensitivity (79%) and good specificity (89%; Hobson et al., 2007).

The Weigl differentiates between people with and without MCI using a cut-score that classifies those needing one prompt as impaired, with low sensitivity (14%) but excellent specificity (99%; values computed using the CAT-maker; Bachenoch, 2004; Bryne et al., 1998), although this cut-score was not recommended in an earlier study (Grewal & Haward, 1984). On the Weigl-revised, those with and without MCI differ significantly $t(53) = 3.97$, p

=.002, although sensivitiy and specificity values could not be computed due to the small sample sizes (Beglinger et al., 2008). Thus, like other screens, there is less evidence supporting the Weigl and Weigl-revised for detecting people with MCI than those with dementia. Despite this limitation, brief sorting tests are commonly used by Australian psychologists when conducting assessments to determine whether cognitive decline is impacting on a person's decision-making capacity (Mullaly et al., 2007).

Overall, brief sorting tests provide a promising alternative to popular cognitive screens because they involve many abilities, such as memory and executive functioning, which decline in dementia (Rabi et al., 2020; Wallace et al., 2020). Although the administration time is shorter for brief sorting tests, compared to many multi-task screens, they are rarely used as cognitive screens because they require sorting stimuli that are not readily accessible, their scoring is complicated, and relatively little is known about their inter-rater and test-retest reliability (Beglinger et al., 2008; Wardill, 2009). Despite their populatiry in research and clinical practice, the effectiveness of sorting tests for detecting neurodegenerative disorders such as dementia and MCI has also not been synthesized.

2.4 Summary

The demand for cognitive screens is growing as the prevalence of neurodegenerative disorders and associated cognitive decline increases in our aging population (Connor, 2021). This demand is intensified by the need to detect cognitive decline early in order to optimise interventions that may improve and prolong the lives of older adults with a neurodegenerative disorder, such as dementia (Livingston et al., 2020). Cognitive screens are necessary because self-reports are often inaccurate or not forthcoming (Olivari et al., 2020), and clinicians rarely have the resources to conduct more detailed neuropsychological assessments with all of the patients for whom cognitive functioning has been questioned (Pink et al., 2018; Summers et al., 2019).

The popular cognitive screens are limited by the abilities they measure, the time they take to administer, and their availability, reliability, and accuracy for detecting dementia and MCI (Larner, 2016). More than one screen (e.g., the MMSE and FAB) or multiple subtests within a screen (MoCA, ACE-III) are typically administered in order to detect the decline in memory and executive functioning that are seen dementia (Coen et al., 2016; Kim et al., 2013). However, administering these multiple sub/tests often exceeds the time available in many healthcare settings (Falk et al, 2021; Pink et al., 2018). Additionally, the reliability of these screens may be overestimated if the reported coefficients have not assessed relative *and* absolute differences in the scores obtained by different clinicians and over time. Most of these screens have large and representative cognitively-healthy normative samples that a patient's performance can be compared to in order to detect cognitive decline, and they are moderate to good for detecting dementia, but they are less effective for detecting MCI. The sensitivity, specificity and LRs of cut-scores for detecting dementia and MCI are provided for most of these screens, although score categories are more accurate (McGee, 2018). Thus, there are limitations to using the popular cognitive screens to detect cognitive decline in older adults but, of these, their administration time is the main limitation for many healthcare settings (Pink et al., 2018).

Given the administration time for the popular cognitive screens exceeds what is available in many healthcare settings, briefer single-task screens have been used, with the CDT being the most common (Brodaty & Moore, 1997). The CDT is a test of executive funcitoning, consequently it draws on multiple cognitive abilities (Floyd et al., 2010; Jewsbury et al., 2016), including response inhibition, which declines in dementia and MCI (Kaiser et al., 2018; Wallace et al., 2022). However, the CDT is becoming outdated as digital clocks increasingly replace analogue clocks (Tappen, 2019). Sorting tests also involve a single-test of executive functioning, requiring response inhibition, and very brief versions are available (Weigl and Weigl-revised; Goldstien & Scheerer, 1941; Berlinger et al., 2008). However, these brief sorting tests are not routinely used by clinicians to screen for cognitive decline,

because their sorting stimuli are not readily available, scoring is often complicated (Byrne et al., 1998), and there is limited information on their reliability. In addition, despite their longstanding and widespread use in research and psychological practice, the effectiveness of sorting tests for detecting the cognitive decline associated with neurodegenerative disorders in older adults needed to be synthesized. Given the current high demand for cognitive screening and the limitations of existing screens, it is timely to consider an alternative, such as a sorting test.

2.5 Thesis aims

The overall aim of this thesis was to develop a new cognitive screen – known as the QuickSort – which was designed to improve upon existing sorting tests and quickly detect the cognitive decline that is associated with the most common neurodegenerative disorders seen in older adults.

The specific aims of this thesis were to:

Aim 1: Examine the effectiveness of existing sorting tests for differentiating between older adults with and without common neurodegenerative disorders, especially dementia and MCI, and identify the most effective sorting tests and scores for detecting the cognitive decline associated with these neurodegenerative disorders.

Aim 2: Develop a new cognitive screen for detecting cognitive decline in older adults – the QuickSort – that utilised the most effective components of existing sorting tests, while also making it briefer and more suitable for use with a wider range of older adults than existing sorting tests.

Aim 3: Develop an iPad-compatible version of the QuickSort – the QuickSort-e – to improve the ease with which the QuickSort could be administered and scored, and test scores could be stored and shared.

Aim 4: Determine whether the QuickSort reliably and effectively detected cognitive impairment in older adults, and make the QuickSort stimuli, manual and record form readily accessible to clinicians.

Aim 5: Determine whether the QuickSort could be used in a more complex clinical decision-making scenario, namely whether it could provide useful information regarding older adults' ability to make independent and informed lifestyle decisions.

These aims were addressed by the following five studies:

Study 1: Involved a systematic review and meta-analysis to determine whether existing sorting tests could differentiate between older adults with and without a neurodegenerative disorder (e.g., dementia, PD, etc.) or MCI. This study also examined which of the available sorting tests and specific scores best-detected cognitive decline in older adults with a neurodegenerative disorder.

Study 2: Developed a new test – the QuickSort – by adapting the most effective components of existing sorting tests for detecting cognitive decline in older adults, especially dementia, which were identified by Study 1. It also integrated a number of innovative features, which were designed to make the QuickSort briefer, more user-friendly and appropriate for a wider range of older adults.

Study 3: Developed an iPad-compatible prototype of the QuickSort – called the QuickSort-e – with computer assisted test administration and scoring, as well as data storage and sharing features, and made it available on Apple's TestFlight platform to approved users.

Study 4: Administered the QuickSort to older community-dwelling adults and inpatients to determine if it could quickly, reliably and accurately detect cognitive impairment on lengthier cognitive screens (MMSE and FAB). The study then determined the best QuickSort cut-scores and score categories for

differentiating between older adults with and without impairment on the MMSE and FAB. The QuickSort stimuli, manual and record form were made available to clinicians in the on-line supplementary materials to the publication associated with this study.

Study 5: Administered the QuickSort to older inpatients referred to a neuropsychological service for an assessment of their lifestyle decision-making capacity and determined its ability to differentiate between those lacking and not-lacking capacity, compared to other patient information (e.g., age, living-supports, cognitive screening results). The study determined the best QuickSort cut-score and score categories for detecting older inpatients' who were at risk of lacking the capacity to make lifestyle decisions.

Chapter 3

The effectiveness of sorting tests for detecting the cognitive decline associated with neurodegenerative disorders in older adults

3.1 Preamble

The previous review highlighted the increasing demand for cognitive screens and some of their shortcomings, including the fact that some assess a narrow range of cognitive abilities, have lengthy administration times, have limited data supporting their reliability and vary in their ability to detect cognitive impairment in older adults who have a neurodegenerative disorder and MCI (Connor, 2021; Lam et al., 2019). None of the popular screens assess sorting ability and sorting tests, themselves, are rarely used for screening, despite brief versions being available (Goldstein, 1941; Goldstein & Scheerer, 1941; Hobson et al., 2007; Nelson, 1967; van Den Broek et al., 1993; Weigl, 1941). Sorting tests are thought to assess executive functioning, which comprise multiple cognitive abilities, making them a promising alternative to other multi-task screens (Beglinger et al., 2008; Jewsbury et al., 2016). Moreover, sorting tests require response inhibition, which makes them more sensitive to brain injury (Nelson, 1967), dementia and MCI (Rabi et al., 2020; Wallace et al., 2022). Sorting tests have also been used to differentiate between AD and bvFTD because executive functioning is more adversely affected by the latter (American Psychiatric Association, 2013; Musa et al., 2020; Neary et al., 1998; Possin et al., 2013; Strauss, 2006). Although sorting tests are amongst the oldest and most widely-used neuropsychological tests, their effectiveness for detecting the cognitive decline associated with the common neurodegenerative disorders in older adults has not previously been synthesized.

Study 1 involved a systematic review and meta-analysis of studies that have used sorting tests to assess older persons with a common neurodegenerative disorder and

compared them to their healthy peers. The effectiveness of sorting tests and their scores for differentiating between those with and without neurodegenerative disorders was calculated, overall, and for specific disorder-types (e.g., AD and bvFTD). Study 1 also controlled for the effect of study risk-of-bias on these analyses using an assessment tool that was developed for this study. Overall, Study 1 examined the effectiveness of sorting tests for detecting cognitive decline associated with the common neurodegenerative disorders in older adults, including dementia and MCI.

Neuroscience and Biobehavioral Reviews provided permission to reproduce the journal article for Study 1 in this thesis (see Appendix A.1). This chapter contains this publication in word format, with the tables and figures embedded into the text to make it easier for the reader. The references for this journal article are at the end of this chapter and appear in the APA format required by the journal. Studies that were included in the meta-analysis are numbered in the reference list.

Supplementary information is provided in Appendix A.2:

Supplementary Table A.2.1	PRISMA Checklist
Supplementary Table A.2	Search strategies for each database
Supplementary Figure A.2.1	Study risk-of-bias assessment
Supplementary Table A.2.3	Published diagnostic or reference criteria for each of the neurodegenerative disorders investigated in the meta-analysis
Supplementary Table A.2.4	Summary demographic information for each of the individual studies that were included in the meta-analysis
Supplementary Figure A.2.2	Publication bias analyses for the Category score, specifically S2a. PD vs healthy controls; S2b. MND vs healthy controls; S2c. MCI vs healthy controls; S2d. Other neurodegenerative disorders vs healthy controls; S2e.

AD vs healthy controls; S2f. bvFTD vs healthy controls;

S2g. VaD vs healthy controls; S2h. LBD vs Controls

A reference list for studies cited in the supplementary material is in Appendix A.3.

Study 1: Effectiveness of sorting tests for detecting cognitive decline in older adults with dementia and other common neurodegenerative disorders: A meta-analysis

- Foran, A. M., Mathias, J. L., & Bowden, S. C. (2021). Effectiveness of sorting tests for detecting cognitive decline in older adults with dementia and other common neurodegenerative disorders: A meta-analysis. *Neuroscience and Biobehavioral Reviews, 120*, 442-454. https://doi.org/10.1016/j.neubiorev.2020.10.013

- Journal Impact Factor: 8.99

- Conference presentations are listed at the start of this thesis.

3.2 Statement of authorship

Statement of Authorship

Title of Paper	Effectiveness of sorting tests for detecting cognitive decline in older adults with dementia and other common neurodegenerative disorders: a meta-analysis
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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Name of Principal Author (Candidate)	A M Foran		
Contribution to the Paper	Literature searching, encoding, data entry, statistical analysis, manuscript preparation and submission. Development of the standardized low-risk-of-bias study criteria.		
Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	16/08/22

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	J L Mathias		
Contribution to the Paper	Supervision of all aspects of the research including study design, analysis and manuscript preparation.		
Signature		Date	25/10/22

Name of Co-Author	S C Bowden		
Contribution to the Paper	Supervision of the study methodology, statistics and manuscript preparation. SCB was the blinded inter-rater that determined the inter-rater reliability for the low risk-of-bias study criteria.		
Signature		Date	24/10/22

3.3 Abstract

The demand for simple, accurate and time-efficient screens to detect cognitive decline at point-of-care is increasing. Sorting tests are often used to detect the 'executive' deficits that are commonly associated with behavioural-variant frontotemporal dementia (bvFTD), but their potential for use as a cognitive screen with older adults is unclear. A comprehensive search of four databases identified 142 studies that compared the sorting test performance (e.g. WCST, DKEFS-ST) of adults with a common neurodegenerative disorder (e.g. Alzheimer's disease, vascular dementia, bvFTD, Parkinson's disease) and cognitively-healthy controls. Hedges' *g* effect sizes were used to compare the groups on five common test scores (Category, Total, Perseveration, Error, Description). The neurodegenerative disorders (combined) showed large deficits on all scores (*g* -1.0 to -1.3), with dementia (combined subtypes) performing more poorly (*g* -1.2 to -2.1), although bvFTD was not disproportionately worse than the other dementias. Overall, sorting tests detected the cognitive impairments caused by common neurodegenerative disorders, especially dementia, highlighting their potential suitability as a cognitive screen for older adults.

3.4 Introduction

The number of older adults with a neurodegenerative disorder is increasing as the population ages (Ecomonics, 2009), with 131.5 million people predicted to be living with dementia by 2050 worldwide (Prince et al., 2015). Cognitive decline is a defining feature of dementia, but is also common in many other neurodegenerative disorders, such as Parkinson's disease and motor neuron disease (Cui, 2015; Mihaescu et al., 2019; Muslimovi, Schmand, Speelman, & De Haan, 2007). Cognitive decline often occurs many years prior to receiving a formal diagnosis (e.g., in Alzheimer's dementia; AD), highlighting the importance of early detection (Bäckman, Jones, Berger, Laukka, & Small, 2005). Indeed, there are multiple benefits to detecting cognitive impairments early in their course, including (i) reduced hospital admissions, readmissions, and outpatient costs (McCarten, Anderson,

Kuskowski, Jonk, & Dysken, 2010; Torisson, Minthon, Stavenow, & Londos, 2013); (ii) lower rates of delirium, morbidity and mortality (Lee. et al., 2008); and (iii) improved psychological and behavioral symptoms, and carer outcomes (McCarten et al., 2010).

Accurate cognitive screens conducted at or near the point-of-care are recommended to assist with the early detection of cognitive decline (Robinson, Tang, & Taylor, 2015). These screens are designed to be quick and easy to administer, and provide immediate information about a patient's risk of cognitive impairment. Effective screening can, in turn, inform interventions and other investigations, while also facilitating timely diagnoses (Borson et al., 2013; Robinson et al., 2015).

The most common point-of-care cognitive screen is the Mini Mental Status Examination (MMSE), which is quick to administer (8-15 minutes) and interpret (Folstein, Folstein, & McHugh, 1975; Mitchell, 2013; O'Bryant et al., 2008; Sheehan, 2012). The MMSE detects dementia with 80% sensitivity and 81% specificity in memory clinic settings, but is less accurate when used to assess the cognitive decline associated with Parkinson's disease and mild cognitive impairment (Athey, Porter, & Walker, 2005; Hu et al., 2014; Mitchell, 2009). As with other commonly-used screens, such as the Montreal Cognitive Assessment (MoCA) and Addenbrooke's Cognitive Exam (ACE), the MMSE assesses multiple cognitive domains (Mathuranath et al., 2000; Nasreddine et al., 2005). Although this feature is particularly pertinent to dementia because the diagnostic criteria require cognitive decline in two or more domains (e.g. AD; McKhann et al., 2011), it is less relevant when screening older adults for cognitive impairment. Instead of domain-specific scores, summary scores are used for screening and those derived from multidomain screens are not necessarily more sensitive than those from single-domain tests (Brodaty & Moore, 1997; Kingery et al., 2011; Larner, 2016; Summers, Bondi, & Bowden, 2019).

Sorting tasks are one example of a single-domain cognitive test. Although often used as part of a comprehensive neuropsychological assessment (Strauss, 2006), they are not included in common cognitive screens, nor are they routinely used when screening older

adults for cognitive impairment. Theoretically, sorting tests are thought to assess inductive reasoning but, clinically, they are often described as assessing 'executive' functioning, although the latter construct conflates a number of the cognitive abilities (Floyd, Bergeron, Hamilton, & Parra, 2010; Schneider & McGrew, 2018; Strauss, 2006).

Sorting tests assess a person's ability to sort stimuli (e.g., cards) according to specific categories (usually colour, shape, number) and then switch between these categories (Feldman & Drasgow, 1959; Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993). They are relatively quick to administer (range: 5 to 25 mins) and score (Strauss, 2006), making them well-suited to point-of-care cognitive assessments. A number of sorting tests have been developed over the years, starting with the Weigl Color-Form Sorting Test, followed by the Berg-Wisconsin Card Sorting Test, the Verbal Visual Test, and the California Card Sort Test, which has since been incorporated into the Delis Kaplan Executive Functioning System (Delis, Kaplan, & Kramer, 2001; Delis, Squire, Bihrle, & Massman, 1992; Feldman & Drasgow, 1959; Goldstein & Scheerer, 1941; Grant & Berg, 1948). Most of these tests generate composite scores, labelled *Category* scores (number of categories correctly sorted) or *Total* scores (also termed 'global' or 'total correct' scores, tallying the number of successful sorts). Many sorting tests also generate *Perseveration* scores (number of repeated responses after failing to shift category) and *Error* scores (when sorts do not fit a single category) (Delis et al., 2001; Heaton et al., 1993). Some also produce a *Description* score, which assesses a person's ability to articulate the category or rule underpinning their sort (e.g., colour, shape, number, Delis et al., 2001).

Sorting tasks are amongst the most sensitive to brain damage (Delis et al., 1992; Reitan, 1993) and have been used to detect the cognitive decline caused by a variety of neurodegenerative disorders, such as dementia (Byrne, Bucks, & Cuerden, 1998), Parkinson's disease (Hobson, Meara, & Taylor, 2007; Paolo, Axelrod, & Troster, 1996) and amyotrophic lateral sclerosis (Barbagallo et al., 2014; Evans et al., 2015). In particular, sorting tests are often used in the assessment of frontotemporal dementia (FTD) because

deficits in reasoning and 'executive' functioning are thought to be a distinguishing feature of FTD (Strauss, 2006). Perseverative speech has additionally been reported in behavioural-variant FTD (bvFTD), with the Perseveration score provided by some sorting tests potentially measuring this characteristic (Strauss, 2006). Sorting tests have therefore been used by clinicians to differentiate between AD and FTD, despite limited research support for this practice (Hutchinson & Mathias, 2007; Roca et al., 2013).

Research comparing the sorting test performance of older adults who have neurodegenerative disorders to that of cognitively-healthy peers is now quite extensive. However, the collective findings have yet to be evaluated. Consequently, our understanding of whether the most common neurodegenerative disorders perform differently on these tests, and whether a specific test best detects the cognitive decline associated with these disorders, is limited. The current meta-analysis therefore examined whether sorting scores differentiate between older adults with a neurodegenerative disorder and their cognitively-healthy peers in order to assess the potential usefulness of sorting tests as a cognitive screen in point-of-care settings. Only the most common older-age neurodegenerative disorders were considered, namely, Parkinsonian disorders (PD), motor neuron disease (MND), mild cognitive impairment (MCI), and 'other' disorders (human immunodeficiency virus [HIV], normal pressure hydrocephalus [NPH], multiple sclerosis [MS], Huntington's disease [HD]), as well as the most common dementia subtypes (AD, bvFTD, vascular [VaD], lewy body [LBD], semantic [SD], primary progressive aphasia [PPA], and not otherwise specified [dementia NOS]). Dementia was of particular interest because cognitive screens are commonly used to assist with its early detection. Given that deficits in 'executive' functioning are thought to characterise bvFTD, and sorting tests are commonly used to assess these deficits, this dementia subtype was a specific focus.

3.5 Method

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (see Supplementary Table A.2.1 for PRISMA checklist; Moher, Liberati, Tetzlaff, & Altman, 2009).

3.5.1 Search strategy and eligibility criteria

The EMBASE PsycINFO, PubMed, and Scopus databases were searched for research published prior to November 1, 2017 that compared the sorting task performance of older adults who were diagnosed with a neurodegenerative disorder to cognitively-healthy controls. The searches were formulated under the guidance of a specialist research librarian. Both general and specific search terms were used to ensure that lesser-known tests and secondary study measures were captured (see Supplementary Table A.2 for logic grids).

All studies had to meet the following criteria to be included in this meta-analysis (1) cognitive functioning was assessed using a published sorting test; (2) samples of older adults (mean age +1SD > 59 years) were recruited, one of which was diagnosed with a neurodegenerative disorder (PD, MND, MCI, HIV, NPH, MS, HD, AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and the other comprising a cognitively-healthy control group; (3) data enabling the calculation of Hedges' *g* effect sizes were provided (e.g., means & SDs, *t*-test or one-way ANOVA, exact *p*-value); and (4) the study was published in English. The first author screened all studies for eligibility, with the second and third authors additionally reviewing studies where eligibility was questionable, after which a consensus decision was made.

Eligible sorting tests were classified as one of the following (1) the Weigl Color-Form Sorting Test (Weigl; Goldstein & Scheerer, 1941; Weigl, 1941), which included the modified Weigl (Beglinger, Unverzagt, Beristain, & Kareken, 2008); (2) the Wisconsin Card Sorting

Test (WCST; Grant & Berg, 1948), which also included the Berg Card Sort (Berg, 1948) and modified WCST (Nelson, 1967); (3) the Verbal Visual Test (VVT; Feldman & Drasgow, 1959); and (4) the Delis Kaplan Executive Functioning System Sorting Test (DKEFS-ST; Delis et al., 2001), including its predecessor, the California Card Sort Test (Delis et al., 1992). The five most common score-types were examined, namely, Category scores (number of categories correctly sorted); global or Total scores (total number of correct trials); Perseveration scores (number or percentage of perseverations); overall Errors (number or percentage); and Description scores (number of times the underlying category or rule was correctly identified).

Studies were excluded from this meta-analysis if (1) the sorting test was used to diagnose the neurodegenerative disorder (i.e., to avoid criterion-contamination, the sorting test could not be both a diagnostic and outcome variable), or (2) study authors did not provide sufficient details regarding the sorting test or score that was used.

Meta-analyses require all data to be independent. Corresponding authors of studies that examined the same neurodegenerative disorder and were published within the past ten years were therefore emailed to determine if there was any overlap in their samples (response rates found to be negligible for older studies). Where authors failed to respond, or could no longer be located, a conservative approach was taken whereby studies were assumed to be non-independent and only data from the largest sample in the most recent publication were analysed.

3.5.2 Data extraction and coding

The following data were extracted from each study using a standardized template that recorded (1) study details (author, publication year, country); (2) information about the neurodegenerative disorder (type, diagnostic criteria, disease duration); (3) method by which controls were screened to ensure that they were cognitively-healthy (e.g. interview, MMSE);

(4) type of control (significant other, other patient group, mixed); (5) recruitment sources for both the neurodegenerative disorders and controls (community, primary care, outpatient clinic, inpatient, other source, not specified); (6) participant selection (random, consecutive, convenience, retrospective, matched, not specified); (7) study-specific selection criteria (e.g., exclusion of participants with psychiatric or other neurological disorders); (8) demographic details (age, gender, education); (9) cognitive screening scores (e.g., MMSE, FAB); and (10) sorting test scores for the neurodegenerative and control groups.

If participants were assessed on multiple occasions, only baseline or pre-treatment scores were recorded. Where studies provided subgroup data that were not relevant to this study (e.g., males and females), the data were combined. Means and standard deviations were estimated from medians or ranges for demographic data using the method recommended by (Hozo, Djulbegovic, & Hozo, 2005). Standard deviations were calculated from standard errors or confidence intervals (CIs), as required (Hedges, 1985).

3.5.3 Study risk-of-bias

Poorly conducted studies are more likely to produce low-quality or biased data, making it important to assess potential sources of bias (Spencer & Brassey, 2017). Four aspects of study methodology that were of specific interest to the current meta-analysis – representative sampling, diagnostic verification, sample attrition and study blinding – were therefore assessed using items from the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) and Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) statements (Von Elm et al., 2007; Whiting et al., 2011). However, blinding was rarely employed because many neurodegenerative disorders ‘unblind' themselves (due to their overt symptoms) and the sorting test was rarely the primary focus of the research, making it necessary to exclude this criterion. Thus, low risk-of-bias was determined on the basis of the remaining three aspects of study methodology (see Supplementary Figure A.2.1 for details of this assessment). First, to have representative

sampling, the neurodegenerative group had to be recruited randomly or consecutively and the age and education of the controls had to be reported or matched to the clinical sample. Second, for diagnostic verification, the neurodegenerative disorders had to be diagnosed using published criteria (e.g., NINDS-ADRDA for AD; see Supplementary Table A.2.3 for accepted diagnostic criteria) or, prior to this, the diagnostic criteria were clearly stated. Third, for sample attrition, there could not be any unexplained attrition that affected the sorting test data. Studies were classified as having either low risk-of-bias, if the information they provided met all three criteria, or high or unknown risk-of-bias, if they did not meet these criteria or failed to provide the information needed to make a determination. The inter-rater reliability of the risk-of-bias classification was tested by having the first and third authors independently rate a randomly selected sample of 10% of studies, which yielded an inter-rater reliability of r = .80.

3.5.4 Data analysis

Effect sizes were calculated using Comprehensive Meta-Analysis Version 3.3 (CMA; 2006 Biostat Inc., Engelwood, NJ, USA) and forest plots were created using Metadata viewer (Boyles, Harris, Rooney, & Thayer, 2011). Hedges' g effect sizes were calculated using a random-effects model to determine whether the sorting test scores of the neurodegenerative and cognitively-healthy control groups differed. A negative g indicated that persons with a neurodegenerative disorder performed more poorly (i.e., lower Category, Total or Description scores; higher Perseveration or Error scores), with values of g = .2, .5, .8, 2.0 and 4.0 equating to small, medium, large, very large and extremely large effects, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). A probability (p) value < .05 was used to assess statistical significance. Between-study heterogeneity in the effect sizes was investigated using Q, which assesses the distribution of observed effects; I^2, which reflects the ratio of true effect to error variance; and Tau^2, which provides an absolute

estimate of variance in the true effects (Borenstein, Hedges, Higgins, Rothstein, & Higgins, 2011).

Subgroup analyses were performed to explore potential sources of heterogeneity in the effects, namely the type of neurodegenerative disorder (PD, MCI, MND, 'other' neurodegenerative disorders [HIV, NPH, MS, HD] and AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and study risk-of-bias (low *vs* high or unknown). Subgroups were deemed to differ significantly if the effect size for one group fell outside of the 95% CIs for the other (Bowden & Finch, 2017).

The next set of analyses focused on dementia because of its particular clinical interest in settings where cognitive screening is frequently conducted. Once again, group differences (all dementias *vs* controls) in each of the five sorting scores were examined and heterogeneity assessed. Subgroup analyses then examined whether the dementia subtype was a significant source of heterogeneity (AD, bvFTD, VaD, LBD, SD, PPA, dementia NOS). Three meta-regressions additionally investigated whether patient education impacted on the dementia subtype findings: (1) all subtypes combined, (2) bvFTD *vs* AD, and (3) FTD *vs* non-FTD. The impact of disease severity was assessed in a further two subgroup analyses: the first compared all of the dementia subgroups and the second compared FTD to all non-FTD dementia because clinicians often want to distinguish between FTD and the other dementias. A final subgroup analysis investigated whether the sorting test itself was a source of between-study variation in the findings for dementia (Weigl, WCST, VVT, DKEFS-ST). Once again, the effect sizes and 95% CIs for each of the subgroups were compared in order to determine statistical significance (Bowden & Finch, 2017). Data permitting, the impact of education and disease severity on the findings was also examined.

Lastly, the potential for publication bias to impact on the findings was assessed using the trim-and-fill procedure (Duval & Tweedie, 2000), if data permitted ($N_{studies}$>3; CMA; 2006). The Category scores for each neurodegenerative disorder were examined because they were most commonly reported. Missing studies on the right of the funnel plots were of

interest (indicative of non-significance or contrary findings [i.e. poorer sorting test performance in controls]). Publication bias was considered inconsequential if there was a trivial difference between observed and adjusted effect sizes or if no studies were trimmed (Borenstein et al., 2011).

3.6 Results

3.6.1 Search results

The literature searches identified 9,116 studies, 955 of which were duplicates and 7,287 were excluded when titles and abstracts were initially screened. A full-text review of the remaining 874 studies revealed that a further 732 did not meet the inclusion criteria, leaving 142 eligible studies (see Figure 3.1 for PRISMA chart and Supplementary Table A.2.4 for summary details for each study).

The final sample comprised 11,862 participants, 6,172 of whom had a neurodegenerative disorder and 5,690 were healthy controls (see Table 3.1). Overall, the neurodegenerative group was significantly older (mean = 68 years) and had significantly more males (53%) than the heathy controls (mean age = 62 years, 49% males). Educational levels were comparable, with both groups averaging a high school education, although the VaD group was significantly less educated than their controls. The mean MMSE score for the neurodegenerative group (all combined) fell above the recommended cut-off for impaired cognition, but the mean FAB score fell just below it (i.e., cut-offs: MMSE <24; FAB <12; Hancock & Larner, 2011; Slachevsky et al., 2004, see Table 3.1). Most of the neurodegenerative samples were recruited from specialist or outpatient clinics and the healthy controls sourced from community or non-specified sources. The WCST ($N_{studies}$ = 127) was the most commonly used sorting test, followed by the Weigl ($N_{studies}$ = 8), DKEFS-ST ($N_{studies}$ = 4) and VVT ($N_{studies}$ = 3), which were used by fewer studies. The Category score ($N_{studies}$ = 108) was the most commonly reported test score, followed by the

Perseveration score ($N_{studies}$ = 89), with substantially fewer studies reporting Error ($N_{studies}$ = 44), and Total ($N_{studies}$ = 35) scores, and many fewer providing Description scores ($N_{studies}$ = 3). The most common neurodegenerative diagnoses were Parkinsonian disorders ($N_{studies}$ = 69), followed by AD ($N_{studies}$ = 34), MCI ($N_{studies}$ = 22), MND ($N_{studies}$ = 13), bvFTD ($N_{studies}$ = 9), dementia NOS ($N_{studies}$ = 6), 'other' neurodegenerative disorders ($N_{studies}$ = 6), LBD ($N_{studies}$ = 4), PPA ($N_{studies}$ = 3), VaD ($N_{studies}$ = 2) and SD ($N_{studies}$ = 2).

Figure 3.1: PRISMA flowchart of search and study review process

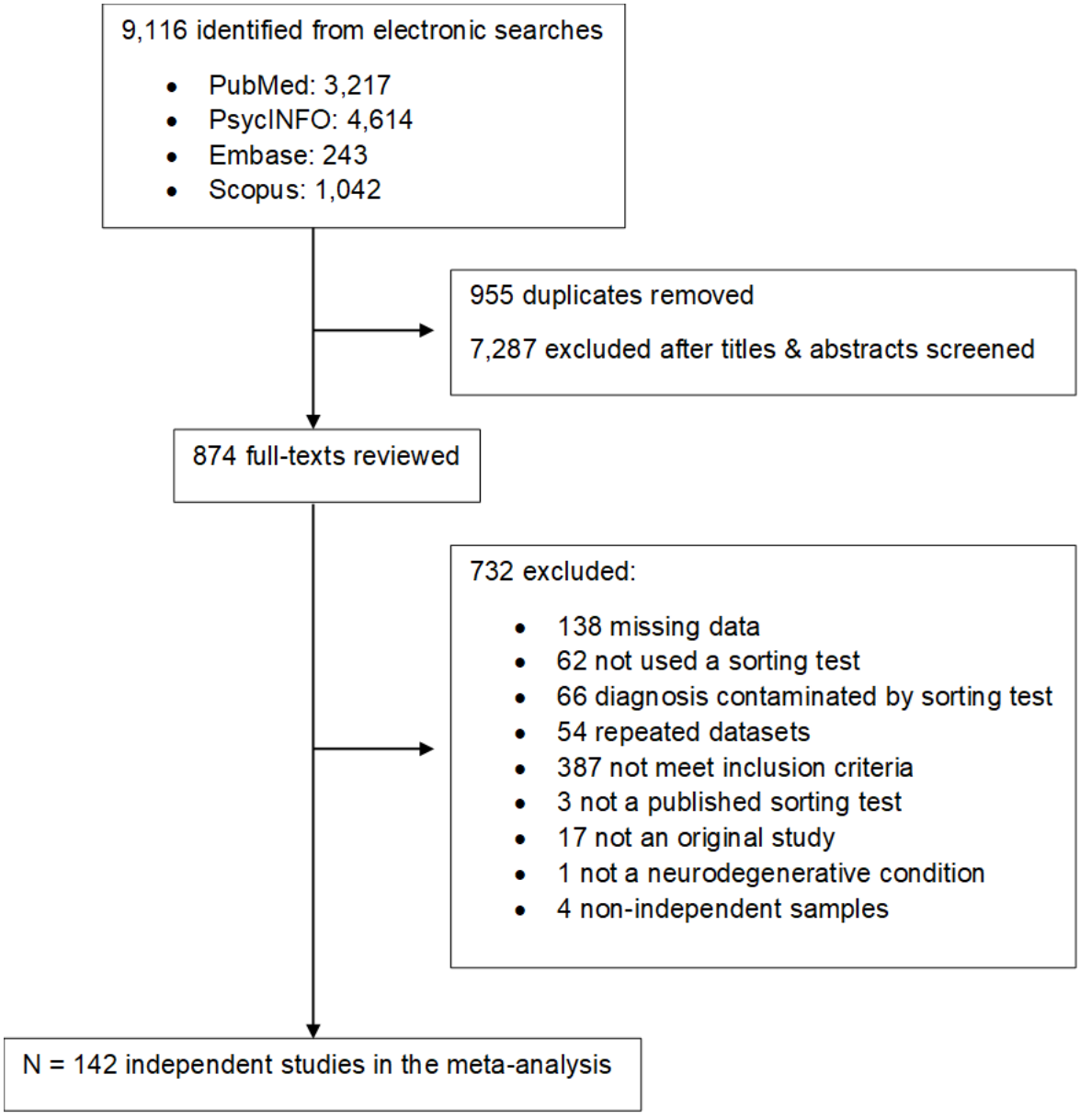


Table 3.1: Summary demographic information for the meta-analysed studies

	Neurodegenerative Disorder			Controls				
	$N_{studies}$	$N_{participants}$	*M (SD)*	$N_{studies}$	$N_{controls}$	*M (SD)*	t/χ^2	*p*
Total sample	142	6172		142	5690			
age	141	5998	67.4 (6.7)	133	5467	65.3 (6.9)	2.5	.01
sex (M/F)	114	2607/2297		112	2413/2526		18.2	.00
education	116	5510	11.7 (3.1)	112	3707	12.2 (2.7)	1.3	.21
disease duration	53	2188	68.9 (57.0)					
MMSE	89	4012	24.7 (4.1)	81	3945	28.4 (2.1)	8.2	.00
FAB	6	404	11.8 (2.7)	5	232	16.0 (1.0)	3.4	.00
Recruitment source								
community	5	498		45	2939			
primary care	0	0						
outpatient clinic	103	4426						
inpatient	1	17						
other source	2	314						
unstated	31	917		48	1015			
Type of control								
significant other				17	655			
other patients				12	333			
mixed controls				20	748			
Sorting Test								
Weigl	8	638		8	414			
WCST	127	5088		127	5053			
VVT	3	132		3	166			
DKEFS-ST	4	314		4	57			
Test score								
category	133	4227		133	4563			
total	43	1837		43	1089			
perseverations	106	3525		106	3785			
errors	46	1871		46	2391			
description	7	250		3	99			
Parkinsonian conditions								
age	69	2400	65.6 (4.2)	65	2269	61.5 (8.6)	3.5	.00
sex (M/F)	53	1131/774		52	1022/1018		34.2	.00
education	55	2019	11.8 (2.8)	54	1619	12.2 (2.9)	0.7	.47
disease duration	36	1337	91.2 (60.7)					
MMSE	35	1352	27.6 (1.2)	35	1452	2853 (0.6)	4.0	.00
FAB	2	133	15.3 (0.3)	2	117	16.7 (0.1)	6.3	.07
Motor neuron disease								
age	13	547	59.7 (2.7)	13	421	59.5 (3.1)	0.2	.86
sex (M/F)	13	329/209		11	215/169		2.5	.12
education	9	473	11.2 (3.2)	8	327	11.2 (1.9)	0.0	1.00
disease duration	8	423	25.6 (9.3)					
MMSE	6	151	24.8 (1.4)	7	151	25.9 (1.3)	-0.3	.76
FAB	1	21	16.4	1	21	17.2		

Table 3.1: Summary demographic information for the meta-analysed studies cont.

	Neurodegenerative Disorder			Controls				
	$N_{studies}$	$N_{participants}$	*M (SD)*	$N_{studies}$	$N_{controls}$	*M (SD)*	t/χ^2	*p*
Mild cognitive impairment								
age	22	890	70.1 (4.7)	21	1154	62.1 (10.0)	3.3	.00
sex (M/F)	19	320/380		19	488/589		0.0	.87
education	20	814	12.1 (2.7)	20	693	12.9 (2.6)	1.0	.35
MMSE	19	819	27.2 (1.1)	20	1136	28.8 (0.4)	6.0	.00
FAB	1	6	12.8	1	11	14.9		
Other neurodegenerative conditions								
age	6	193	59.5 (10.7)	5	190	62.6 (10.6)	0.5	.64
sex (M/F)	5	102/63		5	108/82		0.9	.34
education	4	145	11.3 (3.0)	4	152	11.4 (2.8)	0.5	.96
disease duration	2	84	67.7 (49.7)					
MMSE	1	64	21.8	1	58	28.5		
FAB	1	64	11.5	1	58	15.6		
Alzheimer's disease								
age	34	1225	73.0 (4.2)	34	1393	63.2 (9.5)	5.5	.00
gender (M/F)	27	418/573		26	524/698		0.1	.74
education	33	1119	11.0 (2.6)	32	902	12.2 (2.7)	1.8	.07
disease duration	6	188	35.6 (6.2)					
MMSE	29	1079	20.8 (2.9)	26	1192	28.8 (0.4)	14.7	.00
FAB	2	89	9.8 (0.5)	2	36	15.0 (0.0)	14.7	.00
Frontotemporal dementia behavioural variant								
age	9	188	65.1 (4.2)	9	161	65.0 (2.8)	0.6	.95
gender (M/F)	8	87/76		8	64/88		4.0	.05
education	8	188	13.2 (3.1)	9	161	12.9 (3.2)	0.2	.84
disease duration	2	51	39.8 (27.3)					
MMSE	8	182	24.3 (2.3)	8	145	29.0 (0.5)	5.6	.00
FAB	3	52	10.1 (1.9)	3	53	15.6 (0.9)	4.5	.02
Vascular dementia								
age	2	56	76.8 (4.3)	3	71	71.5 (6.9)	2.1	.17
sex (M/F)	2	32/24		3	26/45		5.3	.02
education	2	56	9.9 (0.6)	3	71	11.4 (0.5)	3.3	.03
disease duration	1	24	34.8					
MMSE	2	33	22.3 (1.5)	3	71	28.8 (0.5)	7.1	.01
FAB	2	36	9.7 (0.3)	2	36	15.0 (0.0)	25.0	.00
Lewy body dementia								
age	4	81	72.6 (2.1)	3	69	71.6 (2.2)	1.0	.36
sex (M/F)	3	40/27		3	25/19		0.1	.71
education	4	81	12.4 (1.2)	3	69	12.4 (2.0)	0.1	.92
disease duration	2	61	42.9 (19.7)					
MMSE	4	81	23.3 (6.3)	3	69	28.8 (0.4)	1.7	.8
FAB	1	6	10.5		11	14.9		
Semantic dementia								
age	2	21	61.8 (1.6)	2	17	60.3 (3.4)	0.6	.63
education	1	13	16.4	1	9	16.4		
MMSE	1	13	23.0	1	9	29.3		

Table 3.1: Summary demographic information for the meta-analysed studies cont.

	Neurodegenerative Disorder			Controls				
	$N_{studies}$	$N_{participants}$	*M (SD)*	$N_{studies}$	$N_{controls}$	*M (SD)*	t/χ^2	*p*
Primary progressive aphasia								
age	3	42	64.2 (3.1)	3	43	62.7 (3.1)	0.6	.59
sex (M/F)	2	17/13		2	16/18		0.6	.44
education	3	42	16.1 (0.5)	3	43	15.4 (1.1)	1.0	.40
disease duration	1	20	3.9					
MMSE	3	42	25.4 (1.5)	3	43	29.4 (0.1)	4.6	.40
Dementia not specified								
age	6	335	75.7 (2.4)	5	208	62.7 (3.1)	3.0	.02
sex (M/F)	5	131/158		5	89/117		0.2	.64
education	4	160	10.9 (2.9)	4	152	15.4 (1.1)	0.4	.70
MMSE	3	94	20.6 (2.8)	3	86	29.0 (0.1)	5.2	.04

$N_{studies}$ = number of studies, $N_{participants}$ = number of participants, M (SD) = weighted mean (standard deviation), t/χ^2 = t-test or Chi-square statistic, p = probability value, disease duration = months, MMSE = Mini Mental Status Examination, FAB = Frontal Assessment Battery

3.6.2 Sorting test performance: all neurodegenerative disorders

Table 3.2 summarises the mean Hedges' *g* effect sizes for the five sorting test scores (Category, Total, Perseveration, Error, Description) for the neurodegenerative disorders (all combined). All five effects were large, in the expected negative direction and significant ($p < .05$), indicating that the sorting test performance of older adults with a neurodegenerative disorder was consistently poorer than their cognitively-healthy peers. Not only was the Category score the most commonly reported, but it was also the most discriminating when all of the disorders were examined together ($g = -1.28$). Although infrequently used, there was also a large group difference in the Description score ($g = -1.11$). Similarly, the Total, Perseveration and Error scores showed large differences. Notably, however, significant heterogeneity remained for all five scores. Subgroup analyses therefore examined whether the (1) type of disorder and (2) study risk-of-bias contributed to this heterogeneity.

3.6.3 Subgroup analyses: disorder type and risk-of-bias

As seen from the significant *Q* statistics in Table 3.2, disorder-type accounted for a significant amount of the variance in the Category, Total and Perseveration scores, but not the Error or Description scores. This variation is illustrated in Figure 3.2, which provides forest plots for each of the five scores, separated by disorder-type (data permitting). Notably, the dementias, which have cognitive decline as a primary symptom, had larger effect sizes than those disorders where cognitive decline is often secondary to other symptoms. For example, people with AD performed significantly worse than persons with PD on the Category, Total, Perseveration and Error scores (i.e., Hedges' *g* for the AD group fell outside the 95% CIs for PD). However, with the exception of the Description score, significant residual heterogeneity remained for many disorders ($p < .05$), indicating that disorder-type did not adequately account for all of the variation in findings (see *Q* statistics in Figure 3.2).

Next, subgroup analyses examined whether the risk-of-bias ratings contributed to the heterogeneity in the sorting scores of older adults with a neurodegenerative disorder (all combined). When the findings from the 19 studies that were rated as having a low risk were compared to the 123 studies that had a high or unknown risk, it was found that risk-of-bias accounted for a significant amount of heterogeneity in the Category and Perseveration scores, but not on the Total, Error or Description scores (see *Q* statistics in Table 3.2). As seen in Figure 3.3, the low risk studies reported significantly smaller effect sizes for the Category and Perseveration scores than the high or unknown risk-of-bias studies (i.e., Hedges' *g* for the low risk-of-bias studies fell outside the 95% CIs for high or unknown risk). However, there was significant residual heterogeneity in the Category and Perseverative scores (significant *Q* statistics; Figure 3.3), indicating that risk-of-bias did not adequately explain the variability.

3.6.4 Sorting test performance: dementia

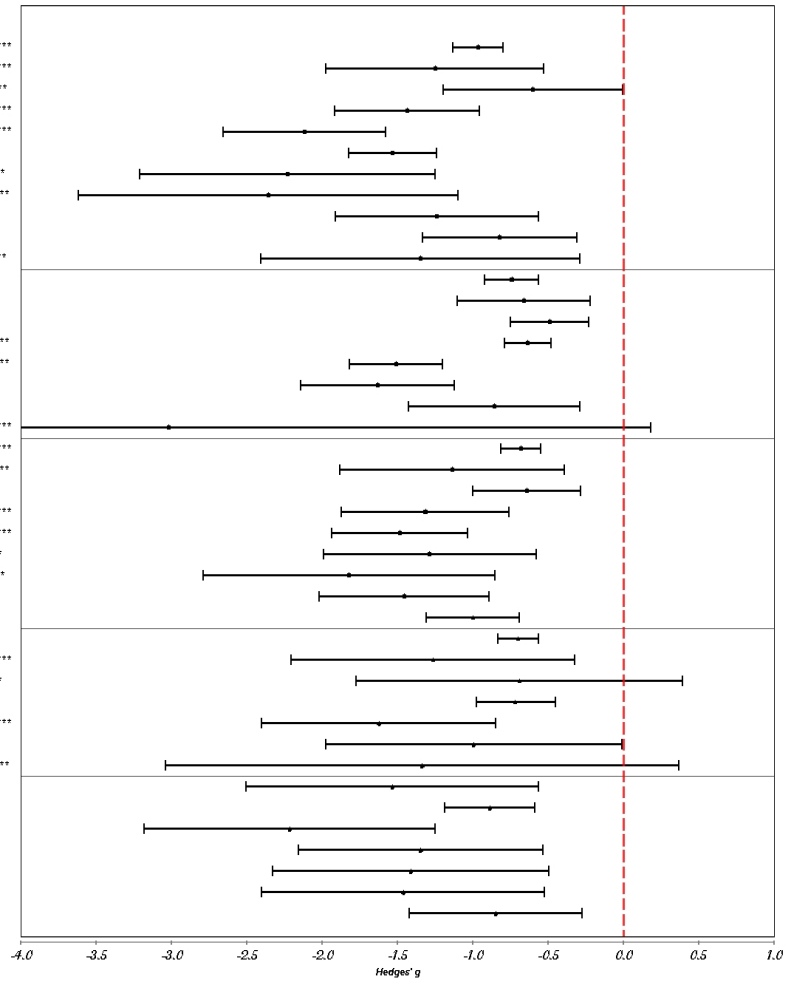
Table 3.2 additionally summarises the mean effect sizes for the dementias (subtypes combined). All effects were significant *(p* < .05), negative and large, indicating that persons with dementia consistently performed more poorly than their cognitively-healthy peers. The Category score was the most commonly reported and the most discriminating of the five scores (*g* = -2.05), followed by the Total, Error, Perseveration and Description scores. There was significant heterogeneity in the effect sizes for the Category, Total, Perseveration and Error scores, but not the Description score, when the dementias were examined together. Subgroup analyses therefore focused on whether dementia subtype (AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and the specific sorting test (Weigl, WCST, VVT, or DKEFS) contributed to the heterogeneity in these four scores. Additional analyses examined whether patient education and disease severity also impacted on the findings.

Table 3.2: Mean Hedges' g effect sizes, heterogeneity statistics and subgroup analyses for all of the neurodegenerative disorders and dementia subtypes

Group	Sorting test score	$N_{studies}$	*g*	*95% CIs*		*Q*	I^2	*Tau*	Tau^2
Neurodegenerative disorders (all)									
	Category	108	-1.28	-1.46	-1.11	1258.78***	91.5	0.87	0.73
	Total	35	-1.10	-1.35	-0.84	353.59***	90.4	0.70	0.49
	Perseveration	89	-1.00	-1.15	-0.84	766.35***	88.5	0.70	0.48
	Errors	44	-1.08	-1.34	-0.82	538.03***	92.0	0.82	0.67
	Description	3	-1.11	-1.58	-0.64	7.76*	74.2	0.36	0.13
Subgroup analyses									
	Disorder-type								
	Category	132				37.94***	90.2	0.88	0.77
	Total	42				42.86***	89.5	0.73	0.53
	Perseveration	106				29.05***	86.9	0.71	0.50
	Error	48				7.28	91.4	0.82	0.67
	Description	7				9.95	39.7	0.28	0.08
	Study risk-of-bias								
	Category	108				5.74*	91.0	0.88	0.78
	Total	35				0.10	90.5	0.76	0.58
	Perseveration	89				11.36***	88.1	0.72	0.52
	Error	44				0.44	92.0	0.84	0.71
	Description								
Dementia subtypes (all)									
	Category	32	-2.05	-2.46	-1.64	521.04***	94.1	1.11	1.24
	Total	14	-1.81	-2.34	-1.24	211.50***	93.9	0.97	0.95
	Perseveration	24	-1.46	-1.82	-1.10	285.17***	91.3	0.84	0.70
	Error	13	-1.57	-2.24	-0.91	285.71***	95.8	1.19	1.41
	Description	2	-1.24	-1.95	-0.52	3.87	74.2	0.45	0.20
Subgroup analyses									
	Dementia subtype								
	Category	45				16.31**	92.0	1.12	1.26
	Total	17				5.72	92.7	0.98	0.96
	Perseveration	33				5.46	89.6	0.85	0.73
	Error	14				0.97	95.5	1.19	1.41
	Sorting test used								
	Category	32				19.23***	94.0	1.20	1.44
	Total	14				6.26*	93.9	1.01	1.03
	Perseveration	24				2.89	91.7	0.88	0.77

$N_{studies}$ = number of studies, *g* = Hedges' *g*, *95% CIs* = 95% confidence intervals, *Q* = distribution of observed effects, I^2, = the ratio of true effect to error variance, Tau^2 = variance in the true effects
***p value <.001, ** p value <.01, * p value <.05

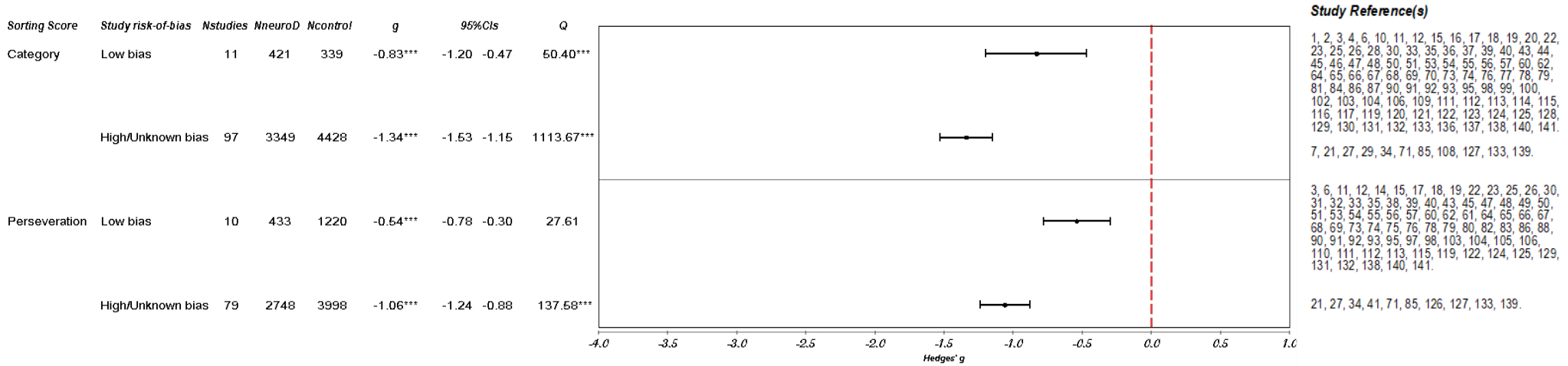
Sorting Score	NeuroD Disorder	Nstudies	NneuroD	Ncontrol	Hedges' g	95%CIs		Q	Study Reference(s)
Category	PD	56	2017	2145	-0.97***	-1.14	-0.80	294.49***	3, 4, 6, 7, 12, 16, 19, 21, 22, 23, 25, 26, 27, 29, 33, 34, 35, 36, 37, 38, 40, 44, 45, 46, 47, 48, 50, 51, 53, 56, 64, 67, 68, 70, 74, 78, 81, 84, 85, 87, 93, 98, 100, 102, 103, 109, 111, 112, 114, 129, 135, 137, 138, 139, 141.
	MND	11	349	290	-1.25***	-1.98	-0.53	153.96***	1, 2, 10, 43, 71, 74, 79, 90, 91, 121, 140.
	Other Neuro. Dis	4	94	87	-0.60*	-1.20	-0.01	11.45**	13, 69, 94, 131.
	MCI	16	520	1061	-1.44***	-1.92	-0.96	164.39***	18, 20, 28, 30, 54, 60, 76, 77, 86, 104, 108, 119, 122, 127, 128, 133.
	AD	25	886	1263	-2.12***	-2.66	-1.53	469.55***	15, 17, 28, 46, 53, 55, 57, 62, 73, 76, 77, 86, 93, 95, 108, 115, 116, 117, 119, 124, 125, 127, 132, 136.
	bvFTD	7	139	116	-1.53***	-1.82	-1.24	6.18	36, 46, 73, 124, 125, 130, 136.
	VaD	3	56	71	-2.23***	-3.21	-1.25	9.05**	73, 127, 132.
	LBD	4	70	79	-2.36***	-3.62	-1.10	21.32***	53, 100, 113, 127.
	SD	2	21	17	-1.24***	-1.91	-0.57	0.21	46, 136.
	PPA	2	31	29	-0.82***	-1.34	-0.31	0.44	46. 123.
	Dementia NOS	2	64	65	-1.35**	-2.41	-0.29	7.50**	3, 34, 38, 61, 63, 70, 72, 78, 80, 82, 83, 94, 97, 110, 137.
Total	PD	15	452	424	-0.74***	-0.92	-0.56	21.50	32, 42.
	MND	2	84	45	-0.66***	-1.11	-0.22	1.36	95, 101, 134.
	Other Neuro. Dis	3	115	119	-0.49***	-0.75	-0.23	1.36	24, 59, 60, 89, 142.
	MCI	5	422	292	-0.64***	-0.79	-0.48	2.72***	5, 8, 9, 13, 24, 59, 80, 95, 107, 136.
	AD	10	534	422	-1.51***	-1.82	-1.20	34.17***	52, 136.
	bvFTD	2	51	34	-1.63***	-2.14	-1.12	0.70	52, 136.
	PPA	2	30	34	-0.86**	-1.43	-0.29	1.23	3, 6, 12, 19, 21, 22, 23, 25, 26, 27, 31, 33, 34, 35, 38, 39, 40, 41, 45, 47, 48, 50, 51, 53, 56, 61, 64, 66-8, 74, 78, 80, 82, 83, 85, 88, 93, 97, 98, 103, 110, 111, 112, 129, 138, 139, 141.
	Dementia NOS	3	149	142	-3.02	-6.22	0.18	158.87***	32, 43, 71, 75, 79, 90, 91, 140.
Perseveration	PD	48	1784	1921	-0.68***	-0.81	-0.55	137.58***	13, 69, 95, 131.
	MND	8	283	232	-1.14***	-1.88	-0.39	94.75***	19, 30, 54, 60, 77, 86, 104, 105, 119, 122, 126, 127, 133.
	Other Neuro. Dis	4	94	87	-0.64***	-1.00	-0.28	4.28	15, 17, 30, 49, 53, 55, 57, 62, 73, 77, 80, 86, 93, 95, 105, 115, 124, 117, 127, 132.
	MCI	13	314	934	-1.32***	-1.87	-0.76	126.36***	49, 73, 124, 127.
	AD	20	820	1181	-1.49***	-1.94	-1.04	275.87***	73. 127. 132.
	bvFTD	4	55	83	-1.29***	-1.99	-0.58	9.82*	3, 6, 19, 25, 34, 37, 41, 51, 53, 67, 70, 74, 82, 85, 88, 93, 110, 111, 129, 138.
	VaD	3	56	71	-1.83***	-2.79	-0.86	9.77**	2, 32, 43, 71, 79, 91, 121, 140.
	LBD	3	25	57	-1.46***	-2.02	-0.89	2.28	69, 131.
	Dementia NOS	3	94	86	-1.00***	-1.31	-0.69	1.97	54, 86, 96, 133.
Error	PD	20	847	1220	-0.70***	-0.84	-0.57	27.61	15, 53, 54, 57, 62, 86, 92, 96, 115, 116, 125.
	MND	8	310	223	-1.27**	-2.21	-0.33	147.51***	53.
	Other Neuro. Dis	2	44	34	-0.69***	-1.78	0.39	5.29*	119. 105.
	MCI	4	81	747	-0.72***	-0.98	-0.45	0.64	46.
	AD	11	485	976	-1.63***	-2.40	-0.85	257.08***	20.
	LBD	1	5	21	-1.00*	-1.98	-0.01	-	46.
	Dementia NOS	2	99	101	-1.34	-3.04	0.37	28.12***	46.
Description	PD	1	11	9	-1.54***	-2.50	-0.57	-	46.
	MCI	1	140	69	-0.89***	-1.19	-0.59	-	46.
	AD	1	19	9	-2.22***	-3.18	-1.25	-	14.
	bvFTD	1	25	9	-1.35***	-2.16	-0.54	-	
	SD	1	13	9	-1.41***	-2.33	-0.49	-	
	PPA	1	12	9	-1.46***	-2.40	-0.52	-	
	Dementia NOS	1	30	21	-0.85***	-1.42	-0.27	-	



Nstudies = number of studies, *NneuroD* = number of participants with a neurodegenerative disorder, *Ncontrol* = number of healthy controls, *g* = Hedges' *g*, *95% CIs* = 95% confidence intervals, *Q* = distribution of observed effects, PD = Parkinsonian disorders, MND = motor neuron disorder, MCI = mild cognitive impairment, other Neuro. Dis = other neurodegenerative disorders, AD = Alzheimer's dementia, bvFTD = behavioural-variant frontotemporal dementia, VaD = vascular dementia, LBD = lewy body dementia, Dementia NOS = dementia not otherwise specified, PPA = primary progressive aphasia, SD = semantic dementia

*** *p* value <.001, ** *p* value <.01, * *p* value <.05

Figure 3.2: Hedges' g effect sizes for the neurodegenerative disorders, grouped by score type and diagnosis



Nstudies = number of studies, *NneuroD* = number of participants with a neurodegenerative disorder, *Ncontrol* = number of healthy controls, *g* = Hedges' *g*, *95% CIs* = 95% confidence intervals, *Q* = distribution of observed effects, WCST = Wisconsin Card Sorting Test, VVT = Visual Verbal Test, DKEFS-ST = Delis Kaplan Executive Functioning System- Sorting Test, Weigl = Weigl Color Form Sort
*** *p* value <.001, ** *p* value <.01, * *p* value <.05

Figure 3.3: Hedges' g effect sizes for all neurodegenerative disorders combined on the category and perseveration scores, grouped by study risk-of-bias

3.6.5 Subgroup (dementia subtype & sorting test) & covariate (education & disease severity) analyses

Dementia subtype

A subgroup analysis, which compared the Category, Total, Perseveration and Error scores for all of the dementia subtypes, revealed that only the Category scores differed (see Q statistics for the Dementia subgroup analysis, Table 3.2). Contrary to clinical expectation, the bvFTD group had significantly *better* Category scores than the AD group (see Figure 3.2: Hedge's *g* for AD fell below the lower 95% CI for bvFTD). However, significant heterogeneity remained in the Category scores of the AD, VaD, LBD and NOS dementia subtypes (see Q statistics, Figure 3.2), suggesting there were additional unaccounted sources of variability. Education and disease severity were therefore investigated to determine whether they contributed to this variability.

Education was examined via three meta-regressions. The first examined the Category scores for all of the dementia subtypes (note: 2 studies were excluded because education was not reported) and found that patient education was not significantly related to performance ($N_{studies}$ = 30, Qmodel = 0.78, df = 1, p = 0.38, R^2 = -0.03). The second meta-regression compared the Category scores of the bvFTD and AD groups, and found these dementia subtypes no longer differed after patient education was taken into consideration ($N_{studies}$ = 31, Qmodel = 1.00, df = 2, p = 0.61, R^2 = -0.08). A final meta-regression compared the Category scores of FTD and non-FTD dementia subtypes because, clinically, FTD is thought to have a greater impact on the cognitive abilities that underpin sorting task performance. This analysis revealed that FTD and non-FTD performed comparably when education was taken into consideration ($N_{studies}$ = 33, Qmodel = 2.01, df = 2, p = 0.37, R^2 = -0.08). In combination, these analyses suggest that the sorting test performance of the various dementia subtypes do not differ when they have comparable education.

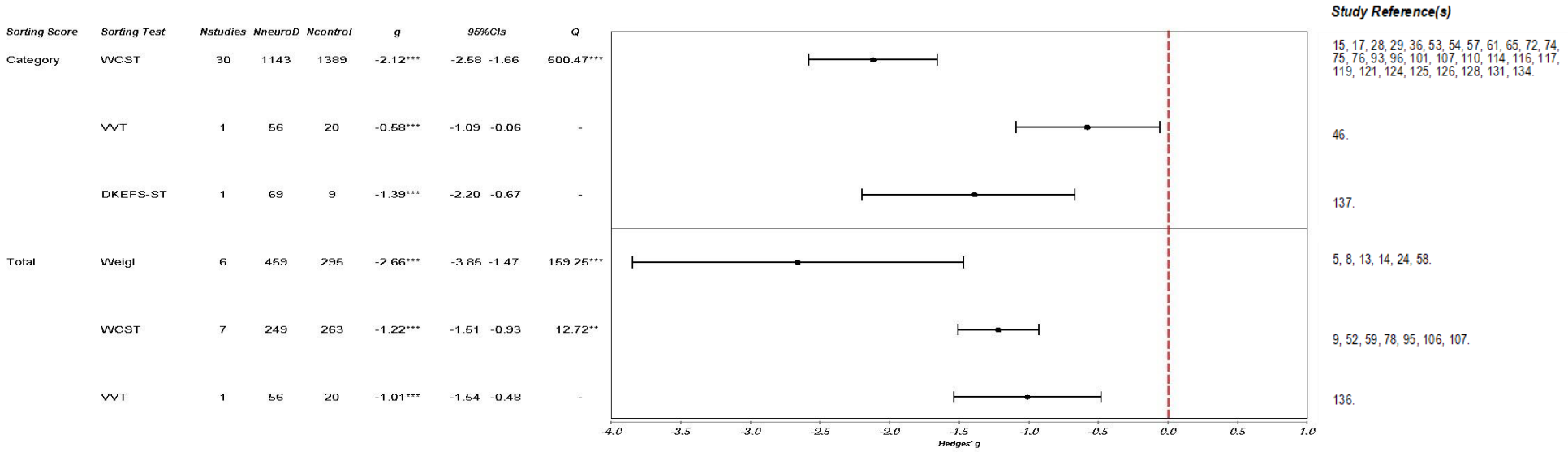
A further two subgroup analyses examined whether disease severity contributed to the heterogeneity in the Category scores of the dementia subtypes. The Clinical Dementia Rating Scale (CDR) was the most commonly-used measure of disease severity in the studies that reported Category scores ($N_{studies}$ = 13), with eight studies examining mild dementia and the remaining five combining multiple disease stages, rendering the latter unsuitable for analysis. The first subgroup analysis compared the Category scores of persons in the mild/early stages of each of the dementias subtypes in order to determine whether they still differed when the samples were more homogenous in terms of their disease severity. This analysis revealed that there were no significant differences between the Category scores of the bvFTD ($N_{studies}$ = 2 g = -1.46, 95%CI -2.72 to -0.20), AD ($N_{studies}$ = 7, g = -1.75, 95%CI -2.43 to -1.07), VaD ($N_{studies}$ = 1 g = -2.02, 95%CI -3.95 to -0.09), or LBD ($N_{studies}$ = 1, g = -1.55, 95%CI -3.49 to 0.40) dementia subtypes. The second analysis compared mild FTD (severity data was only available for bvFTD) to mild non-FTD dementia (because FTD was expected to perform more poorly) and found that they did not differ significantly ($N_{studies}$ = 7, g = -1.78, 95%CI -2.45 to -0.24). Thus, the Category scores of the FTD and other dementia subtypes, including AD, appear to be comparable in the early/mild stages of the disease.

Sorting test

Next, subgroup analyses examined whether the test itself (Weigl, WCST, VVT, DKEFS-ST) contributed to the heterogeneity that was observed in the Category, Total and Perseveration scores of people with dementia (Error scores were only reported for the WCST, precluding an analysis). These analyses revealed that the choice of test contributed significant heterogeneity to the Category and Total scores (see Table 3.2). Visual inspection of Figure 3.4 indicates that (1) the Category score from the WCST was significantly more discriminating than the VVT (Hedges' g for WCST fell outside of 95% CIs for VVT), but not the DKEFS-ST; and (2) the Total score from the Weigl was significantly more discriminating than the WSCT and VVT (Hedges' g for Weigl fell outside of 95% CIs for WCST and VVT).

However, these findings should be considered tentative because the VVT and DKEFS were only examined by single studies and significant heterogeneity remained in the scores of the other tests (WCST Category & Total scores; Weigl Total scores; see Figure 3.4).

Finally, two meta-regressions examined whether patient education influenced the sorting test findings. Unfortunately, test type could not be examined in conjunction with education because there were insufficient data (i.e., VVT and DKEFS were examined by single studies and 6 studies did not report education). These analyses revealed that patient education did not significantly influence the Category ($N_{studies}$ = 29, Qmodel = 1.30, df = 1, p = 0.25, R^2 = -0.02) or Total ($N_{studies}$ = 10, Qmodel = 2.47, df = 1, p = 0.12, R^2 = 0.03) scores. Therefore, education did not appear to be a source of heterogeneity in the findings relating to the choice of sorting test. Disease severity could not be examined in this way due to insufficient data.



Nstudies = number of studies, *NneuroD* = number of participants with a neurodegenerative disorder, *Ncontrol* = number of healthy controls, *g* = Hedges' *g*, *95% CIs* = 95% confidence intervals, *Q* = distribution of observed effects, WCST = Wisconsin Card Sorting Test, VVT = Visual Verbal Test, DKEFS-ST = Delis Kaplan Executive Functioning System- Sorting Test, Weigl = Weigl Color Form Sort

*** *p* value <.001, ** *p* value <.01, * *p* value <.05

Figure 3.4: Hedges' g effect sizes for dementia (all) on the category and total scores grouped by the test used

3.6.6 Publication bias

Publication bias was examined using Duval and Tweedies' trim and fill procedure (see Supplementary Figure A.2.2 (a-h). When the Category scores for each neurodegenerative disorder were inspected separately, there were no missing studies on the right of any of the funnel plots for any disorder (other scores generated similar results and are available upon request), suggesting that publication bias was unlikely to have impacted on the current findings.

3.7 Discussion

The current meta-analysis pooled the data from 142 studies to investigate the effectiveness with which sorting tests were able to differentiate between older adults with and without neurodegenerative disorders. The most common disorders were Parkinsonian disorders ($N_{studies}$ = 69), followed by AD ($N_{studies}$ = 34), MCI ($N_{studies}$ = 22), MND ($N_{studies}$ = 13) and bvFTD ($N_{studies}$ = 9). Dementia was of particular interest because cognitive screens are commonly used to assist in its detection and, in clinical settings, sorting tests are often used to differentiate between certain dementia subtypes (e.g., bvFTD *vs* AD). The WCST ($N_{studies}$ = 127) was much more frequently used than other sorting tests, with the Weigl ($N_{studies}$ = 8), DKEFS ($N_{studies}$ = 4) and VVT ($N_{studies}$ = 3) used by many fewer studies.

Overall, the findings indicate that older adults with a neurodegenerative disorder performed consistently more poorly than their cognitively-healthy peers on all five commonly-used sorting test scores, namely, the Category ($N_{studies}$ = 108), Total ($N_{studies}$ = 35, Perseveration ($N_{studies}$ = 89), Error ($N_{studies}$ = 44), and Description scores ($N_{studies}$ = 3). The Category and Description scores were particularly discriminating, although the latter score was infrequently reported. In addition to being the most discriminating and commonly reported score, Category scores are affected by errors (e.g., perseverations and other

errors), which means that they capture multiple aspects of performance. The effectiveness of the Category, Total and Perseveration scores was influenced by the type of disorder, with larger effects seen in the disorders that have cognitive impairment as one of their core diagnostic features, namely, specific dementia subtypes. Category and Perseveration effect sizes were also influenced by study risk-of-bias, with low risk-of-bias studies providing more conservative estimates, albeit still large and highly significant. Although disorder-type and risk-of-bias both influenced the findings, substantial residual variance remained, suggesting that other factors – such as disease severity or time since diagnosis – may be important.

Older adults with dementia had some of the lowest sorting scores, with the Category and Total scores being particularly effective for discriminating between people with and without dementia. In persons with dementia, there was significant variability in the findings from individual studies, with some of the variability in Category scores being attributable to the specific type of dementia. However, contrary to clinical lore, persons with AD performed *more poorly* (Category scores) than those with bvFTD and other dementia subtypes performed *as poorly* as those with bvFTD, suggesting that sorting test performance is impaired in a wide variety of neurodegenerative disorders. When the impact of education and disease severity was examined, bvFTD performed comparably to the non-FTD dementias. These findings suggest that sorting tests, which are commonly assumed to assess 'executive' functioning, should not be used to differentiate between bvFTD and other types of dementia. Indeed, AD and bvFTD have proven notoriously difficult to differentiate (Ikeda, Ishikawa, & Tanabe, 2004; Mathias & Burke, 2009; Wang, Redmond, Bertoux, Hodges, & Hornberger, 2016), possibly because a historical focus on memory deficits in AD may have meant that changes to 'executive' functioning, working memory and behaviour have not been given adequate attention (Binetti et al., 1996; Mega, Cummings, Fiorello, & Gornbein, 1996). 'Executive' functioning is itself a broad amalgam of constructs, which are articulated in the Cattell-Horn-Carroll model of cognitive functioning, but we do not yet know

exactly which of these constructs are assessed by sorting tests (Jewsbury, Bowden, & Strauss, 2016; McGrew, 2009).

Although sorting tests did not effectively differentiate between the different dementia subtypes, they did detect cognitive impairment in people with dementia, more generally. Sorting tests have comparable or better sensitivity and specificity than the MMSE, which is one of the most commonly-used cognitive screens for detecting cognitive impairment in older adults. Indeed, the Hedges' *g* score of 2.1 for the Category score in people with dementia converts to sensitivity and specificity values of approximately 85% each, which compare favourably with the 80% sensitivity and 81% specificity values reported by a meta-analysis examining the MMSE in memory clinic samples (Mitchell, 2009; note: most of the dementia samples in this meta-analysis came from clinics). The current findings now need to be extended by comparing the effectiveness with which sorting and other cognitive tests or screens differentiate between older adults with neurodegenerative disorders and their cognitively healthy peers.

The Category score from the WCST and the Total score from the Weigl were the most discriminating measures when examining dementia, however, this finding should be considered tentative because the various tests have not been equally researched. There was also significant variability in the findings from studies that used the same sorting test, which may be related to sample characteristics (e.g., education), dementia subtype or disease severity. Clinicians are likely to consider the cost of a sorting test, the time taken to administer and score it, how well it is tolerated by their patients, its reliability and validity, as well as its sensitivity and specificity when used to detect cognitive decline in their patient group. The Weigl is desirable because it is free, and brief to administer and score (<5 minutes). It has also been used with a variety of older adult samples, including persons who have had a stroke, or have Parkinson's disease, an isolated memory impairment and dementia (Byrne et al., 1998; Hobson et al., 2007). In addition, the revised Weigl has been found to detect cognitive decline in older adults with dementia and, although it would benefit

from more normative and psychometric data (e.g., test-retest reliability), has the added advantage of including a Description score (Beglinger et al., 2008). The Description score warrants further investigation because it was the most discriminating score in AD and PD, and was significantly impaired in the other neurodegenerative disorders for which there were data (PD, MCI, AD, bvFTD, SD, PPA and Dementia NOS).

This meta-analysis was limited to the common neurodegenerative disorders of older age. Consequently, the findings may not generalize to younger age groups or other neurological conditions. The findings suggest that older adults who are suffering from the most common neurological disorders, including but not limited to dementia, perform more poorly on a variety of sorting tests and scores. Indeed, the Category and Description scores appear to be the most promising measures, although the latter, which assesses a person's ability to articulate the category or rule underlying their sort, requires further research to establish its worth. Unfortunately, it was not possible to directly compare the effectiveness with which sorting tests and other cognitive screens, such as the MMSE and FAB, detect cognitive impairment in older adults because the latter screens were often used as part of the diagnostic process (i.e., these screens could not be used as both a diagnostic and outcome measure). This is something that now needs to be researched. Another limitation relates to the patient characteristics that have the potential to influence sorting performance, which were not able to be comprehensively analysed in this meta-analysis. In clinical practice disease severity and years of formal education are routinely considered when interpreting cognitive test performances. Furthermore, when formulating specific clinical diagnoses multiple sources of evidence are routinely utilized – such as the person's medical and psychological history, physical examination and the results of other investigations – not just performance on a single cognitive test or screen (Walterfang, Siu, & Velakoulis, 2006). The clinical utility of sorting tests should now be optimised by investigating their sensitivity and specificity in a variety of different point-of-care settings to enable clinicians to tailor their interpretation of these tests to their own practice and patients.

3.8 Conclusion

Sorting ability is not measured by existing cognitive screens, such as the MMSE and MoCA, but appears to decline in the common neurodegenerative disorders of older age, particularly dementia. The fact that brief and simple sorting tests can effectively detect cognitive decline in older adults suggests that these tests may provide a valuable alternative to current cognitive screens and, consequently, assist in meeting the growing demand for point-of-care cognitive assessments. However, sorting tests should not be used to differentiate between the different types of dementia.

3.9 Acknowledgements

The authors would like to thank Maureen Bell (Research Librarian, Research and Reference Services, Barr Smith Library, University of Adelaide) for her expert assistance with developing the search terms for this meta-analysis.

3.10 Study 1 reference list

Numbers 1–142 correspond to the study references given in Figure 3.2, Figure 3.3 and Figure 3.4, as detailed in Supplementary Table A.2.3

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Chapter 4

The QuickSort: A brief new cognitive screen

4.1 Preamble

Study 1 found that sorting tests are able to detect the cognitive decline associated with the neurodegenerative disorders that are most common in older adults, including dementia and MCI. In addition, the performance of sorting tests appears to rival that of the most popular cognitive screen, the MMSE (Mitchell, 2009). In particular, the briefest sorting test, the Weigl, was effective for detecting dementia, which supports their screening potential. The sorting scores that involved grouping stimuli into categories (Category score) and explaining the correct sorting categories (Description score) were the most effective for detecting dementia. Although sorting tests detected cognitive decline in older adults, even the briefest versions are considered too lengthy to administer, and they have limited reliability data, and modest normative and clinical samples. A new cognitive screen – the QuickSort – was therefore designed to be quicker and more suitable for use with a wider range of older adults (e.g., those with verbal communication difficulties and severe cognitive impairment) than existing sorting tests. The record form, stimuli and test manual represent the first stages in the development of this test, and are published in the on-line supplementary material of a later journal article that describes the psychometric properties and clinical utility of the QuickSort (Study 4).

This chapter contains the QuickSort Manual, Stimuli and Record Form, as it appeared in the on-line supplementary material of an article published by Foran, Mathias & Bowden (2021) in the Journal of the American Geriatrics Society. The journal provided permission to reproduce these materials in this thesis. The references and appendixes in the manual are at the end of this chapter.

4.2 Statement of authorship/copyright

Statement of Authorship

Title of Paper	QuickSort Manual, Stimuli and Record Form
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted w ork w ritten in manuscript style
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Contribution to the Paper	Designed the QuickSort, which includes the option of early discontinuation for cognitively-healthy older adults. Development of the Manual, Stimuli and Record Form. Supervision of a graphic designer who developed the PDF version of the QuickSort.		
Overall percentage (%)	90		
Certification:	The Manual, Stimuli and Record Form were completed during the period of my Higher Degree by Research candidature and are not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary designer and owner of the QuickSort.		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Contribution to the Paper	Supervision and feedback on the QuickSort Manual and Record Form.		
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4.3 QuickSort Manual, Stimuli and Record Form

The QuickSort Manual, Stimuli and Record Form were published in the on-line supplementary material of the journal article entitled: “The development of a brief screen to detect cognitive impairment in older adults: The QuickSort” in the *Journal of the American Geriatrics Society (JAGS)*, 69, 2, 441-449.

- Journal Impact Factor = 7.54

- Conference presentations are provided in a complete list at the start of this thesis.

QuickSort

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QuickSort

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1 Introduction

The QuickSort is a brief cognitive task that requires examinees to sort nine cards into one of three categories, while also articulating the basis for the sort. The QuickSort is designed to quickly screen a person's cognitive functioning.

The QuickSort is intended to identify impaired individuals who would benefit from a more detailed cognitive investigation. It is shorter than widely-used sorting tests [1-3] because it allows an early discontinuation for intact performance. The QuickSort contains simple stimuli, similar to those used by other short sorting tests [4,5], while also having fewer items that need to be grouped and an additional sorting category. There is a standardized method of administering and scoring the QuickSort. Sorting errors (e.g., repetitions) and the need for prompts are recorded, as are concrete responses.

Task

The QuickSort uses nine cards, which must be sorted into each of three categories within a maximum of 6 trials. The cards can be correctly sorted by color, shape or number of dots. Examinees are not told whether their sort is correct or not. Instead, after a correct sort, the examinee is asked to explain how they have sorted the cards. Examinees are also not informed if the explanation they provide is correct, concrete or incorrect. Incorrect sorts are classified into one of four error types, each of which has a specific prompt that is provided to the examinee, so that they can attempt to sort the cards differently on the next trial. Examinees are not asked to provide an explanation for an incorrect sort.

QuickSort correct sorting categories:

- **Color:** red, green, blue.
- **Shape:** triangle, rectangle, circle.
- **Number:** 1, 2, 3 (all of the cards in a particular group have the same number of dots).

QuickSort explanations of correct sorts:

- **Correct:** the underlying concept is correctly stated (color, shape, or number of dots).
- **Concrete:** each group of cards is individually described instead of identifying the underlying concept. For example, an examinee states they have grouped the red, green and blue cards together, instead of saying they were sorted by color.
- **Incorrect:** the examinee does not provide either a correct or concrete explanation. For example, they may say they do not know or they say that they have made a design, pattern or sequence.

QuickSort sorting errors:

- **Repetition error:** repeating a sort (correct or incorrect) that has already been done.
- **Set-loss error:** the person makes a pattern/design or sequence using the cards (with three cards in each group), but the sort does not involve classifying the cards by colour, shape or number of dots.
- **Grouping error:** the cards are not evenly divided into three groups of three cards (i.e., uneven numbers in the groups) or the cards are not clearly displayed in three distinct groups (e.g. cards within a group are placed equally close to those in another group, giving the appearance of a larger group).
- **Completion error:** the person is unable to sort the cards in any way.

A specific prompt follows each type of sorting error, so that the examinee is aware of the nature of the error. The examiner can provide as many prompts as needed (up to the fifth prompt); but each new attempt by the examinee constitutes a new trial. If a correct sort occurs on the trial following a prompt, it is scored accordingly, and not awarded the same as a correct sort that is performed spontaneously.

Incomplete rule: If the examinee discontinues the QuickSort due to difficulty, the remaining trials should be scored as errors and the Total score computed as usual.

Minimum number of trials: Three, if all three sorts are completed without error.

Maximum number of trials: The examinee is given a maximum of six attempts to achieve three correct sorts (color, shape, or number of dots).

Materials

- Nine QuickSort stimulus cards, comprising three shapes (rectangle, triangle, circle) that are printed in three colors (red, blue, green) and attached to thick/firm cardboard (≥ 2mm thick). Templates for these shapes are provided in the Appendix 1 of this Manual; thereby ensuring consistent dimensions for each: Rectangle (95mm x 70mm sides), Triangle (60mm height x 120mm base), and Circle (80mm diameter).
- A template for the QuickSort Record and Scoring Form is also provided in this manual (see Appendix 2) and should be placed on a clipboard (or other flat surface) during testing, away from the view of the examinee.
- A smooth working surface is required to administer the task, such as a desk or, where a bed-side assessment is being performed, on a table or tray over the bed.

Examinees

The QuickSort is a screening measure that is designed to identify who may benefit from a more detailed cognitive assessment. Initial research has focused on the QuickSort in adults aged 60 years and over.

The QuickSort should not be used with persons who are severely color-blind such that they cannot differentiate between red/blue/green, or have significant visual impairment.

2 QuickSort Administration and Recording

Examinee Information

Record the following patient details on the QuickSort Record Form (Appendix 2):

- Date
- Examiner's name
- Examinee's name
- Other patient identifier, if required (e.g., medical record number)
- Age or date of birth

The examiner should consider any factors that may independently cause poor performance on the QuickSort in order to determine whether it is an appropriate measure and/or what factors need to be considered when interpreting the QuickSort. The examiner may identify the following confounds: color blindness, learning disability, previous brain injury or neurological illness, the presence of a delirium, English being a second language, or an examinee's previous exposure to the task. These items are listed on the Confound Checklist, which is located underneath the patient details on the QuickSort Record Form (Appendix 2). For each respective confound, the examiner should tick the 'Not Present' box if the confound is not present. Tick the 'Present' box if the confound is likely to be present. Tick the 'Unsure' box whether it cannot be determined if the confound has the potential to affect the examinee's QuickSort performance.

The examiner can note other issues that have the potential to influence the administration or interpretation of the QuickSort in the specified area, located under the Confound Checklist. Other possible confounds or issues include: interruptions to administration, background noise, suspected suboptimal effort, poor rapport, etc.

QuickSort Instructions (shown in italic print below) are printed on the QuickSort Record Form to facilitate standardized administration.

QuickSort Introduction

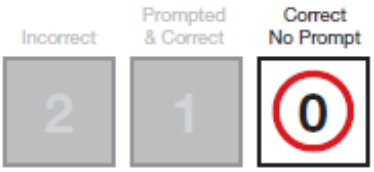
The nine QuickSort cards should be randomly placed in front of the examinee on a flat surface, colored side up.
Introduce the task by saying:

> *"These cards need to be sorted into three groups.*
> *There needs to be three cards in each group.*
> *The cards in each group must have something in common.*
> *There are a few different ways you can sort the cards into the three groups.*
> *Can you group the cards into three sets of three cards?"*

Arrows are provided on the QuickSort Record Form to direct the examiner to their next action, based on the examinee's performance. Please refer to the QuickSort Record Form (Appendix 2).

Scoring: Correct Sort With No Prompt

Sorting



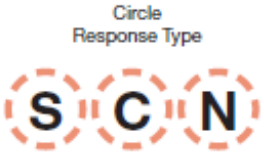
A correct sort is when the cards are sorted by:

Shape: triangles, rectangles/ squares, circles.

Color: red, green, blue.

Number: cards with 1 dot are grouped, cards with 2 dots are grouped and cards with 3 dots are grouped.

In the Sorting column Circle the Correct score ⓪



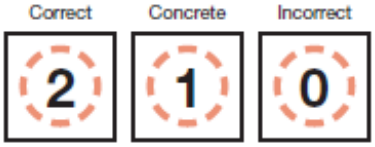
Circle the type of correct sort under **Response Type:**

S = shape

C = color

N = number

Explanation



The examinee is not told that he/she has made a correct sort, but is asked to explain how he/she has sorted the cards.
"How have you grouped the cards?"

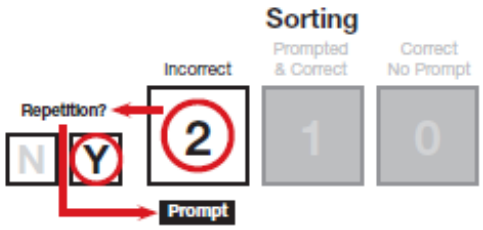
Correct Explanation:
The examinee explains the concept underlying the sort: color, shape/form or number.
In the Explanation column, circle the Correct score ②

Concrete Explanation:
The examinee fails to state the underlying concept.
For example, they state that they have grouped the red, green and blue cards, instead of saying color.
Or, the examinee states they have grouped the rectangles/ squares, triangles and circles, instead of saying shape/form.
Or, the examinee says they have grouped the ones, twos and threes, instead of stating dots/number.
In the Explanation column, circle the Concrete score ①

Incorrect Explanation:
The examinee fails to provide either a correct or concrete response.
For example, they respond with "I do not know".
In the Explanation column, circle the Incorrect score ⓪

SHUFFLE CARDS THOROUGHLY
"There is another way to sort the cards. Can you group the cards into three sets of three cards, another way?"

Scoring: Incorrect Sort



An examinee sorts the cards incorrectly, making one of four possible errors:

Repetition error: repeating a sort (whether it was correct or incorrect) that has already been made.

Set-loss error: where a pattern/design or sequence is made with three cards in each group, but the response does not involve classifying the cards by colour, shape or number. For example, they place the cards into the shape of a house or a rocket, or in a sequence of 1-2-3.

Grouping error: where cards are not evenly divided into three groups of three cards. For example, there are uneven numbers of cards in the groups or the cards are not clearly displayed in three distinct groups (e.g. cards within a group are placed equally close to those in another group, giving the appearance of a larger group).

Completion error: the person is unable to sort the cards in any way. For example, the person says "I don't know".

In the Sorting column circle the Incorrect score ②. If the error involved repeating a sort, circle Ⓨ in the Repetition box. If the error did not involve repeating a sort, circle Ⓝ in the Repetition box.

Specific Prompts Given After a Sorting Error

After an incorrect sort, examinees are prompted according to the type of error that was made.

Repetition error: "No. You cannot repeat the groups you have made before."

Set-loss error: "No. The cards in each group need to have something in common with each other.

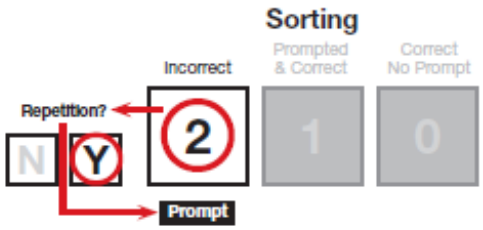
Grouping error: "No. The cards need to be grouped into three groups of three cards."

Completion error: The initial instructions are repeated.

"These cards need to be sorted into three groups. There needs to be three cards in each group. The cards in each group must have something in common. There are a few different ways to sort the cards into three groups. Can you group the cards into three sets of three cards?"

After providing the specific prompt **SHUFFLE CARDS THOROUGHLY**

Scoring: A Consecutive Incorrect Sort



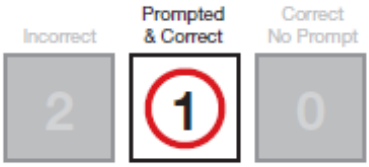
A consecutive error in sorting is treated the same as any error in sorting. In the Sorting column circle the Incorrect score ②. If the error involved repeating a sort, circle Ⓨ in the Repetition box. If the error did not involve repeating a sort, circle the Ⓝ in the Repetition box.

Provide the prompt that is specific to the sorting error (see above).

After providing the specific prompt **SHUFFLE CARDS THOROUGHLY**

Scoring: Correct Sort Following A Prompt Due To An Incorrect Sort

Sorting



Following the provision of a prompt due to an incorrect sort on the last trial the cards are correctly sorted by:

Shape: triangles, rectangles/ squares, circles.

Color: red, green, blue.

Number: cards with 1 dot are a group, cards with 2 dots are a group and cards with 3 dots are a group.

In the Sorting column, Circle the Prompted & Correct score ①

Circle Response Type

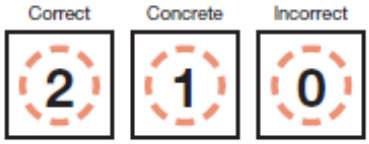
Circle the type of correct sort under **Response Type:**

S = shape

C = color

N = number

Explanation



The examinee is not told that he/she has made a correct sort, but is asked to explain how he/she has sorted the cards.
"How have you grouped the cards?"

Correct Explanation:
The examinee explains the concept underlying the sort: color, shape/form or number.
In the Explanation column, circle the Correct score ②

Concrete Explanation:
The examinee fails to state the underlying concept.
For example, they say they have grouped the red, green and blue cards, instead of saying color.
Or, the examinee states they have grouped the rectangles/ squares, triangles and circles, instead of saying shape/form.
Or, the examinee says they have grouped the ones, twos and threes, instead of stating dots/number.
In the Explanation column, circle the Concrete score ①

Incorrect Explanation:
The examinee fails to provide either a correct or concrete response.
For example, they respond with "I do not know".
In the Explanation column, circle the Incorrect box ⓪

SHUFFLE CARDS THOROUGHLY
"There is another way to sort the cards. Can you group the cards into three sets of three cards, another way?"

Discontinuation Rule

The QuickSort is ceased once all three possible correct sorts (color, shape, number) have been achieved (minimum of three trials) or after six trials have been attempted, whichever comes first.

Time Allowed

Each trial should be completed within 60 seconds. If the patient has not completed the sort within 60 seconds it should be recorded as a completion error.

Task Completion

At the end of the testing session it is recommended that the examiner say:

"Thank you. This task is now complete."

Examinee Requests Feedback

If the examinee requests feedback about their performance or asks whether they were correct or passed the test, the examiner should say:

"Sorry, I am not allowed to tell you because you may need to do this task again"

If the examinee asks whether they have completed a sort before (e.g. "have I grouped them by color before?") the examiner should say:

"I can't tell you how you have grouped the cards previously."

3 QuickSort Scoring

QuickSort Sorting Score

In the Sorting column, add up the scores for the Incorrect responses (which are given a score of 2 for each incorrect response) and write the total in the equation under this column. Then add up the scores for the Prompted & Correct responses (which are given a score of 1 each) and write the total in the equation under this column. Then add these two values together and subtract them from 12. This is the Sorting Score.

QuickSort Explanation Score

In the Explanation column, add up the scores for the Correct explanations (which are given a score of 2 each) and write the total under the Correct column, then add up the scores for the Concrete explanations (which are given a score of 1 each) and write the total under the Concrete column. Then, add the Concrete and Correct scores together. This is the Explanation Score.

QuickSort Total Score

The Total QuickSort Score is obtained by adding the QuickSort Sorting Score and QuickSort Explanation Score.

QuickSort Incomplete Score

If the examinee discontinues the QuickSort due to difficulty, the remaining trials should be scored as errors, the QuickSort NOT completed box ticked, and the Total QuickSort Score computed as usual.

Number of Repetitions

The total number of repetition errors is calculated by tallying the number of Y Repetition boxes that are circled on the far left of the Sorting column. Write this value in the Number of Repetitions box, which is located on the bottom left of the record form.

Number of Concrete Responses

The total number of Concrete explanations (which are given a score of 1 in the Explanation column) are also calculated. (Note: this step may have been completed when calculating the Explanation Score, above, in which case the examiner can use the value in the equation under the Concrete column). Write this value in the Number of Concrete Responses box, located below the Concrete column at the bottom of the record form.

4 References

1. Reitan, R. (1985). *Halstead-Reitan Neuropsychological Test Battery: Theory and Clinical Interpretation*. Tucson, Arizona: Reitan Neuropsychology.

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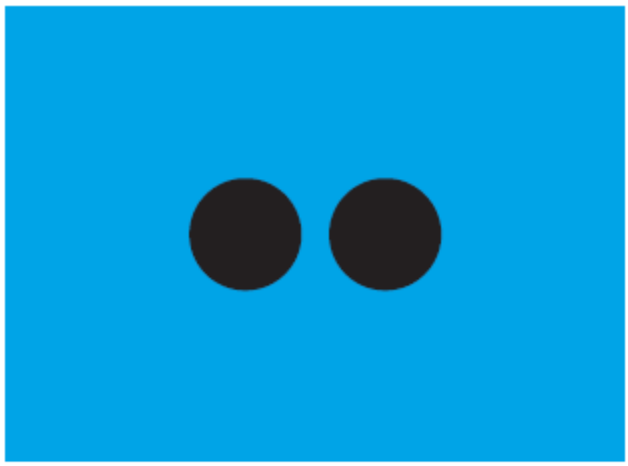
3. Grant, D. A., & Berg, E., A. (1948). *Wisconsin Card Sorting Test*. Odessa, Florida: Psychological Assessment Resources Inc.

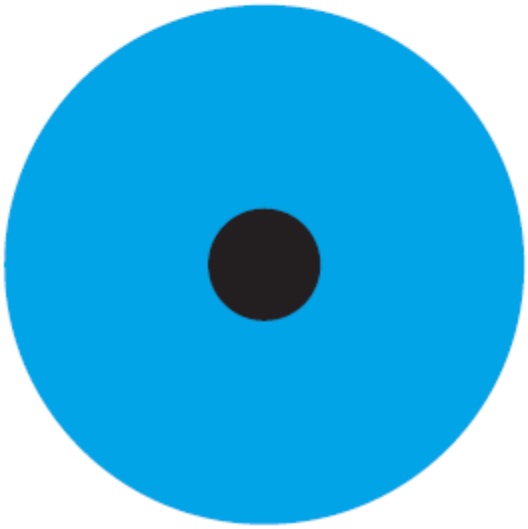
4. Weigl, E. (1941). On the psychology of so-called processes of abstraction. *The Journal of Abnormal and Social Psychology*, 63(1), 3-33.

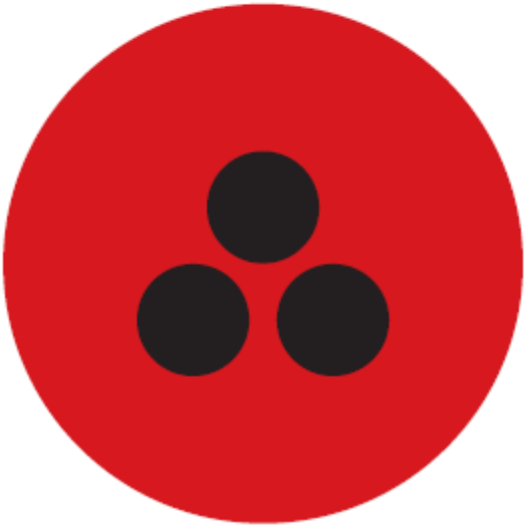
5. Beglinger, L. J., Unverzagt, F. W., Beristain, X., & Kareken, D. (2008). An updated version of the Weigl discriminates adults with dementia from those with mild impairment and healthy controls. *Archives of Clinical Neuropsychology*, 23(2), 149-156.

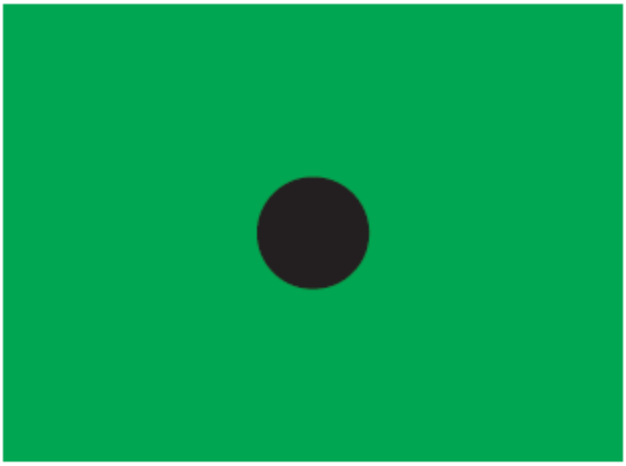
Appendix 1

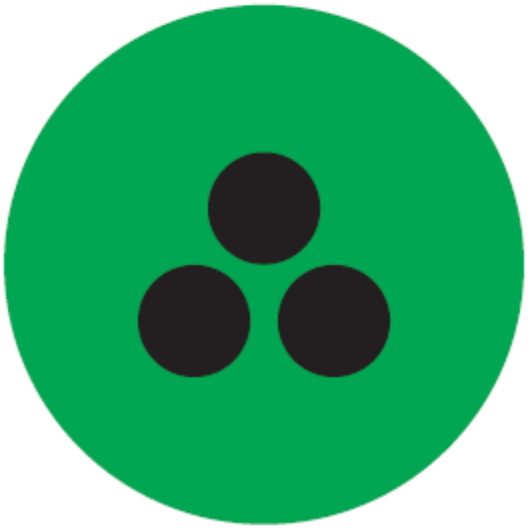
QuickSort Stimulus











Appendix 2

QuickSort Record Form

QuickSort

Foran A.M, Mathias J.L and Bowden S.C.

Introduction

"These cards need to be sorted into three groups. There needs to be three cards in each group. The cards in each group must have something in common. There are a few different ways to sort the cards into three groups. Can you group the cards into three sets of three cards?"

Specific prompts (after sorting errors)

Repeated sort: "No. You cannot repeat the groups you have made before."
Set loss error: "No.The cards in each group need to have something in common with each other."
Grouping error: "No. The cards need to be grouped into three groups of three cards."
Completion error: Repeat introduction above

Request for verbal explanation (of correct sorts)

"How have you grouped the cards?"

Start new trials with

"There is another way to sort the cards. Can you group the cards into three sets of three cards, another way?"

Date _____

Examiner _____

Patient Details

Name _____

Patient ID _____

Age _____

Confound Checklist	Not present	Present	Unsure
Colour blind	☐	☐	☐
Learning disability	☐	☐	☐
Brain injury/Neurological illness	☐	☐	☐
Delirium present	☐	☐	☐
English second language	☐	☐	☐
Previous exposure to the task	☐	☐	☐

Other possible confounds or issues: _____

SHUFFLE CARDS between trials Discontinue after 3 correct sorts achieved or 6 trials have been attempted

Trial Number	Sorting				Explanation		
	Incorrect	Prompted & Correct	Correct No Prompt		Correct	Concrete	Incorrect
Start Time 1	2		0	S–C–N	2	1	0
2	2	1	0	S=C=N	2	1	0
3	2	1	0	S=C=N	2	1	0
4	2	1	0	S=C=N	2	1	0
5	2	1	0	S=C=N	2	1	0
End Time 6	2	1	0	S=C=N	2	1	0

Circle Response Type

Prompt

Repetition? N Y

12 - (Total Incorrect + Total Prompted & Correct) = Sorting Score

(Total Correct + Total Concrete) = Explanation Score

Number of Repetitions ☐

Number of Concrete Responses ☐

QuickSort NOT completed ☐

Total QuickSort

Sorting Score + Explanation Score

Chapter 5

The QuickSort-e prototype

5.1 Preamble

The previous chapter described how the QuickSort is based on the most effective sorting scores for detecting cognitive decline in older adults, but is it quicker and more suitable for a wider range of older adults than existing sorting tests. However, a notable shortcoming of the QuickSort is that clinicians need to be familiar with its administration and scoring procedures. An iPad-compatible prototype – called the QuickSort-e – was developed to address this issue. The QuickSort-e retains the main features of the original QuickSort, with the nine stimuli appearing as images, which are moved around by the examinee using an iPad touch screen. An algorithm determines whether the stimuli have been grouped by colour, shape or number, and whether the examinee has repeated a response or made one of a number of errors (set-loss, grouping, or completion error), after which the QuickSort-e provides an instruction or prompt for the next trial. Sorting, Explanation and Total scores are automatically calculated by the QuickSort-e, along with the number of repeated sorts, concrete explanations and the time taken to complete the task. Scoring was updated after Study 4 to include a comparison of examinees' QuickSort-e Total and Sorting scores to the normative sample (otherwise referred to as base-rates; details of which are provided in the next study). There are also Help files on each screen that describe the administration and scoring procedures, which may be particularly useful when clinicians are not familiar with the QuickSort-e. Currently, the QuickSort-e can be installed using Apple's TestFlight platform, once approved users have been provided the link and login password.

The software code for the QuickSort-e was created by an off-shore software developer who followed detailed documents that specified the screen layout, user interface,

functions on each screen (Help text, General Information text, Back, Discontinue, Pause buttons, etc), scoring algorithms and the recording of performances. These specification documents are available on request. A comprehensive testing protocol that consisted of over 50 mock QuickSort-e trials was used to identify and resolve problems in the software, resulting in many revisions before it was deemed suitable for use in Study 4. This testing protocol is also available on request. This chapter outlines the main advantages of the QuickSort-e, the steps involved in downloading the QuickSort-e prototype to an iPad using TestFlight, and the major aspects of its functionality.

5.2 The advantages of the QuickSort-e prototype

The QuickSort-e was designed to improve the clinical utility of the QuickSort by:

- making administration easier because it identifies correct and incorrect sorts, and provides clinicians with the next instruction or prompt,
- ensuring it is administered in a standardized way by automating all instructions,
- making scoring easier and more accurate by calculating all scores,
- reducing the time required to train clinicians by having information from the QuickSort manual accessible on each screen through the Help icon,
- removing the need for hard copies of the sorting stimuli and record forms,
- using base-rates to compare an examinee's score to their cognitively-healthy peers (normative sample) in order to assist with detecting cognitive decline,
- sharing QuickSort-e records electronically, which may assist with continuity of patient care, and
- saving examinees' QuickSort-e records in a local database so that the data can be used for auditing a clinical service and for research purposes.

5.3 Statement of authorship/copyright

Statement of Authorship

Title of Paper	QuickSort-e
Publication Status	☐ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted w ork w ritten in manuscript style
Publication Details	The QuickSort-e has been developed on the iOS platform and can be downloaded using Test Flight in readiness for controlled release on the Apple App Store: Foran, A. M., Mathias, J. L., & Bowden, S. C. (2020). The QuickSort-e. iPad compatible version of the QuickSort.

Principal Author

Name of Principal Author (Candidate)	A M Foran		
Contribution to the Paper	Development of specification documents, scoring algorithms and the back-end data-base. Supervision of source code development and implementation of a testing protocol for the QuickSort-e. Testing and trialling the QuickSort-e prior to its use in the studies.		
Overall percentage (%)	90		
Certification:	The QuickSort-e was developed during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary developer and owner of the QuickSort-e.		
Signature		Date	16/08/22

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	J L Mathias		
Contribution to the Paper	Supervision of the specification documents, assistance in trouble-shooting issues arising from electronic test development and involvement in trialling the QuickSort-e.		
Signature		Date	25/10/22

Name of Co-Author	S C Bowden		
Contribution to the Paper	Assistance in trouble-shooting issues arising from electronic test development and involvement in trialling the QuickSort-e.		
Signature		Date	24/10/22

5.4 How to download the QuickSort-e prototype

Content embargoed.

5.5 Overview of the functionality of the QuickSort-e prototype

Content embargoed.

5.6 Future QuickSort-e updates

As indicated, the QuickSort-e outlined above is a prototype that will undergo further revisions and enhancements. More specifically, future revisions will focus on improving the user interface. For example, on the summary screen, the additional black lines will be removed, text will not appear in bold, and the information will be reduced in size so that it fits on the screen (currently the clinician must scroll down to see the administration time on some records). These updates will not alter the scores generated by the QuickSort-e, consequently, the current version is a functioning prototype. Ideally, future versions of the QuickSort-e will also compute LRs to determine how likely or unlikely the older adult is to be cognitive impaired. There are plans to make the updated QuickSort-e available on the Apple App Store and a password will be used to restrict non-authorised users.

5.7 Summary

The iPad compatible version of the QuickSort-e improves on the original paper-and-pencil version of the QuickSort. While its functionality clearly aligns closely with the original version, it removes the need for hard copies of the stimuli and record forms. The main benefit of the QuickSort-e relates to the fact that administration and scoring are automated, which improves its ease of use and standardized administration, and reduces the risk of administrative errors. In addition, the administration procedures are described in the QuickSort-e, which largely replaces the manual and makes it easier for clinicians to be

trained in its use. Dissemination of QuickSort-e scores via email is also efficient and may assist with the continuity of patient care. Lastly, the QuickSort-e database of examinee's performances will be advantageous to clinicians who are interested in auditing their practice or contributing to further research relating to this measure. Currently, the QuickSort-e prototype can be downloaded via TestFlight and used for clinical and research purposes by approved users who have been granted a password.

Chapter 6

Development of a brief screen to detect cognitive impairment in older adults: The QuickSort

6.1 Preamble

The QuickSort was developed in response to a growing demand for cognitive screens that can be used with older adults (Connor, 2021) and limitations identified with existing screens (Falk et al., 2021; Larner, 2016). It was designed to be briefer and use fewer stimuli than existing sorting tests, and to provide an early discontinuation for intact performances. The QuickSort was also designed to be used with a wider range of older adults, including those with severe cognitive impairment, lower English proficiency and expressive language difficulties. An automated iPad-compatible version – the QuickSort-e – was additionally designed to make it easier for clinicians to administer and score, share patient information, and keep records for auditing and research purposes. Thus, the QuickSort and QuickSort-e were specifically created to screen older adults for cognitive impairment.

Study 4 investigated the user-friendliness of the QuickSort, and its inter-rater reliability, before it was administered to community-dwelling older adults and older inpatients. The software for the QuickSort-e was developed in parallel to Study 4, consequently most of the study focused on the original hard-copy version. However, Study 4 established the equivalence of the QuickSort-e to the original version and examined the test-retest reliability of the QuickSort. The study also provided a cognitively-healthy normative sample for the QuickSort in order to assist with the detection of cognitive decline in older adults. Additionally, whether the QuickSort could differentiate between older adults who were and were not impaired on the MMSE, FAB, or both of these screens, was evaluated. The score that optimised the sensitivity and specificity of the QuickSort for detecting impairment on the

MMSE and FAB was used as a cut-score. QuickSort scores that provided limited sensitivity and specificity information when trying to detect impairment on the MMSE and FAB were also identified and grouped into a middle score category. Finally, the QuickSort was customised for specific healthcare settings by considering the local prevalence of older adults who were cognitively impaired, which was combined with the LR for a patient's score in order to determine the probability that he/she may be cognitively impaired. Overall, Study 4 evaluates the clinical utility of the QuickSort and whether it provides a viable alternative to lengthier cognitive screens for detecting cognitive impairment in older adults.

The Journal of the American Geriatrics Society provided permission to reproduce the journal article for Study 4 in this thesis (see Appendix B.1 for the published journal article). The references are in the American Medical Association stye, as required by the journal, rather than APA format. This chapter provides this publication in Word form, with the tables and figures embedded into the text to make it easier for the reader. Supplementary information is in Appendix B.2, and the specific contents are:

Supplementary Table B.2.1	Demographic and test data for the Cognitively-Healthy normative subsample, with additional data showing the distribution of scores
Supplementary Table B.2.2	Results of linear regression analyses examining the influence of demographic variables on the QuickSort Total and Sorting scores in the normative subsample
Supplementary Table B.2.3	Summary demographic and tests scores for the impaired and non-impaired Diagnostic groups, formed using MMSE scores
Supplementary Table B.2.4	Summary demographic and tests scores for the impaired and non-impaired Diagnostic groups, formed using the FAB

Study 4: Development of a brief screen to detect cognitive impairment in older adults: The QuickSort

- Foran, A. M., Mathias, J. L., & Bowden, S. C. (2021). Development of a brief screen to detect cognitive impairment in older adults: The QuickSort. *Journal of the American Geriatrics Society (JAGS)*, 69, 2, 441-449

- Journal Impact Factor: 7.54

- Conference presentations are listed at the start of this thesis.

6.2 Statement of authorship

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Name of Principal Author (Candidate)	A M Foran		
Contribution to the Paper	Study design, ethic applications, recruitment, data collection. Grant applications and supervision of research assistants. Statistical analysis and manuscript preparation and submission.		
Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	16/08/22

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	J L Mathias		
Contribution to the Paper	Supervision of all aspects of study design, ethics applications, recruitment techniques, grant applications, statistical analysis and manuscript preparation.		
Signature		Date	25/10/22

Name of Co-Author	S C Bowden		
Contribution to the Paper	Supervision and contribution to study design and statistical analysis. Supervised and reviewed evidence-based modelling and manuscript review.		
Signature		Date	24/10/22

6.3 Abstract

Background: Sorting tests detect cognitive decline in older adults who have a neurodegenerative disorder, such as Alzheimer's and Parkinson's disease. Although equally effective at detecting impairment as other cognitive screens (e.g., Mini Mental Status Examination; MMSE), sorting tests are not commonly used in this context. This study examines the QuickSort, which is a new very brief sorting test that is designed to screen older adults for cognitive impairment.

Design: Observational cohort study.

Setting: General community and inpatients, Australia.

Participants: Older (≥60 years) community-dwelling adults (*n*=187) and inpatients referred for neuropsychological assessment (*n*=78). A normative subsample (*n*=115), screened for cognitive and psychological disorders, was formed from the community sample.

Measurements: Participants were administered the QuickSort, MMSE, Frontal Assessment Battery (FAB) and Depression Anxiety and Stress Scale-21. The QuickSort requires people to sort 9-stimuli by color, shape and number, and to explain the basis for their correct sorts. Sorting (range: 0-12), Explanation (range: 0-6), and Total (range: 0-18) scores were calculated for the QuickSort.

Results: The Cognitively-Healthy subsample completed the QuickSort within 2-minutes, 50% had errorless performance, and 95% had Total scores ≥10. The likelihood of community-dwelling older adults and inpatients (*n*=260) being impaired on either the MMSE or FAB, or both, increased by a factor of 3.75 for QuickSort Total scores <10 and reduced by a factor of 0.23 for scores ≥10.

Conclusion: The QuickSort provides a quick, reliable and valid alternative to lengthier cognitive screens (e.g., MMSE, FAB) when screening older adults for cognitive impairment. The QuickSort performance of an older adult can be compared to a cognitively-healthy

normative sample and used to estimate the likelihood they will be impaired on either the MMSE or FAB, or both. Clinicians can also use evidence-based modelling to customize the QuickSort for their setting.

6.4 Background

The need to screen older adults for cognitive impairment is growing as the number of people with neurodegenerative disorders increases (e.g. dementia).[1, 2] However, clinicians' time is limited, making efficient cognitive screening imperative.[3] The Mini-Mental Status Examination (MMSE) is the most commonly-used cognitive screen and is often supplemented with the Frontal Assessment Battery (FAB) to detect frontal or 'executive' deficits.[3, 4] The MMSE and FAB each take 10 minutes to administer, with additional time for scoring.[5, 6] Although brief, this may exceed the time available in some settings.

Sorting tests are amongst the most sensitive tests for detecting cognitive impairment,[7, 8] but are rarely used to screen older adults. There are a number of such tests, all requiring respondents to sort stimuli according to colour, shape or number.[9-11] Although commonly assumed to measure 'executive' functioning, sorting tests assess multiple cognitive abilities[12-14] and may, therefore, provide an alternative to the MMSE and FAB.

Of note, a recent meta-analysis found that sorting tests identify cognitive decline caused by neurodegenerative disorders of older age.[15] The ability to switch categories was frequently assessed (Category score) and best detected cognitive decline in dementia, with sensitivity and specificity values both approximately 85%. These figures are comparable to those reported for the MMSE when detecting dementia in memory clinics (80% & 81%, respectively).[13] Verbal explanations about the rule underpinning a correct sort (Explanation or Description scores) were less common, but had the greatest sensitivity for detecting the most common neurodegenerative disorders of older age, namely Alzheimer's and Parkinsonian disorders.[15]

Although promising, there are multiple limitations to using existing sorting tests to screen older adults for cognitive decline, including their complexity (up to 64 stimuli) and administration time (up to 30 minutes), an inability to discontinue early when performance is intact, complicated scoring procedures, and floor effects when scoring.[8, 11, 17] The QuickSort was developed to retain the best features of existing tests, while overcoming some of the aforementioned limitations. Specifically, the QuickSort has nine stimuli, an early discontinuation rule, a one-page record-form (reducing administration & scoring time), and a lower floor. Erroneous sorts are also explained (enabling learning) and the test can be scored even if a person is unable to complete the test or has expressive language problems.

This study was designed to evaluate the QuickSort when screening older adults for cognitive impairment by: (1) examining its user-friendliness, and inter-rater and test-retest reliability, (2) developing normative data so that the performance of older adults can be compared to their cognitively-healthy peers, and (3) evaluating its discriminant validity by assessing its ability to detect impairment on lengthier cognitive screens (MMSE, FAB) in community and clinical samples. In combination, this study will determine whether the QuickSort provides a quick, reliable and valid alternative to lengthier cognitive screens that are often used with older adults.

6.5 Method

6.5.1 Participants

Two samples of older adults (≥60 years) participated: (1) community-dwelling visitors, outpatients and volunteers at the Royal Adelaide Hospital (RAH), and (2) RAH inpatients who were consecutively referred for neuropsychological assessment (mostly relating to mental capacity), hereafter referred to as the Community (*n*=187) and Inpatient (*n*=78) samples, respectively. Participants were excluded if they (Community) or their medical team

(Inpatients) reported they were acutely unwell or non-English speaking, or had red-green color blindness.

A cognitively-healthy normative subsample (hereafter named the Cognitively-Healthy subsample, *n*=115) was formed from the Community sample by excluding 72 participants who (1) were unable to complete the cognitive tests, (2) had a history indicating significant or multiple concussions, a diagnosed head injury, or an intellectual or learning disability, (3) were impaired on the MMSE (<24)[18] or FAB (<11),[6] or (4) were psychologically distressed (Depression, Anxiety and Stress Scale-21 [DASS-21] scores: depression >20, anxiety >14, or stress >25) (see Figure 6.1).[19] The high exclusion rate resulted from recruiting through a large publicly-funded tertiary hospital that services a broad socio-demographic area. A similar exclusion rate has been reported for the MMSE.[20]

6.5.2 Measures

Background demographic (age, gender, education, nationality) and medical information (visual & hearing disabilities, color blindness, conditions affecting cognition, e.g., head trauma, epilepsy) was recorded for each participant. Cognitive functioning was assessed using the MMSE (scored: 0-30), FAB (scored: 0-18) and Quicksort (see below), with higher scores indicating better cognition. Psychological distress was assessed using the DASS-21, with lower scores indicative of less symptomatology.[21]

The QuickSort uses nine cards, which are sorted according to three categories (colour, shape, number) over a maximum of 6 trials. The QuickSort Manual, Stimuli and Record Form are provided in Appendix B (JAGS on-line Supplementary Materials)[ii]. An early discontinuation rule reduces administration time when cognition is intact. Three scores are calculated: (1) a 'Sorting' score (named the Category score in other tests), which

[ii] The QuickSort Manual, Stimuli and Record Form are in Chapter 4, section 4.3.

aggregates the number of successful sorts, errors (repetition, set-loss, grouping, completion errors) and prompts during a maximum of six trials (range: 0-12); (2) an 'Explanation' score, which assesses an examinee's ability to explain the basis for their correct sorts (range:0-6); and (3) a 'Total' score, which sums the Sorting and Explanation scores (range: 0-18). Sorting scores are used when a person has problems with verbal expression, and both Sorting and Total scores can be calculated when someone fails to complete the QuickSort (incomplete trials scored zero). Repetition errors (repeated sorts using the same rule) and concrete explanations are also recorded for clinical purposes, but are not examined here.

An electronic version of the QuickSort (QuickSort-e), which generates the same scores as the original version, was developed to reduce clinician's training and scoring time, and to facilitate score-interpretation using the methods recommended by evidence-based medicine (EBM). Information regarding the participants' prior familiarity with, and comfort using, an iPad was also recorded.

6.5.3 Procedure

The Human Research and Ethics Committee of the RAH, South Australia, approved this project. Written informed consent was obtained according to the Declaration of Helsinki.

The QuickSort underwent initial focus group development using a convenience sample of nine clinical neuropsychologists, who provided subjective evaluations of its user-friendliness (administration, scoring & interpretation) prior to its use here. Three clinical psychologists additionally viewed and scored videos of 15 QuickSort performances (simulated impaired and actual older adults) to assess inter-rater reliability.

Participants were recruited between October 2013 and December 2017. A neuropsychologist or research assistant (post-graduate) conducted individual assessments in an office (Community sample) or bedside (Inpatients). The QuickSort was administered to (1) the Community sample, prior to the MMSE and FAB (same session), and (2) Inpatients, prior to their neuropsychological consultation, in order to blind assessors to the person's

cognitive status. Forty-six Inpatients were re-administered the QuickSort while in hospital to assess test-retest reliability.

The QuickSort-e was piloted in a subset of consecutively recruited community-dwelling participants (*n*=29) during the final stages of the study.

6.5.4 Data-analysis

Data was analysed using the Statistical Package for the Social Sciences[22] using $p<.05$ and excluding missing data list-wise. Summary demographic, cognitive and psychological scores (means, SDs, n, %) were calculated for the Community and Inpatient samples, and the Cognitively-Healthy subsample.

A focus group of clinicians examined the user-friendliness and clinical acceptability of the QuickSort. Intraclass correlations (ICC), measuring absolute agreement (single measures), were used to asses inter-rater reliability (*n*=3 raters) and test-retest reliability (*n*=46 Inpatients), with .8 considered acceptable and .9 excellent.[23] Practice effects were indicated by differences between ICCs measuring consistency and absolute agreement.[23]

Normative data for the QuickSort Total and Sorting scores were created using the Cognitively-Healthy subsample. Cumulative frequencies (base-rates) were calculated for the Total and Sorting scores, enabling the scores of older adults to be compared to their cognitively-healthy peers. Linear regressions determined whether this normative data needed to be stratified by age, education or gender. Norms were stratified if any variable accounted for >10% of the variance (small effect).[24]

Next, the QuickSort discriminant validity was examined in terms of its ability to detect impairment on: (1) the MMSE, (2) the FAB, and (3) either the MMSE or FAB, or both. The Community and Inpatient samples were combined for this purpose, after which participants were classified into one of two Diagnostic groups: *cognitively impaired* on (1) the MMSE<24, (2) the FAB<11, and (3) either the MMSE or FAB, or both, and *non-impaired* (MMSE≥25, FAB≥12) (See Figure 6.1 for details).

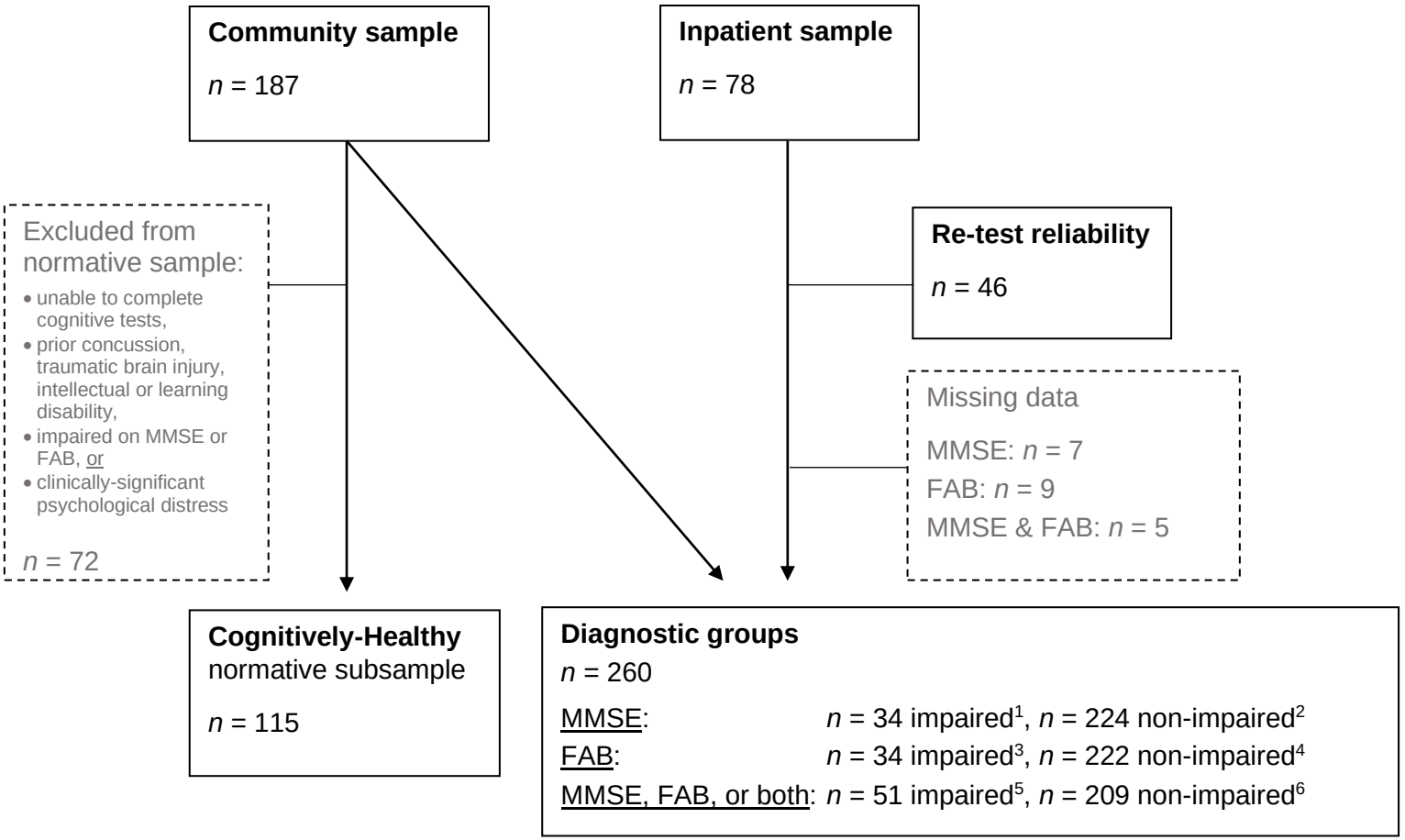

Figure 6.1: Participant flow chart

t-tests assessed whether the Diagnostic groups (impaired & non-impaired) were demographically comparable (age & education can independently affect cognition) and whether their QuickSort scores differed (Sorting, Explanation & Total scores, Repetition errors, Concrete responses). ANCOVAs further investigated whether demographic differences between the Diagnostic groups significantly contributed to differences in their QuickSort performance (Sorting & Total scores).

A logistic regression identified the QuickSort Total cut-score that correctly classified the largest number of participants into the Diagnostic groups. A power analysis indicated that a minimum sample size of 42 was required to detect a large difference (Cohen's *d*=.80) in the QuickSort scores with 95% power and alpha=.05.[24] In addition, the most clinically-useful QuickSort cut-score was obtained by tallying the numbers of people who scored above and below each score and who were impaired and non-impaired on (1) the MMSE, (2) the FAB, and (3) either the MMSE or FAB, or both. The CATmaker[25] was used to calculate sensitivity and specificity, likelihood ratios (LRs) and 95% confidence intervals (CIs). The Total cut-scores that were most clinically-useful for ruling-in (sensitivity important) or ruling-out (specificity important) cognitive impairment were identified. LRs >1 indicate that QuickSort scores were associated with impairment on the MMSE or FAB, with LRs <1 indicating an absence of impairment on these screens.[26] Clinically, scores with LRs >3 or <0.3 are considered most useful because they substantially change the likelihood of the person being impaired or non-impaired, respectively.[27]

ICCs, measuring absolute agreement (single measures), were used to assess convergent validity between the original QuickSort and the QuickSort-e.[23]

6.6 Results

6.6.1 Community and inpatient samples summary information

Table 6.1 provides summary demographic and test information (MMSE, FAB, QuickSort, DASS-21) for the Community (*n*=187) and Inpatient (*n*=78) samples, from which the Cognitively-Healthy normative subsample and Diagnostic groups were formed. Both samples had a mean age in their seventies and had completed approximately four years of high school. There was a slightly higher proportion of males and most participants were born in Australia. On average, the Inpatient group had poorer cognition (MMSE, FAB, QuickSort), greater psychological distress (DASS-21), and took longer to complete the QuickSort than the Community sample

6.6.2 QuickSort clinical acceptability, inter-rater reliability & test-retest reliability

All clinicians in the focus group indicated that the QuickSort was user-friendly. The QuickSort Sorting, Explanation and Total scores (*n*=15 cases) provided by three independent raters were also in agreement (ICC=1.00), indicating that the scoring procedures are clear and have very high inter-rater reliability.

Test-retest reliability was assessed in 46 Inpatients who were readministered the QuickSort after an average 4.6 days (*SD*=3.0). The Sorting (ICC=.75), Explanation (ICC=.79) and Total (ICC=.81) scores all showed acceptable absolute agreement (stability) over time. These coefficients were similar to the ICCs for consistency in the Sorting, Explanation and Total scores, (ICC= .76, .79, .81 respectively), indicating there were minimal practice effects, even after a short interval.

Table 6.1: Summary demographic and test data for the Community and Inpatient samples, and Cognitively-Healthy normative subsample

	Community sample (*n* = 187)				Inpatient sample (*n* = 78)				Cognitively-healthy normative subsample (*n* = 115)			
	n	*%*	*M*	*SD*	*n*	*%*	*M*	*SD*	*n*	*%*	*M*	*SD*
Age	187		71.3	7.48	78		74.6	8.76	115		71.2	7.70
Education (years)	187		11.5	2.96	72		11.1	3.88	115		11.7	2.84
Gender												
Male	98	52%			47	60%			53	46%		
Female	89	48%			31	40%			62	54%		
Nationality												
Australian[1]	121	65%			54	69%			72	63%		
European	57	30%			20	26%			36	31%		
Asian	3	2%			0	0%			3	3%		
Other	6	3%			2	3%			4	4%		
MMSE[2]												
Total score (range: 0-30)	187		28.2	1.68	71		23.7	3.87	115		28.5	1.29
Impaired: MMSE <24	3	2%			31	40%			0	0%		
FAB[3]												
Total score (range: 0-18)	187		15.1	2.59	69		11.8	3.09	115		15.6	1.99
Impaired: FAB <11	11	6%			23	29%			0	0%		
MMSE and FAB												
Impaired: either or both screens	12[6]	6%			39	50%			0	0%		
QuickSort												
Sorting score (range: 0-18)	187		9.4	3.53	78		4.2	3.83	115		10.4	2.66
Explanation score (range: 0-9)	187		4.9	1.59	78		2.6	2.22	115		5.4	1.14
Total score (range: 0-18)	187		14.3	4.80	78		6.8	5.88	115		15.8	3.37
Total score <10	34	18%			58	74%			6	5%		
Administration time[4]	26		2_{min} 8_{s}	1_{min} 17_{s}	17		4_{min} 92_{s}	2_{min} 37_{s}	19		1_{min} 43_{s}	51_{s}
Repetition errors (range: 0-5)	187		0.5	0.96	78		1.7	1.51	115		0.3	0.53
Concrete responses (range: 0-3)	187		0.4	0.68	78		0.2	0.50	115		0.4	0.74
DASS-21[5]												
Depression (range: 0-21)	187		2.3	3.36	4		5.5	2.05	115		2.3	3.35
Anxiety (range: 0-21)	187		2.6	2.87	4		6.0	5.60	115		2.6	2.83
Stress (range: 0-21)	187		4.3	3.97	4		3.5	3.70	115		4.3	3.88

[1]*n*=1 person identified as Indigenous in each of the Community and Inpatient samples, [2]MMSE = Mini Mental Status Examination, [3]FAB = Frontal Assessment Battery, [4]min = minutes, s = seconds [5]DASS-21 Depression, Anxiety and Stress Scale-2

6.6.3 QuickSort normative data

Norms for the QuickSort were created from the Cognitively-Healthy subsample (*n*=115). As seen in Table 6.1, this subsample closely resembled the Community sample from which it was drawn, but had slightly fewer males. On average, the Cognitively-Healthy participants completed the QuickSort in under 2-minutes. Not unexpectedly, the QuickSort scores for this subsample were skewed (see Supplementary Table B.2.1 for interquartiles), with the average Total score approaching 16 (max=18). Of note, 54% (*n*=62) achieved the maximum Total score and 95% (*n*=109) scored ≥10. The base-rates for the Total and Sorting score are provided in Table 6.2.

Linear regressions performed on both the QuickSort Total and Sorting scores of the Cognitively-Healthy subsample revealed that age (r^2=3.4% & 3.2%) and education (r^2=8.8% & 8.4%), but not gender (r^2<0.1% & 0.1%), had a significant but very small (<10%) impact on performance. Thus, the test norms did not need to be demographically-stratified (see Supplementary Table B.2 for analyses).

6.6.4 QuickSort validity: Detecting impairment & non-impairment on the MMSE & FAB

As indicated above, Diagnostic groups (impaired & non-impaired) were formed from the Community and Inpatient data (total *n*=260) to assess the QuickSort ability to identify those impaired on the: (1) MMSE<24, (2) FAB<11, and (3) either the MMSE<24 or FAB<11, or both.

When the Diagnostic groups were compared, the impaired groups had lower QuickSort scores (Sorting, Explanation & Total scores, Repetition errors, but not Concrete responses; see Supplementary Table B.2.3-5), and took longer to complete it (excluding those only impaired on the FAB).

Table 6.2: Cumulative frequency (base-rates) for the QuickSort Total & Sorting scores in the Cognitively-Healthy normative subsample (n = 115)

Total	QuickSort cut-score	Cumulative Frequency[1]
	<3	0
	<4	1.7
	<5	1.7
	<6	2.6
	<7	4.3
	<8	4.3
	<9	5.2
	<10	5.2
	<11	7.0
	<12	9.6
	<13	12.2
	<14	21.7
	<15	24.3
	<16	36.5
	<17	37.4
	<18	46.1
	18	53.9
Sorting		
	<1	0
	<2	0.9
	<3	2.6
	<4	4.3
	<5	4.3
	<6	7.0
	<7	8.7
	<8	16.5
	<9	16.5
	<10	32.2
	<11	32.2
	<12	32.2
	12	67.8

[1]percentage of the normative sample with scores below the cut score

Although significantly older and less educated than the non-impaired group, ANCOVAs revealed that the QuickSort scores of the impaired groups remained significantly lower after controlling for these demographic differences (see Supplementary Table B.2.6). Thus, the QuickSort showed good discriminant validity.

A logistic regression identified the QuickSort Total cut-score that optimised the classification of participants as cognitively impaired versus non-impaired on either the MMSE or FAB, or both (the only analysis that was sufficiently powered). A cut-score <4 correctly classified 84% of participants, with 43% sensitivity and 94% specificity. Scores <4 increased the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 6.95 (95%CI: 3.75–8.41), but scores ≥4 only reduced the likelihood of impairment by a factor of 0.61 (95%CI: 0.48–0.77). The high specificity resulted from scores <4 being infrequent in the Cognitively-Healthy normative group (1.7%, Table 6.2).

There may be situations where detecting cognitive impairment (sensitivity) takes precedence over ruling it out (specificity), or vice versa. Sensitivity, specificity and LR (& 95% CIs) statistics are therefore provided for every QuickSort Total score when predicting impairment on the MMSE, FAB, and either the MMSE or FAB, or both (see Table 6.3). These data were also calculated for Sorting scores (see Supplementary Table B.2.7), but should only be used when a person has problems with verbal expression because the Total score had larger positive and smaller negative LRs.

In clinical settings where ruling-in (sensitivity) and ruling-out (specificity) cognitive impairment are both important, a cut-score <10 may be preferable because sensitivity increases to 78%, with 82% specificity (see Table 6.3). LRs indicate that scores <10 increase the likelihood that a person is impaired by a factor of 3.18 (95%CI: 2.43–4.17), 3.63 (95%CI: 2.74–4.72), 3.75 (95%CI: 2.81–4.98) on the MMSE, FAB, and either the MMSE or FAB, or both, respectively. Alternatively, scores of ≥10 reduce the likelihood that a person is impaired by a factor of 0.24 (95%CI: 0.11–0.49), 0.16 (95%CI: 0.06–0.39) and 0.23 (95%CI: 0.13–0.41) on the MMSE, FAB, and either the MMSE or FAB, or both, respectively.

Table 6.3: Diagnostic data for QuickSort Total scores, when predicting impairment on the MMSE (left columns), FAB (centre columns) and either the MMSE or FAB, or both (right columns)

QuickSort Total cut-score	Impaired MMSE (<24) (*n* = 258)				Impaired FAB (<11) (*n* = 256)				Impaired on either the MMSE or FAB, or both (*n* = 260)			
	Se	Sp	LR+	LR-	Se	Sp	LR+	LR-	Se	Sp	LR+	LR-
<1	0.06	0.98	3.29 (0.63 – 17.30)	0.96 (0.88 – 1.04)	0.15	0.99	16.32 (3.30 – 80.82)	0.86 (0.75 – 0.99)	0.10	0.99	9.80 (2.05 – 51.31)	0.91 (0.83 – 1.00)
<2	0.15	0.97	5.49 (1.77 – 17.01)	0.88 (0.76 – 1.01)	0.21	0.97	7.62 (2.72 – 21.32)	0.82 (0.69 – 0.97)	0.18	0.98	9.26 (2.96 – 28.75)	0.84 (0.74 – 0.96)
<3	0.38	0.95	7.79 (3.80 – 15.95)	0.65 (0.50 – 0.85	0.32	0.96	8.98 (3.89 – 20.72)	0.70 (0.56 – 0.89)	0.35	0.96	9.29 (4.25 – 20.01)	0.67 (0.55 – 0.83)
<4	0.44	0.92	5.49 (3.07 – 9.83)	0.61 (0.45 – 0.82)	0.44	0.92	5.44 (3.04 – 9.74)	0.61 (0.45 – 0.82)	0.43	0.94	6.95 (3.75 – 8.41)	0.61 (0.48 – 0.77)
<5	0.53	0.89	4.14 (2.92 – 7.72)	0.53 (0.37 – 0.76)	0.50	0.88	4.27 (2.61– 6.99)	0.57 (0.40 – 0.80)	0.51	0.91	5.60 (3.38 – 9.30)	0.54 (0.41 – 0.72)
<6	0.62	0.85	4.19 (2.78 – 6.33)	0.45 (0.29 – 0.69)	0.56	0.86	4.00 (2.57 – 6.23)	0.51 (0.35 – 0.75)	0.63	0.89	5.45 (3.55 – 8.41)	0.42 (0.29 – 0.61)
<7	0.62	0.81	3.22 (2.21 – 4.69)	0.47 (0.31 – 0.73)	0.74	0.82	4.19 (2.95 – 5.93)	0.32 (0.18 – 0.56)	0.65	0.84	4.10 (2.82 – 5.95)	0.42 (0.29 – 0.61)
<8	0.76	0.79	3.57 (2.61 – 4.88)	0.30 (0.16 – 0.55)	0.76	0.80	3.77 (2.74 – 5.20)	0.30 (0.16 – 0.54)	0.77	0.82	4.32 (3.11 – 6.01)	0.29 (0.17 – 0.47)
<9	0.82	0.74	3.18 (2.43 – 4.17)	0.24 (0.11 – 0.49)	0.88	0.76	3.63 (3.63 – 4.72)	0.16 (0.06 – 0.39)	0.82	0.78	3.75 (2.81 – 4.98)	0.23 (0.13 – 0.41)
<10	0.82	0.74	3.18 (2.43 – 4.17)	0.24 (0.11 – 0.49)	0.88	0.76	3.63 (2.74 – 4.72)	0.16 (0.06 – 0.39)	0.82	0.78	3.75 (2.81 – 4.98)	0.23 (0.13 – 0.41)
<11	0.82	0.73	3.02 (2.32 – 3.94)	0.24 (0.12 – 0.50)	0.88	0.74	3.44 (2.66 – 4.40)	0.16 (0.06 – 0.40)	0.82	0.77	3.52 (2.67 – 4.63)	0.23 (0.13 – 0.42)
<12	0.82	0.70	2.75 (2.14 – 3.55)	0.25 (0.12 – 0.52)	0.91	0.72	3.26 (2.53 – 4.13)	0.12 (0.04 – 0.36)	0.84	0.74	3.27 (2.52 – 4.23)	0.21 (0.11 – 0.40)
<13	0.82	0.68	2.56 (2.00 – 3.28)	0.26 (0.13 – 0.54)	0.91	0.70	3.02 (2.41 – 3.79)	0.13 (0.04 – 0.37)	0.84	0.72	1.65 (1.36 – 2.09)	0.31 (0.16 – 0.61)
<14	0.82	0.61	2.12 (1.69 – 2.66)	0.24 (0.14 – 0.60)	0.91	0.63	2.47 (2.02 – 3.02)	0.14 (0.05 – 0.41)	0.84	0.64	2.83 (2.83 – 0.24)	0.24 (0.13 – 0.46)
<15	0.85	0.57	1.97 (1.60 – 2.42)	0.26 (0.11 – 0.59)	0.91	0.58	2.18 (1.81 – 2.62)	0.15 (0.05 – 0.45)	0.86	0.60	2.15 (1.76 – 2.62)	0.23 (0.11 – 0.46)
<16	0.88	0.48	1.70 (1.43 – 2.03)	0.24 (0.10 – 0.62)	0.94	0.50	1.87 (1.60 – 2.18)	0.12 (0.03 – 0.46)	0.90	0.51	1.85 (1.57 – 2.18)	0.19 (0.08 – 0.45)
<17	0.88	0.46	1.65 (1.39 – 1.96)	0.25 (0.10 – 0.64)	0.97	0.49	1.90 (1.65 – 2.19)	0.06 (0.01 – 0.42)	0.92	0.50	1.84 (1.57 – 2.15)	0.16 (0.06 – 0.41)
<18	0.97	0.40	1.61 (1.43 – 1.82)	0.07 (0.01 – 0.51)	0.97	0.40	1.62 (1.43 – 0.51)	0.07 (0.01 – 0.51)	0.98	0.43	1.71 (1.51 – 1.93)	0.05 (0.01 – 0.32)

MMSE = Mini Mental Status Examination; FAB = Frontal Assessment Battery; Se = sensitivity; Sp = specificity; LR+ = positive likelihood ratio (& 95% Confidence intervals), LR- = negative likelihood ratio (& 95% Confidence Intervals); LR are calculated from raw frequencies as reported from the CATmaker

Therefore, a cut-score of <10 may prove more useful because it can both rule-in *and* rule-out impairment on lengthier cognitive screens.

As with most tests, there is greater certainty surrounding very high or low scores. For example, Total scores <2 increase the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 9.26 (95%CI: 2.96–28.75) and Total scores ≥17 reduce the likelihood of impairment by a factor of 0.16 (95%CI: 0.06–0.41). Thus, the most informative way to interpret any QuickSort score is to use the associated LR.

According to EBM, the local prevalence of impairment (pre-test probability, which can be estimated from published research or a clinical audit) should be taken into consideration when estimating a patient's probability of impairment on the MMSE or FAB.[28, 29] As seen in Figure 6.2, the likelihood of impairment on either the MMSE or FAB, or both, can be calculated for two patients who score 5 on the QuickSort (see <6 cut-score LR+=5.45, Table 6.3, right panel), but are seen in different clinical settings: one with a pre-test probability of impairment of 20% (solid line) and the other with a 50% pre-test probability (dotted line). Lines from these two different pre-test probabilities (left Y-axis) through the LR+ of 5.45 (centre Y-axis), yield post-test probabilities (right Y-axis) of 58% and 85%, respectively.

6.6.5 QuickSort-e preliminary findings

Twenty-nine consecutive community-dwelling participants were additionally administered the QuickSort-e. Everyone reported being very comfortable using the iPad, despite 45% having not previously used an iPad. The QuickSort-e took slightly longer to administer than the original version (M = 3.08, SD = 1.84), but this is offset by automatic scoring. The two versions of the QuickSort had satisfactory to good convergent validity (Sorting ICC=.72, Explanation ICC=.86, Total ICC=.84).

Nomogram showing the post-test probability of impairment on the MMSE or FAB, or both, for a person with a QuickSort Total score of 5 and LR+ = 5.54 (see Table 6.3).

Example 1 (yellow line) shows a clinical setting where the pre-test probability (left Y-axis) is estimated to be 20%, resulting in an estimated post-test probability of approximately 58% (right Y-axis).

Example 2 (red line) shows a situation where the pre-test probability is estimated to be 50% resulting in a post-test probability of approximately 85%.

Adapted from Fagan (1975) Nomogram for Bayes's Theorem

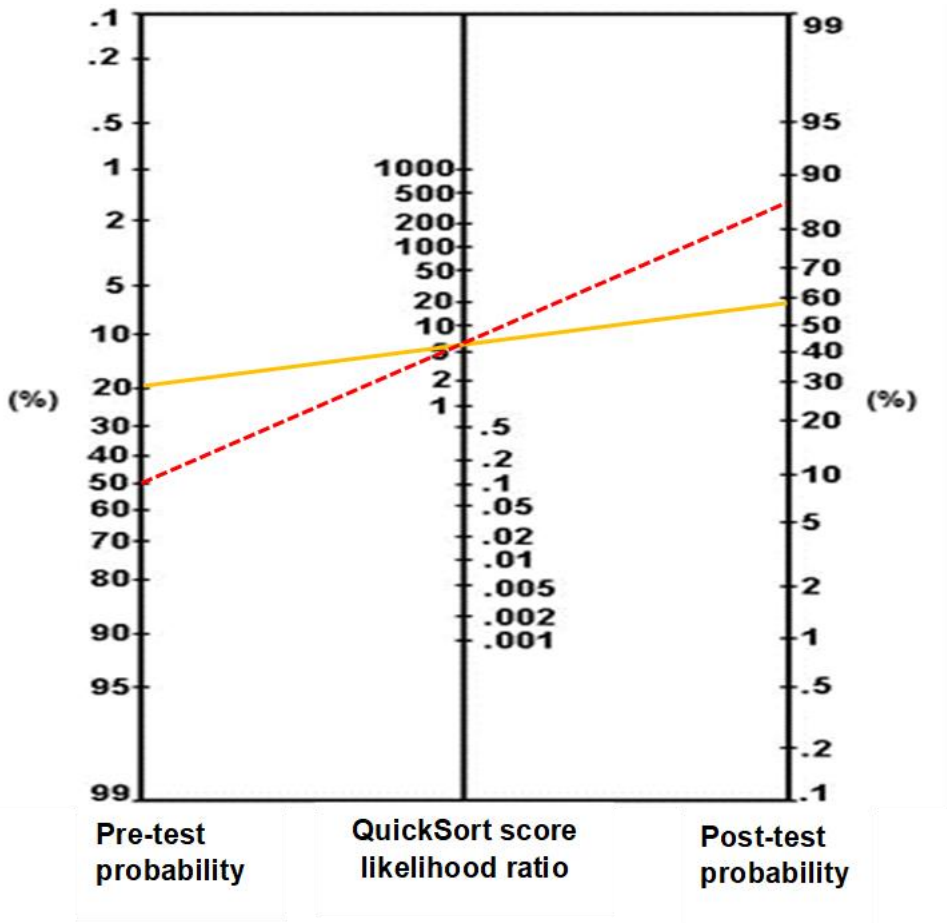

Figure 6.2: Nomogram showing the post-test probability of impairment on the MMSE or FAB, or both

6.7 Discussion

The QuickSort is a brief new cognitive screen that is designed to identify cognitive impairment in clinical settings where resources are very limited. The

QuickSort assesses sorting ability, which deteriorates as a consequence of multiple neurodegenerative disorders,[15] and seeks to improve on existing sorting tests. Specifically, the QuickSort is quicker to administer and score, simpler for older adults, provides a larger range of scores, and can be used even when a person is unable to complete the test or has expressive language problems. This study examined whether the QuickSort provides a fast, reliable and valid screen for older adults that can be used as an alternative to two of the most common, but lengthier, cognitive screens: the MMSE and FAB.

Although simple from a test-taker's perspective, the QuickSort requires clinicians to follow detailed instructions, including specific prompts for different types of errors and early discontinuation when cognition is intact. Despite these complexities, clinicians reported that the QuickSort was user-friendly; a finding that was supported by its good inter-rater reliability. Test-retest data additionally indicated that the QuickSort provides stable scores in an inpatient setting and is not impacted by practice effects. Preliminary findings for the QuickSort-e suggest that it is also very brief, even when participants were unfamiliar with an iPad, and it generates scores that are comparable to those of the original version.

The normative data for the QuickSort was based on a subgroup of cognitively- and psychologically-healthy older adults, most of whom completed the task within two minutes, with over half achieving a perfect score. Cumulative frequencies for the Sorting and Total scores enable clinicians to evaluate whether a person's performance is common or unusual, relative to their cognitively-healthy peers. Age, education and gender did not significantly affect QuickSort performance, eliminating the need for demographically-adjusted norms.

Discriminant validity was evaluated by comparing people who were impaired with those who were not impaired on the MMSE or FAB. The impaired group had significantly lower QuickSort scores than the non-impaired group, a finding that was not attributable to

the former being older and less educated. The QuickSort Total cut-score that correctly classified the largest number of people as impaired on either the MMSE or FAB, or both, was <4, however sensitivity (43%) was sacrificed for specificity (94%). A cut-score <10 may therefore be preferred in clinical settings because it can be used to rule-in (82% sensitivity) and rule-out (78% specificity) impairment (see Table 6.3).

Although useful, single cut-scores fail to utilize the information provided by low and high scores.[26] LRs help to address these problems. For example, QuickSort scores <2 were not seen in cognitively-healthy older adults and increase the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 9.26 (95% CI: 2.96 – 28.75). Conversely, QuickSort scores ≥17, which were common in cognitively-healthy adults (63%), reduce the likelihood of impairment by a factor of 0.16.

The use of a nomogram or on-line calculator[31] to estimate a person's post-test probability of impairment – based on their QuickSort score and the prevalence of impairment in that clinical setting – further enhances its clinical utility. For example, a patient who gets a QuickSort score of five in a clinical setting where approximately 50% of patients are cognitively impaired has an 85% likelihood that they will be impaired on lengthier cognitive screens, suggesting they need to undergo further investigations into the presence of cognitive decline.

A limitation of this study relates to the sample sizes. Test-retest reliability was assessed using a small convenience sample of inpatients and now needs to be evaluated in a community-dwelling sample. Administration time was only recorded for a subset of participants and needs to be assessed further. Although the QuickSort normative sample is larger than those originally reported for the MMSE and FAB,[32, 33] larger normative datasets, stratified by age and education, are now available for these measures,[20, 34-37] suggesting the QuickSort norms should be expanded. Lastly, cumulative frequencies above and below cut-scores were reported because the small samples precluded multiple level LRs and interpretation of stand-alone scores.

Future research should examine patients who have more overt cognitive impairments, such as adults with dementia. The QuickSort-e also needs to be developed further by integrating decision-making algorithms that instantaneously provide post-test probabilities in response to clinical questions that are relevant to specific settings (e.g., the likelihood the patient is cognitively impaired, has a neurodegenerative disorder, or will be readmitted to hospital). Lastly the QuickSort-e may be suitable for telehealth assessments, which are in much greater demand as a result of COVID-19, but additional reliability and validity studies are needed to support this type of use.

Overall, the QuickSort assesses the cognitive decline associated with various neurodegenerative disorders of older age.[15] It provides a quick, easy, reliable and valid cognitive screen that is suitable for use in busy clinical settings. Importantly, the QuickSort provides a viable alternative to lengthier screens, such as the MMSE and FAB. Clinicians are encouraged to customize it to their clinical setting, using post-test calculators, to improve the accuracy and efficiency of their cognitive screening.

6.8 Acknowledgements

6.8.1 Conflict of interest

The authors have no conflicts of interest to disclose.

6.8.2 Author contributions

A M Foran designed and created the QuickSort, and was responsible for study inception and execution, data collection and coding, data analysis and reporting, and final manuscript preparation. J L Mathias supervised all aspects of this research, particularly the study design, data analysis, and preparation of both the QuickSort manual and study

manuscript. S C Bowden also contributed throughout all stages of the study, and was particularly involved in providing statistical advice and oversight.

6.8.3 Sponsors role

The research was partially funded by a Royal Adelaide Hospital Allied Health Grant, which assisted with participant recruitment and data collection. The first author was supported by an Australian Government Research Training Stipend.

6.9 Study 4 Reference List

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Chapter 7

Use of the QuickSort with older adults whose lifestyle decision-making capacity is being questioned

7.1 Preamble

The previous study found that the QuickSort is quick to administer, user-friendly, has good inter-rater and test-retest reliability, and can be used in an iPad-compatible format (QuickSort-e). It also found that the QuickSort could detect cognitive decline (by comparing an older adult's performance to their cognitively-healthy peers) and can predict cognitive impairment on lengthier screens (MMSE and FAB). This supports the use of the QuickSort for screening older adults for cognitive impairment. However, in addition to detecting cognitive impairment, screens are often also used in complex clinical scenarios, such as the provision of information regarding older adults' capacity to make independent and informed life-style decisions; hereafter referred to as lifestyle decision-making capacity (LS-DMC).

LS-DMC assessments are becoming more common due to the increasing prevalence of neurodegenerative disorders and associated cognitive impairment (Moye et al., 2013; Pennington et al., 2018; Shibu et al., 2020). Comprehensive assessments are often required to identify older adults who are lacking LS-DMC, but these can be expensive, time-consuming and require expertise that may not be available in some healthcare settings (Barry & Docherty, 2018; Demakis, 2012). Consequently, the older adults who require these assessments often have more complex and longer hospital admissions (Chen et al., 2016; Miller et al., 1999; Torke et al., 2014), which increases their risk of hospital-acquired infections and death (Bai et al., 2019). Cognitive screens, along with information from initial interviews, are frequently used to identify inpatients who need LS-DMC assessments early in their hospital admission (Kim et al., 2002; Shibu et al., 2020). However, whether cognitive

screens, such as the QuickSort, can help to differentiate between those lacking and not-lacking LS-DMC has not been investigated.

The following study (Study 5) examined inpatients who were consecutively referred for a neuropsychological LS-DMC assessment and examined information that was available at their initial clinical interviews, including their cognitive (QuickSort, MMSE and FAB), demographic, medical and personal information (e.g., living supports). The inpatients that did/did-not require a legal hearing to determine their LS-DMC were compared because this may be of interest to clinicians involved in these legal proceedings. The primary analysis in this study involved a comparison between inpatients who the medical and neuropsychological teams deemed to lack LS-DMC and those who did not-lack LS-DMC. The score that optimised the sensitivity and specificity of the QuickSort for differentiating between inpatients who lacked and did not-lack LS-DMC was used as a cut-score. The QuickSort scores that had limited sensitivity and specificity for differentiating between these two groups of inpatients were also identified and grouped into a middle score category. Lastly, the QuickSort was customised for specific healthcare settings by considering the local prevalence of inpatients who lacked LS-DMC, which was combined with the LR for a patient's score in order to determine the probability that he/she may be lacking LS-DMC. The iPad compatible version of the QuickSort (the QuickSort-e) was not used in this study because the software was still under development. Overall, Study 5 applied the QuickSort to the complex clinical scenario of identifying older inpatients' who may be at risk of lacking LS-DMC using information that was available at the initial interview.

The Journal of International Neuropsychology Society provided permission to reproduce the journal article for Study 5 in this thesis (see Appendix C.1 for the published journal article). This chapter provides this publication in Word form, with the tables and figures embedded into the text to make it easier for the reader. The references for this article are at the end of this chapter and appear in the APA format required by the journal.

Supplementary information is in Appendix C.2, and the specific contents are:

Supplementary Table C.2.1	Total score categories for the MMSE when predicting inpatients who *lacked*/did *not-lack* lifestyle decision-making capacity
Supplementary Table C.2.2	The MMSE Total scores within the QuickSort Total score categories that inform LS-DMC

Study 5: Use of the QuickSort with older adults whose lifestyle decision-making capacity is being questioned

- Foran, A. M., Mathias, J. L., & Bowden, S. C. (2022). Use of the QuickSort with older adults whose lifestyle decision-making capacity is being questioned. *Journal of the International Neuropsychology Society*, 1-12. DOI:10.1017/S1355617722000479

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7.2 Statement of authorship

Statement of Authorship

Title of Paper	Screening older-adults for their capacity to make lifestyle decisions using a brief new test: the QuickSort
Publication Status	☐ Published ☑ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	**Foran, A. M., Mathias, J. L., & Bowden, S. C. (2021). Use of the QuickSort with older adults who have questionable lifestyle decision-making capacity.** *Journal of the International Neuropsychology Society, accepted for publication* **IF: 3.11**

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Name of Principal Author (Candidate)	A M Foran		
Contribution to the Paper	Study design, ethic applications, recruitment, data collection. Grant applications and supervision of research assistants. Statistical analysis and manuscript preparation and submission.		
Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	16/08/22

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	J L Mathias		
Contribution to the Paper	Supervision of all aspects of study design, ethics applications, recruitment techniques, grant applications, statistical analysis and manuscript preparation.		
Signature		Date	25/10/22

Name of Co-Author	S C Bowden		
Contribution to the Paper	Supervision and contribution to study design and statistical analysis. Supervised and EBM modelling and reviewed manuscript.		
Signature		Date	24/10/22

7.3 Abstract

Objective: Cognitive impairment affects older adults' capacity to live independently and make lifestyle decisions (lifestyle decision-making capacity; LS-DMC). Cognitive screens and clinical interviews are often used to assess people's need for living-supports prior to conducting comprehensive LS-DMC assessments in busy clinical settings. This study investigated whether the QuickSort – a brief new cognitive screen – provides efficient and accurate information regarding patients' LS-DMC when initially interviewed.

Method: This is an observational and diagnostic accuracy study of consecutive older adult inpatients referred for neuropsychological assessment of LS-DMC (*n*=124). The resources required by inpatients with questionable LS-DMC were quantified (length of hospital stay, living-supports). QuickSort scores, patient background information, and two common cognitive screens were used to differentiate between older inpatients (*n*=124) who lacked (64%)/did not-lack (36%) LS-DMC.

Results: Hospitalisations averaged 49 days, with 62% of inpatients being readmitted within 1-year. The QuickSort differentiated between those lacking/not-lacking LS-DMC better than two common cognitive screens and patient information. The likelihood that inpatients lacked LS-DMC increased by a factor of 65.26 for QuickSort scores <2 and reduced by a factor of 0.32 for scores ≥13. Modelling revealed that the post-test likelihood of lacking LS-DMC increased to 99% (scores <2) and reduced to 30% (scores ≥13) in settings where many inpatients lack LS-DMC.

Conclusions: Older adult inpatients with questionable LS-DMC have a high risk of extended hospitalisation and readmission. The QuickSort provides time-efficient and sensitive information regarding patients' LS-DMC, making it a viable alternative to longer cognitive screens that are used at the initial interview stage.

Keywords: screen, cognition, decision-making capacity, lifestyle, older adults

7.4 Introduction

The number of hospital admissions for older adults is growing as the population ages and the prevalence of cognitive problems increases (Li et al., 2020). Although a defining feature of dementia, cognitive decline is common in many neurodegenerative disorders (e.g., Parkinson's disease, motor neuron disease, Cui et al., 2015; Mihaescu et al., 2019) and may precede other core disease-specific diagnostic criteria (Fields, 2017). This cognitive decline can affect a person's independent functioning, leading to an increase in the demand for assessments of mental capacity (APA & ABA, 2008).

In many countries, there is a distinction between mental *capacity*, which is a clinical evaluation of a person's ability to independently make an informed decision or perform a specific task, and *competence*, which is a legal determination by an administrative tribunal (also termed conservatorship/guardianship board or probate court) regarding a person's ability to make their own decisions or perform activities (Darby & Dickerson, 2017). Although comprehensive evidence-based capacity assessments are required to inform legal determinations about competence (APA & ABA, 2008), these assessments do not inevitably lead to a formal hearing or legal decision, with informal living supports often trialled first (e.g., assistance with cleaning, shopping and meals; McSwiggan et al., 2016). The legislation guiding administrative tribunals differs between countries and jurisdictions (Tosh et al., 2015), but typically prioritises a person's independence and their continued involvement in decision-making (United Nation's General Assembly, 2007). Indeed, the appointment of a surrogate decision-maker or guardian to act on a person's behalf is the least preferred option when mental capacity is compromised (Davidson et al., 2015).

Capacity assessments are conducted by a variety of health professionals (e.g., neuropsychologists, geriatricians, medical practitioners, psychiatrists), and require considerable clinical expertise. Decision-making capacity (DMC; Kolva & Rosenfeld, 2012) refers to a person's ability to make independent and informed decisions, which is reliant on their ability to understand relevant information, different opinions and possible outcomes,

and to express a clear and consistent choice (Appelbaum & Grisso, 1988). DMC has many aspects, including the ability to make lifestyle (where to live, necessary supports), financial (manage financial affairs), testamentary (make/alter a will), sexual (consent to sexual relations), driving (safely operate a motor vehicle), medical (consent to/refuse treatment), and research (consent to research) decisions. Lifestyle DMC (LS-DMC), which is the focus of this study, includes decisions regarding independent living and self-care (Demakis, 2012).

LS-DMC assessments are very common in hospital settings (Brindle & Holmes, 2005) and are often associated with longer and more complex admissions (Chen et al., 2016; Miller et al., 1999; Torke et al., 2014; see Figure 7.1 for flowchart). Clinical interviews are used to initially identify a specific lifestyle issue (e.g., provision of in-home supports or placement in residential care), the risks associated with not receiving supports, the persons' preferences, and any existing supports. Clinicians often also administer cognitive screens at this stage to investigate whether cognitive impairment may be affecting a person's independent living and decision-making. The Mini-Mental Status Examination (MMSE) is commonly-used for this purpose (Pachet et al., 2010; Shibu et al., 2020) and is often supplemented with the Frontal Assessment Battery (FAB) in order to assess the 'executive' functions that are assumed to underpin decision-making (Darby & Dickerson, 2017). If both the interview and cognitive screens support the need for additional living-supports, but the patient rejects the recommended supports, a comprehensive LS-DMC assessment may be required to determine whether they *lack* or do *not-lack* LS-DMC. As seen in Figure 7.1, a LS-DMC assessment can result in several different outcomes, which are designed to facilitate patient discharge.

Sorting tests are also often used in DMC assessments, with 51% to 75% of Australian psychologists using the Colour Form Sort for this purpose (Mullaly et al., 2007). Sorting tests assess multiple cognitive domains (Schneider & McGrew, 2018), including 'executive' functioning, and detect the cognitive decline caused by common neurodegenerative disorders (e.g., dementia; Foran et al., 2020).

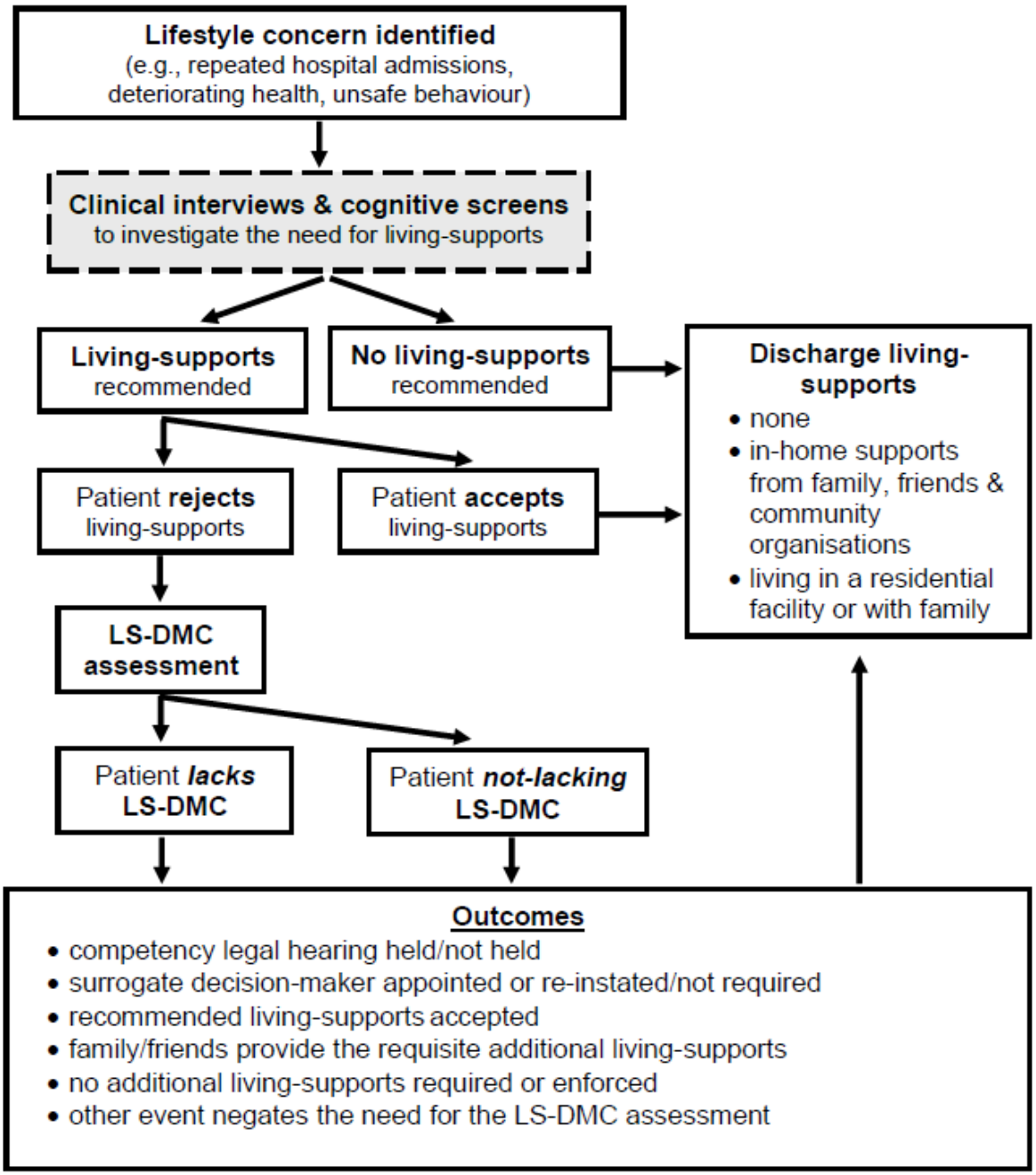


Figure 7.1: Stages involved in determining which older adult inpatients need a comprehensive assessment of lifestyle decision-making capacity and the possible outcomes from this process

Although not traditionally used during initial interviews to investigate the need for living supports, sorting tests – and more particularly, the QuickSort – may prove useful for this purpose. The QuickSort is a brief standardized sorting test (healthy older adults take <2 mins) in which stimuli are sorted by colour/shape/number and the category underpinning the sort is identified. It includes multiple improvements to existing sorting tasks that enhance its usefulness (e.g., reduced administration & scoring time, early discontinuation for intact performance, larger range of impaired scores, freely accessible stimuli and A4 record form that provides instructions for administration and records all scores).

The fact that the QuickSort has good inter-rater and test-retest reliability, has Australian norms for cognitively-healthy older adults, and successfully predicts impairment on the MMSE and FAB, additionally supports its use as a brief cognitive screen (Foran et al., 2021). Whether the QuickSort is useful when interviewing patients with questionable LS-DMC, however, has yet to be determined.

The present study was designed to validate the QuickSort for use during the initial clinical interview with inpatients who have questionable LS-DMC. Sensitivity and specificity values were used to determine which QuickSort cut-scores (and score range/categories) differentiated between inpatients who *lacked* and did *not-lack* LS-DMC. Likelihood ratios (LRs) quantified how more- or less-likely inpatients were to *lack* LS-DMC if they had certain QuickSort scores and, when combined with the local prevalence of inpatients *lacking* LS-DMC, were used to calculate the probability that an inpatient in the current clinical setting *lacked* LS-DMC.

7.5 Method

7.5.1 Participants

Participants comprised 124 inpatients, aged 60 years and over, who were consecutive referrals to the Royal Adelaide Hospital (RAH) Neuropsychology Service for an

assessment of LS-DMC. Inpatients were identified in one of two ways: (1) retrospectively, by auditing recent Neuropsychology records, hereafter referred to as *Retrospective-inpatients* (*n*=48), and (2) prospectively, by recruiting new inpatients for a study investigating the QuickSort, hereafter referred to as *Prospective-inpatients* (*n*=76). An additional three *Prospective-inpatients* had their requests for LS-DMC assessments retracted and six were eligible but declined to take part in the study, although unfortunately the reasons they declined participation were not recorded.

7.5.2 Measures

Patient characteristics were obtained from clinical interviews or medical records and included: (i) demographic details (age, sex, education, nationality), (ii) relationship status (partnered/not partnered), (iii) living-supports when admitted to hospital (none, in-home supports provided by family/friends/community organisations, living in a residential facility/with family), (iv) history of a stroke or dementia and delirium (yes/no), (v) alcohol intake (daily or almost daily: yes/no), (vi) the presence of challenging behaviours (e.g., self-neglect, non-compliance with medications, placing themselves in dangerous situations, or verbal or physical abuse toward others: yes/no), and (vii) their scores on the MMSE (<24 considered impaired; Hancock & Larner, 2011) and FAB (<11 considered impaired; Kim et al., 2010).

The QuickSort, which was only administered to the *Prospective-inpatient* group (*n*=76), required participants to sort nine cards by colour, shape and number within a maximum of six trials. The QuickSort manual, stimuli and psychometric properties are published elsewhere (Foran et al., 2021). Total scores (range: 0-18) were calculated by summing: (1) a 'Sorting' score, which aggregated the number of correct sorts (0=correct without prompt; 1=prompted, but correct; 2=incorrect), sorting errors (repetition, set-loss, grouping or completion errors) and verbal prompts (range: 0-12); and (2) an 'Explanation' score, which assessed the ability to verbalise the reason for the correct sort (0=incorrect;

1=concrete; 2=correct, range: 0-6). Total scores <10 have optimal sensitivity (82%) and specificity (78%) for detecting impairment on either the MMSE, FAB, or both screens (Foran et al., 2021).

The primary outcome for this study was whether inpatients *lacked* or did *not-lack* LS-DMC, which was determined after independent medical and neuropsychological assessments. Medical assessments were completed by general physicians, often with the assistance of psychiatrist and geriatricians, using information from the clinical interview, including questions regarding mood and safety, cognitive screens (MMSE and FAB), in addition to other reports (e.g., nursing or occupational therapy). Neuropsychological assessments involved: patient and informant interviews; comprehensive assessments of patients' cognition (e.g., the Weschler Adult Intelligence and Memory Scales); and a review of functional and medical reports (including MMSE and FAB scores) and any prior neuropsychological assessments (to identify cognitive changes). Inpatients were classified as: (1) *lacking* LS-DMC, when the medical and neuropsychology teams both agreed that the inpatient did not have the capacity to make an informed and reasoned decision regarding a lifestyle matter, or (2) *not-lacking* LS-DMC, if one or both teams indicated that either (a) the inpatient had the capacity to make lifestyle decisions or (b) the available evidence was inconclusive. This dichotomous classification (*lacking* vs *not-lacking* LS-DMC) aligns with international legislation, which states that people should be assumed to have capacity unless there is clear and convincing evidence to the contrary (Davidson et al., 2015).

A number of other/secondary outcomes were also examined (see Figure 7.1), namely the number of inpatients who: (1) underwent a competency hearing with the South Australian Civil and Administrative Tribunal; (2) had a surrogate decision-maker appointed after a tribunal hearing, or re-instated based on an existing tribunal determination with/without a formal hearing; (3) accepted the recommended living-supports; (4) had family/friends agree to provide additional living-supports; (5) received no additional living-supports, and (6) experienced another event that negated the need for a LS-DMC assessment outcome (e.g., death or other medical event that prevented hospital discharge).

Whether living-supports were increased at discharge was also recorded, as was the final level of support (which combined previous supports with new supports). Finally, the length of hospital stay and the number of inpatients who were readmitted (within the local public health network) within one-year of their initial admission were recorded.

7.5.3 Procedure

The RAH Human Research and Ethics Committee approved the inclusion of inpatients with questionable capacity if they provided written consent. A neuropsychologist or post-graduate assistant administered the QuickSort prior to the neuropsychological LS-DMC assessment and before accessing MMSE and FAB scores from medical records in order to blind the assessors. Medical and neuropsychology staff were not privy to patients' QuickSort performance when determining capacity.

7.5.4 Data-analysis

Data was analysed using the Statistical Package for the Social Sciences (IBM, 2017). Missing data were excluded list-wise and $p<.05$ determined statistical significance.

Data for the *Retrospective-inpatient* and *Prospective-inpatient* samples were initially combined to characterise the inpatients who were referred to the Neuropsychology Service for LS-DMC assessments. The primary (LS-DMC: *lacking* or *not-lacking*) and secondary outcomes for the combined sample were also recorded, as was summary information for all inpatients (combined sample) who had an administrative tribunal hearing in order to determine how they differed from those who did not require a hearing.

The combined sample was also used to investigate the variables that were relevant to inpatients' LS-DMC. Inpatients were classified into one of two groups, based on whether they *lacked* or did *not-lack* LS-DMC, after which *t*-tests and chi-square analyses examined their comparability. Although the MMSE and FAB scores of these groups were expected to differ because this information was used when determining capacity, they provide useful

benchmarks against which to determine whether the QuickSort (*not* part of the capacity assessment) better differentiated between those who *lacked* and did *not-lack* LS-DMC (Hedges' *g*). A minimum sample size of 42 was required in each of the two groups (*lacking/not-lacking* LS-DMC) in order to detect a large difference (Cohen's *d*=.80) with 95% power at *p*=.05 (Cohen, 1988).

A logistic regression then identified which variables in the combined sample best differentiated between those who *lacked/*did *not-lack* LS-DMC (dependent variable), with inpatient demographics, relationship status, living-supports, history of dementia, stroke or delirium, alcohol use, challenging behaviours and the cognitive screens (MMSE, FAB, QuickSort) being the independent variables. The 'forward' method was used, which enters the most significant independent variable first, then adds others based on their contribution to predicting the dependent variable. An additional logistic regression with simultaneous entry of all variables then determined the contribution that each variable made to the LS-DMC determination.

The remaining analyses investigated the QuickSort for informing LS-DMC and used only the *Prospective-Inpatient* sample. A final logistic regression was used to identify the QuickSort (independent variable) cut-score that correctly classified the largest number of inpatients according to whether they *lacked/*did *not-lack* LS-DMC (dependent variable). Having statistically identified a cut-score for the QuickSort, the CAT-maker (Badenoch et al., 2004) computed its sensitivity, specificity and LRs. The sensitivity and specificity values for the recommended cut-scores on the MMSE (<24) and FAB (<11) were also calculated for comparative purposes using the *Prospective-Inpatient* sample. Sensitivity was of particular interest because the priority was to minimise the chance of missing someone who lacked capacity (Larner, 2013).

Although useful, cut-scores can be misleading for small samples because cases that do not conform to the general pattern (e.g., low QuickSort score for someone with intact capacity) disproportionately affect the sensitivity and specificity of specific scores. As an alternative, the number of inpatients who *lacked*/did *not-lack* LS-DMC for each QuickSort

score were entered into the CAT-maker to identify scores that could be grouped (categories), with minimal or no changes to sensitivity and specificity. Multiple level LRs were then generated for each category by entering the number of inpatients who *lacked/*did *not-lack capacity* into the CAT-maker. Multiple LRs cannot be computed for scores or categories that have a frequency of zero, which occurred in the group that did *not-lack* LS-DMC (no-one scored 0 or 1). A nominal low value of 0.4 was therefore used to compute multiple LRs (Straus et al., 2019), while also avoiding rounding errors (which occur with a value of 0.5). QuickSort scores that fell within a category that had a LR >1 were more likely to occur in inpatients who *lacked* LS-DMC and scores within a category with a LR <1 were more likely in inpatients who did *not-lack* capacity (Deeks & Altman, 2004). Clinically, scores with LRs >3 or <0.3 are considered particularly useful because they substantially change the likelihood that a patient has/does not have a target condition, which in this case was LS-DMC (McGee, 2016).

As with the QuickSort, the number of *Prospective-Inpatients* who *lacked*/did *not-lack* LS-DMC for each MMSE score were entered into the CAT-maker to identify scores that could be grouped into 3 categories, with minimal or no changes to sensitivity and specificity. These MMSE categories were expected to be more sensitive and specific than the QuickSort because the medical and neuropsychology staff used MMSE scores when determining capacity. The screens were deemed to differ significantly if the QuickSort LRs for the low, middle, and high score categories fell outside of the 95% confidence intervals for the corresponding MMSE LRs. The range and average MMSE scores for *Prospective-Inpatients* who scored in the low, middle, and high QuickSort score categories were additionally calculated, but only for patients who were administered both screens.

Finally, EBM modelling customized the QuickSort for investigating LS-DMC in older adults referred to the current Neuropsychology Service (Straus et al., 2019). This modelling calculated the post-test probability that inpatients with a given QuickSort score would *lack* LS-DMC after taking into consideration the client-base for that service (local prevalence or pre-test probability of patients *lacking* LS-DMC). The pre-test probability of patients *lacking*

LS-DMC was estimated from the *Retrospective-inpatients*, who were not administered the QuickSort, having established that they were demographically comparable to the *Prospective-inpatients,* who did complete the QuickSort*.* The CAT-maker used the LRs for each QuickSort score category and the pre-test probability to calculate the post-test probability of an inpatient *lacking* LS-DMC. This modelling was additionally repeated using 10% and 25% pre-test probabilities to make it applicable to other clinical settings with different base-rates, such as community medical practices and medical inpatient units.

7.6 Results

7.6.1 Inpatients referred for LS-DMC assessments

7.6.1.1 Inpatient characteristics

Table 7.1 provides summary information for all inpatients who underwent a LS-DMC assessment (*Retrospective*- and *Prospective-inpatients* combined). On average, inpatients were almost 76 years of age and had completed some high school education (*M*=10.6, *SD*=3.2). Most were male (62%) and Australian (70%), and relatively few were partnered (22%). On admission, many had no living-supports (42%) or received some in-home support from friends, family and/or community organisations (42%), with many fewer living in a residential care facility or with family (16%). A history of dementia or stroke was documented in less than half of all inpatients (40%) and 20% had experienced a delirium. Almost one in four drank alcohol daily or almost daily (26%) and many exhibited challenging behaviours (81%). On average, inpatients fell within the impaired range on the MMSE (<24; *M*=23.1, *SD*=4.3) and just above the cut-score for impairment on the FAB (<11; *M*=11.6, *SD*=3.4). The average QuickSort score in *Prospective-Inpatients* was <10 (*M*=6.5, *SD*=5.7), which in a previous study occurred in as few as 4% of cognitively-healthy older adults (Foran et al., 2021).

Table 7.1: Summary characteristics for inpatients referred to the Neuropsychology Service for an assessment of lifestyle decision-making capacity (LS-DMC)

	Inpatient sample (*n* = 124)			***LS-DMC determination***							
				Lacking (*n* = 78)			***Not-lacking*** (*n* = 46)				
	n	***%***		***n***	***%***		***n***	***%***		χ^2	***p***
Inpatient characteristics											
Recruitment source										0.7	0.40
Retrospective-inpatients	48	38		28	36		20	43			
Prospective-inpatients	76	62		50	64		26	57			
Demographics											
sex										0.3	0.59
male	76	62		49	64		27	59			
female	47	38		28	36		19	41			
	n	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***	***t***	***p***
age (years)	124	75.8	9.7	78	75.3	9.4	46	76.6	10.2	0.8	0.45
education (years)	118	10.6	3.2	76	10.4	3.2	42	10.8	3.3	0.6	0.55
	n	***%***		***n***	***%***		***n***	***%***		χ^2	***p***
nationality										3.6	0.61
Australian	85	70		55	72		30	68			
Indigenous, Torres Islander	1	1		1	1		0	0			
European	20	17		11	15		9	21			
American	1	1		1	1		0	0			
Asian	1	1		0	0		1	2			
other	12	10		8	11		4	9			
Relationship status										0.5	0.47
partnered	26	22		18	24		8	19			
not partnered	91	78		56	76		35	81			
Level of living-supports at admission										1.5	0.48
no supports with living	51	42		35	46		16	35			
in-home supports	52	42		31	40		21	45			
in-facility, living with family	20	16		11	14		9	20			
Medical history											
stroke or dementia										0.3	0.57
yes	49	40		32	44		17	37			
no	73	60		44	58		29	63			
delirium										0.9	0.34
yes	24	20		17	22		7	15			
no	98	80		59	78		39	85			
Behavioural issues											
alcohol daily, almost daily										<0.1	0.96
yes	32	26		20	26		12	26			
no	92	74		58	74		34	74			
challenging behaviours										4.5	0.03
yes	98	81		66	87		32	71			
no	23	19		10	13		13	29			

Table 7.1: Summary characteristics for inpatients referred to the Neuropsychology Service for an assessment of lifestyle decision-making capacity (LS-DMC) cont.

	Inpatient sample (*n* = 124)			***LS-DMC determination***							
				Lacking (*n* = 78)			***Not-lacking*** (*n* = 46)				
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Cognitive screening											
Mini Mental State Examination (MMSE)	104	23.1	4.3	69	22.5	4.3	35	24.3	4.0	2.1	0.04
Frontal Assessment Battery (FAB)	99	11.6	3.4	67	11.2	3.1	32	12.6	3.6	2.0	0.05
QuickSort	76	6.5	5.7	50	5.3	5.2	26	8.9	6.1	2.7	0.01
	n	*%*		*n*	*%*		*n*	*%*		χ^2	*p*
Primary & secondary Outcomes											
LS-DMC											
lacking	78	63									
not-lacking	46	37									
Administrative tribunal hearing										21.4	<0.01
yes	49	40		43	55		6	13			
no	75	60		35	45		40	87			
Outcome of the LS-DMC assessment										30.5	<0.01
surrogate decision-maker appointed/reinstated	43	35		39	51		4	9			
living-supports accepted	45	37		25	32		20	44			
new informal living-supports	10	8		2	3		8	18			
no changes to supports	14	12		4	5		10	22			
other outcome	10	8		7	9		3	7			
Living-supports at discharge										6.3	0.01
increased	103	86		69	92		34	76			
not changed	17	14		6	8		11	24			
Level of living-supports at discharge										9.0	0.01
no supports	7	6		1	2		6	13			
in-home support	35	32		18	27		17	38			
in-facility or living with family	69	62		47	71		22	49			
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Hospitalization											
length of stay	124	49.4	37.8	78	54.3	33.3	46	41.1	43.5	1.9	0.06
	n	*%*		*n*	*%*		*n*	*%*		χ^2	*p*
readmitted within 1-year										2.4	0.12
yes	76	62		44	57		32	71			
no	46	38		33	43		13	29			

This earlier study also reported that a QuickSort cut-score <10 was optimal for detecting impairment on the MMSE and FAB.

7.6.1.2 Primary and secondary outcomes

Of the 124 inpatients who underwent LS-DMC assessment, 63% were deemed to *lack* capacity and 37% did *not-lack* capacity (see Table 7.1). In total, 40% of inpatients had an administrative tribunal hearing. Comparable numbers of inpatients had a surrogate decision-maker appointed/re-instated (35%) or accepted the recommended living-supports (37%). Many fewer had family and friends who could provide new informal supports (<8%), had no changes to their supports (<12%), or experienced another outcome that negated the LS-DMC assessment (8%). Of note, most inpatients (86%) had their living-supports increased from their pre-admission levels following their LS-DMC assessment, with the majority living in residential care or with family (62%), some having in-home supports organised (32%) and many fewer not requiring support (6%). On average, inpatients were hospitalised for approximately 49 days (*SD*=37.8), with 62% readmitted to hospital within one year of their discharge.

7.6.1.3 Inpatients who had an administrative tribunal hearing

Table 7.2 provides the characteristics and outcomes for the 40% of inpatients who had (*n*=49) and 60% who did not have (*n*=75) an administrative tribunal hearing. Prospectively-recruited inpatients were less likely to have a tribunal hearing, however this coincided with increased staffing, which meant that less-urgent higher-functioning inpatients, who may have been more likely to accept the recommended supports, were assessed sooner.

Table 7.2: Inpatient characteristics and outcomes for those who did/did not have an administrative tribunal hearing

	Administrative tribunal hearing							
	Yes (*n* = 49)			***No*** (*n* = 75)				
	n	*%*		*n*	*%*		χ^2	*p*
Inpatient characteristics								
Recruitment source							7	<0.01
Retrospective-inpatients	26	53		22	29			
Prospective-inpatients	23	47		53	71			
Demographics								
sex							0	0.92
male	30	61		46	62			
female	19	39		28	38			
	n	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
age[1]	49	75.9	10.3	75	75.7	9.3	0.1	0.91
education[2]	48	10.4	3.2	70	10.7	3.2	0.5	0.62
	n	*%*		*n*	*%*		χ^2	*p*
nationality							3.6	0.61
Australian	32	65		53	72			
Indigenous, Torres Islander	1	2		0	0			
European	8	16		12	16			
American	1	2		0	0			
Asian	0	0		1	1			
other	7	14		8	11			
Relationship status							0	0.99
partnered	13	27		20	27			
not partnered	36	73		55	73			
Level of living-supports at admission							2.5	0.28
no supports with living	22	45		26	35			
in-home supports	21	43		31	42			
in-facility, living with family	6	12		17	23			
Medical history								
stroke or dementia							1	0.31
yes	19	39		36	48			
no	30	61		39	52			
delirium							2.9	0.09
yes	13	27		11	15			
no	35	73		64	85			

Table 7.2: Inpatient characteristics and outcomes for those who did/did not have an administrative tribunal hearing cont.

	Administrative tribunal hearing							
	Yes (*n* = 49)			***No*** (*n* = 75)				
	n	*%*		*n*	*%*		χ^2	*p*
Behavioural issues								
alcohol daily, almost daily							0.3	0.57
yes	14	29		18	24			
no	35	71		57	76			
challenging behaviours							0.8	0.37
yes	38	78		63	84			
no	11	22		12	16			
	n	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Cognitive screening								
Mini Mental State Examination (MMSE)	42	21.93	4.8	62	23.9	3.7	2.4	0.02
Frontal Assessment Battery (FAB)	37	10.9	3.3	62	12.1	3.3	1.9	0.06
QuickSort	23	6.3	6.1	53	6.6	5.6	0.2	0.84

Of note, inpatients who had and did not have a hearing were comparable in terms of their: demographic characteristics, relationship status, living-supports, medical history, alcohol use and challenging behaviours. However, inpatients were more likely to have an administrative tribunal hearing if they had low MMSE and FAB scores and *lacked* LS-DMC (88%). As expected, inpatients who had a hearing were more likely to have a surrogate decision-maker appointed (73%) and less likely to accept the recommended living-supports (12%). They also had significantly longer hospital stays than those who did not require a hearing; however their one-year readmission rates were comparable.

7.6.2 Comparison between inpatients who lacked/did not-lack LS-DMC

7.6.2.1 Inpatient characteristics

Table 7.1 also provides information for inpatients who were deemed to *lack* and *not-lack* LS-DMC. Both groups were comparable in terms of their demographic characteristics, relationship status, living-supports, medical history, and alcohol use. However, inpatients who *lacked* LS-DMC were significantly more likely to exhibit challenging behaviours and have poorer cognition (MMSE, FAB, QuickSort). Of the three cognitive screens, the QuickSort showed the largest group difference (Hedges' g = 0.65), followed by the MMSE (g = 0.43) and FAB (g = 0.43). This was unexpected because, unlike the QuickSort, MMSE and FAB scores were used by clinicians when assessing LS-DMC.

7.6.2.2 Secondary outcomes

Table 7.1 reveals that the secondary outcomes for inpatients differed according to whether they were deemed to *lack* or *not-lack* LS-DMC. Not surprisingly, inpatients who *lacked* LS-DMC were significantly more likely to have an administrative tribunal hearing (55%) and a surrogate decision-maker appointed or re-instated (51%), with very few being discharged with new informal supports from family or friends (3%) or with no additional living-supports (5%). The majority of inpatients who *lacked* LS-DMC (92%) had their living-supports increased from pre-admission levels and were more likely to be discharged to live in residential care facilities or with family (71%), and less likely to receive in-home supports (27%) or have no supports (2%). The length of hospitalisation and one-year readmission rates did not differ between those who *lacked* and did *not-lack* LS-DMC, although there was a trend toward longer hospitalisations for those who *lacked* capacity (p=.06).

7.6.2.3 Variables related to inpatient LS-DMC

A logistic regression revealed that the QuickSort was the variable that best differentiated between those who *lacked* and did *not-lack* LS-DMC (*B* =-0.11, *SE*=0.05, β =-0.90, *Wald*=5.19, *p*=.02). None of the remaining independent variables (demographic, relationship, living-supports, medical history, alcohol use, challenging behaviours, MMSE, FAB) made a significant contribution, once the QuickSort entered the model (see Table 7.3). Surprisingly, the MMSE and FAB were not significant predictors of capacity (although the MMSE approached significance), despite being used by clinicians when determining LS-DMC.

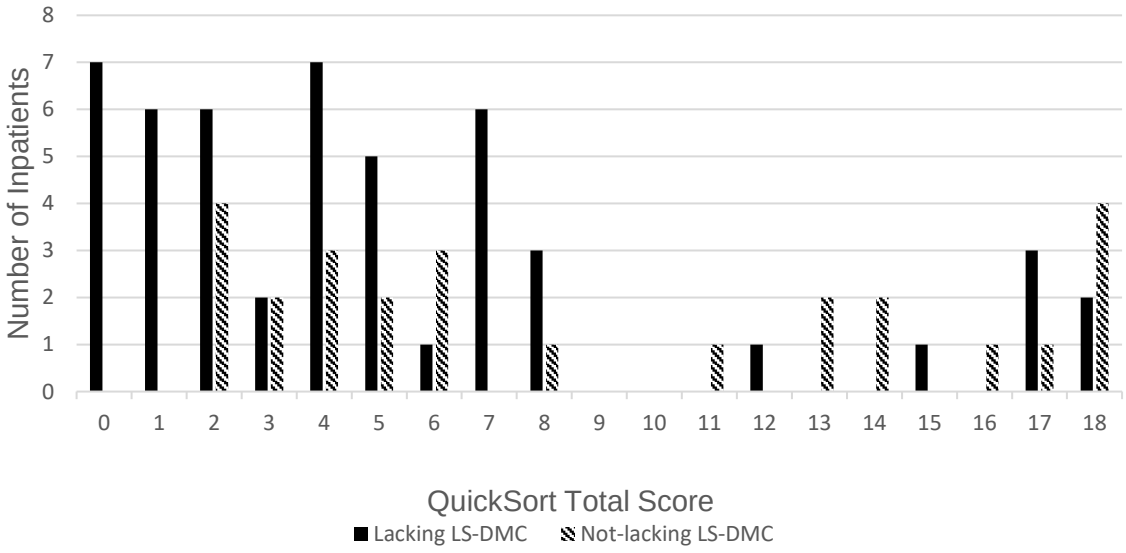
Table 7.3: Logistic regression examining whether demographic information, living supports, medical history, alcohol use, challenging behaviours and cognition influenced older adults' lifestyle decision-making capacity

	B	*SE*	*β*	*Wald*	*p*
Demographics					
age[a]	-0.15	0.05	0.99	0.11	0.75
education (years)	0.02	0.11	1.02	0.04	0.85
sex (male/female)	0.76	0.78	2.15	0.96	0.33
in relationship (yes/no)[b]	-1.59	1.12	0.20	2.01	0.16
Living supports at admission[c]	-0.90	0.62	0.41	2.11	0.15
Medical history					
stroke or dementia (yes/no)	0.18	0.74	1.19	0.06	0.81
delirium (yes/no)	-0.33	0.86	0.72	0.15	0.70
Alcohol use					
daily or almost daily (yes/no)	-0.18	0.86	0.84	0.04	0.84
Challenging behaviours					
to self or others (yes/no)[d]	-1.68	1.02	0.19	2.70	0.10
Cognitive screens					
MMSE	-0.26	0.13	0.77	3.71	0.05
FAB	0.16	0.14	1.18	1.30	0.25
QuickSort	-0.13	0.06	0.88	4.30	0.04

B = unstandardized Beta; *SE* = standard error; *β* = standardized Beta; *Wald* = Wald test; *p* = p-value; [a]only inpatients aged over 59 years of age were investigated in this study; [b]partnered compared to being single, divorced, separated or widowed; [c]there were three levels of supports with living at admission, no supports, in-home supports, and in-facility supports or living with family; [d]challenging behaviours could be to self, such as self-neglect, or verbal or physical abuse of others; MMSE = Mini Mental Status Examination; FAB = Frontal Assessment Battery

7.6.3 QuickSort cut-scores and categories to inform LS-DMC

The *Prospective-Inpatients* who *lacked* LS-DMC performed quite differently on the QuickSort than those who did *not-lack* LS-DMC, with 86% of inpatients who *lacked* LS-DMC having scores <9 (see Figure 7.2). A logistic regression, which examined which QuickSort cut-score most accurately differentiated between inpatients who *lacked* and did *not-lack* LS-DMC, found that Total scores <13 correctly classified 44 of the 50 inpatients who *lacked* LS-DMC (88% sensitivity) and scores ≥13 correctly classified 10 out of the 26 inpatients who did *not-lack* capacity (38% specificity). The QuickSort cut-score <13 had better sensitivity than the recommended cut-scores for the MMSE (<24; 50% sensitivity: detected 22 of 44 *Prospective-Inpatients* who *lacked* LS-DMC) and FAB (<11; 39% sensitivity: detected 17 of the 44 *Prospective-Inpatients* who *lacked* capacity). However, the MMSE and FAB had better specificity (MMSE: 67% specificity; identified 16 of 21 *Prospective-Inpatients* who did *not-lack* capacity; FAB: 73% specificity; identified 16 of 22 *Prospective-Inpatients* who did *not-lack* capacity).



LS-DMC = life-style decision-making capacity

Figure 7.2: Histogram showing the distribution of QuickSort Total scores for Prospective-Inpatients who lacked and did not-lack LS-DMC

Next, *Prospective-Inpatient* QuickSort scores were grouped into three categories to improve the accuracy of interpretation and multiple LRs then computed for each category (Table 7.4). Two score categories were most informative: one defined by the lowest two scores (0-1), which increased the likelihood that inpatients *lacked* LS-DMC by a factor of 65.26 (95%CI: 2.91 - 1463.90), and one defined by the highest six scores (13-18), which reduced the likelihood inpatients *lacked* LS-DMC by a factor 0.32 (95%CI: 0.18 - 0.57). Scores 2-12 were not clinically informative because equivalent numbers of inpatients in both groups achieved these scores (*lacked* LS-DMC: 62%; did *not-lack* LS-DMC: 62%).

Table 7.4: Total score categories for the QuickSort when predicting inpatients who lacked/did not-lack lifestyle decision-making capacity

QuickSort Total Score	Inpatients		LR (95% CI)	Pre-test probability of lacking LS-DMC 58%[a]	25%[b]	10%[c]
	Lacking LS-DMC	Not-lacking LS-DMC		Post-test probability of lacking LS-DMC		
0 – 1	26%	0[d]	65.26 (2.91 – 1463.90)	99%	96%	88%
2 – 12	62%	62%	1.01 (0.81 – 1.25)	58%	25%	10%
13 -18	12%	38%	0.32 (0.18 – 0.57)	30%	9%	3%

LR = likelihood ratio; 95% CI = 95 percent confidence interval; [a]pre-test probability of inpatients lacking LS-DMC who were referred to the Neuropsychology service was estimated to be 58%, based on the Retrospective-inpatients group; [b]25% hypothetical prevalence of LS-DMC; [c]10% hypothetical prevalence of LS-DMC; [d]no inpatient who did not-lack LS-DMC scored 0 or 1 on the QuickSort, therefore a nominal value of 0.4 was used to compute the multi-level likelihood ratios

Although the CIs were extremely large – probably due to the small sample – it is important to note that the lower CIs approached the target LRs of >3 (scores < 2) and <0.3 (scores ≥ 13), both of which substantially change the likelihood of a patient *lacking* and *not-lacking* LS-DMC (McGee, 2016). The upper CIs far exceed what is considered clinically useful.

Prospective-Inpatient MMSE scores were also grouped into three categories to provide a comparison to the QuickSort, although the findings are only tentative given the medical and neuropsychology team used the MMSE when determining LS-DMC and more score categories could have optimised the sensitivity and specificity of the MMSE. The lowest MMSE score category (score range: 0-17) increased the likelihood an inpatient *lacked* LS-DMC by a factor of 5.42 (95%CI: 0.22 – 134.72), which was less sensitive than the lowest score category on the QuickSort, although this difference did not reach significance due to the large confidence intervals (Supplementary Table C.2.1). The highest MMSE score category (score range: 28-30) reduced the likelihood that an inpatient *lacked* LS-DMC by a factor 0.23 (95%CI: 0.07 – 0.82), which was more specific than the highest category on the QuickSort, although this difference was not significant. Like the QuickSort, the middle category for the MMSE (score range: 18-27) was not clinically informative, although there were more inpatients who *lacked* (84%) than did *not-lack* (70%) LS-DMC who achieved these scores. The *Prospective-Inpatients'* average MMSE scores differed less than three points between the highest and lowest QuickSort categories and a wide range of MMSE scores were seen in each QuickSort category, which may suggest the abilities measured by the screens are not equivalent (Supplementary Table C.2.2).

7.6.4 Customization of the QuickSort for specific clinical services

Modelling was undertaken to improve the accuracy of the QuickSort for use in the current Neuropsychology Service by additionally using the LRs for the three QuickSort score categories and the pre-test probability that an inpatient referred to this service would *lack* LS-DMC. The latter probability was estimated from the *Retrospective-inpatient* sample because it was demographically comparable to the *Prospective-inpatient* sample, but was not included in the QuickSort analyses (see Table 7.5). Of the 48 *Prospective-inpatients,* 28 *lacked* LS-DMC, resulting in a pre-test probability of 58%.

Table 7.5: Demographic differences between the Retrospectively- and Prospectively-recruited inpatients

	Retrospective-inpatients		Prospective-inpatients				
	n	*M (SD)*	*n*	*M (SD)*	*t*	χ^2	*p*
age[a]	48	77.33 (10.85)	76	74.80 (8.75)	1.43		0.16
education (years)	48	10.23 (3.54)	70	10.79 (3.54)	0.84		0.40
sex	47		76			0.13	0.71
male	30		46				
female	17		30				

n = number of participants; *M* = mean; *SD* = standard deviation; *t* = *t*-test; χ^2 = chi square; *p* = p-value; [a]only inpatients aged over 59 years of age were investigated in this study

Modelling revealed that the lowest (<2) and highest (≥13) QuickSort categories were most useful, clinically, because they substantially changed the probability of an inpatient *lacking* LS-DMC (from 26% to 99% for QuickSort scores <2 and from 12% to 30% for scores ≥13; see Table 7.4). Figure 7.3 provides a nomogram to illustrate how the QuickSort can be interpreted by the Neuropsychology Service using the three score categories. The first example (solid line) depicts inpatients scoring within the lowest category (<2), which increases the likelihood of them *lacking* LS-DMC by a factor of 65.26 (95% CI: 2.91–1463.90), resulting in a 99% chance (post-test probability) that they will *lack* LS-DMC. The second example (dashed line) depicts inpatients scoring in the middle category (2–12), which is associated with a LR of 1.01 (95% CI: 0.81–1.25) and does not change the probability of them *lacking* LS-DMC from the pre-test level of 58%. The third example (dotted line) depicts inpatients scoring within the highest category (≥13), which reduces the likelihood of them *lacking* LS-DMC by a factor of 0.32 (95% CI: 0.18–0.57), resulting in a 30% probability that they will *lack* capacity.

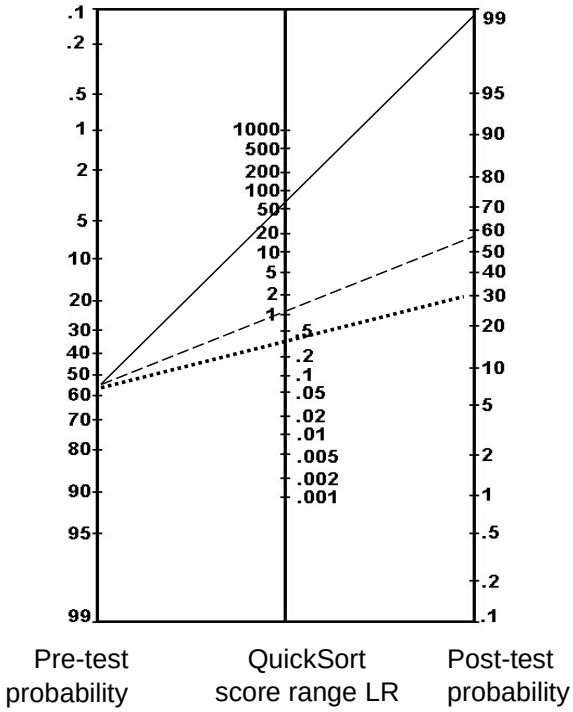


Figure legend:
Nomogram[a] showing interpretation[b] of the three QuickSort ranges in a setting where the pre-test probability of inpatients lacking LS-DMC is 58%[c]. Example 1 (solid line) QuickSort score <2, LR+ = 65.26, post-test probability of 99%. Example 2 (dashed line) QuickSort score 2-12, LR+ = 1.01, post-test probability of 58%. Example 3 (dotted line) QuickSort score ≥13, LR+ = 0.32, post- test probability of 30%.

[a]adapted from Fagan (1975) Nomogram for Bayes's Theorem; [b]interpretation should consider the confidence intervals around the likelihood ratios; [c]pre-test probability of 58% is based on the Retrospective-inpatient sample

Figure 7.3: Nomogram customizing the QuickSort for screening lifestyle decision-making capacity in the RAH Neuropsychology service

Clinical settings vary in terms of their patient profiles (age, education, referral problem etc) and, consequently, the prevalence of patients who *lack* LS-DMC. In generalist settings, for example, it is likely that many fewer patients would *lack* LS-DMC. Table 7.4 therefore additionally models the QuickSort for other clinical settings where the pre-test probability a person *lacks* LS-DMC is either 25% or 10%: In settings where the pre-test probability is 25%, the post-test probability a person lacks capacity increases to 96% for QuickSort scores <2 and decreases to 9% for scores ≥13. In settings where the pre-test probability is 10%, the post-test probability increases to 25% for QuickSort scores <2 and decreases to 3% for scores ≥13. Once again, there was no change in the probability of

inpatients *lacking* or *not-lacking* LS-DMC if they score within the middle category of the QuickSort (2–12). Modelling of the MMSE for clinical settings with 58%, 25% and 10% pre-test probability of inpatients *lacking* LS-DMC, although only a tentative finding, indicated the lowest category (0–17) produced inferior post-test probabilities compared to the lowest QuickSort score category (0–1; Supplementary Table B.2.2).

7.7 Discussion

LS-DMC assessments are increasing in hospital settings as the population ages and more people suffer from cognitive decline, which can impact on their ability to live independently and make lifestyle decisions (Usher & Stapleton, 2019). In busy settings, the initial clinical interviews that explore patients' need for living-supports often also include cognitive screens to investigate some of the abilities that underpin DMC (Pachet et al., 2010). This study investigated whether the QuickSort can provide efficient and accurate information regarding patients' LS-DMC during the initial clinical interview.

In the current setting, 63% of the hospital inpatients who were referred to the Neuropsychology Service for a LS-DMC assessment were deemed to *lack* LS-DMC. Administrative tribunal hearings were often avoided because inpatients accepted the recommended supports or the appointment/reinstatement of a surrogate decision-maker. Accordingly, living-supports increased for many, with almost two-thirds discharged to live in residential care or with family. Community living supports and residential care placements are notoriously difficult to arrange (Bai et al., 2019), which may have extended inpatients' hospital stays, especially for those who had a tribunal hearing and/or needed significant additional living-supports. In general, inpatients referred for LS-DMC assessment were hospitalised for up to five times longer than other geriatric patients (Basic & Khoo, 2015), increasing their risk of hospital-acquired infections and death (Bai et al., 2019). These risks emphasize the importance of conducting clinical interviews to ascertain patients' need for additional living-supports early in their admission to assist in care-planning and to avoid

unnecessary delays in accessing resources. Not only are patients with questionable LS-DMC at risk of having extended hospital admissions, but they were also twice as likely to be readmitted to hospital than older adult trauma inpatients (Crijns et al., 2018), which suggests they are a high-risk group who would benefit from continued monitoring.

This study found that it is worthwhile administering cognitive screens when initially interviewing patients with questionable LS-DMC because they better differentiated between those who *lacked/*did *not-lack* LS-DMC than a range of other patient characteristics (including demographic, relationship status, living supports at admission, history of stroke, dementia, delirium, alcohol use, and challenging behaviours). Sensitivity is important when trying to avoid missing inpatients who *lack* LS-DMC (Larner, 2013) and of the three cognitive screens, the QuickSort had better sensitivity than the MMSE and FAB, when a cut-score of <13 was used (88% sensitivity, 38% specificity). However, QuickSort scores in the middle range were achieved infrequently and by equivalent number of inpatients who *lacked* and did *not-lack* LS-DMC. Consequently, a cut-score of <10 produces similar sensitivity (86%) and specificity (42%) values, although it may be more clinically useful given a previous study found it also optimises the detection of cognitive impairment (Foran et al., 2021). Greater certainty was associated with low (<2) and high (≥13) QuickSort scores, which increased or reduced the likelihood that a person *lacked* LS-DMC by a factor of 65.26 and 0.32, respectively. These categories are also useful for detecting cognitive decline, with psychologically- and cognitively-healthy older adults rarely scoring <2 and most (98%) scoring ≥13 (Foran et al., 2021). Therefore, like many other screens, score categories are recommended to improve the accuracy of interpreting the QuickSort, because cut-scores can conceal scores that occur infrequently or cannot discriminate groups (Pachet et al., 2010; Bowden & Loring., 2009).

Finally, modelling enhanced the usefulness of the QuickSort by considering the local prevalence of inpatients *lacking* LS-DMC (which can be estimated from local or similar service audits) together with the LR for a patient's QuickSort score (current LRs are suitable if patients are demographically comparable to the *Prospective-inpatient* group). In the

current setting, inpatients had to show some decline in their functioning in order to be referred to the Neuropsychology Service for a LS-DMC assessment, consequently the prevalence of them *lacking* LS-DMC was high (pre-test: 58%), but increased to 99% (post-test) if their QuickSort scores were <2 and remained at 30% (post-test) if they scored ≥13.

The main limitation of this study relates to the fact that LS-DMC is not solely dependent on cognition with, for example, the supports available to patients and their risk of not accepting the recommended supports also being considered. In addition, depression was not objectively assessed, although it may have influenced inpatients' willingness to accept living-supports and the determination of their LS-DMC. Brain damage affecting specific regions may also influence individuals' DMC (see Damasio's somatic marker hypothesis; Damasio, 1998; Dunn et al., 2006), although this was not investigated in this study. These factors may help to explain why some patients who lacked capacity performed adequately on the QuickSort, and vice versa, which impacted on the LRs for a few individual scores. Categories were therefore created to highlight a more general pattern in the LRs, whereby the likelihood of *lacking* LS-DMC increased with low QuickSort scores and reduced with high scores. Score categories may not have been required if a larger sample was examined because the impact of patients who did not conform to the general pattern would be counteracted by a greater number of patients who did. Larger samples could be achieved by collecting data over-time using electronic health records and routinely using the QuickSort, when interviewing patients with questionable LS-DMC.

In conclusion, the QuickSort is freely accessible and provides a more time-efficient and sensitive source of information regarding an inpatient's LS-DMC, compared to the MMSE or FAB, making it a viable alternative cognitive screen in settings where clinical resources are limited. The likelihood that a patient *lacked* LS-DMC increased in a clinically meaningful way when QuickSort scores were <2 and reduced substantially when they were ≥13. Moreover, the accuracy of detecting those *lacking* capacity increased when modelling additionally took into account the local prevalence of older adults *lacking* LS-DMC.

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7.9 Declaration of conflicting interests

The QuickSort is free. The authors have no conflicts of interest to report.

7.10 Study 5 Reference list

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Chapter 8

Discussion and conclusion

8.1 Overview

This thesis involved the development and validation of a new cognitive screen – the QuickSort – using a systematic and rigorous approach. The project commenced with a meta-analysis to determine whether sorting tests are able to detect cognitive decline in older adults (Chapter 3). Having established that they could, the goal was to combine the best aspects of existing sorting tests with additional innovative design features in order to make the QuickSort briefer and better-suited for use with a wider range of older adults than existing sorting tests and other cognitive screens (Chapter 4). In addition, it aimed to develop an iPad compatible version – the QuickSort-e – in order to make administration and scoring easier, and to support the electronic sharing and storage of test results (Chapter 5). The remaining studies were designed to investigate the clinical utility and psychometric properties of the QuickSort, including its user-friendliness, administration time, reliability, and accuracy for detecting cognitive impairment in older community-dwelling adults and hospital inpatients (Chapter 6). Lastly, the QuickSort was applied to a more complex clinical scenario, namely the provision of preliminary information for use when older inpatients' capacity to make independent and informed lifestyle decisions is called into question (LS-DMC; Chapter 7). Although the main focus of this research revolved around the QuickSort and its potential use as a cognitive screen, the findings from this thesis have broader implications regarding the effectiveness of sorting tests for detecting neurodegenerative disorders in older adults, differentiating between the different types of dementia, screening older adults for cognitive decline, and assessing LS-DMC. This chapter provides an overview of the studies in this thesis and their clinical implications, discusses the limitations of the research, and makes suggestions for future research.

8.2 Study findings and clinical implications

Chapters 1 and 2 provided a context for developing the QuickSort by reviewing the ever-increasing demand for brief cognitive screens that are suitable for use with older adults and the limitations associated with the most commonly-used screens. As the number of people living longer increases, so too does the prevalence of neurodegenerative disorders and associated cognitive decline (Hou et al., 2019; Erkkinen et al., 2018). Ideally, this decline needs to be detected early to prolong and improve the lives of affected individuals (Livingston et al., 2020). However, healthcare settings often have limited clinical resources to conduct thorough cognitive assessments, making them more reliant on self-reports of cognitive decline, which may be unforthcoming or inaccurate (Olivari et al., 2020). Cognitive screens are therefore commonly used as a brief and objective means by which to detect cognitive decline in older adults (Lam et al., 2019).

Even relatively short cognitive screens, such as the MMSE, FAB, MoCA and ACE, involve the administration of multiple tasks, which can exceed the limited time available in many healthcare settings (Pink et al., 2018). Some multi-task screens also involve a financial cost to the user (e.g., MMSE, MoCA) and their reliability and accuracy for detecting cognitive decline have been questioned (for reviews see Larner, 2013; Summers et al, 2019). Tests of executive functioning may provide an alternative to multi-task cognitive screens because they draw on multiple cognitive abilities (Jewsbury et al., 2016), with tests that require examinees to inhibit automatic responses – such as sorting tests – being particularly useful for detecting dementia and mild cognitive impairment in older adults (Rabi et al., 2020). Given the increased demand for cognitive screens, this thesis examined the potential for a newly developed sorting test – the QuickSort – to be used when screening older adults for cognitive decline and those lacking LS-DMC.

8.2.1 Study 1: A meta-analysis examining the effectiveness of sorting tests for detecting the cognitive decline associated with neurodegenerative disorders in older adults

Study 1 (Chapter 3) synthesized the evidence from 142 studies that compared the sorting test performance of older adults who had been diagnosed with a neurodegenerative disorder to that of their healthy peers, in order to determine whether (and how well) these tests could detect cognitive decline. Poorer sorting test performance was consistently observed in older adults with a neurodegenerative disorder, including disorders that have pronounced physical symptoms (e.g., Parkinson's disease, motor neuron disease) and more subtle cognitive decline (mild cognitive impairment). Sorting test performance was poorest in people with dementia, consistent with their prominent cognitive symptomology. Of the different scores that could be obtained from sorting tests (Category, Total, Perseveration, Error and Description), the Category score, which measures the number of categories correctly sorted, and the Description score, which assesses a person's ability to articulate the category or rule underpinning their correct sort, proved to be particularly effective for detecting dementia (g = -2.12 & g = -2.22, respectively). Overall, this study concluded that sorting tests were very effective for detecting the cognitive decline associated with neurodegenerative disorders in older adults.

Notably, this meta-analysis found that, although sorting tests are often used by clinicians to differentiate between AD and bvFTD (American Psychiatric Association, 2013; Musa et al., 2020; Possin et al., 2013), older adults diagnosed with bvFTD did not perform more poorly than those with AD on these tasks. This finding may be attributable to fact that persons with AD also often experience problems with executive functioning (Guarino et al., 2019); something that has tended to be downplayed due to the emphasis on memory problems (Binetti et al., 1996; Mega et al., 1996). Like many tests of executive functioning, sorting tests also draw on multiple cognitive abilities, including memory (Floyd et al., 2010; Jewsbury & Bowden, 2017; Schneider & McGrew, 2018), which is another possible

explanation for why AD and bvFTD perform similarly on such tests. The findings from this meta-analysis therefore suggest that, although sorting tests are able to detect cognitive decline in persons with bvFTD and AD, they should *not* be used to differentiate between these two types of dementia.

Clinicians often report the findings from tests of executive functioning (e.g., sorting tests) and compare them to tests of other cognitive abilities; the underlying assumption being that they assess a distinct construct (Ikeda et al., 2004; Jewsbury & Bowden, 2017). This is consistent with the DSM-5, which also describes executive tests separately from other cognitive tests (American Psychiatric Association, 2013). However, given mounting evidence to suggest that executive functioning may not be a distinct construct (McGrew; 2009; Schneider & McGrew, 2018; Wang et al., 2016), it may be more accurate for clinicians to describe executive tests, such as sorting tests, as 'higher-order' or 'multi-cognitive' tasks in order to more accurately reflect the fact that they assess many cognitive abilities.

Also important, was the finding that the briefest sorting test – the Weigl – proved to be most effective for detecting dementia (g = -2.66). The Weigl is typically quicker to administer than the MMSE, which is one of the most widely-used cognitive screens (Creavin et al., 2016; Sheehan, 2012; Tsoi et al., 2015), and appears to be just as effective for detecting dementia (Mitchell, 2009). However, the Weigl is rarely used for screening purposes because the test materials are somewhat difficult to access (the 12 stimuli of varying shapes and colours that are specified in the published articles are not available from a test publisher), the scoring procedures are complex (scores differ for sorts that are spontaneously correct, correct after the examiner provides clues, incorrect, and correctly explained when the examiner makes a sort), there is limited data regarding its reliability, and only a few studies report its sensitivity and specificity for detecting cognitive decline in older adults (Beglinger et al., 2008; Goldstein & Scheerer, 1941; Hobson et al., 2007; Weigl, 1927). Thus, these limitations need to be addressed in order for the Weigl, or a similar sorting test, to be an effective screen for detecting cognitive decline in older adults.

8.2.2 Study 2 & 3: Developing a brief new cognitive screen – the QuickSort & QuickSort-e

Study 2 (Chapters 4 & 5) outlined the development of the QuickSort, which integrated the best scores from existing sorting tests (the Category and Description scores) for detecting the cognitive decline that is associated with the common neurodegenerative disorders in older adults, especially dementia. Although it appears simple to examinees because they are asked to sort and explain familiar categories (colour, shape and number), additional trials, specific prompts, and scoring rules cover all response contingencies and enable the QuickSort to capture different levels of cognitive impairment. The QuickSort was specifically designed to be quicker than existing measures, with an early discontinue rule for intact performances and less stimuli to sort than the Weigl. Additionally, the QuickSort is better-suited for use with a wider range of older adults than existing screens, including those with verbal expression difficulties, low English proficiency (their sorting performances can be interpreted without them explaining the sorting categories) and severe cognitive impairment (those who find the test too difficult to complete can have their remaining trials scored as errors). Examinees who tend to respond in a perseverative or inflexible manner may also be detected on the QuickSort if they repeat sorts or are unable to explain the sorting categories in a concise manner. Thus, the QuickSort was designed to appear simple to examinees, quickly exclude older adults who are cognitively-healthy, and accommodate a wide range of older adults with varying levels of communication and cognitive difficulties.

The stimuli, manual and record form for the QuickSort are available to clinicians in the supplementary material provided for an article by Foran, Mathias & Bowden (2021) in order to improve accessibility, which has been a problem with some existing sorting tests. Additionally, all the administration and scoring procedures are provided on a single A4 record form in order to enhance the user-friendliness of the QuickSort. This record form uses a series of arrows to guide clinicians on its scoring, making it less complicated than the

Weigl. However, the administration and scoring of the QuickSort are quite complicated, which is a shortcoming.

Recognising that the QuickSort administration and scoring procedures are quite complex, an iPad compatible version – known as the QuickSort-e – was developed in Study 3 (Chapter 5). The QuickSort-e simplified the administration and scoring procedures by automatically determining whether an examinee has made a correct or incorrect sort and then providing clinicians with the next instruction or prompt, based on that determination. It also instantly scores an examinees' performance and compares that person's scores to their cognitively-healthy peers, thereby helping to identify cognitive decline (Bowden, 2017; Strauss, 2006). The QuickSort-e also removes the need for physical stimuli and paper record forms, improving the ease of administration. It also provides all necessary instructions and information to assist clinicians in its use, removing the need for a hard copy of the manual. Moreover, QuickSort records can be shared with other clinicians electronically, which may help with the continuity of patient care. These patient records are also stored in a local database to assist with audits of local healthcare services and research into the QuickSort. Although it is currently considered a prototype, the QuickSort-e can be downloaded on iOS devices to approved users via the TestFlight app (which is freely available from the Apple store). Thus, the QuickSort and QuickSort-e were specifically designed for use in healthcare settings where there is a need to screen large numbers of older adults for cognitive decline, but there are limited clinical resources to do so.

8.2.3 Studies 4 & 5: Using the QuickSort & QuickSort-e to screen older adults

Studies 4 and 5 (Chapters 6 & 7) examined the usefulness of the QuickSort for detecting cognitive decline and providing preliminary information regarding older adults' LS-DMC. A focus group of nine neuropsychologists evaluated whether the QuickSort was user-friendly prior to undertaking these studies. Additionally, the inter-rater reliability of the

QuickSort was confirmed by having three registered psychologists score 15 videoed performances. The QuickSort was then administered to 187 community-dwelling older adults and 78 older hospital inpatients who were referred for neuropsychological assessment. A cognitively-healthy subsample, consisting of community-dwelling older adults (normative sample; *n* = 115), found that the QuickSort was quick (it was completed in less than two minutes) and easy for most older adults (most achieved perfect scores). The QuickSort also proved to be reliable, with test scores being consistent between clinicians (inter-rater reliability) and over time (test-retest reliability). Thus, the QuickSort provided a quick, easy and reliable cognitive screen when used with older adults.

The computerized version of the QuickSort – the QuickSort-e – was also found to be very brief to administer and score. Older adults who were given both versions of the QuickSort had similar scores, which suggested the reliability and interpretation of the QuickSort-e should be comparable to the hard-copy version. In addition, older adults who had not previously used a touch screen/iPad found the QuickSort-e easy to use. The QuickSort-e is currently considered a prototype and underwent only preliminary investigations in this thesis because the software was being developed in parallel to research examining the validity of the hard-copy version of the test. Thus, the QuickSort-e is like the hard-copy version, but it is easier to administer, score, share patient information and keep records, making it a more useful cognitive screen.

Study 4 (Chapter 6) examined the accuracy of the QuickSort for detecting cognitive decline in older adults. Base-rates were calculated to compare an older adult's QuickSort Total and Sorting scores to that of their cognitively-healthy peers (the normative sample) in order to determine whether their performance was common or unusual (Strauss, 2006). This approach to detecting cognitive decline is popular in psychological assessments because it provides information that can be readily understood by both clinicians and patients. For example a QuickSort Total score of 4 can be interpreted as impaired because it was seen in only 2% of cognitively-healthy older adults. Although useful, base-rates are

rarely used to interpret screening test scores because they are not often published and take time to compute (Bowden, 2017). The QuickSort-e addresses this by automatically calculating the base-rates for older adults' test scores, thereby improving the accuracy with which scores are interpreted and highlighting another advantage of the computerized version of this cognitive screen.

Cognitive screens are most often interpreted using cut-scores that quickly classify patients as cognitively 'impaired' or 'not-impaired', based on their score being below or above a predetermined score (Carson et al., 2018). A QuickSort Total cut-score of <10 detected impairment on the MMSE, FAB or both of these screens with good sensitivity (82%) and specificity (78%). However, in keeping with other cognitive screens, scores on either side of the QuickSort Total cut-score provided limited diagnostic information (McGee, 2018), and grouping scores into low, middle and high categories provided more useful information. The likelihood of impairment on either the MMSE or FAB, or both screens increased substantially (by a factor of 9.26) for low QuickSort Total scores (<2) and reduced (by a factor of 0.16) for high QuickSort Total scores (≥17). Despite there being a large number of scores in the middle category that provided limited information, these QuickSort Total score categories were deemed clinically useful because cognitively-healthy older adults did not have scores in the lowest score category, and over half had scores in the highest category.

Study 4 demonstrated that the QuickSort was most accurate when Total scores were interpreted according to how much they increase or decrease a person's likelihood of cognitive impairment, in combination with the prevalence of impairment on the MMSE and FAB in the local healthcare service. For example, a patient who has a QuickSort Total score of 5 in a setting where 50% of patients are impaired on the MMSE and FAB, has an 85% likelihood of being impaired on these lengthier cognitive screens. Overall, Study 4 found that, in addition to the QuickSort and QuickSort-e being brief and easy for most older adults to complete, its high and low scores could accurately detect cognitive decline. Thus, the

QuickSort and QuickSort-e may detect a wider range of older adults with cognitive decline in a shorter amount of time than existing screens.

Study 5 (Chapter 7) built on the previous study by using the QuickSort in the complex clinical scenario involving the early identification of older adults who were at risk of lacking LS-DMC. This scenario is becoming more common given the increasing prevalence of neurodegenerative disorders and associated cognitive decline, which can affect LS-DMC (Moye et al., 2013). Clinical interviews that incorperate cognitive screens are commonly used in healthcare settings that have limited clinical resources to provide preliminary information regarding a patient's LS-DMC and to identify those requiring more comprehensive assessments (Pachet et al., 2010; Shibu et al., 2020). Study 5 investigated a consecutive series of older inpatients (*n* = 124) who had undergone comprehensive neuropsychological LS-DMC assessments, 63% of whom were deemed to lack LS-DMC by the medical and neuropsychological teams. The study highlighted the importance of early investigations into LS-DMC, given that inpatients who lacked LS-DMC were hospitalized up to five times longer, and were twice as likely to be readmitted to hospital, than other older inpatients (Basic & Khoo, 2015; Crijns et al., 2018), placing them at a higher risk of hospital-acquired infections and death (Bai et al., 2019). Early assessments of inpatients who are at risk of lacking LS-DMC may therefore help to reduce the length and frequency of their hospital admissions and, in turn, result in healthcare savings.

Study 5 (Chapter 7) also found that cognitive screens were useful for providing preliminary information regarding a patient's LS-DMC because the MMSE, FAB and QuickSort differentiated between those who lacked/did not-lack LS-DMC better than a range of other patient characteristics (including demographic, relationship status, living supports at admission, history of stroke, dementia, delirium, alcohol use, and challenging behaviors). Of the cognitive screens, the QuickSort was the best for providing preliminary information regarding inpatients' LS-DMC. A cut-score of <13 had good sensitivity (88%), but poor specificity (34%), suggesting the QuickSort provided a viable alternative to lengthier

cognitive screens in healthcare settings that need to prioritize the detection of inpatients who lack LS-DMC. Low (<2) and high (≥13) QuickSort Total scores provided more accurate information than this cut-score because they increased or reduced the likelihood that a person lacked LS-DMC substantially (by a factor of 65.26 and 0.32, respectively). The QuickSort was most accurate when a Total score was interpreted according to how much it increased or decreased the likelihood of an inpatient lacking LS-DMC, in combination with the prevalence of inpatients' who lacked LS-DMC in a specific healthcare service. For example, where there was a high prevalence of inpatients who lacked LS-DMC (58%), a patient's probability of lacking LS-DMC increased to 99% with scores less than two and reduced to 30% with scores 13 and above. The QuickSort may provide useful information regarding an inpatient's likelihood of lacking LS-DMC and the risks associated with them being discharged without an assessment, which may be particularly helpful in Australia where patients often wait for a long time before receiving a neuropsychological assessment (Wong, et al 2022).

In summary, Studies 4 and 5 found that the QuickSort provides time-efficient and sensitive information that can detect older adults with cognitive decline and provide preliminary information regarding their LS-DMC. Although these studies focused mainly on the QuickSort because the software development for the QuickSort-e was done in parallel with Study 4 and 5, preliminary investigations suggested the original hard-copy and computerized versions are comparable. The QuickSort and QuickSort-e may facilitate more routine cognitive screening for older adults because clinicians, older community dwelling adults, and inpatients found both versions easy to use. Additionally, a wider range of older adults can be screened in less time using the QuickSort and QuickSort-e than many other cognitive screens (e.g., MMSE and MoCA), which may result in healthcare savings. Most importantly, these efficiencies and the accuracy with which the QuickSort and QuickSort-e detect cognitive decline and those at risk of lacking LS-DMC may mean that affected older

adults are detected earlier, when interventions and supports may be able to prolong and improve their lives.

8.2.4 Implications for screening older adults for cognitive decline

The studies in this thesis provide broader insights into screening older adults for cognitive decline and some of the associated complications (such as lacking LS-DMC) in healthcare settings that have limited clinical resources. Test developers could make some existing tests quicker by having an early-discontinuation rule for people who are cognitively intact. In addition, test developers could make cognitive tests and screens more suitable for use with a wider range of older adults by having scores that can be computed for those with verbal communication difficulties, low English proficiency and severe cognitive impairment. Currently, multi-task screens, such as the MMSE and FAB, are the most popular method of screening for cognitive decline, however the current studies found that a brief single test of executive functioning could detect cognitive decline with equivalent accuracy and proved to be more useful in a complex clinical scenario where information regarding a person's LS-DMC was required.

Computerization may be able to improve cognitive screening by making tests easier to administer and score. In addition, they can share test scores electronically, which may assist with the continuity of patient care, and keep test records for auditing healthcare services and conducting research. Cognitive screens that use touch screens should also be suitable for most older adults, even those who have not previously used an iPad. Arguably the greatest advantage of computerized cognitive screens is their potential to assist clinicians in making accurate interpretations of tests scores by instantaneously calculating base-rates and the likelihood or probability that a patient is cognitively impaired (Centre for Evidence-Based Medicine, 2018; Roebuck-Spencer et al., 2017). Thus, a brief computerized executive test may be able to detect more older adults with cognitive decline in less time than existing cognitive screens.

8.3 Limitations and future research

The specific limitations of the individual studies have been addressed in Chapters 3 to 7, consequently the following discussion focuses on the broader limitations of this thesis.

A major limitation was that most of the older adults that were assessed achieved either low or high QuickSort scores. Many fewer people scored in the middle range, limiting the diagnostic usefulness of these scores. A larger sample is now needed to provide a better spread of scores and to improve their diagnostic utility. With larger samples, it should be possible to interpret individual QuickSort scores (rather than score categories) in terms of the likelihood that an older adult was cognitively impaired or lacked LS-DMC.

Unlike other popular cognitive screens, the QuickSort was not used to differentiate between those with and without dementia (see Chapter 2). Instead, Study 4 (Chapter 6) used the QuickSort to differentiate between older adults with and without cognitive impairment, which was determined using the cut-scores for the MMSE and FAB. However, the scores either side of the MMSE and FAB cut-scores can be achieved by both cognitively impaired and non-impaired individuals, meaning there was likely to be some cognitively impaired individuals in the non-impaired group and vice versa (McGee, 2018; Pachet et al., 2010). Similarly, in Chapter 7 (Study 5) the QuickSort differentiated between those lacking and not-lacking LS-DMC, but the group that did not-lack LS-DMC contained inpatients whose assessments were inconclusive. Consequently, in both studies, some participants were likely to have been misclassified and this may have detrimentally impacted on the diagnostic accuracy of the QuickSort scores. Therefore, future research should use the QuickSort to differentiate between more clearly defined groups, namely those who meet the diagnostic criteria for dementia and cognitively-healthy controls. In addition, it is recommended that a popular cognitive screen (e.g., the MMSE) is included in such a study so that the diagnostic accuracy of the QuickSort can be objectively compared to this measure.

Although the accuracy of interpreting a person's QuickSort score improved when the local prevalence of impaired cognition and those who lacked LS-DMC were considered, this interpretation involved only two types of information (prevalence rates and the how much a QuickSort Total score increased or decreased the likelihood of impaired cognition or compromised LS-DMC). Other information may further improve the accuracy of interpreting the QuickSort. For example, using local prevalence rates for people from different educational and occupational backgrounds may provide a more accurate estimate of a person's likelihood of cognitive impairment and lacking LS-DMC because demographic factors are known to influence cognitive performance (Crum et al., 1993; Strauss, 2006). Likewise, considering a person's depression, anxiety and stress levels (e.g., scores on the Depression, Anxiety and Stress Scale) may also improve the accuracy of the QuickSort for detecting cognitive impairment because low mood can detrimentally impact cognition and is associated with cognitive decline (Hommel et al., 2020; Kuring et al., 2020).

The detection of older adults with cognitive impairment and those lacking LS-DMC may also be improved by combining a patient's QuickSort score with other cognitive test results (e.g., their performance on a speed of processing task) because composite test scores are typically more accurate than individual test scores (Bowden, 2017). It may also be useful to interpret QuickSort scores in combination with other clinical information, such as previous hospital admissions or LS-DMC assessments, which may place people at an increased risk of having impaired cognition and lacking LS-DMC. Thus, future research should evaluate whether the accuracy of the QuickSort for detecting cognitive decline and providing information regarding older adults' LS-DMC is improved by using prevalence rates for people from different educational and occupational backgrounds and considering additional mood, cognitive and clinical information.

Given the clinical usefulness of the QuickSort was supported by Studies 4 and 5, its impact on patients, clinicians and healthcare services now needs to be examined. Older patients who have been screened or not-screened for cognitive decline using the QuickSort

should be compared to determine if it contributes to differences in patient outcomes (e.g., consumer satisfaction with the healthcare service), clinicians' decision-making (e.g., their confidence in making diagnoses and recommendations), and healthcare resources (e.g., the duration of hospitalization and readmissions to hospital). The QuickSort-e is likely to be very useful for this research because it has an in-built database and instantaneously compares an older adult's performance to their cognitively-healthy peers (it calculates base-rates). Prior to future research, the QuickSort should be updated to additionally calculate how much an older adult's performance increases or decreases the probability that he/she cognitively impaired or lacking LS-DMC in the local healthcare setting (the data for these updates is provided in Studies 4 & 5). These updates will ensure the QuickSort-e is accurately interpreted, which should improve its impact on patients, clinicians and healthcare services.

Cognitive screens that can be administered online, remotely, or via telehealth are currently in much higher demand because of COVID-19 (Emmerton & Abdelhafiz, 2021). The QuickSort-e has the potential to be administered via these remote methods, given the general availability of touchscreen technology (e.g., iPads). However, the QuickSort-e will need to be modified for remote administration to ensure examinee's do not see the examiner-only screens. Additional studies will also be required to determine if this modified version of the QuickSort-e generates equivalent scores to the original hard-copy version (Bowden et al., 2021).

8.4 Conclusion

The QuickSort was developed to meet the growing demand to screen an increasing number of older adults for cognitive decline in healthcare settings where clinicians have limited time and resources. It uses scores from existing sorting tests that proved to be highly effective for detecting the cognitive decline that is associated with the most common neurodegenerative disorders in older adults, especially dementia. The QuickSort was designed to be quicker and better-suited for use with a wider range of older adults than

existing screens. An iPad-compatible version, the QuickSort-e, was additionally created to improve the ease of administration and scoring, reduce training requirements, remove the need for stimuli and record forms, as well as electronically share and store patients' records with view to facilitate continuity of care, clinical audits and research into the QuickSort-e. Although it underwent only preliminary investigations because the software was being developed in parallel to research examining the validity of the hard-copy version, the QuickSort-e appeared comparable to the original version. In its original hard-copy format, the QuickSort is easily accessible and the QuickSort-e can be made available to clinicians and researchers on request. The studies in this thesis found that the QuickSort can be completed by most older adults in less than two minutes, it can reliably detect cognitive impairment and provide preliminary information regarding inpatients' LS-DMC, which makes it a viable alternative to lengthier screens. Thus, the QuickSort and QuickSort-e can accurately screen more older adults for cognitive decline (and its complications, e.g., lacking LS-DMC) in less time than existing screens, which may result in affected individuals accessing interventions and supports earlier.

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Appendix A Supplementary information for Study 1 (Chapter 3)

Appendix A.1: Published Article for Study 1

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Review article

Effectiveness of sorting tests for detecting cognitive decline in older adults with dementia and other common neurodegenerative disorders: A meta-analysis

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ABSTRACT

The demand for simple, accurate and time-efficient screens to detect cognitive decline at point-of-care is increasing. Sorting tests are often used to detect the 'executive' deficits that are commonly associated with behavioural-variant frontotemporal dementia (bvFTD), but their potential for use as a cognitive screen with older adults is unclear. A comprehensive search of four databases identified 142 studies that compared the sorting test performance (e.g. WCST, DKEFS-ST) of adults with a common neurodegenerative disorder (e.g. Alzheimer's disease, vascular dementia, bvFTD, Parkinson's disease) and cognitively-healthy controls. Hedges' *g* effect sizes were used to compare the groups on five common test scores (Category, Total, Perseveration, Error, Description). The neurodegenerative disorders (combined) showed large deficits on all scores (*g* -1.0 to -1.3), with dementia (combined subtypes) performing more poorly (*g* -1.2 to -2.1), although bvFTD was not disproportionately worse than the other dementias. Overall, sorting tests detected the cognitive impairments caused by common neurodegenerative disorders, especially dementia, highlighting their potential suitability as a cognitive screen for older adults.

1. Introduction

The number of older adults with a neurodegenerative disorder is increasing as the population ages (Ecomonics, 2009), with 131.5 million people predicted to be living with dementia by 2050 worldwide (Prince et al., 2015). Cognitive decline is a defining feature of dementia, but is also common in many other neurodegenerative disorders, such as Parkinson's disease and motor neuron disease (Cui et al., 2015; Mihaescu et al., 2019; Muslimovi et al., 2007). Cognitive decline often occurs many years prior to receiving a formal diagnosis (e.g., in Alzheimer's dementia; AD), highlighting the importance of early detection (Bäckman et al., 2005). Indeed, there are multiple benefits to detecting cognitive impairments early in their course, including (i) reduced hospital admissions, readmissions, and outpatient costs (McCarten et al., 2010; Torisson et al., 2013); (ii) lower rates of delirium, morbidity and mortality (Lee. et al., 2008); and (iii) improved psychological and behavioral symptoms, and carer outcomes (McCarten et al., 2010).

Accurate cognitive screens conducted at or near the point-of-care are recommended to assist with the early detection of cognitive decline (Robinson et al., 2015). These screens are designed to be quick and easy to administer, and provide immediate information about a patient's risk of cognitive impairment. Effective screening can, in turn, inform interventions and other investigations, while also facilitating timely diagnoses (Borson et al., 2013; Robinson et al., 2015).

The most common point-of-care cognitive screen is the Mini Mental Status Examination (MMSE), which is quick to administer (8–15 min) and interpret (Folstein et al., 1975; Mitchell, 2013; O'Bryant et al., 2008; Sheehan, 2012). The MMSE detects dementia with 80% sensitivity and 81% specificity in memory clinic settings, but is less accurate when used to assess the cognitive decline associated with Parkinson's disease and mild cognitive impairment (Athey et al., 2005; Hu et al., 2014; Mitchell, 2009). As with other commonly-used screens, such as the Montreal Cognitive Assessment (MoCA) and Addenbrooke's Cognitive Exam (ACE), the MMSE assesses multiple cognitive domains (Mathuranath et al., 2000; Nasreddine et al., 2005). Although this feature is particularly pertinent to dementia because the diagnostic criteria require cognitive decline in two or more domains (e.g. AD; McKhann et al., 2011), it is less relevant when screening older adults for cognitive

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impairment. Instead of domain-specific scores, summary scores are used for screening and those derived from multidomain screens are not necessarily more sensitive than those from single-domain tests (Brodaty and Moore, 1997; Kingery et al., 2011; Larner, 2016; Summers et al., 2019).

Sorting tasks are one example of a single-domain cognitive test. Although often used as part of a comprehensive neuropsychological assessment (Strauss, 2006), they are not included in common cognitive screens, nor are they routinely used when screening older adults for cognitive impairment. Theoretically, sorting tests are thought to assess inductive reasoning but, clinically, they are often described as assessing 'executive' functioning, although the latter construct conflates a number of cognitive abilities (Floyd et al., 2010; Schneider and McGrew, 2018; Strauss, 2006).

Sorting tests assess a person's ability to sort stimuli (e.g., cards) according to specific categories (usually colour, shape, number) and then switch between these categories (Feldman and Drasgow, 1959; Grant and Berg, 1948; Heaton et al., 1993). They are relatively quick to administer (range: 5–25 min.) and score (Strauss, 2006), making them well-suited to point-of-care cognitive assessments. A number of sorting tests have been developed over the years, starting with the Weigl Color-Form Sorting Test, followed by the Berg-Wisconsin Card Sorting Test, the Verbal Visual Test, and the California Card Sort Test, which has since been incorporated into the Delis Kaplan Executive Functioning System (Delis et al., 2001, 1992; Feldman and Drasgow, 1959; Goldstein and Scheerer, 1941;Grant and Berg, 1948). Most of these tests generate composite scores, labelled *Category* scores (number of categories correctly sorted) or *Total* scores (also termed 'global' or 'total correct' scores, tallying the number of successful sorts). Many sorting tests also generate *Perseveration* scores (number of repeated responses after failing to shift category) and *Error* scores (when sorts do not fit a single category) (Delis et al., 2001; Heaton et al., 1993). Some also produce a *Description* score, which assesses a person's ability to articulate the category or rule underpinning their sort (e.g., colour, shape, number, Delis et al., 2001).

Sorting tasks are amongst the most sensitive to brain damage (Delis et al., 1992; Reitan, 1993) and have been used to detect the cognitive decline caused by a variety of neurodegenerative disorders, such as dementia (Byrne et al., 1998), Parkinson's disease (Hobson et al., 2007; Paolo et al., 1996) and amyotrophic lateral sclerosis (Barbagallo et al., 2014; Evans et al., 2015). In particular, sorting tests are often used in the assessment of frontotemporal dementia (FTD) because deficits in reasoning and 'executive' functioning are thought to be a distinguishing feature of FTD (Strauss, 2006). Perseverative speech has additionally been reported in behavioural-variant FTD (bvFTD), with the Perseveration score provided by some sorting tests potentially measuring this characteristic (Strauss, 2006). Sorting tests have therefore been used by clinicians to differentiate between AD and FTD, despite limited research support for this practice (Hutchinson and Mathias, 2007; Roca et al., 2013).

Research comparing the sorting test performance of older adults who have a neurodegenerative disorder to that of cognitively-healthy peers is now quite extensive. However, the collective findings have yet to be evaluated. Consequently, our understanding of whether the most common neurodegenerative disorders perform differently on these tests, and whether a specific test best detects the cognitive decline associated with these disorders, is limited. The current meta-analysis therefore examined whether sorting scores differentiate between older adults with a neurodegenerative disorder and their cognitively-healthy peers in order to assess the potential usefulness of sorting tests as a cognitive screen in point-of-care settings. Only the most common older-age neurodegenerative disorders were considered, namely, Parkinsonian disorders (PD), motor neuron disease (MND), mild cognitive impairment (MCI), and 'other' disorders (human immunodeficiency virus [HIV], normal pressure hydrocephalus [NPH], multiple sclerosis [MS], Huntington's disease [HD]), as well as the most common dementia subtypes (AD, bvFTD, vascular [VaD], lewy body [LBD], semantic [SD], primary progressive aphasia [PPA], and not otherwise specified [dementia NOS]). Dementia was of particular interest because cognitive screens are commonly used to assist with its early detection. Given that deficits in 'executive' functioning are thought to characterise bvFTD, and sorting tests are commonly used to assess these deficits, this dementia subtype was a specific focus.

2. Method

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (see Supplementary Table S1 for PRISMA checklist; Moher et al., 2009).

2.1. Search strategy and eligibility criteria

The EMBASE PsycINFO, PubMed, and Scopus databases were searched for research published prior to November 1, 2017 that compared the sorting task performance of older adults who were diagnosed with a neurodegenerative disorder to cognitively-healthy controls. The searches were formulated under the guidance of a specialist research librarian. Both general and specific search terms were used to ensure that lesser-known tests and secondary study measures were captured (see Supplementary Table S2 for logic grids).

All studies had to meet the following criteria to be included in this meta-analysis (1) cognitive functioning was assessed using a published sorting test; (2) samples of older adults (mean age +1SD > 59 years) were recruited, one of which was diagnosed with a neurodegenerative disorder (PD, MND, MCI, HIV, NPH, MS, HD, AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and the other comprising a cognitively-healthy control group; (3) data enabling the calculation of Hedges' *g* effect sizes were provided (e.g., means & SDs, *t*-test or one-way ANOVA, exact *p*-value); and (4) the study was published in English. The first author screened all studies for eligibility, with the second and third authors additionally reviewing studies where eligibility was questionable, after which a consensus decision was made.

Eligible sorting tests were classified as one of the following (1) the Weigl Color-Form Sorting Test (Weigl; Goldstein and Scheerer, 1941; Weigl, 1941), which included the modified Weigl (Beglinger et al., 2008); (2) the Wisconsin Card Sorting Test (WCST; Grant and Berg, 1948), which also included the Berg Card Sorting Test (Berg, 1948) and modified WCST (Nelson, 1967); (3) the Verbal Visual Test (VVT; Feldman and Drasgow, 1959); and (4) the Delis Kaplan Executive Functioning System Sorting Test (DKEFS-ST; Delis et al., 2001), including its predecessor, the California Card Sort Test (Delis et al., 1992). The five most common score-types were examined, namely, Category scores (number of categories correctly sorted); global or Total scores (total number of correct trials); Perseveration scores (number or percentage of perseverations); overall Errors (number or percentage); and Description scores (number of times the underlying category or rule was correctly identified).

Studies were excluded from this meta-analysis if (1) the sorting test was used to diagnose the neurodegenerative disorder (i.e., to avoid criterion-contamination, the sorting test could not be both a diagnostic and outcome variable), or (2) study authors did not provide sufficient details regarding the sorting test or score that was used.

Meta-analyses require all data to be independent. Corresponding authors of studies that examined the same neurodegenerative disorder and were published within the past ten years were therefore emailed to determine if there was any overlap in their samples (response rates were found to be negligible for older studies). Where authors failed to respond, or could no longer be located, a conservative approach was taken whereby studies were assumed to be non-independent and only data from the largest sample in the most recent publication were analysed.

2.2. Data extraction and coding

The following data were extracted from each study using a standardized template that recorded (1) study details (author, publication year, country); (2) information about the neurodegenerative disorder (type, diagnostic criteria, disease duration); (3) method by which controls were screened to ensure that they were cognitively-healthy (e.g. interview, MMSE); (4) type of control (significant other, other patient group, mixed); (5) recruitment sources for both the neurodegenerative disorders and controls (community, primary care, outpatient clinic, inpatient, other source, not specified); (6) participant selection (random, consecutive, convenience, retrospective, matched, not specified); (7) study-specific selection criteria (e.g., exclusion of participants with psychiatric or other neurological disorders); (8) demographic details (age, gender, education); (9) cognitive screening scores (e.g., MMSE, FAB); and (10) sorting test scores for the neurodegenerative and control groups.

If participants were assessed on multiple occasions, only baseline or pre-treatment scores were recorded. Where studies provided subgroup data that were not relevant to this study (e.g., males and females), the data were combined. Means and standard deviations were estimated from medians or ranges for demographic data using the method recommended by (Hozo et al., 2005). Standard deviations were calculated from standard errors or confidence intervals (CIs), as required (Hedges, 1985).

2.3. Study risk-of-bias

Poorly conducted studies are more likely to produce low-quality or biased data, making it important to assess potential sources of bias (Spencer & Brassey, 2017). Four aspects of study methodology that were of specific interest to the current meta-analysis – representative sampling, diagnostic verification, sample attrition and study blinding – were therefore assessed using items from the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) and Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) statements (Von Elm et al., 2007; Whiting et al., 2011). However, blinding was rarely employed because many neurodegenerative disorders 'unblind' themselves (due to their overt symptoms) and the sorting test was rarely the primary focus of the research, making it necessary to exclude this criterion. Thus, low risk-of-bias was determined on the basis of the remaining three aspects of study methodology (see Supplementary Figure S1 for details of this assessment). First, to have representative sampling, the neurodegenerative group had to be recruited randomly or consecutively and the age and education of the controls had to be reported or matched to the clinical sample. Second, for diagnostic verification, the neurodegenerative disorders had to be diagnosed using published criteria (e.g., NINDS-ADRDA for AD; see Supplementary Table S3 for accepted diagnostic criteria) or, prior to this, the diagnostic criteria were clearly stated. Third, for sample attrition, there could not be any unexplained attrition that affected the sorting test data. Studies were classified as having either low risk-of-bias, if the information they provided met all three criteria, or high or unknown risk-of-bias, if they did not meet these criteria or failed to provide the information needed to make a determination. The inter-rater reliability of the risk-of-bias classification was tested by having the first and third authors independently rate a randomly selected sample of 10% of studies, which yielded an inter-rater reliability of $r = .80$.

2.4. Data analysis

Effect sizes were calculated using Comprehensive Meta-Analysis Version 3.3 (CMA; 2006 Biostat Inc., Engelwood, NJ, USA) and forest plots were created using Metadata viewer (Boyles et al., 2011). Hedges' *g* effect sizes were calculated using a random-effects model to determine whether the sorting test scores of the neurodegenerative and cognitively-healthy control groups differed. A negative *g* indicated that persons with a neurodegenerative disorder performed more poorly (i.e., lower Category, Total or Description scores; higher Perseveration or Error scores), with values of $g = .2, .5, .8, 2.0$ and 4.0 equating to small, medium, large, very large and extremely large effects, respectively (Hopkins et al., 2009). A probability (p) value $< .05$ was used to assess statistical significance. Between-study heterogeneity in the effect sizes was investigated using Q, which assesses the distribution of observed effects; I^2, which reflects the ratio of true effect to error variance; and Tau^2, which provides an absolute estimate of variance in the true effects (Borenstein et al., 2011).

Subgroup analyses were performed to explore potential sources of heterogeneity in the effects, namely the type of neurodegenerative disorder (PD, MCI, MND, 'other' neurodegenerative disorders [HIV, NPH, MS, HD] and AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and study risk-of-bias (low *vs* high or unknown). Subgroups were deemed to differ significantly if the effect size for one group feel outside of the 95% CIs for the other (Bowden and Finch, 2017).

The next set of analyses focused on dementia because of its particular clinical interest in settings where cognitive screening is frequently conducted. Once again, group differences (all dementias *vs* controls) in each of the five sorting scores were examined and heterogeneity assessed. Subgroup analyses then examined whether the dementia subtype was a significant source of heterogeneity (AD, bvFTD, VaD, LBD, SD, PPA, dementia NOS). Three meta-regressions additionally investigated whether patient education impacted on the dementia subtype findings: (1) all subtypes combined, (2) bvFTD *vs* AD, and (3) FTD *vs* non-FTD. The impact of disease severity was assessed in a further two subgroup analyses: the first compared all of the dementia subgroups and the second compared FTD to all non-FTD dementia because clinicians often want to distinguish between FTD and the other dementias. A final subgroup analysis investigated whether the sorting test itself was a source of between-study variation in the findings for dementia (Weigl, WCST, VVT, DKEFS-ST). Once again, the effect sizes and 95% CIs for each of the subgroups were compared in order to determine statistical significance (Bowden and Finch, 2017). Data permitting, the impact of education and disease severity on the findings was also examined.

Lastly, the potential for publication bias to impact on the findings was assessed using the trim-and-fill procedure (Duval and Tweedie, 2000), if data permitted ($N_{studies} > 3$; CMA; 2006). The Category scores for each neurodegenerative disorder were examined because they were most commonly reported. Missing studies on the right of the funnel plots were of interest (indicative of non-significance or contrary findings [i.e. poorer sorting test performance in controls]). Publication bias was considered inconsequential if there was a trivial difference between observed and adjusted effect sizes or if no studies were trimmed (Borenstein et al., 2011).

3. Results

3.1. Search results

The literature searches identified 9116 studies, 955 of which were duplicates and 7287 were excluded when titles and abstracts were initially screened. A full-text review of the remaining 874 studies revealed that a further 732 did not meet the inclusion criteria, leaving 142 eligible studies (see Fig. 1 for PRISMA chart and Supplementary Table 4 for summary details for each study).

The final sample comprised 11,862 participants, 6172 of whom had a neurodegenerative disorder and 5690 were healthy controls (see Table 1). Overall, the neurodegenerative group was significantly older (mean = 68 years) and had significantly more males (53%) than the heathy controls (mean age = 62 years, 49% males). Educational levels were comparable, with both groups averaging a high school education, although the VaD group was significantly less educated than their controls. The mean MMSE score for the neurodegenerative group (all

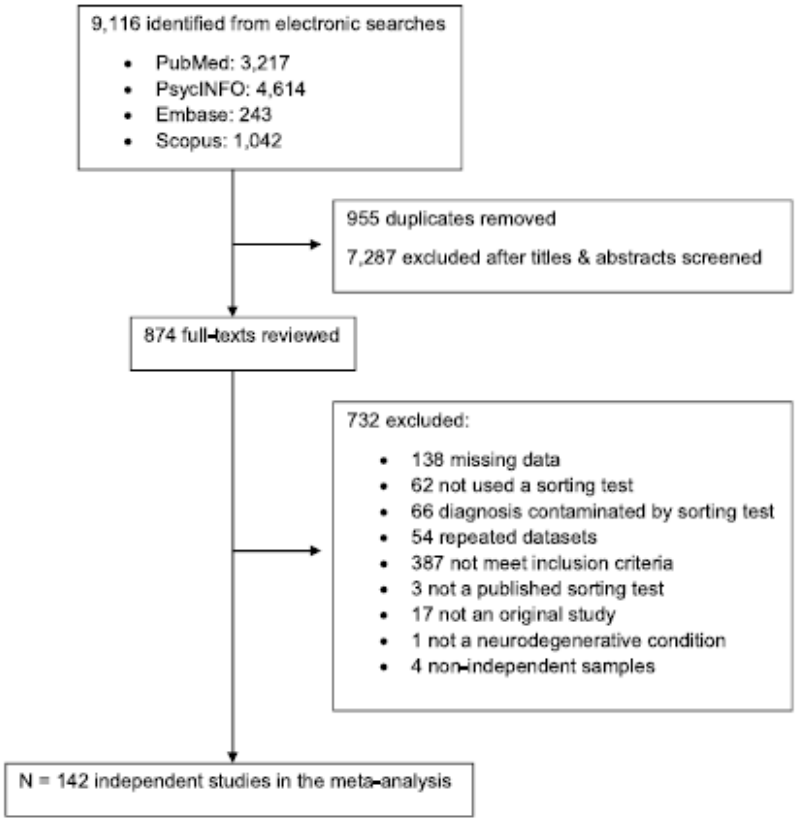

Fig. 1. PRISMA flowchart of search and study review process.

combined) fell above the recommended cut-off for impaired cognition, but the mean FAB score fell just below it (i.e., cut-offs: MMSE < 24; FAB < 12; Hancock and Larner, 2011; Slachevsky et al., 2004, see Table 1). Most of the neurodegenerative samples were recruited from specialist or outpatient clinics and the healthy controls sourced from community or non-specified sources. The WCST ($N_{studies}$ = 127) was the most commonly used sorting test, followed by the Weigl ($N_{studies}$ = 8), DKEFS-ST ($N_{studies}$ = 4) and VVT ($N_{studies}$ = 3), which were used by fewer studies. The Category score ($N_{studies}$ = 108) was the most commonly reported test score, followed by the Perseveration score ($N_{studies}$ = 89), with substantially fewer studies reporting Error ($N_{studies}$ = 44), and Total ($N_{studies}$ = 35) scores, and many fewer providing Description scores ($N_{studies}$ = 3). The most common neurodegenerative diagnoses were Parkinsonian disorders ($N_{studies}$ = 69), followed by AD ($N_{studies}$ = 34), MCI ($N_{studies}$ = 22), MND ($N_{studies}$ = 13), bvFTD ($N_{studies}$ = 9), dementia NOS ($N_{studies}$ = 6), 'other' neurodegenerative disorders ($N_{studies}$ = 6), LBD ($N_{studies}$ = 4), PPA ($N_{studies}$ = 3), VaD ($N_{studies}$ = 2) and SD ($N_{studies}$ = 2).

3.2. Sorting test performance: all neurodegenerative disorders

Table 2 summarises the mean Hedges' *g* effect sizes for the five sorting test scores (Category, Total, Perseveration, Error, Description) for the neurodegenerative disorders (all combined). All five effects were large, in the expected negative direction and significant ($p < .05$), indicating that the sorting test performance of older adults with a neurodegenerative disorder was consistently poorer than their cognitively-healthy peers. Not only was the Category score the most commonly reported, but it was also the most discriminating when all of the disorders were examined together (g = -1.28). Although infrequently used, there was also a large group difference in the Description score (g = -1.11). Similarly, the Total, Perseveration and Error scores showed large differences. Notably, however, significant heterogeneity remained for all five scores. Subgroup analyses therefore examined whether the (1) type of disorder and (2) study risk-of-bias contributed to this heterogeneity.

3.2.1. Subgroup analyses: disorder type and risk-of-bias

As seen from the significant *Q* statistics in Table 2, disorder-type accounted for a significant amount of the variance in the Category, Total and Perseveration scores, but not the Error or Description scores. This variation is illustrated in Fig. 2, which provides forest plots for each of the five scores, separated by disorder-type (data permitting). Notably, the dementias, which have cognitive decline as a primary symptom, had larger effect sizes than those disorders where cognitive decline is often secondary to other symptoms. For example, people with AD performed significantly worse than persons with PD on the Category, Total, Perseveration and Error scores (i.e., Hedges' g for the AD group fell outside the 95% CIs for PD). However, with the exception of the Description score, significant residual heterogeneity remained for many disorders ($p < .05$), indicating that disorder-type did not adequately account for all of the variation in findings (see *Q* statistics in Fig. 2).

Next, subgroup analyses examined whether the risk-of-bias ratings contributed to the heterogeneity in the sorting scores of older adults with a neurodegenerative disorder (all combined). When the findings from the 19 studies that were rated as having a low risk were compared to the 123 studies that had a high or unknown risk, it was found that risk-of-bias accounted for a significant amount of heterogeneity in the Category and Perseveration scores, but not on the Total, Error or Description scores (see *Q* statistics in Table 2). As seen in Fig. 3, the low risk studies reported significantly smaller effect sizes for the Category and Perseveration scores than the high or unknown risk-of-bias studies (i.e., Hedges' g for the low risk-of-bias studies fell outside the 95% CIs for high or unknown risk). However, there was significant residual heterogeneity in the Category and Perseverative scores (significant *Q*

Table 1
Summary demographic information for the meta-analysed studies.

	Neurodegenerative Disorder			Controls				
	$N_{studies}$	$N_{participants}$	*M (SD)*	$N_{studies}$	$N_{controls}$	*M (SD)*	t/χ^2	*p*
Total sample	142	6172		142	5690			
age	141	5998	67.4 (6.7)	133	5467	65.3 (6.9)	2.5	.01
sex (M/F)	114	2607/2297		112	2413/2526		18.2	.00
education	116	5510	11.7 (3.1)	112	3707	12.2 (2.7)	1.3	.21
disease duration	53	2188	68.9 (57.0)					
MMSE	89	4012	24.7 (4.1)	81	3945	28.4 (2.1)	8.2	.00
FAB	6	404	11.8 (2.7)	5	232	16.0 (1.0)	3.4	.00
Recruitment source								
community	5	498		45	2939			
primary care	0	0						
outpatient clinic	103	4426						
inpatient	1	17						
other source	2	314						
unstated	31	917		48	1015			
Type of control								
significant other				17	655			
other patients				12	333			
mixed controls				20	748			
Sorting Test								
Weigl	8	638		8	414			
WCST	127	5088		127	5053			
VVT	3	132		3	166			
DKEFS-ST	4	314		4	57			
Test score								
Category	133	4227		133	4563			
Total	43	1837		43	1089			
Perseverations	106	3525		106	3785			
Errors	46	1871		46	2391			
Description	7	250		3	99			
Parkinsonian conditions								
age	69	2400	65.6 (4.2)	65	2269	61.5 (8.6)	3.5	.00
sex (M/F)	53	1131/774		52	1022/1018		34.2	.00
education	55	2019	11.8 (2.8)	54	1619	12.2 (2.9)	0.7	.47
disease duration	36	1337	91.2 (60.7)					
MMSE	35	1352	27.6 (1.2)	35	1452	2853 (0.6)	4.0	.00
FAB	2	133	15.3 (0.3)	2	117	16.7 (0.1)	6.3	.07
Motor neuron disease								
age	13	547	59.7 (2.7)	13	421	59.5 (3.1)	0.2	.86
sex (M/F)	13	329/209		11	215/169		2.5	.12
education	9	473	11.2 (3.2)	8	327	11.2 (1.9)	0.0	1.00
disease duration	8	423	25.6 (9.3)					
MMSE	6	151	24.8 (1.4)	7	151	25.9 (1.3)	−0.3	.76
FAB	1	21	16.4	1	21	17.2		
Mild cognitive impairment								
age	22	890	70.1 (4.7)	21	1154	62.1 (10.0)	3.3	.00
sex (M/F)	19	320/380		19	488/589		0.0	.87
education	20	814	12.1 (2.7)	20	693	12.9 (2.6)	1.0	.35
MMSE	19	819	27.2 (1.1)	20	1136	28.8 (0.4)	6.0	.00
FAB	1	6	12.8	1	11	14.9		
Other neurodegenerative conditions								
age	6	193	59.5 (10.7)	5	190	62.6 (10.6)	0.5	.64
sex (M/F)	5	102/63		5	108/82		0.9	.34
education	4	145	11.3 (3.0)	4	152	11.4 (2.8)	0.5	.96
disease duration	2	84	67.7 (49.7)					
MMSE	1	64	21.8	1	58	28.5		
FAB	1	64	11.5	1	58	15.6		
Alzheimer's disease								
age	34	1225	73.0 (4.2)	34	1393	63.2 (9.5)	5.5	.00
gender (M/F)	27	418/573		26	524/698		0.1	.74
education	33	1119	11.0 (2.6)	32	902	12.2 (2.7)	1.8	.07
disease duration	6	188	35.6 (6.2)					
MMSE	29	1079	20.8 (2.9)	26	1192	28.8 (0.4)	14.7	.00
FAB	2	89	9.8 (0.5)	2	36	15.0 (0.0)	14.7	.00
Frontotemporal dementia behavioural variant								
age	9	188	65.1 (4.2)	9	161	65.0 (2.8)	0.6	.95
gender (M/F)	8	87/76		8	64/88		4.0	.05
education	8	188	13.2 (3.1)	9	161	12.9 (3.2)	0.2	.84
disease duration	2	51	39.8 (27.3)					
MMSE	8	182	24.3 (2.3)	8	145	29.0 (0.5)	5.6	.00
FAB	3	52	10.1 (1.9)	3	53	15.6 (0.9)	4.5	.02
Vascular dementia								

(continued on next page)

Table 1 (*continued*)

	Neurodegenerative Disorder			Controls				
	$N_{studies}$	$N_{participants}$	*M (SD)*	$N_{studies}$	$N_{controls}$	*M (SD)*	t/χ^2	*p*
age	2	56	76.8 (4.3)	3	71	71.5 (6.9)	2.1	.17
sex (M/F)	2	32/24		3	26/45		5.3	.02
education	2	56	9.9 (0.6)	3	71	11.4 (0.5)	3.3	.03
disease duration	1	24	34.8					
MMSE	2	33	22.3 (1.5)	3	71	28.8 (0.5)	7.1	.01
FAB	2	36	9.7 (0.3)	2	36	15.0 (0.0)	25.0	.00
Lewy body dementia								
age	4	81	72.6 (2.1)	3	69	71.6 (2.2)	1.0	.36
sex (M/F)	3	40/27		3	25/19		0.1	.71
education	4	81	12.4 (1.2)	3	69	12.4 (2.0)	0.1	.92
disease duration	2	61	42.9 (19.7)					
MMSE	4	81	23.3 (6.3)	3	69	28.8 (0.4)	1.7	.8
FAB	1	6	10.5		11	14.9		
Semantic dementia								
age	2	21	61.8 (1.6)	2	17	60.3 (3.4)	0.6	.63
education	1	13	16.4	1	9	16.4		
MMSE	1	13	23.0	1	9	29.3		
Primary progressive aphasia								
age	3	42	64.2 (3.1)	3	43	62.7 (3.1)	0.6	.59
sex (M/F)	2	17/13		2	16/18		0.6	.44
education	3	42	16.1 (0.5)	3	43	15.4 (1.1)	1.0	.40
disease duration	1	20	3.9					
MMSE	3	42	25.4 (1.5)	3	43	29.4 (0.1)	4.6	.40
Dementia not specified								
age	6	335	75.7 (2.4)	5	208	62.7 (3.1)	3.0	.02
sex (M/F)	5	131/158		5	89/117		0.2	.64
education	4	160	10.9 (2.9)	4	152	15.4 (1.1)	0.4	.70
MMSE	3	94	20.6 (2.8)	3	86	29.0 (0.1)	5.2	.04

$N_{studies}$ = number of studies, $N_{participants}$ = number of participants, $N_{controls}$ = number of controls, *M (SD)*= weighted mean (standard deviation), t/χ^2 = *t*-test or Chi-square statistic, *p* = probability value, disease duration = months, MMSE = Mini Mental Status Examination, FAB = Frontal Assessment Battery.

statistics; Fig. 3), indicating that risk-of-bias did not adequately explain the variability.

3.3. Sorting test performance: dementia

Table 2 additionally summarises the mean effect sizes for the dementias (subtypes combined). All effects were significant ($p < .05$), negative and large, indicating that persons with dementia consistently performed more poorly than their cognitively-healthy peers. The Category score was the most commonly reported and the most discriminating of the five scores ($g = -2.05$), followed by the Total, Error, Perseveration and Description scores. There was significant heterogeneity in the effect sizes for the Category, Total, Perseveration and Error scores, but not the Description score, when the dementias were examined together. Subgroup analyses therefore focused on whether dementia subtype (AD, bvFTD, VaD, LBD, SD, PPA, or dementia NOS) and the specific sorting test (Weigl, WCST, VVT, or DKEFS) contributed to the heterogeneity in these four scores. Additional analyses examined whether patient education and disease severity also impacted on the findings.

3.3.1. Subgroup (dementia subtype & sorting test) & covariate (education & disease severity) analyses

3.3.1.1. Dementia subtype. A subgroup analysis, which compared the Category, Total, Perseveration and Error scores for all of the dementia subtypes, revealed that only the Category scores differed (see *Q* statistics for the Dementia subgroup analysis, Table 2). Contrary to clinical expectation, the bvFTD group had significantly *better* Category scores than the AD group (see Fig. 2: Hedge's *g* for AD fell below the lower 95% CI for bvFTD). However, significant heterogeneity remained in the Category scores of the AD, VaD, LBD and NOS dementia subtypes (see *Q* statistics, Fig. 2), suggesting there were additional unaccounted sources of variability. Education and disease severity were therefore investigated to determine whether they contributed to this variability.

Education was examined via three meta-regressions. The first examined the Category scores for all of the dementia subtypes (note: 2 studies were excluded because education was not reported) and found that patient education was not significantly related to performance ($N_{studies} = 30$, $Q\text{model} = 0.78$, $df = 1$, $p = 0.38$, $R^2 = -0.03$). The second meta-regression compared the Category scores of the bvFTD and AD groups, and found these dementia subtypes no longer differed after patient education was taken into consideration ($N_{studies} = 31$, $Q\text{model} = 1.00$, $df = 2$, $p = 0.61$, $R^2 = -0.08$). A final meta-regression compared the Category scores of FTD and non-FTD dementia subtypes because, clinically, FTD is thought to have a greater impact on the cognitive abilities that underpin sorting task performance. This analysis revealed that FTD and non-FTD performed comparably when education was taken into consideration ($N_{studies} = 33$, $Q\text{model} = 2.01$, $df = 2$, $p = 0.37$, $R^2 = -0.08$). In combination, these analyses suggest that the sorting test performance of the various dementia subtypes do not differ when they have comparable education.

A further two subgroup analyses examined whether disease severity contributed to the heterogeneity in the Category scores of the dementia subtypes. The Clinical Dementia Rating Scale (CDR) was the most commonly-used measure of disease severity in the studies that reported Category scores ($N_{studies} = 13$), with eight studies examining mild dementia and the remaining five combining multiple disease stages, rendering the latter unsuitable for analysis. The first subgroup analysis compared the Category scores of persons in the mild/early stages of each of the dementias subtypes in order to determine whether they still differed when the samples were more homogenous in terms of their disease severity. This analysis revealed that there were no significant differences between the Category scores of the bvFTD ($N_{studies} = 2$ $g = -1.46$, 95% CI -2.72 to -0.20), AD ($N_{studies} = 7$, $g = -1.75$, 95% CI -2.43 to -1.07), VaD ($N_{studies} = 1$ $g = -2.02$, 95% CI -3.95 to -0.09), or LBD ($N_{studies} = 1$, $g = -1.55$, 95% CI -3.49 to 0.40) dementia subtypes. The second analysis compared mild FTD (severity data was only available for bvFTD) to mild non-FTD dementia (because FTD was expected to perform more poorly) and found that they did not differ significantly ($N_{studies} = 7$, $g = -1.78$, 95% CI -2.45 to -0.24). Thus, the Category scores

Table 2
Mean Hedges' *g* effect sizes, heterogeneity statistics and subgroup analyses for all of the neurodegenerative disorders and dementia subtypes.

Group	Sorting test score	$N_{studies}$	*g*	95% *CIs*		*Q*	I^2	*Tau*	Tau^2
Neurodegenerative disorders (all)									
	Category	108	−1.28	−1.46	−1.11	1258.78***	91.5	0.87	0.73
	Total	35	−1.10	−1.35	−0.84	353.59***	90.4	0.70	0.49
	Perseveration	89	−1.00	−1.15	−0.84	766.35***	88.5	0.70	0.48
	Errors	44	−1.08	−1.34	−0.82	538.03***	92.0	0.82	0.67
	Description	3	−1.11	−1.58	−0.64	7.76*	74.2	0.36	0.13
Subgroup analyses									
	Disorder-type								
	Category	132				37.94***	90.2	0.88	0.77
	Total	42				42.86***	89.5	0.73	0.53
	Perseveration	106				29.05***	86.9	0.71	0.50
	Error	48				7.28	91.4	0.82	0.67
	Description	7				9.95	39.7	0.28	0.08
	Study risk-of-bias								
	Category	108				5.74*	91.0	0.88	0.78
	Total	35				0.10	90.5	0.76	0.58
	Perseveration	89				11.36***	88.1	0.72	0.52
	Error	44				0.44	92.0	0.84	0.71
	Description								
Dementia subtypes (all)									
	Category	32	−2.05	−2.46	−1.64	521.04***	94.1	1.11	1.24
	Total	14	−1.81	−2.34	−1.24	211.50***	93.9	0.97	0.95
	Perseveration	24	−1.46	−1.82	−1.10	285.17***	91.3	0.84	0.70
	Error	13	−1.57	−2.24	−0.91	285.71***	95.8	1.19	1.41
	Description	2	−1.24	−1.95	−0.52	3.87	74.2	0.45	0.20
Subgroup analyses									
	Dementia subtype								
	Category	45				16.31**	92.0	1.12	1.26
	Total	17				5.72	92.7	0.98	0.96
	Perseveration	33				5.46	89.6	0.85	0.73
	Error	14				0.97	95.5	1.19	1.41
	Sorting test used								
	Category	32				19.23***	94.0	1.20	1.44
	Total	14				6.26*	93.9	1.01	1.03
	Perseveration	24				2.89	91.7	0.88	0.77

$N_{studies}$ = number of studies, *g* = Hedges' *g*, 95% CI = 95% confidence intervals, *Q* = distribution of observed effects, I^2, = the ratio of true effect to error variance, Tau^2 = variance in the true effects.
* *p value* <.05.
** *p value* <.01.
*** *p value* <.001.

of the FTD and other dementia subtypes, including AD, appear to be comparable in the early/mild stages of the disease.

3.3.1.2. Sorting test. Next, subgroup analyses examined whether the test itself (Weigl, WCST, VVT, DKEFS-ST) contributed to the heterogeneity that was observed in the Category, Total and Perseveration scores of people with dementia (Error scores were only reported for the WCST, precluding an analysis). These analyses revealed that the choice of test contributed significant heterogeneity to the Category and Total scores (see Table 2). Visual inspection of Fig. 4 indicates that (1) the Category score from the WCST was significantly more discriminating than the VVT (Hedges' *g* for WCST fell outside of 95% CIs for VVT), but not the DKEFS-ST; and (2) the Total score from the Weigl was significantly more discriminating than the WSCT and VVT (Hedges' *g* for Weigl fell outside of 95% CIs for WCST and VVT). However, these findings should be considered tentative because the VVT and DKEFS were only examined by single studies and significant heterogeneity remained in the scores of the other tests (WCST Category & Total scores; Weigl Total scores; see Fig. 4).

Finally, two meta-regressions examined whether patient education influenced the sorting test findings. Unfortunately, test type could not be examined in conjunction with education because there were insufficient data (i.e., VVT and DKEFS were examined by single studies and 6 studies did not report education). These analyses revealed that patient education did not significantly influence the Category ($N_{studies}$ = 29, Qmodel = 1.30, df = 1, p = 0.25, R^2 = -0.02) or Total ($N_{studies}$ = 10, Qmodel = 2.47, df = 1, p = 0.12, R^2 = 0.03) scores. Therefore, education did not appear to be a source of heterogeneity in the findings relating to the choice of sorting test. Disease severity could not be examined in this way due to insufficient data.

3.4. Publication bias

Publication bias was examined using Duval and Tweedies' trim and fill procedure (see Supplementary Figures S2a-S2h). When the Category scores for each neurodegenerative disorder were inspected separately, there were no missing studies on the right of any of the funnel plots for any disorder (other scores generated similar results and are available upon request), suggesting that publication bias was unlikely to have impacted on the current findings.

4. Discussion

The current meta-analysis pooled the data from 142 studies to investigate the effectiveness with which sorting tests were able to differentiate between older adults with and without neurodegenerative disorders. The most common disorders were Parkinsonian disorders ($N_{studies}$ = 69), followed by AD ($N_{studies}$ = 34), MCI ($N_{studies}$ = 22), MND ($N_{studies}$ = 13) and bvFTD ($N_{studies}$ = 9). Dementia was of particular interest because cognitive screens are commonly used to assist in its detection and, in clinical settings, sorting tests are often used to differentiate between certain dementia subtypes (e.g. bvFTD *vs* AD). The WCST ($N_{studies}$ = 127) was much more frequently used than other sorting tests, with the Weigl ($N_{studies}$ = 8), DKEFS ($N_{studies}$ = 4) and VVT

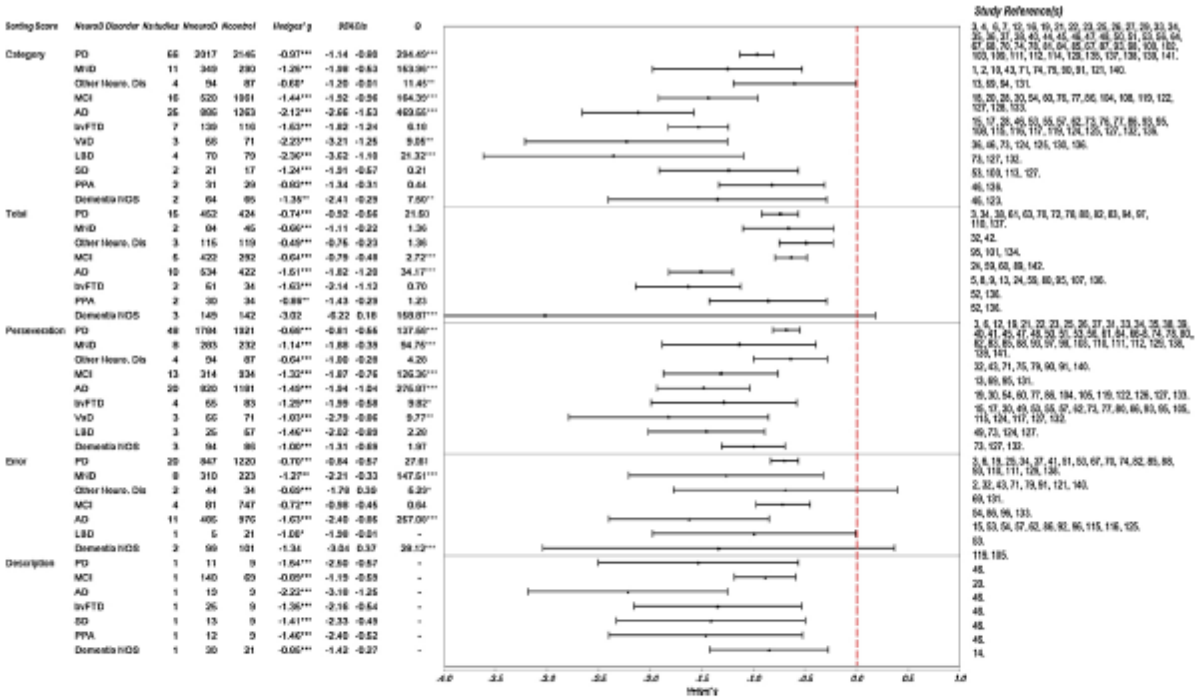

Fig. 2. Hedges' *g* effect sizes for the neurodegenerative disorders, grouped by score type and diagnosis.
NeuroD Disorder= neurodegenerative disorder, $N_{studies}$ = number of studies, N_{neuroD} = number of participants with a neurodegenerative disorder, $N_{control}$ = number of healthy controls, 95% CI = 95% confidence intervals, *Q* = distribution of observed effects, PD = Parkinsonian disorders, MND = motor neuron disorder, MCI = mild cognitive impairment, Other Neuro. Dis = other neurodegenerative disorders, AD = Alzheimer's dementia, bvFTD = behavioural-variant frontotemporal dementia, VaD = vascular dementia, LBD = lewy body dementia, Dementia NOS = dementia not otherwise specified, PPA = primary progressive aphasia, SD = semantic dementia.
*** *p* value <.001, ** *p* value <.01, * *p* value <.05.

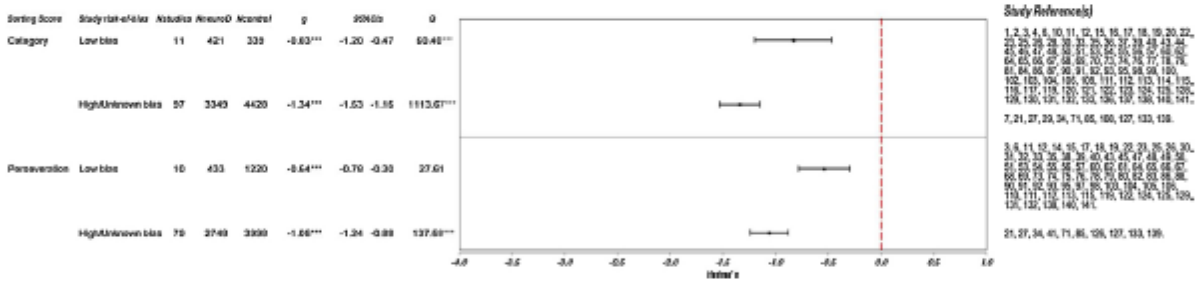

Fig. 3. Hedges' *g* effect sizes for all neurodegenerative disorders combined on the Category and Perseveration scores, grouped by study risk-of-bias.
$N_{studies}$ = number of studies, N_{neuroD} = number of participants with a neurodegenerative disorder, $N_{control}$ = number of healthy controls, *g* = Hedges' *g*, 95% CI = 95% confidence intervals, *Q* = distribution of observed effects.
***p value <.001, ** *p* value <.01, * *p* value <.05.

($N_{studies}$ = 3) used by many fewer studies.

Overall, the findings indicate that older adults with a neurodegenerative disorder performed consistently more poorly than their cognitively-healthy peers on all five commonly-used sorting test scores, namely, the Category ($N_{studies}$ = 108), Total ($N_{studies}$ = 35, Perseveration ($N_{studies}$ = 89), Error ($N_{studies}$ = 44), and Description scores ($N_{studies}$ = 3). The Category and Description scores were particularly discriminating, although the latter score was infrequently reported. In addition to being the most discriminating and commonly reported score, Category scores are affected by errors (e.g., perseverations and other errors), which means that they capture multiple aspects of performance. The effectiveness of the Category, Total and Perseveration scores was influenced by the type of disorder, with larger effects seen in the disorders that have cognitive impairment as one of their core diagnostic features, namely, specific dementia subtypes. Category and Perseveration effect sizes were also influenced by study risk-of-bias, with low risk-of-bias studies providing more conservative estimates, albeit still large and highly significant. Although disorder-type and risk-of-bias both influenced the findings, substantial residual variance remained, suggesting that other factors – such as disease severity or time since diagnosis – may be important.

Older adults with dementia had some of the lowest sorting scores, with the Category and Total scores being particularly effective for discriminating between people with and without dementia. In persons with dementia, there was significant variability in the findings from individual studies, with some of the variability in Category scores being attributable to the specific type of dementia. However, contrary to clinical lore, persons with AD performed *more poorly* (Category scores) than those with bvFTD and other dementia subtypes performed *as poorly* as those with bvFTD, suggesting that sorting test performance is

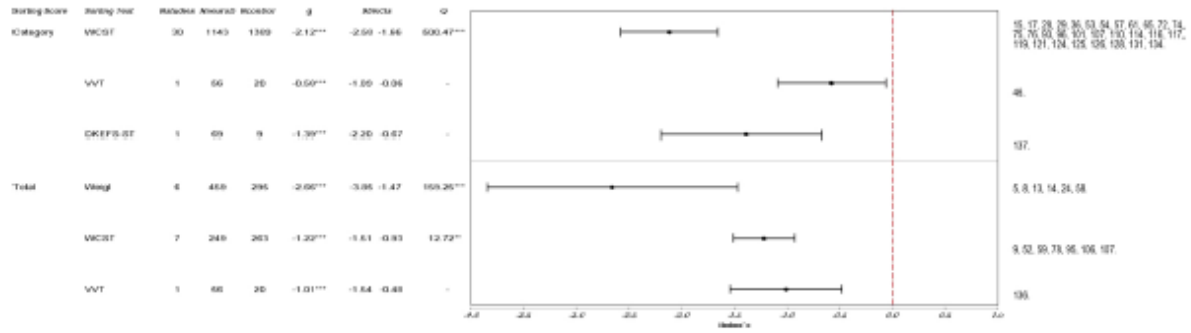

Fig. 4. Hedges' *g* effect sizes for dementia (all) on the Category and Total scores grouped by the test used.
$N_{studies}$ = number of studies, N_{neuroD} = number of participants with a neurodegenerative disorder, $N_{control}$ = number of healthy controls, *g* = Hedges' *g*, 95% CI = 95% confidence intervals, *Q* = distribution of observed effects WCST = Wisconsin Card Sorting Test, VVT = Visual Verbal Test, DKEFS-ST = Delis Kaplan Executive Functioning System- Sorting Test, Weigl = Weigl Color Form Sort.
*** *p* value <.001, ** *p* value <.01, * *p* value <.05.

impaired in a wide variety of neurodegenerative disorders. When the impact of education and disease severity was examined, bvFTD performed comparably to the non-FTD utive' functioning, should not be used to differentiate between bvFTD and other types of dementia. Indeed, AD and bvFTD have proven notoriously difficult to differentiate (Ikeda et al., 2004; Mathias and Burke, 2009; Wang et al., 2016), possibly because a historical focus on memory deficits in AD may have meant that changes to 'executive' functioning, working memory and behaviour have not been given adequate attention (Binetti et al., 1996; Mega et al., 1996). 'Executive' functioning is itself a broad amalgam of constructs, which are articulated in the Cattell-Horn-Carroll model of cognitive functioning, but we do not yet know exactly which of these constructs are assessed by sorting tests (Jewsbury et al., 2016; McGrew, 2009).

Although sorting tests did not effectively differentiate between the different dementia subtypes, they did detect cognitive impairment in people with dementia, more generally. Sorting tests have comparable or better sensitivity and specificity than the MMSE, which is one of the most commonly-used cognitive screens for detecting cognitive impairment in older adults. Indeed, the Hedges' *g* score of 2.1 for the Category score in people with dementia converts to sensitivity and specificity values of approximately 85% each, which compare favourably with the 80% sensitivity and 81% specificity values reported by a meta-analysis examining the MMSE in memory clinic samples (Mitchell, 2009; note: most of the dementia samples in this meta-analysis came from clinics). The current findings now need to be extended by comparing the effectiveness with which sorting and other cognitive tests or screens differentiate between older adults with neurodegenerative disorders and their cognitively healthy peers.

The Category score from the WCST and the Total score from the Weigl were the most discriminating measures when examining dementia, however, this finding should be considered tentative because the various tests have not been equally researched. There was also significant variability in the findings from studies that used the same sorting test, which may be related to sample characteristics (e.g., education), dementia subtype or disease severity. Clinicians are likely to consider the cost of a sorting test, the time taken to administer and score it, how well it is tolerated by their patients, its reliability and validity, as well as its sensitivity and specificity when used to detect cognitive decline in their patient group. The Weigl is desirable because it is free, and brief to administer and score (<5 min). It has also been used with a variety of older adult samples, including persons who have had a stroke, or have Parkinson's disease, an isolated memory impairment and dementia (Byrne et al., 1998; Hobson et al., 2007). In addition, the revised Weigl has been found to detect cognitive decline in older adults with dementia and, although it would benefit from more normative and psychometric data (e.g., test-retest reliability), has the added advantage of including a Description score (Beglinger et al., 2008). The Description score warrants further investigation because it was the most discriminating score in AD and PD, and was significantly impaired in the other neurodegenerative disorders for which there were data (PD, MCI, AD, bvFTD, SD, PPA and Dementia NOS).

This meta-analysis was limited to the common neurodegenerative disorders of older age. Consequently, the findings may not generalize to younger age groups or other neurological conditions. The findings suggest that older adults who are suffering from the most common neurodegenerative disorders, including but not limited to dementia, perform more poorly on a variety of sorting tests and scores. Indeed, the Category and Description scores appear to be the most promising measures, although the latter, which assesses a person's ability to articulate the category or rule underlying their sort, requires further research to establish its worth. Unfortunately, it was not possible to directly compare the effectiveness with which sorting tests and other cognitive screens, such as the MMSE and FAB, detect cognitive impairment in older adults because the latter screens were often used as part of the diagnostic process (i.e., these screens could not be used as both a diagnostic and outcome measure). This is something that now needs to be researched. Another limitation relates to the patient characteristics that have the potential to influence sorting performance, which were not able to be comprehensively analysed in this meta-analysis. In clinical practice disease severity and years of formal education are routinely considered when interpreting cognitive test performances. Furthermore, when formulating specific clinical diagnoses multiple sources of evidence are routinely utilized – such as the person's medical and psychological history, physical examination and the results of other investigations – not just performance on a single cognitive test or screen (Walterfang et al., 2006). The clinical utility of sorting tests should now be optimised by investigating their sensitivity and specificity in a variety of different point-of-care settings to enable clinicians to tailor their interpretation of these tests to their own practice and patients.

5. Conclusion

Sorting ability is not measured by existing cognitive screens, such as the MMSE and MoCA, but appears to decline in the common neurodegenerative disorders of older age, particularly dementia. The fact that brief and simple sorting tests can effectively detect cognitive decline in older adults suggests that these tests may provide a valuable alternative to current cognitive screens and, consequently, assist in meeting the growing demand for point-of-care cognitive assessments. However, sorting tests should not be used to differentiate between the different types of dementia.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2020.10.013.

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Appendix A.2: Supplementary tables and figures for Study 1 (Chapter 3)

Supplementary Table A.2.1: PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; ADa sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	6
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	6
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	n/a
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	7
Information sources	7	Describe all information sources (e.g., ADabases with ADes of coverage, contact with study authors to identify additional studies) in the search and ADe last searched.	7
Search	8	Present full electronic search strategy for at least one ADabase, including any limits used, such that it could be repeated.	Table S2 4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	7
ADa collection process	10	Describe method of ADa extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming ADa from investigators.	9
ADa items	11	List and define all variables for which ADa were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	9

Supplementary Table A.2.1: PRISMA Checklist cont.

Section/topic	#	Checklist item	Reported on page #
METHODS			
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any ADa synthesis.	10
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	11
Synthesis of results	14	Describe the methods of handling ADa and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	11

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Supplementary Table A.2.2: Logic grids used to search each database

PubMed Log Grid
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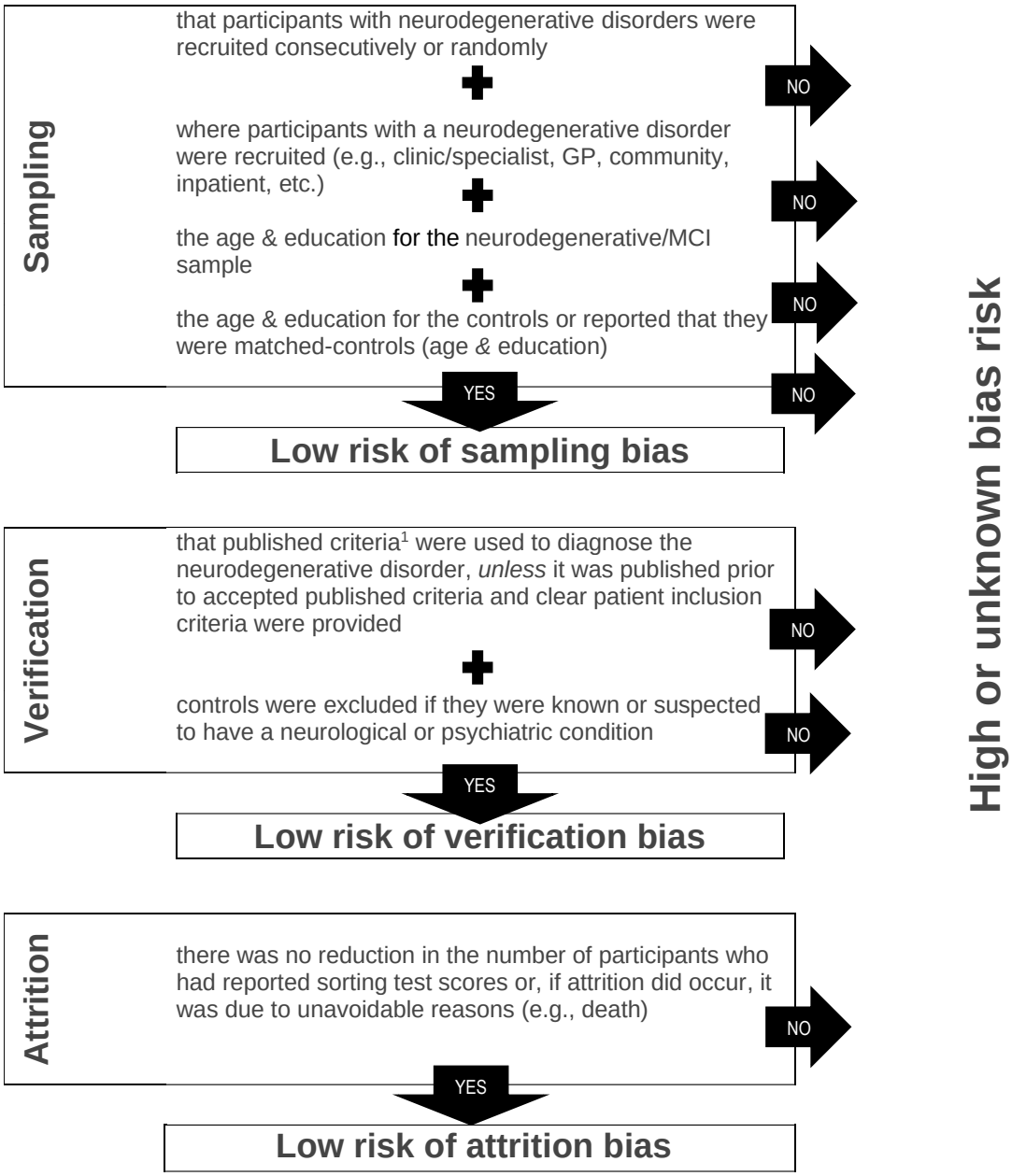
Supplementary Table A.2.2: Logic grids used to search each database cont.

Embase
‘Colour Form Sort’ OR ‘Color Form Sort’ OR ‘Colour Form Sorting’ OR ‘Color Form Sorting’ OR ‘Weigl Color Form Sort’ OR ‘ Weigl Colour Form Sort’ OR ‘Weigl Color Form Sorting’ OR ‘Weigl Colour Form Sorting’ OR ‘Modified Weigl Color Form Sort’ OR ‘Modified Weigl Colour Form Sort’ OR ‘Modified Weigl Color Form Sorting’ OR ‘Modified Weigl Colour Form Sorting’ OR ‘CFST’ OR ‘Wisconsin Card Sorting’ OR ‘Wisconsin Card Sort’ OR ‘WCST’ OR ‘Modified Wisconsin Card Sort’ OR ‘Modified Wisconsin Card Sorting’ OR ‘Madrid Modified Card Sort’ OR ‘Madrid Modified Card Sorting’ OR ‘Berg Color Form Sort’ OR ‘Berg Colour Form Sort’ OR ‘Berg Color Form Sorting’ OR ‘Berg Colour Form Sorting’ OR ‘Halstead Category’ OR ‘Adaptive Category Test’ OR ‘Short Category Test’ OR ‘Russell Revised Short Version’ OR ‘ Delis-Kaplan Executive Functioning System Sorting’ OR ‘Delis-Kaplan Executive Functioning System Sort’ OR ‘DKEFS Sorting’ OR ‘DKEFS Sort’ OR ‘California Card Sort’ OR ‘California Card Sorting’ OR ‘Sort Test’ OR ‘Sorting Test’ OR ‘Sort Testing’ OR ‘Sorting Testing’ OR ‘Sort Task’ OR ‘Sorting Task’ OR ‘Category Task’ OR ‘Category Test’ OR ‘Category Testing’ AND [english]/lim NOT [medline]/lim AND ([middle aged]/lim OR [aged]/lim OR [very elderly]/lim)

The study clearly reported:



Supplementary Figure A.2.1: Risk of bias assessment

Supplementary Table A.2.3: Published diagnostic or reference criteria for each of the neurodegenerative disorders

	Neurodegenerative disorder	**Diagnostic criteria**
Parkinsonian	Parkinson's Disease (PD)	Barbeau (1986); Gelb, Oliver, and Gilman (1999); Hughes, Daniel, Kilford, and Lees (1992); Lang and Lozano (1998); Postuma et al. (2015); Ward and Gibb (1990)
	Multiple System Atrophy (MSA)	Quinn (1989)
	Progressive Supranuclear Palsy (PSP)	Shibayama et al. (2007)
Motor Neuron Disease	Motor Neuron Disease (MND) & Amyotropic Lateral Sclerosis (LS)	Andersen et al. (2005); Beghi et al. (2002); Brooks (1994); Brooks, Miller, Swash, and Munsat (2000); *World Federation of Neurology Research Group on Neuromuscular Diseases Subcommittee on Motor Neuron Disease. Airlie House guidelines. Therapeutic trials in amyotrophic lateral sclerosis. Airlie House "Therapeutic Trials in ALS" Workshop Contributors* 1995)
MCI	Mild Cognitive Impairment (MCI)	Crook et al. (1986); Morris et al. (2006); Petersen (2004); Petersen et al. (2001); Winblad et al. (2004)
Other NeuroD	Normal Pressure Hydrocephalus (NPH)	Lumber puncture
	Human immunodeficiency virus (HIV+) Multiple Sclerosis	Seropositive Poser et al. (1983)
Dementia	Dementia of the Alzheimer's Type (AD)	American Psychiatric and American Psychiatric Association (2013); McKhann et al. (1984); Morris et al. (1989); Morris et al. (2006); Weintraub et al. (2009)
	Behavioural variant fronto-temporal degeneration/dementia (bvFTD)	Lund-Manchester (1994); Neary et al. (1998); Neary, Snowden, and Mann (2000); Neary, Snowden, Northen, and Goulding (1988); Rascovsky et al. (2007)
	Vascular dementia (VaD)	Roman et al. (1993)
	Lewy Body Dementia (LBD)	McKeith (2006); McKeith et al. (2017); McKeith et al. (1996); McKeith, Perry, Fairbairn, Jabeen, and Perry (1992)
	Semantic Dementia (SD)	Neary et al. (1998)
	Primary Progressive Aphasia (PPA)	Neary et al. (1998)
	Dementia general or not otherwise specified (NOS)	Diagnostic and Statistical Manual of Mental Disorders, National Institute of Neurological Disorders and Stroke

NeuroD = Neurodegenerative disorders

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis

ref[1]	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
1	Abe et al., 2001	ALS	Brooks (1994)	-	65.8 (9.9)		31.0 (20.4)			Japan	14	14
2	Abrahams et al., 1997	ALS	not provided	Clinic/Specialist/Unit	56.9 (11.6)	17.4 (2.8)	22.0 (10.6)			United Kingdom	52	28
3	Alevriadou et al., 1999	PD	not provided	-	62.1 (6.8)	7.9 (3.4)				Greece	37	37
4	Alonso, Martin, Carvajal, Ruiz, Serrano, 2013	PD	not provided	Clinic/Specialist/Unit	65.5 (6.7)	15.5 (3.58)	78.1 (51.5)			Spain	23	18
5	Aresi & Giovagnoli, 2009	Posterior Cortical Atrophy	not provided	Clinic/Specialist/Unit	59.1 (6.1)	5.5 (3.2)	37.7 (4.3)	14.3 (2.1)		Italy	17	17
		AD	McKhann et al. (1984)	Clinic/Specialist/Unit	63.0 (6.6)	6.12 (3.0)	53.6 (29.8)	15.1 (4.6)		Italy	17	17
6	Asahina et al., 1998	PD	Ward and Gibb (1990)	not provided	59.2 (10.0)				27.4 (4.3)	Japan	12	8
7	Azuma, Cruz, Bayles, Tomoeda & Montgomery, 2003	PD	not provided	Clinic/Specialist/Unit	68.9 (7.2)	14.8 (2.7)	68.4 (57.2)	28.4 (1.4)	28.4 (1.4)	United States	69	37
8	Baddeley, Baddeley, Buck & Wilcock, 2001	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	76.3 (6.3)	10.8 (1.8)		19.9 (1.8)		United Kingdom	36	36
9	Bandera, Capitani, Sala & Spinnler, 1985	AD	not provided	Clinic/Specialist/Unit	65.7 (8.2)	8.2 (5.4)				Italy	30	60
10	Barbagallo et al., 2014	ALS	Brooks (1994)	Clinic/Specialist/Unit	61.9 (8.4)		20.4 (19.5)	8.9 (4.0)		Italy	24	22
11	Beatty & Monson, 1994	MS	Poser et al. (1983)	Community/Population	47.0 (14.1)	14.4				United States	30	33
12	Beatty, Staton, Weir, Monson & Whitaker, 1989	PD	not provided	Clinic/Specialist/Unit	65.8 (8.6)	12.3 (1.2)	65.4 (57.6)	27.1 (1.3)		United States	43	28
13	Becker, Boller, Lopez, Saxton & McGonigle, 1994	AD	DSM[3]	Clinic/Specialist/Unit	71.4 (8.3)	12.1 (2.9)		18.4 (5.2)		United States	181	101

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
14	Belinger, Unverzagt, Beristain & Kareken, 2008	Dementia	McKhann et al. (1984); Roman et al. (1993) DSM^3-IV	Clinic/Specialist/Unit	69.8 (8.5)	13.7 (1.9)		19.1 (5.6)		United States	30	21
15	Binetti et al., 1996	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	71.6 (8.7)	7.0 (3.8)	30.9 (19.2)	21.5 (2.4)		Italy	22	21
16	Bokura, Yamaguchi & Kobayashi, 2005	PD	not provided	not provided	69.5 (11.9)	9.9 (2.4)	56.8 (58.6)			Japan	13	14
17	Bondi, Monsch, Butters, Salmon & Paulsen, 1993	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	72.3 (6.6)	13.1 (3.3)		21.0 (2.0)		United States	87	75
18	Borkowska, Drozdz, Jurkowski & Rybakowski, 2009	MCI	not provided	Clinic/Specialist/Unit	61.9 (5.6)	11.7 (5.6)		25.3 (0.9)		Poland	30	30
19	Brand et al., 2004	PD	not provided	not provided	66.9 (9.7)	9.1 (1.2)	106.1 (81.1)	28.2 (1.7)		Germany	20	20
20	Brandt et al., 2009	MCI	Petersen (2004)	Mixed	75.8 (7.4)	15.6 (3.0)		28.2 (0.2)		United States	140	69
21	Broeders et al., 2013	PD	Gelb et al. (1999)	Clinic/Specialist/Unit	62.5 (9.5)	11.6 (2.4)		27.9 (1.8)		Neverlands	59	40
22	Broussolle et al., 1999	PD	not provided	Clinic/Specialist/Unit	55.9 (1.0)		83.5 (2.1)			French	27	10
23	Brown & Marsden, 1988	PD	not provided	not provided	59.2 (6.6)	11.3 (2.2)	134.4 (79.2)			United Kingdom	16	16
24	Byrne, Bucks & Cuerden, 1998	Dementia	not provided	Clinic/Specialist/Unit	78.0 (8.0)					United Kingdom	109	34
		MCI	not provided	Clinic/Specialist/Unit	68.0 (11.1)					United Kingdom	58	34
25	Caltagirone, Carlesimo, Nocentini & Vicari, 1989	PD	not provided	Clinic/Specialist/Unit	61.5 (7.6)	6.5 (3.3)	49.2 (16.8)			Italy	24	21

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
26	Campos-Sousa, Campos-Sousa, Ataide, Soares & Almeida, 2010	PD	Lang and Lozano (1998)	Clinic/Specialist/Unit	61.5 (8.6)	6.0 (3.7)	22.0 (2.1)			Brazil	44	25
27	Canu et al., 2015	PD	Hughes et al. (1992)	Clinic/Specialist/Unit	66.9 (8.0)	11.1 (4.2)		27.7 (1.8)		Italy	23	35
28	Carter, Caine, Burns, Herholz & Ralp, 2012	AD	NINCDS	Clinic/Specialist/Unit	77.3 (5.6)	10.7 (2.5)		22.3 (3.5)		United Kingdom	15	13
		MCI	Petersen (2004)	Clinic/Specialist/Unit	73.3 (9.7)	11.8 (3.7)		28.0 (1.5)		United Kingdom	17	13
29	Chen, Lin, Liu, Tai & Lai, 2006	PD	not provided	Clinic/Specialist/Unit	63.3 (10.5)	9.1 (4.2)				Taiwan	27	27
30	Chen et al., 2009	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	76.7 (8.5)	7.8 (4.9)				Taiwan	11	16
		MCI	Petersen (2004)	Clinic/Specialist/Unit	73.2 (9.3)	11.4 (4.3)				Taiwan	13	16
31	Cohen et al., 2014	PD	not provided	Clinic/Specialist/Unit	66.2 (9.7)	12.8 (-)	102.6			United States	28	16
32	Consonni et al., 2013	ALS & MND	Andersen et al. (2005); Brooks (1994)	Clinic/Specialist/Unit	61.3 (9.8)	8.6	27.4	25.3 (4.3)		Italy	34	39
33	Costa et al., 2015	PD	Hughes et al. (1992)	not provided	64.7 (8.9)	12 (3.3)		29.0 (1.1)		Italy	81	20
34	Dalrymple-Alford, Jamieson & Dolaldson, 1995	PD	not provided	Clinic/Specialist/Unit	65.6 (9.1)	11.4 (2.3)				New Zealand	20	11
35	Davidson, Cook, McGhan, Bouchard & Camiciolo, 2013	PD	not provided	Clinic/Specialist/Unit	71.0 (2.8)	15.0 (2.5)		27.8 (1.8)		Canada	18	23
36	de Souza et al., 2010	FTD	Lund-Manchester (1994)	not provided	71.1 (9.1)	5.2 (1.7)		24.9 (3.9)	12.9 (3.5)	France	17	17
		PD	Hughes et al. (1992)	Clinic/Specialist/Unit	65.9 (3.0)	5.7 (1.3)		27.4 (1.2)	16.3 (1.5)	France	12	17

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
37	Diaz-Santos et al., 2015	PD	not provided	Clinic/Specialist/Unit	64.2 (6.4)	17.5 (2.1)	64.8 (48.0)	28.8 (0.7)		United States	28	26
38	Dimitrov, Grafman, Soares & Clark, 1999	PD	not provided	not provided	67.6 (6.2)	15.8 (2.3)				United States	8	8
39	Dirksen, Howard, Cronin-Golomb & Oscar-Berman, 2006	PD	Hughes et al. (1992)	Clinic/Specialist/Unit	63.3 (6.4)	17.9 (3.6)	81.6 (58.8)	29.2 (1.1)		United States	18	28
40	dos Santos et al., 2010	PD	Hughes et al. (1992)	Clinic/Specialist/Unit	74.0 (2.5)	7.1 (1.1)	83.2 (1.7)	25.7 (0.6)		Brazil	21	22
41	Ekman et al., 2012	PD	Hughes et al. (1992)	Community/population	67.6 (9.8)	10.1 (4.4)		29.1 (1.0)		Sweden	77	24
42	Evans et al., 2015	ALS	Brooks (1994)	Clinic/Specialist/Unit	58.9 (12.6)	14.9 (2.9)	6.7 (8.4)	27.4 (4.0)		United States	65	29
43	Evdokimidis et al., 2002	ALS	Brooks (1994)	Inpatient	58.8 (10.2)	9.4 (4.2)	25.5 (19.7)			Greece	51	28
44	Fama & Sullivan, 2002	PD	not provided	Mixed	62.4 (7.3)	16.5 (2.6)	80.4 (76.8)	27.3 (2.5)		United States	16	48
45	Filoteo, Maddox, Ing, Zizak & Song, 2005	PD	not provided	not provided	67.4 (10.3)	16.6 (1.7)				United States	19	19
46	Fine et al., 2009	AD	McKhann et al. (1984)	not provided	57.4 (5.8)	15.9 (2.7)		22.0 (4.0)		United States	19	9
		FTD	Neary et al. (2000)	not provided	58.6 (6.9)	16.5 (2.2)		25.8 (3.5)		United States	25	9
		SD	Neary et al. (2000)	not provided	63.1 (7.8)	16.4 (3.2)		23.0 (5.5)		United States	13	9
		PNFA	Shibayama et al. (2007)	not provided	63.7 (10.9)	15.0 (2.8)		23.2 (4.1)		United States	12	9
		PSNP	Neary et al. (2000)	not provided	65.7 (7.6)	16.6 (7.6)		26.2 (3.0)		United States	11	9

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
47	Flensbord Damholdt, Shevlin, Borhammer, Larsen & Østergaard, 2012	PD	Hughes et al. (1992)	Clinic/Specialist/Unit	69.4 (6.4)	13.1 (3.4)		27.1 (1.5)		Denmark	71	30
48	Fonoff et al., 2015	PD	not provided	Clinic/Specialist/Unit	59.3 (10.3)	10.3 (4.5)		28.4 (1.5)		Brazil	28	28
49	Freedman, Binns, Blak, Murphy, 2013	AD	McKhann et al. (1984)	not provided	71.6 (13.3)	14.1 (4.0)		24.6 (3.4)		Canada	21	31
		bvFTD	Neary et al. (1998)	not provided	60.7 (7.4)	14.1 (4.1)		26.7 (3.6)		Canada	14	31
50	Gasparini et al., 2001	PD	not provided	Clinic/Specialist/Unit	66.6 (7.3)	6.2 (1.5)	86.4 (28.8)			Italy	15	15
51	Gawrys et al., 2008	PD	not provided	not provided	57.0 (10.7)	15.1 (2.2)		29.2 (1.1)		Poland	19	21
52	Gleichgerrcht et al., 2012	PPA	Neary et al. (1998)	Clinic/Specialist/Unit	69.6 (8.9)	16.6 (2.4)		25.9 (2.7)		Argentina	10	14
		bvFTD	Neary et al. (1998)	Clinic/Specialist/Unit	68.5 (7.3)	13.6 (4.5)		26.8 (2.9)		Argentina	35	14
53	Gnanalingham, Byrne, Thornton, Sambrook & Bannister, 1997	LBD	McKeith et al. (1992)	Clinic/Specialist/Unit	76.4 (1.8)	11.0 (1.1)	75.6 (13.2)	12.5 (1.8)		United Kingdom	16	22
		AD	McKhann et al. (1984) S	Clinic/Specialist/Unit	75.7 (1.4)	9.9 (0.4)	44.4 (4.8)	13.4 (1.6)		United Kingdom	25	22
		PD	Hughes et al. (1992)	Clinic/Specialist/Unit	72.6 (2.1)	10.3 (0.9)	110.4 (24.0)	24.1 (1.3)		United Kingdom	15	22
54	Godefroy et al., 2010	MCI	not provided	Clinic/Specialist/Unit	72.2 (11.1)			25.8 (2.9)		France	18	461
55	Godefroy et al., 2014	AD	not provided	Clinic/Specialist/Unit	76.3 (8.0)			23.1 (2.7)		France	73	461
56	Gotham, Brown & Marsen, 1988	PD	not provided	Clinic/Specialist/Unit	64.4 (5.9)		118.8			United Kingdom	16	16

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
57	Gour et al., 2014	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	67.7 (4.3)	10.6 (4.0)		20.2 (3.7)		France	28	28
58	Grewal & Haward, 1984	Dementia	not provided	not provided	76.8 (5.5)					United Kingdom	86	56
59	Hammers et al, 2015	AD	Morris et al. (2006)	Mixed	not provided					United States	66	81
		MCI	Morris et al. (2006)	Mixed	not provided					United States	89	81
60	Hanninen et al., 1997	MCI (AAMI)	Crook et al. (1986)	Clinic/Specialist/Unit	69.9 (5.4)	8.2 (3.2)		27.6 (1.6)		Finland	43	47
61	Harley, Oliver, Jessiman & ManAndrew, 2013	PD	not provided	Clinic/Specialist/Unit	68.8 (8.3)	12.0 (2.7)	118.8 (57.6)	28.6 (1.2)		United Kingdom	21	14
62	Hart, Kwentus, Wade & Taylor, 1988	AD	not provided	Clinic/Specialist/Unit	71.3 (6.6)	13.0 (3.0)				United States	34	18
63	Hobson, Meara & Taylor, 2007	PD	not provided	Clinic/Specialist/Unit	75.6 (7.4)	9.7 (1.7)		25.3 (4.2)		United Kingdom	40	91
64	Hozumi, Hirata, Tanaka & Yamazaki, 2000	PD	not provided	not provided	65.4 (9.4)		67.2 (43.2)	27.9 (1.9)		Japan	15	13
65	Ihnen, Antivilo, Muńoz-Neira & Slachevsky, 2013	Dementia	DSM^3-IV NINDS	Clinic/Specialist/Unit	74.1 (9.2)	9.7 (4.7)		18.1 (6.6)		Chile	31	30
66	Iijima, Osawa, Iwata, Miyazaki & Tei, 2000	PD	not provided	not provided	63.1 (10.4)		58.8 (33.6)			Japan	20	55
67	Inzelberg et al., 2001	PD	not provided	not provided	73.3 (8.1)					Israel	8	6
68	Jahanshahi et al., 2002	PD	not provided	Clinic/Specialist/Unit	57.0 (7.1)		174.0 (78)			United Kingdom	13	12
69	Justice et al., 2004	HIV	not provided	Clinic/Specialist/Unit	50.6 (12.5)					United States	28	16

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

70	Katsarou, Bostantiopoulou, Kimiskidis, Rossopoulos & Kazis, 2004	PD	not provided	not provided	59.3 (6.7)		73.2 (3.7)			Greece	45	40
71	Kilani et al., 2004	ALS	Brooks (1994)	Clinic/Specialist/Unit	58.5 (10.1)					France	19	19
72	Krishna, Ali & Moustafa, 2014	PD	Hughes et al. (1992),UK Brain Bank	Clinic/Specialist/Unit	66.3 (4.5)	13.0 (2.3)	102.4 (47.4)	27.6 (1.3)		Egypt	76	43
73	Kugo et al., 2007	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	75.3 (7.8)	10.4 (2.7)	39.6 (21.6)	19.3 (4.1)	9.5 (2.9)	Japan	58	25
		VaD	Roman et al. (1993)	Clinic/Specialist/Unit	75.1 (9.3)	9.8 (3.7)	34.8 (22.8)	20.7 (4.7)	9.5 (3.3)	Japan	24	25
		FTD	Neary et al. (1998)	Clinic/Specialist/Unit	64.7 (9.5)	11.2 (2.5)	60.0 (46.8)	19.6 (5.9)	8.7 (4.3)	Japan	23	25
74	Lange et al., 2016	PD	not provided	Clinic/Specialist/Unit	62.6 (9.6)	14.3 (3.8)	93.6 (69.6)	26.8 (1.8)		Germany	32	35
75	Lange et al., 2016	ALS	Brooks (1994)	Clinic/Specialist/Unit	58.9 (9.6)	13.9 (2.3)		26.6 (3.1)	16.3 (2.2)	Germany	21	21
76	Lee et al., 2016	AD	not provided	Clinic/Specialist/Unit	69.4 (8.1)	6.5 (5.0)		16.1 (5.2)		Taiwan	28	40
		MCI	not provided	Clinic/Specialist/Unit	68.4 (6.4)	7.3 (4.6)		25.5 (4.2)		Taiwan	62	40
77	Lin et al., 2014	AD	not provided	Clinic/Specialist/Unit	74.7 (8.2)	8.3 (2.9)		19.0		Taiwan	9	15
		MCI	not provided	Clinic/Specialist/Unit	73.8 (10.4)	10.4 (4.3)		28.5		Taiwan	8	15
78	Liozidou, Potagas, Papageorgiou & Zalonis, 2012	PD	not provided	Clinic/Specialist/Unit	61.2 (9.1)	10.9 (4.2)	124.8 (87.5)			Greece	73	48
79	McCullagh, Moore, Gawel & Feinstein, 1999	ALS	Brooks (1994)	Clinic/Specialist/Unit	62.2 (8.5)	14.8 (2.3)	27.2 (51.4)	28.8 (1.1)		Canada	18	10
80	McDowd et al., 2011	AD	not provided	Clinic/Specialist/Unit	73.8 (7.2)			25.2 (4.9)		United States	33	30
		PD	not provided	Clinic/Specialist/Unit	71.9 (6.0)			27.9 (2.1)		United States	30	30

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
81	Meco, Gasparini & Doricchi, 1996	PD & MSA	Hughes et al. (1992); Quinn (1989), UK Brain Bank	Clinic/Specialist/Unit	65.8 (6.2)	7.2 (3.0)	69.6 (24.6)	25.7 (2.6)		Italy	11	12
82	Mollion, Ventry-Dominey, Dominey & Broussolle, 2003	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	57.6 (10.3)		96.0 (39.6)	29.3 (0.7)		France	18	9
83	Monchi et al., 2004	PD	not provided	Clinic/Specialist/Unit	56.6 (6.4)					Canada	8	9
84	Münte et al., 2015	PD	not provided	not provided	66.5 (8.9)	11.4 (3.1)	124.8 (81.6)			Germany	12	12
85	Muslimovic, Post, Johannes, Speelman & Schmand, 2005	PD	Gelb et al. (1999)	Clinic/Specialist/Unit	66.2 (10.1)	11.7 (2.4)	18.8 (10.7)	27.9 (1.6)		Netherlands	115	70
86	Nagahama et al., 2003	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	74.2 (5.1)	10.3 (2.5)		20.8 (3.3)		Japan	54	22
		MCI	Petersen et al. (2001)	Clinic/Specialist/Unit	72.8 (5.4)	10.9 (2.7)		26.4 (2.0)		Japan	17	22
87	Nichelli, Appollonio, Clark & Grafman, 1994	PD	Barbeau (1986)	not provided	58.6 (10.8)	14.4 (2.4)				Italy	18	14
88	Nojszewska, Pilczuk, Sakrzewks-Pniewska & Rowinska-Marcinska, 2009	PD	not provided	not provided	65.8 (9.1)		93.6 (60.0)	26.5 (3.5)		Poland	53	14
89	Norlund et al., 2008	MCI	not provided	Clinic/Specialist/Unit	66.7 (7.1)	11.4 (3.5)				Sweden	120	60
90	Ogawa, Tanaka & Hirata, 2009	ALS	Beghi et al. (2002)	not provided	67.7 (7.4)	10.3 (2.3)	8.1 (3.8)	27.2 (1.8)		Japan	19	19
91	Palmeiri et al., 2014	ALS	Brooks et al. (2000)	Clinic/Specialist/Unit	60.0 (8.8)	8.7 (4.0)	34.1 (41.3)			Italy	165	134

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
92	Paolo, Axelrod, Tröster, Blackwell & Koller, 1996	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	71.1 (5.8)	12.9 (2.2)	25.3 (6.0)			United States	35	35
93	Paolo, Tröster, Axelrod & Koller, 1995	PD	not provided	Community/population	68.9 (8.3)	14.2 (3.0)	67.1 (49.7)			United States	181	187
94	Parker, Chen, Kingyon, Cavanagh & Narayanan, 2015	PD	not provided	Clinic/Specialist/Unit	64.8 (2.9)	16.0				United States	13	13
95	Paulsen et al., 1995	AD	McKhann et al. (1984) DSM^3-III-R	Clinic/Specialist/Unit	70.0 (6.9)	14.1 (2.9)				United States	20	20
		HD	not provided	Clinic/Specialist/Unit	49.7 (11.6)	13.5 (2.2)				United States	20	20
96	Peltsch, Hemraj, Garcia & Munoz, 2014	AD	McKhann et al. (1984)	not provided	76.0 (8.0)	15.0 (4.0)		27.0 (2.0)		Canada	24	72
		aMCI	Petersen (2004)	not provided	76.0 (8.0)	14.0 (4.0)		27.0 (2.0)		Canada	22	72
97	Perfetti et al., 2010	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	69.8 (7.2)	8.7 (4.9)		27.0 (1.8)		Italy	25	24
98	Perretta, Pari & Beninger, 2005	PD	not provided	Clinic/Specialist/Unit	75.1 (1.9)	14.4 (0.9)		28.6 (1.0)		Canada	32	19
99	Petrova et al., 2015	LBD	Hughes et al. (1992), McKeith (2006)	Clinic/Specialist/Unit	71.0 (6.2)	13.2 (3.6)	31.2 (18.0)	28.3 (1.5)		Bulgaria	45	22
100	Petrova, Raycheva & Traykov, 2012	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	71.5 (6.5)	11.5 (3.2)	100.8 (53.4)	24.1 (1.4)		Bulgaria	58	26
101	Picascia et al., 2016	NPH	Lumber puncture	Clinic/Specialist/Unit	73.7 (7.5)	8.0 (5.0)	40.1 (31.8)	21.8 (4.9)	11.5 (3.6)	Italy	64	58
102	Pirogovsky-Turk, et al., 2016	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	67.0 (7.3)	16.4 (2.6)	73.2 (69.6)			United States	68	30

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
103	Poletti et al., 2012	PD	Hughes et al. (1992)	Clinic/Specialist/Unit	66.6 (7.3)	9.2 (4.1)	13.9 (11.3)	27.5 (2.1)	15.2 (2.6)	Italian	121	100
104	Rabin et al., 2006	MCI	Petersen et al. (2001)	Community/population	74.1 (5.6)	16.7 (2.8)		26.8 (1.7)		United States	29	30
105	Rafii, Taylor, Coutinho, Kim & Galasko, 2011	AD	not provided	Clinic/Specialist/Unit	76.4 (9.8)	15.2 (2.8)		22.2 (4.7)		United States	49	25
		MCI	not provided	Clinic/Specialist/Unit	74.8 (9.0)	14.7 (2.5)		28.9 (1.8)		United States	12	25
106	Razani et al., 2007	Dementia	Neary et al. (1998)	Clinic/Specialist/Unit	73.8 (8.8)	15.1 (3.1)		24.3 (5.1)		United States	33	35
107	Rendondo, Beltrán-Brotóns, Reales & Ballesteros 2016	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	77.7 (3.9)	6.9 (1.1)		23.7 (4.3)		Spain	22	23
108	Risacher et al., 2013	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	76.7 (2.2)	15.3 (0.8)		24.2 (0.5)		United States	10	29
		MCI	Petersen (2004)	Clinic/Specialist/Unit	76.4 (1.3)	15.4 (0.5)		27.8 (0.3)		United States	28	29
109	Roca et al., 2012	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	62.3 (10.2)	13.9 (4.8)	17.6 (17.5)			Argentina	32	22
110	Rosen, Rott, Ebersbach & Kalbe, 2015	PD	Hughes et al. (1992), UK Brain Bank	Clinic/Specialist/Unit	67.5 (6.8)	13.5 (2.7)	100.8 (83.0)	28.8 (1.1)		Germany	20	23
111	Roussel et al., 2017	PD	not provided	Clinic/Specialist/Unit	61.7 (10.2)		100.8 (76.8)	26.7 (2.4)		France	45	461
112	Sagar, Sullivan, Cooper & Jordan, 1991	PD	not provided	not provided	60.1 (9.2)	9.9 (1.5)	13.2 (10.8)			United Kingdom	56	32
113	Salmon et al., 2015	LBD	not provided	Clinic/Specialist/Unit	73.1 (6.7)	12.9 (3.0)		21.1 (4.8)		United States	14	25
114	Saltzman, Strauss, Hunter & Archibald, 2000	PD	not provided	Clinic/Specialist/Unit	71.0 (13.4)	12.8 (0.8)				Canada	11	8

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
115	Sánchez, Martín, & López, 2017	AD	not provided	Clinic/Specialist/Unit	75.1 (7.3)	7.18 (2.3)		22.1 (4.7)		Spain	41	72
116	Satler & Tomaz, 2013	AD	not provided	Clinic/Specialist/Unit	78.6 (6.7)	6.8 (4.1)		18.0 (4.3)		Brazil	21	22
117	Saxton, Munro, Butters, Schramke & McNeil, 2000	AD	not provided	Clinic/Specialist/Unit	73.4 (5.5)	11.9 (2.5)		22.3 (4.4)		United States	9	15
118	Serra et al., 2016	MCI	not provided	Clinic/Specialist/Unit	70.5 (8.2)	9.8 (4.5)		26.5 (1.7)		Italy	31	26
119	Serra et al., 2014	AD	not provided	Clinic/Specialist/Unit	71.4 (6.4)	8.8 (4.2)		19.0 (3.3)		Italy	48	20
120	Serrani, 2013	Dementia	DSM[3]-IV	Clinic/Specialist/Unit	74.7 (7.5)	8.2 (2.7)				Spain	66	66
121	Shaunak et al., 1995	ALS	not provided	Inpatient	50.4 (11.9)		24.5	29.1 (1.4)		United Kingdom	17	11
122	Silveri, Reali, Jenner & Puopolo, 2007	MCI	not provided	Clinic/Specialist/Unit	71.8 (6.0)	10.7 (4.9)		26.5 (2.0)		Italy	33	21
123	Simons et al., 2002	SD	not provided	not provided	59.8 (6.4)					United Kingdom	8	8
124	Souchay, Isingrini, Pillon & Gil, 2003	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	73.1 (10.3)	9.7 (2.5)				France	16	16
		FTD	Lund-Manchester (1994)	Clinic/Specialist/Unit	57.7 (9.3)	9.8 (1.8)				France	6	16
125	Stokholm, Vogel, Gade & Waldemar, 2006	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	76.0 (5.6)	10.7 (2.8)		25.9 (1.5)		Demark	36	32
126	Sun et al., 2016	MCI	Petersen et al. (2001)	Clinic/Specialist/Unit	68.8 (5.9)	12.1 (2.9)		26.6 (1.3)		China	50	38

Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
127	Takeda et al., 2010	AD	McKhann et al. (1984)	Clinic/Specialist/Unit	74.8 (5.7)	10.7 (2.4)	34.8 (16.8)	21.3 (3.2)	10.5 (2.6)	Japan	31	11
		FTD	Neary et al. (1998)	Clinic/Specialist/Unit	60.2 (8.1)	12.2 (1.9)	54.0 (39.6)	22.8 (6.0)	9.0 (5.2)	Japan	12	11
		LBD	McKeith et al. (1996)	Clinic/Specialist/Unit	7.37 (3.3)	9.5 (2.3)	21.6 (0.8)	19.8 (4.8)	10.5 (2.4)	Japan	6	11
		VaD	Roman et al. (1993)	Clinic/Specialist/Unit	69.9 (8.3)	11.2 (3.0)	36.0 (20.4)	22.1 (2.9)	10.2 (2.2)	Japan	9	11
		MCI	not provided	Clinic/Specialist/Unit	67.7 (10.5)	11.7 (2.5)		28.6 (1.2)	14.9 (1.6)	Japan	6	11
128	Taler, Voronchikhina, Gofine & Luskasik, 2016	MCI	not provided	Clinic/Specialist/Unit	75.0 (5.4)	16.0 (3.5)				Canada	21	39
129	Tomer, Fisher, Giladi & Aharon-Peretz, 2002	PD	not provided	not provided	66.4 (9.5)	12.2 (4.1)		28.5 (1.3)		Israel	28	19
130	Torralva, Gleichgerrcht, Torres, Roca & Manes, 2015	FTD	not provided	Clinic/Specialist/Unit	67.9 (7.8)	14.9 (5.2)		22.9 (4.7)		Argentina	40	18
131	Towgood et al., 2012	HIV+		not provided	58.7 (6.6)		156 (68.4)			United Kingdom	20	22
132	Traykov et al., 2005	VaD	not provided	Clinic/Specialist/Unit	81.4 (5.1)	9.6 (4.5)		24.0 (2.0)		France	23	35
		AD	not provided	Clinic/Specialist/Unit	80.9 (6.5)	9.9 (4.5)		24.3 (2.7)		France	45	35
133	Traykov et al., 2007	MCI	not provided	Clinic/Specialist/Unit	73.2 (8.0)	12.1 (3.1)		29.0 (1.1)		France	20	20
134	Vance, Fazeli & Gakumo, 2012	HIV	not provided	Clinic/Specialist/Unit	56.8 (5.9)	13.7				United States	31	41
135	Venneri et al., 1997	PD	not provided	Clinic/Specialist/Unit	60.4 (7.3)	5.8 (1.9)		28.7 (1.1)		Italy	25	22

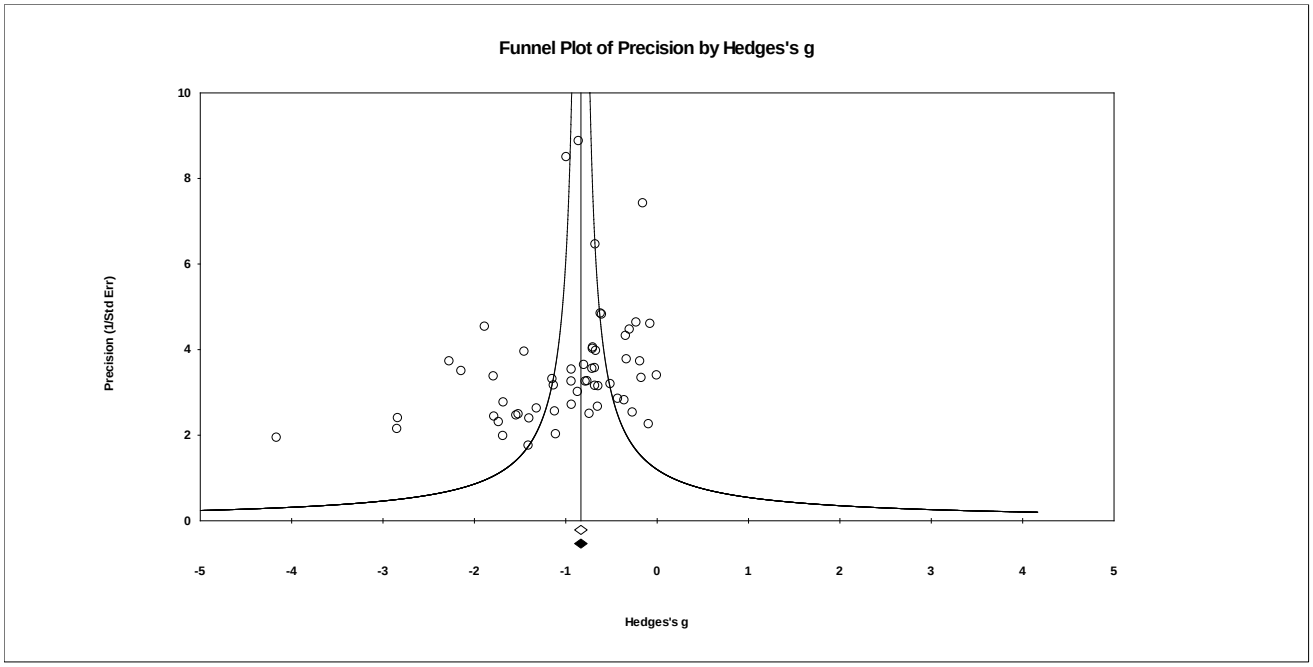
Supplementary Table A.2.4: Summary details for each of the studies that were included in the meta-analysis cont.

ref	*Study*	*NeuroD type*	*Published diagnostic criteria*	*Recruitment source*	*Age M(SD)*	*Educat-*	*Illness duration*	*MMSE/ MoCA*	*FAB*	*Country*	N_{neuroD}	$N_{controls}$
136	Wickund, Johnson & Weintraub, 2004	PPA	not provided	Clinic/Specialist/Unit	61.9 (9.5)	16.3 (3.3)	3.9	26.5 (2.7)		United States	20	20
		bvFTD	Neary et al. (1998)	Clinic/Specialist/Unit	65.1 (9.3)	15.7 (2.4)		24.7 (3.5)		United States	16	20
		AD	McKhann et al. (1984)	Clinic/Specialist/Unit	74.6 (7.4)	14.9 (2.4)		22.3 (3.0)		United States	20	20
137	Wild et al, 2013	PD	not provided	Clinic/Specialist/Unit	69.3 (2.7)	6.2 (0.7)		26.4 (0.5)		Brazil	18	18
138	Witt et al., 2006	PD	not provided	not provided	58.0 (8.3)	10.5 (1.8)	97.2 (64.0)			German	22	22
139	Yu et al., 2012	PD	not provided	Clinic/Specialist/Unit	62.7 (4.2)	11.4 (4.6)	51.6 (33.6)	27.9 (1.8)		Taiwan	39	40
140	Zalsonis et al., 2012	ALS	not provided	Clinic/Specialist/Unit	60.6 (11.0)	9.71 (4.1)	21.0 (18.9)			Greece	48	47
141	Zeng et al., 2002	PD	not provided	not provided	64.3 (9.6)	11.6 (2.5)		27.7 (2.5)		Japan	40	20
142	Zhou & Jia, 2009	MCI	not provided	Clinic/Specialist/Unit	69.7 (6.7)	10.1 (2.8)		26.5 (1.7)		China	86	80

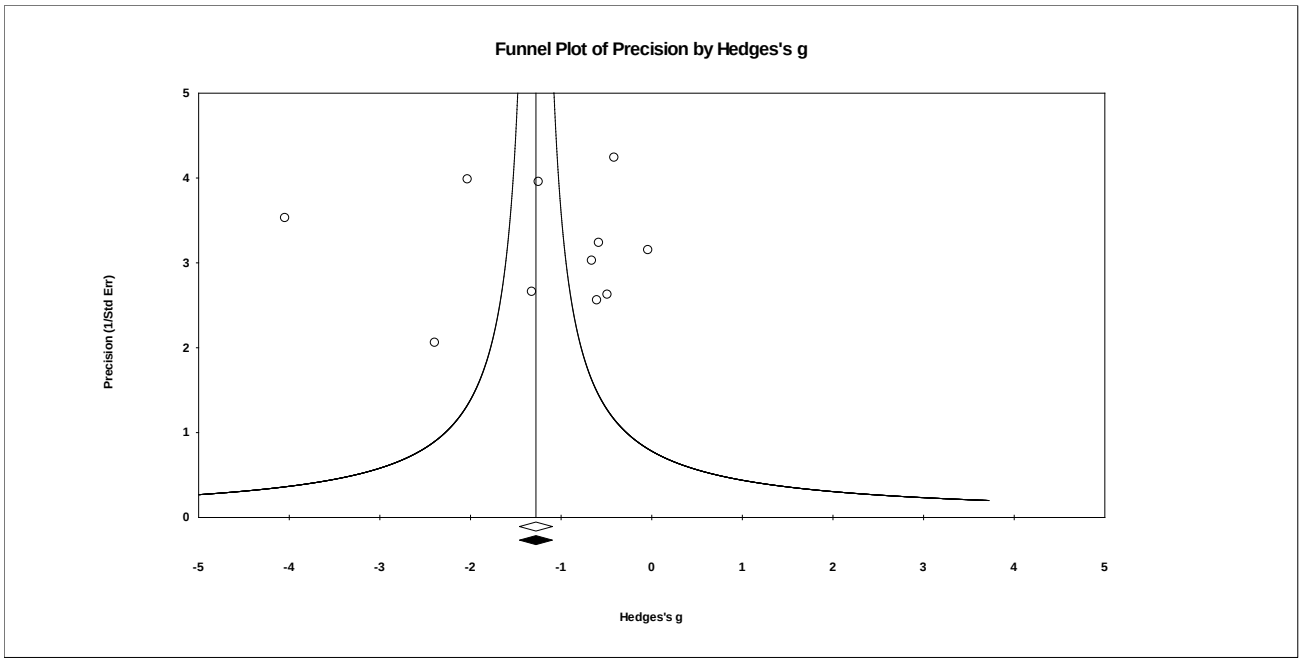
ref = corresponds to citation number in the tables, NeuroD = type of neurodegenerative disorder or dementia, M(SD) = mean (standard deviation), Educat- = years of education, MMSE = Mini Mental Status Examination, MoCA = Montreal Cognitive Assessment, FAB = Frontal Assessment Battery, NneuroD = number of participants with a neurodegenerative disorder, Ncontrol = number of healthy controls, PD = Parkinsonian disorders, MSA = multiple system atrophy, MND = motor neuron disorder, PSNP = progressive supra nuclear palsy, MCI = mild cognitive impairment, aMCI = amnesic MCI, AAMI = age associated memory impairment meeting the requirement for MCI, other Neuro. Dis = other neurodegenerative disorders, AD = Alzheimer's dementia, bvFTD = behavioural-variant frontotemporal dementia, VaD = vascular dementia, LBD = lewy body dementia, Dementia NOS = dementia not otherwise specified, PPA = primary progressive aphasia, SD = semantic dementia, HIV+ = human immunodeficiency virus, NPH = normal pressure hydrocephalus, MS = multiple sclerosis, HD = Huntington's disease, PNFA = progressive non-fluent aphasia, DSM = Diagnostic and Statistical Manual of Mental Disorders, NINCDS- National Institute of Neurological Disorders and Stroke

Supplementary Figure A.2.2: Publication bias analyses for the category score

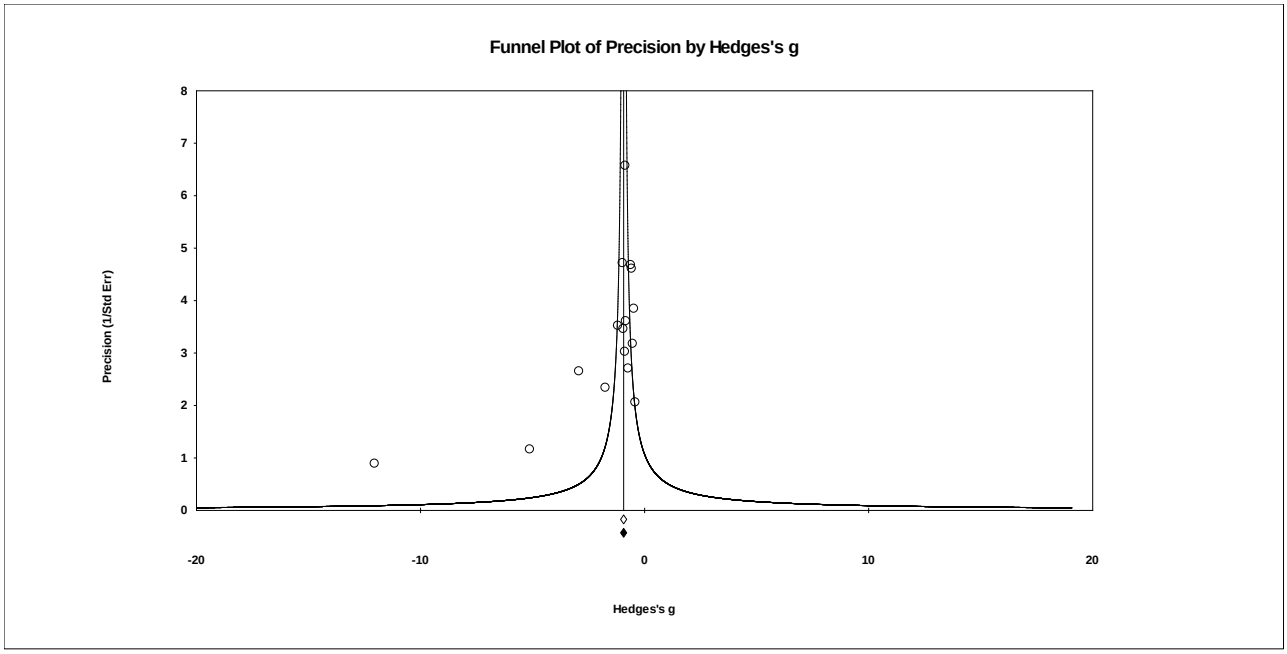
A.2.2a. PD vs healthy controls



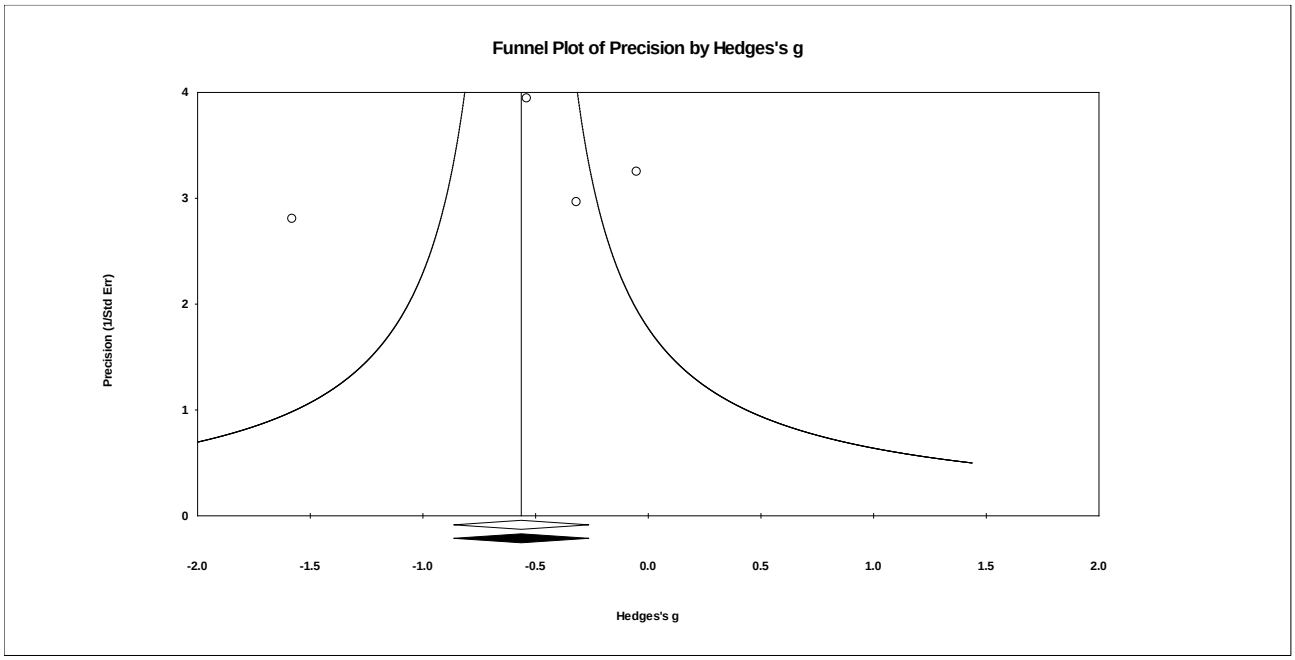
A.2.2b. MND vs healthy controls



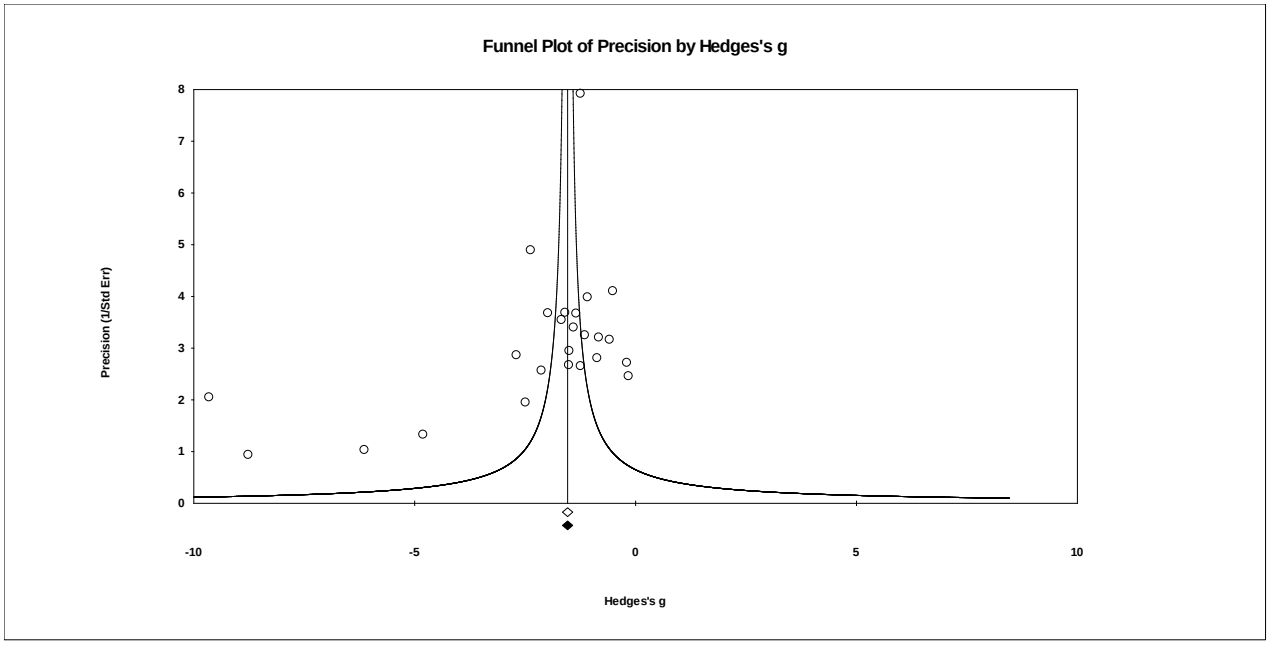
A.2.2c. MCI vs healthy controls



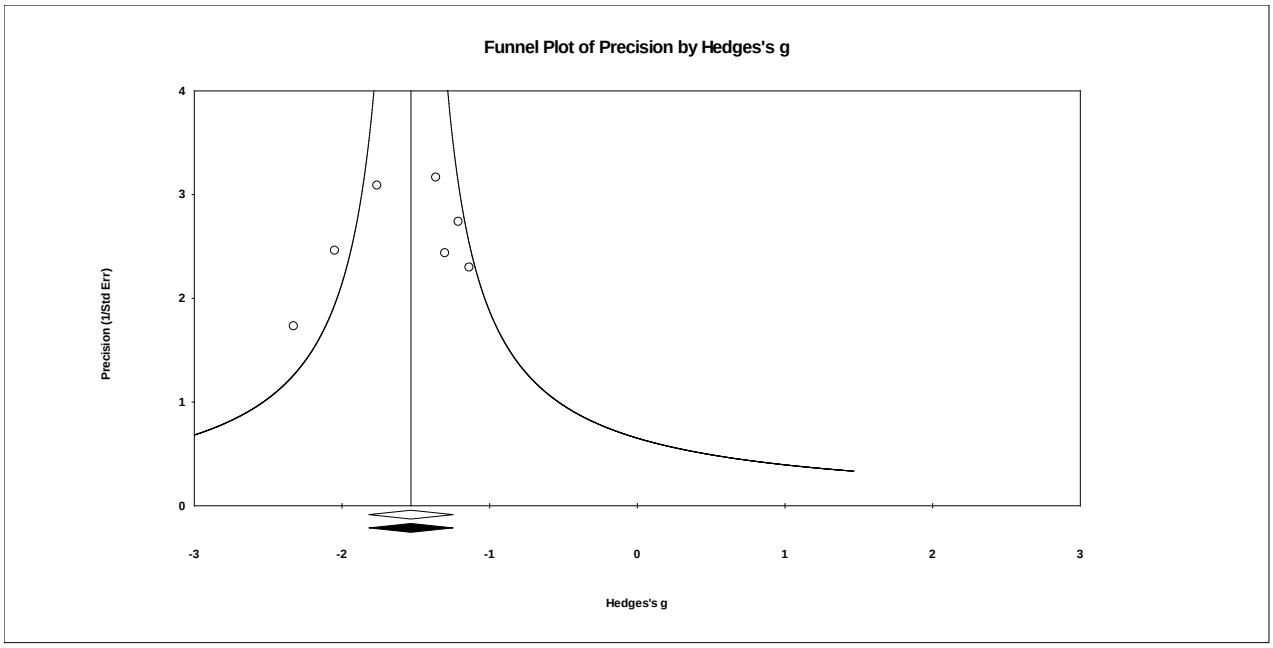
A.2.2d. Other neurodegenerative disorders vs healthy controls



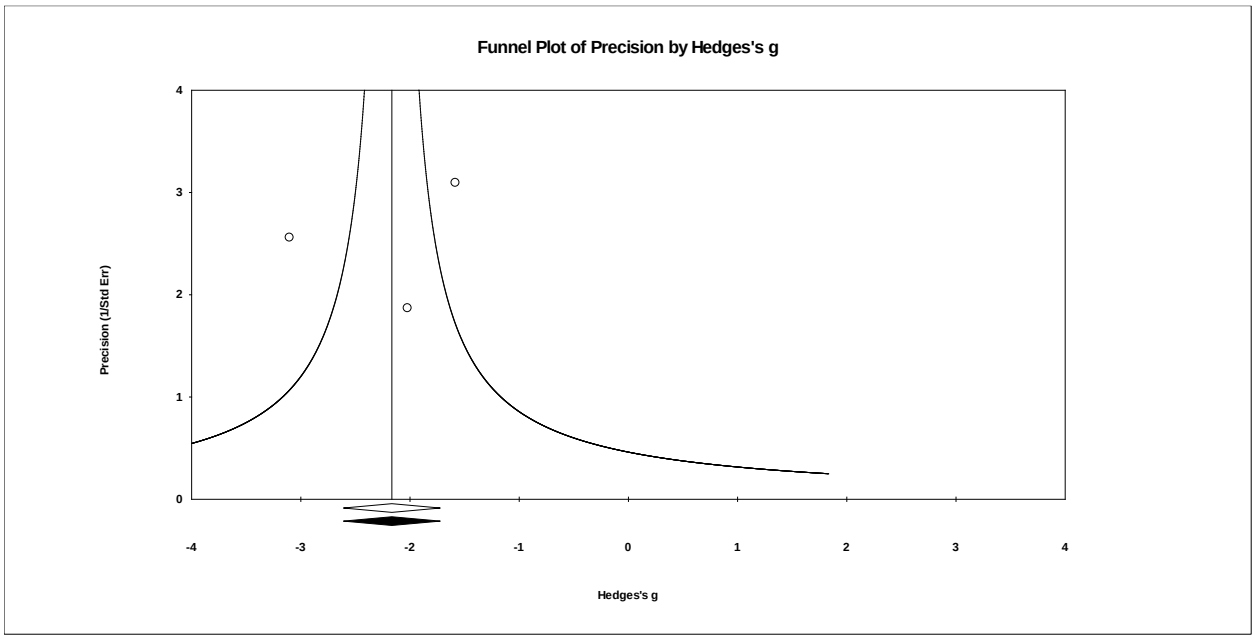
A.2.2e. AD vs healthy controls



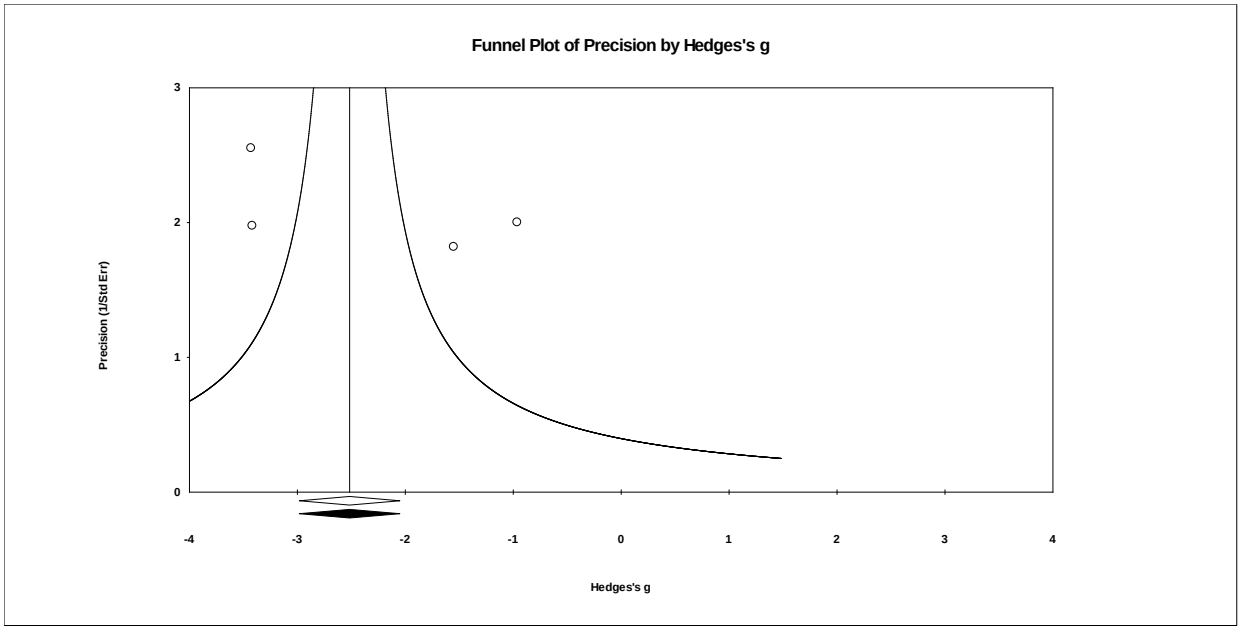
A.2.2f. bvFTD vs healthy controls



A.2.2g. VaD vs healthy controls



A.2.2h. LBD vs Controls



PD = Parkinsonian disorders, MND = motor neuron disorder, MCI = mild cognitive impairment, other Neuro. Dis = other neurodegenerative disorders, AD = Alzheimer's dementia, bvFTD = behavioural-variant frontotemporal dementia, VaD = vascular dementia, LBD = lewy body dementia

Appendix A.3: Reference list for supplemental material

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Appendix B Supplementary information for Study 4 (Chapter 6)

Appendix B.1: Published Article for Study 4

Development of a Brief Screen to Detect Cognitive Impairment in Older Adults: The QuickSort

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BACKGROUND: Sorting tests detect cognitive decline in older adults who have a neurodegenerative disorder, such as Alzheimer's and Parkinson's disease. Although equally effective at detecting impairment as other cognitive screens (e.g. Mini-Mental State Examination (MMSE)), sorting tests are not commonly used in this context. This study examines the QuickSort, which is a new brief sorting test that is designed to screen older adults for cognitive impairment.

DESIGN: Observational cohort study.

SETTING: General community and inpatients, Australia.

PARTICIPANTS: Older (≥60 years) community-dwelling adults (n = 187) and inpatients referred for neuropsychological assessment (n = 78). A normative subsample (n = 115), screened for cognitive and psychological disorders, was formed from the community sample.

MEASUREMENTS: Participants were administered the QuickSort, MMSE, Frontal Assessment Battery (FAB), and Depression Anxiety and Stress Scale-21. The QuickSort requires people to sort nine stimuli by color, shape, and number, and to explain the basis for their correct sorts. Sorting (range = 0–12), Explanation (range = 0–6), and Total (range = 0–18) scores were calculated for the QuickSort.

RESULTS: The Cognitively Healthy subsample completed the QuickSort within 2 minutes, 50% had errorless performance, and 95% had Total scores of 10 or greater. The likelihood of community-dwelling older adults and inpatients (n = 260) being impaired on either the MMSE or FAB, or both, increased by a factor of 3.75 for QuickSort Total scores of less than 10 and reduced by a factor of 0.23 for scores of 10 or greater.

CONCLUSION: The QuickSort provides a quick, reliable, and valid alternative to lengthier cognitive screens (e.g., MMSE and FAB) when screening older adults for cognitive impairment. The QuickSort performance of an older adult can be compared with a cognitively healthy normative sample and used to estimate the likelihood they will be impaired on either the MMSE or FAB, or both. Clinicians can also use evidence-based modeling to customize the QuickSort for their setting. **J Am Geriatr Soc 69:441-449, 2021.**

Keywords: older adult; cognitive impairment; screening; QuickSort

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INTRODUCTION

The need to screen older adults for cognitive impairment is growing as the number of people with neurodegenerative disorders increases (e.g., dementia).[1,2] However, clinicians' time is limited, making efficient cognitive screening imperative.[3] The Mini-Mental State Examination (MMSE) is the most commonly used cognitive screen and is often supplemented with the Frontal Assessment Battery (FAB) to detect frontal or "executive" deficits.[3,4] The MMSE and FAB each take 10 minutes to administer, with additional time for scoring.[5,6] Although brief, this may exceed the time available in some settings.

Sorting tests are among the most sensitive tests for detecting cognitive impairment,[7,8] but are rarely used to screen older adults. There are a number of such tests, all requiring respondents to sort stimuli according to color, shape, or number.[9-11] Although commonly assumed to measure "executive" functioning, sorting tests assess multiple cognitive abilities[12-14] and may, therefore, provide an alternative to the MMSE and FAB.

Of note, a recent meta-analysis found that sorting tests identify cognitive decline caused by neurodegenerative disorders of older age.[15] The ability to switch categories was

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frequently assessed (Category score) and best detected cognitive decline in dementia, with sensitivity and specificity values both approximately 85%. These figures are comparable to those reported for the MMSE when detecting dementia in memory clinics (80% and 81%, respectively).[16] Verbal explanations about the rule underpinning a correct sort (Explanation or Description scores) were less common, but had the greatest sensitivity for detecting the most common neurodegenerative disorders of older age, namely Alzheimer's disease and parkinsonian disorders.[15]

Although promising, there are multiple limitations to using existing sorting tests to screen older adults for cognitive decline, including their complexity (up to 64 stimuli) and administration time (up to 30 minutes), an inability to discontinue early when performance is intact, complicated scoring procedures, and floor effects when scoring.[8,11,17] The QuickSort was developed to retain the best features of existing tests, while overcoming some of the aforementioned limitations. Specifically, the QuickSort has nine stimuli, an early discontinuation rule, a one-page record form (reducing administration and scoring time), and a lower floor. Erroneous sorts are also explained (enabling learning), and the test can be scored even if a person is unable to complete the test or has expressive language problems.

This study was designed to evaluate the QuickSort when screening older adults for cognitive impairment by: (1) examining its user friendliness and inter-rater and test-retest reliability, (2) developing normative data so that the performance of older adults can be compared with that of their cognitively healthy peers, and (3) evaluating its discriminant validity by assessing its ability to detect impairment on lengthier cognitive screens (MMSE and FAB) in community and clinical samples. In combination, this study will determine whether the QuickSort provides a quick, reliable, and valid alternative to lengthier cognitive screens that are often used with older adults.

METHODS

Participants

Two samples of older adults (≥60 years) participated: (1) community-dwelling visitors, outpatients, and volunteers at the Royal Adelaide Hospital (RAH), and (2) RAH inpatients who were consecutively referred for neuropsychological assessment (mostly relating to mental capacity), hereafter referred to as the Community (n = 187) and Inpatient (n = 78) samples, respectively. Participants were excluded if they (Community) or their medical team (Inpatients) reported they were acutely unwell or non-English speaking, or had red-green color blindness.

A cognitively healthy normative subsample (hereafter named the Cognitively Healthy subsample; n = 115) was formed from the Community sample by excluding 72 participants who (1) were unable to complete the cognitive tests, (2) had a history indicating significant or multiple concussions, a diagnosed head injury, or an intellectual or learning disability, (3) were impaired on the MMSE (<24)[18] or FAB (<11),[6] or (4) were psychologically distressed (Depression, Anxiety, and Stress Scale-21 (DASS-21) scores: depression >20, anxiety >14, or stress >25) (Figure 1).[19] The high exclusion rate resulted from recruiting through a large publicly funded tertiary hospital that services a broad sociodemographic area. A similar exclusion rate has been reported for the MMSE.[20]

Measures

Background demographic (age, sex, education, and nationality) and medical information (visual and hearing disabilities, color blindness, conditions affecting cognition (e.g., head trauma and epilepsy)) was recorded for each participant. Cognitive functioning was assessed using the MMSE (scored: 0–30), FAB (scored: 0–18), and Quicksort (see below), with higher scores indicating better cognition. Psychological distress was assessed using the DASS-21, with lower scores indicative of fewer symptoms.[19]

The QuickSort uses nine cards, which are sorted according to three categories (color, shape, and number) over a maximum of six trials. The QuickSort Manual, Stimuli, and Record Form are provided in Supplementary Appendix S2 (Online Supplementary Materials). An early discontinuation rule reduces administration time when cognition is intact. Three scores are calculated: (1) a "Sorting" score (named the Category score in other tests), which aggregates the number of successful sorts, errors (repetition, set loss, grouping, and completion errors) and prompts during a maximum of six trials (range = 0–12); (2) an "Explanation" score, which assesses an examinee's ability to explain the basis for their correct sorts (range = 0–6); and (3) a "Total" score, which sums the Sorting and Explanation scores (range = 0–18). Sorting scores are used when a person has problems with verbal expression, and both Sorting and Total scores can be calculated when someone fails to complete the QuickSort (incomplete trials scored zero). Repetition errors (repeated sorts using the same rule) and concrete explanations are also recorded for clinical purposes, but are not examined here.

An electronic version of the QuickSort (QuickSort-e), which generates the same scores as the original version, was developed to reduce clinician's training and scoring time, and to facilitate score interpretation using the methods recommended by evidence-based medicine (EBM). Information regarding the participants' prior familiarity with, and comfort using, an iPad was also recorded.

Procedure

The Human Research and Ethics Committee of the RAH, South Australia, approved this project. Written informed consent was obtained according to the Declaration of Helsinki.

The QuickSort underwent initial focus group development using a convenience sample of nine clinical neuropsychologists, who provided subjective evaluations of its user friendliness (administration, scoring, and interpretation) before its use here. Three clinical psychologists additionally viewed and scored videos of 15 QuickSort performances (simulated impaired and actual older adults) to assess inter-rater reliability.

Participants were recruited between October 2013 and December 2017. A neuropsychologist or research assistant (postgraduate) conducted individual assessments in an office (Community sample) or bedside (Inpatients). The

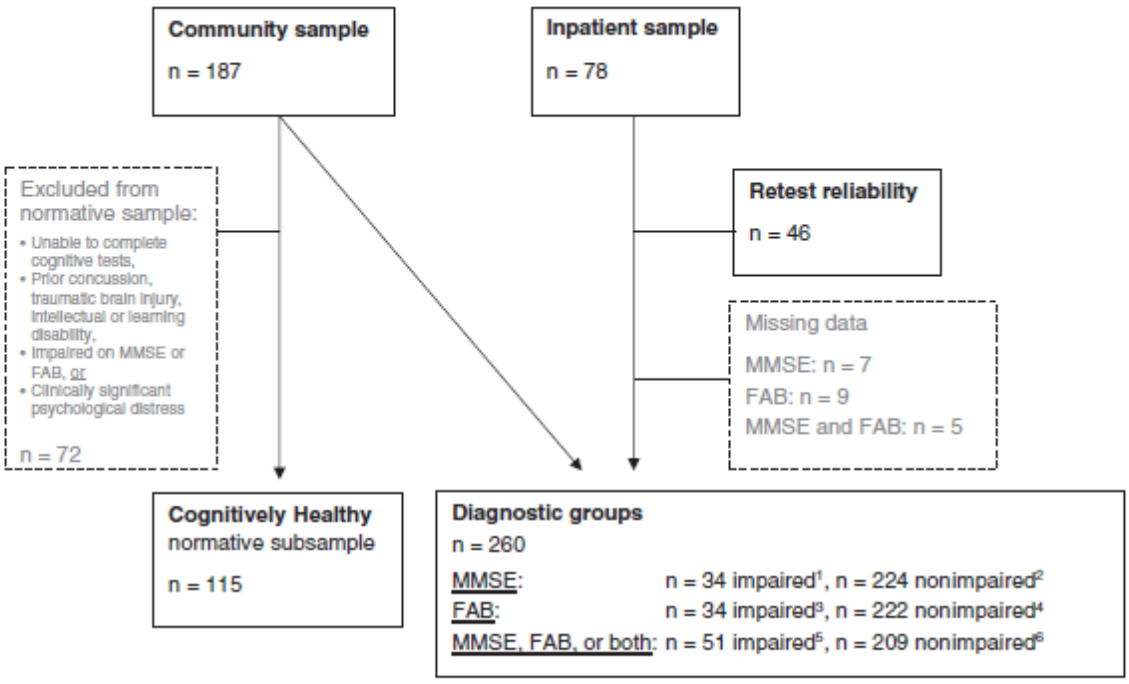

Figure 1. Participant flow chart. [1]Mini-Mental State Examination (MMSE) (score <24); [2]MMSE (score ≥24) (n = 1 in the Community sample and n = 6 in the Inpatient sample were intact on the MMSE, but impaired on the Frontal Assessment Battery (FAB)); [3]FAB (score <11); [4]FAB (score ≥11) (n = 1 in the Community sample and n = 14 in the Inpatient sample were intact on the FAB, but impaired on the MMSE); [5]MMSE (score ≥24) and FAB (score ≥11); [6]impaired on either the MMSE (score <24) or FAB (score <11), or both.

QuickSort was administered to (1) the Community sample, before the MMSE and FAB (same session), and (2) Inpatients, before their neuropsychological consultation, to blind assessors to the person's cognitive status. Forty-six Inpatients were readministered the QuickSort while in hospital to assess test-retest reliability.

The QuickSort-e was piloted in a subset of consecutively recruited community-dwelling participants (n = 29) during the final stages of the study.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences[21] using $P < .05$ and excluding missing data listwise. Summary demographic, cognitive, and psychological scores (means, standard deviations (SDs), numbers, and percentages) were calculated for the Community and Inpatient samples, and the Cognitively Healthy subsample.

A focus group of clinicians examined the user friendliness and clinical acceptability of the QuickSort. Intraclass correlations (ICCs), measuring absolute agreement (single measures), were used to assess inter-rater reliability (n = 3 raters) and test-retest reliability (n = 46 Inpatients), with 0.8 considered acceptable and 0.9 excellent.[22] Practice effects were indicated by differences between ICCs measuring consistency and absolute agreement.[22]

Normative data for the QuickSort Total and Sorting scores were created using the Cognitively Healthy subsample. Cumulative frequencies (base rates) were calculated for the Total and Sorting scores, enabling the scores of older adults to be compared with their cognitively healthy peers. Linear regressions determined whether these normative data needed to be stratified by age, education, or sex. Norms were stratified if any variable accounted for more than 10% of the variance (small effect).[23]

Next, the QuickSort discriminant validity was examined in terms of its ability to detect impairment on: (1) the MMSE, (2) the FAB, and (3) either the MMSE or FAB, or both. The Community and Inpatient samples were combined for this purpose, after which participants were classified into one of two Diagnostic groups: *cognitively impaired* on (1) the MMSE (score <24), (2) the FAB (score <11), and (3) either the MMSE or FAB, or both, and *nonimpaired* (MMSE score ≥25, FAB score ≥12) (Figure 1 provides details). Independent samples *t*-tests assessed whether the Diagnostic groups (impaired and nonimpaired) were demographically comparable (age and education can independently affect cognition) and whether their QuickSort scores differed (Sorting, Explanation, and Total scores, repetition errors, concrete responses). Analyses of covariance (ANCOVAs) further investigated whether demographic differences between the Diagnostic groups significantly contributed to differences in their QuickSort performance (Sorting and Total scores).

A logistic regression identified the QuickSort Total cut-score that correctly classified the largest number of participants into the Diagnostic groups. A power analysis indicated that a minimum sample size of 42 was required to detect a large difference (Cohen $d = 0.80$) in the QuickSort scores with 95% power and $\alpha = .05$.[23] In addition, the most clinically useful QuickSort cut-score was obtained by tallying the numbers of people who scored above and below

each score and who were impaired and nonimpaired on (1) the MMSE, (2) the FAB, and (3) either the MMSE or FAB, or both. The CATmaker[24] was used to calculate sensitivity and specificity, likelihood ratios (LRs), and 95% confidence intervals (CIs). The Total cut-scores that were most clinically useful for ruling in (sensitivity important) or ruling out (specificity important) cognitive impairment were identified. LRs greater than 1 indicate that QuickSort scores were associated with impairment on the MMSE or FAB, with LRs less than 1 indicating an absence of impairment on these screens.[25] Clinically, scores with LRs greater than 3 or less than 0.3 are considered most useful because they substantially change the likelihood of the person being impaired or nonimpaired, respectively.[26]

ICCs, measuring absolute agreement (single measures), were used to assess convergent validity between the original QuickSort and the QuickSort-e.[22]

RESULTS

Community and Inpatient Sample Summary Information

Table 1 provides summary demographic and test information (MMSE, FAB, QuickSort, and DASS-21) for the Community (n = 187) and Inpatient (n = 78) samples, from which the Cognitively Healthy normative subsample and Diagnostic groups were formed. Both samples had a mean age in their 70s and had completed approximately 4 years of high school. There was a slightly higher proportion of males, and most participants were born in Australia. On average, the Inpatient sample had poorer cognition (MMSE, FAB, and QuickSort), greater psychological distress (DASS-21), and took longer to complete the QuickSort than the Community sample.

QuickSort Clinical Acceptability, Inter-rater Reliability, and Test-Retest Reliability

All clinicians in the focus group indicated that the QuickSort was user friendly. The QuickSort Sorting, Explanation, and Total scores (n = 15 cases) provided by three independent raters were also in agreement (ICC = 1.00), indicating that the scoring procedures are clear and have high inter-rater reliability.

Test-retest reliability was assessed in 46 Inpatients who were readministered the QuickSort after an average 4.6 days (SD = 3.0 days). The Sorting (ICC = 0.75), Explanation (ICC = 0.79), and Total (ICC = 0.81) scores all showed acceptable absolute agreement (stability) over time. These coefficients were similar to the ICCs for consistency in the Sorting, Explanation, and Total scores (ICC = 0.76, 0.79, and 0.81, respectively), indicating there were minimal practice effects, even after a short interval.

QuickSort Normative Data

Norms for the QuickSort were created from the Cognitively Healthy subsample (n = 115). As seen in Table 1, this subsample closely resembled the Community sample from which it was drawn, but had slightly fewer males. On average, the Cognitively Healthy participants completed the QuickSort in under 2 minutes. Not unexpectedly, the QuickSort scores for this subsample were skewed (see Supplementary Table S1 for interquartiles), with the average Total score approaching 16 (maximum = 18). Of note, 54% (n = 62) achieved the maximum Total score and 95% (n = 109) scored 10 or greater. The base rates for the Total and Sorting score are provided in Table 2.

Linear regressions performed on both the QuickSort Total and Sorting scores of the Cognitively Healthy subsample revealed that age (r^2 = 3.4% and 3.2%) and education (r^2 = 8.8% and 8.4%), but not sex (r^2 < 0.1% and 0.1%), had a significant but small (<10%) impact on performance. Thus, the test norms did not need to be demographically stratified (see Supplementary Table S2 for analyses).

QuickSort Validity: Detecting Impairment and Nonimpairment on the MMSE and FAB

As indicated above, Diagnostic groups (impaired and nonimpaired) were formed from the Community and Inpatient data (total n = 260) to assess the QuickSort ability to identify those impaired on the: (1) MMSE (score <24), (2) FAB (score <11), and (3) either the MMSE (score <24) or FAB (score <11), or both.

When the Diagnostic groups were compared, the impaired groups had lower QuickSort scores (Sorting, Explanation, and Total scores, repetition errors, but not concrete responses; see Supplementary Tables S3–S5), and took longer to complete it (excluding those who were only impaired on the FAB). Although significantly older and less educated than the nonimpaired group, ANCOVAs revealed that the QuickSort scores of the impaired groups remained significantly lower after controlling for these demographic differences (Supplementary Table S6). Thus, the QuickSort showed good discriminant validity.

A logistic regression identified the QuickSort Total cut-score that optimized the classification of participants as cognitively impaired versus nonimpaired on either the MMSE or FAB, or both (the only analysis that was sufficiently powered). A cut-score of less than 4 correctly classified 84% of participants, with 43% sensitivity and 94% specificity. Scores of less than 4 increased the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 6.95 (95% CI = 3.75–8.41), but scores of 4 or greater only reduced the likelihood of impairment by a factor of 0.61 (95% CI = 0.48–0.77). The high specificity resulted from scores less than 4 being infrequent in the Cognitively Healthy normative group (1.7%; Table 2).

There may be situations where detecting cognitive impairment (sensitivity) takes precedence over ruling it out (specificity), or vice versa. Sensitivity, specificity, and LR (and 95% CI) statistics are therefore provided for every QuickSort Total score when predicting impairment on the MMSE, FAB, and either the MMSE or FAB, or both (Table 3). These data were also calculated for Sorting scores (Supplementary Table S7), but should only be used when a person has problems with verbal expression because the Total score had larger positive and smaller negative LRs.

In clinical settings where ruling in (sensitivity) and ruling out (specificity) cognitive impairment are both important, a cut-score of less than 10 may be preferable because sensitivity increases to 78%, with 82% specificity (Table 3).

Table 1. Summary Demographic and Test Data for the Community and Inpatient Samples, and Cognitively Healthy Normative Subsample

	Community sample (n = 187)				Inpatient sample (n = 78)				Cognitively healthy normative subsample (n = 115)			
Variable	No.	%	Mean	SD	No.	%	Mean	SD	No.	%	Mean	SD
Age, y	187		71.3	7.48	78		74.6	8.76	115		71.2	7.70
Education, y	187		11.5	2.96	72		11.1	3.88	115		11.7	2.84
Sex												
Male	98	52			47	60			53	46		
Female	89	48			31	40			62	54		
Nationality												
Australian[a]	121	65			54	69			72	63		
European	57	30			20	26			36	31		
Asian	3	2			0	0			3	3		
Other	6	3			2	3			4	4		
MMSE												
Total score (range = 0–30)	187		28.2	1.68	71		23.7	3.87	115		28.5	1.29
Impaired: MMSE score <24	3	2			31	40			0	0		
FAB												
Total score (range = 0–18)	187		15.1	2.59	69		11.8	3.09	115		15.6	1.99
Impaired: FAB score <11	11	6			23	29			0	0		
MMSE and FAB												
Impaired: either or both screens	12	6			39	50			0	0		
QuickSort												
Sorting score (range = 0–18)	187		9.4	3.53	78		4.2	3.83	115		10.4	2.66
Explanation score (range = 0–9)	187		4.9	1.59	78		2.6	2.22	115		5.4	1.14
Total score (range = 0–18)	187		14.3	4.80	78		6.8	5.88	115		15.8	3.37
Total score <10	34	18			58	74			6	5		
Administration time	26		2 min 8 s	1 min 17 s	17		4 min 92 s	2 min 37 s	19		1 min 43 s	51 s
Repetition errors (range = 0–5)	187		0.5	0.96	78		1.7	1.51	115		0.3	0.53
Concrete responses (range = 0–3)	187		0.4	0.68	78		0.2	0.50	115		0.4	0.74
DASS-21												
Depression (range = 0–21)	187		2.3	3.36	4		5.5	2.05	115		2.3	3.35
Anxiety (range = 0–21)	187		2.6	2.87	4		6.0	5.60	115		2.6	2.83
Stress (range = 0–21)	187		4.3	3.97	4		3.5	3.70	115		4.3	3.88

Abbreviations: DASS-21, Depression, Anxiety, and Stress Scale-21; FAB, Frontal Assessment Battery; MMSE, Mini-Mental State Examination; SD, standard deviation.

[a]n = 1 person identified as indigenous in each of the Community and Inpatient samples.

LRs indicate that scores less than 10 increase the likelihood that a person is impaired by a factor of 3.18 (95% CI = 2.43–4.17), 3.63 (95% CI = 2.74–4.72), and 3.75 (95% CI = 2.81–4.98) on the MMSE, FAB, and either the MMSE or FAB, or both, respectively. Alternatively, scores of 10 or greater reduce the likelihood that a person is impaired by a factor of 0.24 (95% CI = 0.11–0.49), 0.16 (95% CI = 0.06–0.39), and 0.23 (95% CI = 0.13–0.41) on the MMSE, FAB, and either the MMSE or FAB, or both, respectively. Therefore, a cut-score of less than 10 may prove more useful because it can both rule in *and* rule out impairment on lengthier cognitive screens.

As with most tests, there is greater certainty surrounding high or low scores. For example, Total scores of less than 2 increase the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 9.26 (95% CI = 2.96–28.75), and Total scores of 17 or greater reduce the likelihood of impairment by a factor of 0.16 (95% CI = 0.06–0.41). Thus, the most informative way to interpret any QuickSort score is to use the associated LR.

According to EBM, the local prevalence of impairment (pretest probability, which can be estimated from published research or a clinical audit) should be taken into consideration when estimating a patient's probability of impairment on the MMSE or FAB.[27,28] As seen in Figure 2, the likelihood of impairment on either the MMSE or FAB, or both, can be calculated for two patients who score 5 on the QuickSort (see <6 cut score LR+ = 5.45; Table 3, right panel), but are seen in different clinical settings: one with a pretest probability of impairment of 20% (solid yellow line) and the other with a 50% pretest probability (dotted red line). Lines from these two different pretest probabilities (left y axis) through the LR+ of 5.45 (center y axis) yield posttest probabilities (right y axis) of 58% and 85%, respectively.

QuickSort-e Preliminary Findings

Twenty-nine consecutive community-dwelling participants were additionally administered the QuickSort-e. Everyone reported being comfortable using the iPad, despite 45% having not previously used an iPad. The QuickSort-e took slightly longer to administer than the original version (mean = 3.08 min; SD = 1.84), but this is offset by automatic scoring. The two versions of the QuickSort had satisfactory to good convergent validity (Sorting ICC = 0.72; Explanation ICC = 0.86; Total ICC = 0.84).

DISCUSSION

The QuickSort is a brief new cognitive screen that is designed to identify cognitive impairment in clinical settings where resources are limited. The QuickSort assesses sorting ability, which deteriorates as a consequence of multiple neurodegenerative disorders,[15] and seeks to improve on existing sorting tests. Specifically, the QuickSort is quicker to administer and score, simpler for older adults, provides a larger range of scores, and can be used even when a person is unable to complete the test or has expressive language problems. This study examined whether the QuickSort provides a fast, reliable, and valid screen for older adults that can be used as an alternative to two of the most common, but lengthier, cognitive screens: the MMSE and FAB.

Table 2. Cumulative Frequency (Base Rates) for the QuickSort Total and Sorting Scores in the Cognitively Healthy Normative Subsample (n = 115)

QuickSort cut score	Cumulative frequency[a]
Total	
<3	0
<4	1.7
<5	1.7
<6	2.6
<7	4.3
<8	4.3
<9	5.2
<10	5.2
<11	7.0
<12	9.6
<13	12.2
<14	21.7
<15	24.3
<16	36.5
<17	37.4
<18	46.1
18	53.9
Sorting	
<1	0
<2	0.9
<3	2.6
<4	4.3
<5	4.3
<6	7.0
<7	8.7
<8	16.5
<9	16.5
<10	32.2
<11	32.2
<12	32.2
12	67.8

[a]Percentage of the normative sample with scores below the cut score.

Although simple from a test taker's perspective, the QuickSort requires clinicians to follow detailed instructions, including specific prompts for different types of errors and early discontinuation when cognition is intact. Despite these complexities, clinicians reported that the QuickSort was user friendly, a finding that was supported by its good inter-rater reliability. Test-retest data additionally indicated that the QuickSort provides stable scores in an inpatient setting and is not impacted by practice effects. Preliminary findings for the QuickSort-e suggest that it is also brief, even when participants were unfamiliar with an iPad, and it generates scores that are comparable to those of the original version.

The normative data for the QuickSort were based on a subgroup of cognitively and psychologically healthy older adults, most of whom completed the task within 2 minutes, with over half achieving a perfect score. Cumulative frequencies for the Sorting and Total scores enable clinicians to evaluate whether a person's performance is common or unusual, relative to their cognitively healthy peers. Age, education, and sex did not significantly affect QuickSort performance, eliminating the need for demographically adjusted norms.

Table 3. Diagnostic Data for QuickSort Total Scores when Predicting Impairment on the MMSE, FAB, and either the MMSE or FAB, or both

	Impaired MMSE (score <24) (n = 258)				Impaired FAB (score <11) (n = 256)				Impaired on either the MMSE or FAB, or both (n = 260)			
QuickSort Total cut-score	Se	Sp	LR+	LR−	Se	Sp	LR+	LR−	Se	Sp	LR+	LR−
<1	0.06	0.98	3.29 (0.63–17.30)	0.96 (0.88–1.04)	0.15	0.99	16.32 (3.30–80.82)	0.86 (0.75–0.99)	0.10	0.99	9.80 (2.05–51.31)	0.91 (0.83–1.00)
<2	0.15	0.97	5.49 (1.77–17.01)	0.88 (0.76–1.01)	0.21	0.97	7.62 (2.72–21.32)	0.82 (0.69–0.97)	0.18	0.98	9.26 (2.96–28.75)	0.84 (0.74–0.96)
<3	0.38	0.95	7.79 (3.80–15.95)	0.65 (0.50–0.85)	0.32	0.96	8.98 (3.89–20.72)	0.70 (0.56–0.89)	0.35	0.96	9.29 (4.25–20.01)	0.67 (0.55–0.83)
<4	0.44	0.92	5.49 (3.07–9.83)	0.61 (0.45–0.82)	0.44	0.92	5.44 (3.04–9.74)	0.61 (0.45–0.82)	0.43	0.94	6.95 (3.75–8.41)	0.61 (0.48–0.77)
<5	0.53	0.89	4.14 (2.92–7.72)	0.53 (0.37–0.76)	0.50	0.88	4.27 (2.61–6.99)	0.57 (0.40–0.80)	0.51	0.91	5.60 (3.38–9.30)	0.54 (0.41–0.72)
<6	0.62	0.85	4.19 (2.78–6.33)	0.45 (0.29–0.69)	0.56	0.86	4.00 (2.57–6.23)	0.51 (0.35–0.75)	0.63	0.89	5.45 (3.55–8.41)	0.42 (0.29–0.61)
<7	0.62	0.81	3.22 (2.21–4.69)	0.47 (0.31–0.73)	0.74	0.82	4.19 (2.95–5.93)	0.32 (0.18–0.56)	0.65	0.84	4.10 (2.82–5.95)	0.42 (0.29–0.61)
<8	0.76	0.79	3.57 (2.61–4.88)	0.30 (0.16–0.55)	0.76	0.80	3.77 (2.74–5.20)	0.30 (0.16–0.54)	0.77	0.82	4.32 (3.11–6.01)	0.29 (0.17–0.47)
<9	0.82	0.74	3.18 (2.43–4.17)	0.24 (0.11–0.49)	0.88	0.76	3.63 (3.63–4.72)	0.16 (0.06–0.39)	0.82	0.78	3.75 (2.81–4.98)	0.23 (0.13–0.41)
<10	0.82	0.74	3.18 (2.43–4.17)	0.24 (0.11–0.49)	0.88	0.76	3.63 (2.74–4.72)	0.16 (0.06–0.39)	0.82	0.78	3.75 (2.81–4.98)	0.23 (0.13–0.41)
<11	0.82	0.73	3.02 (2.32–3.94)	0.24 (0.12–0.50)	0.88	0.74	3.44 (2.66–4.40)	0.16 (0.06–0.40)	0.82	0.77	3.52 (2.67–4.63)	0.23 (0.13–0.42)
<12	0.82	0.70	2.75 (2.14–3.55)	0.25 (0.12–0.52)	0.91	0.72	3.26 (2.53–4.13)	0.12 (0.04–0.36)	0.84	0.74	3.27 (2.52–4.23)	0.21 (0.11–0.40)
<13	0.82	0.68	2.56 (2.00–3.28)	0.26 (0.13–0.54)	0.91	0.70	3.02 (2.41–3.79)	0.13 (0.04–0.37)	0.84	0.72	1.65 (1.36–2.09)	0.31 (0.16–0.61)
<14	0.82	0.61	2.12 (1.69–2.66)	0.24 (0.14–0.60)	0.91	0.63	2.47 (2.02–3.02)	0.14 (0.05–0.41)	0.84	0.64	2.83 (2.83–0.24)	0.24 (0.13–0.46)
<15	0.85	0.57	1.97 (1.60–2.42)	0.26 (0.11–0.59)	0.91	0.58	2.18 (1.81–2.62)	0.15 (0.05–0.45)	0.86	0.60	2.15 (1.76–2.62)	0.23 (0.11–0.46)
<16	0.88	0.48	1.70 (1.43–2.03)	0.24 (0.10–0.62)	0.94	0.50	1.87 (1.60–2.18)	0.12 (0.03–0.46)	0.90	0.51	1.85 (1.57–2.18)	0.19 (0.08–0.45)
<17	0.88	0.46	1.65 (1.39–1.96)	0.25 (0.10–0.64)	0.97	0.49	1.90 (1.65–2.19)	0.06 (0.01–0.42)	0.92	0.50	1.84 (1.57–2.15)	0.16 (0.06–0.41)
<18	0.97	0.40	1.61 (1.43–1.82)	0.07 (0.01–0.51)	0.97	0.40	1.62 (1.43–0.51)	0.07 (0.01–0.51)	0.98	0.43	1.71 (1.51–1.93)	0.05 (0.01–0.32)

Note: LRs are calculated from raw frequencies, as reported from the CATmaker.

Abbreviations: FAB, Frontal Assessment Battery; MMSE, Mini-Mental State Examination; LR−, negative likelihood ratio (and 95% confidence interval); LR+, positive likelihood ratio (and 95% confidence interval); Se, sensitivity; Sp, specificity.

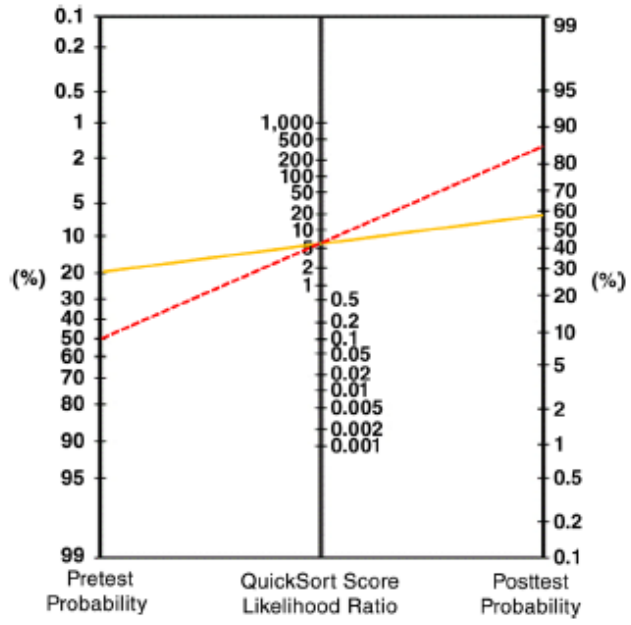

Figure 2. Nomogram showing the posttest probability of impairment on the Mini-Mental State Examination (MMSE) or Frontal Assessment Battery (FAB), or both. Nomogram showing the posttest probability of impairment on the MMSE or FAB, or both, for a person with a QuickSort Total score of 5 and positive likelihood ratio = 5.54 (Table 3). Example 1 (solid yellow line) shows a clinical setting where the pretest probability (left y axis) is estimated to be 20%, resulting in an estimated posttest probability of approximately 58% (right y axis). Example 2 (dotted red line) shows a situation where the pretest probability is estimated to be 50%, resulting in a posttest probability of approximately 85%. Adapted from Fagan (1975) Nomogram for Bayes' Theorem.[29]

Discriminant validity was evaluated by comparing people who were impaired with those who were not impaired on the MMSE or FAB. The impaired group had significantly lower QuickSort scores than the nonimpaired group, a finding that was not attributable to the former being older and less educated. The QuickSort Total cut-score that correctly classified the largest number of people as impaired on either the MMSE or FAB, or both, was less than 4; however, sensitivity (43%) was sacrificed for specificity (94%). A cut-score of less than 10 may therefore be preferred in clinical settings because it can be used to rule in (82% sensitivity) and rule out (78% specificity) impairment (Table 3).

Although useful, single cut-scores fail to utilize the information provided by low and high scores.[25] LRs help to address these problems. For example, QuickSort scores of less than 2 were not seen in cognitively healthy older adults and increase the likelihood of impairment on either the MMSE or FAB, or both, by a factor of 9.26 (95% CI = 2.96–28.75). Conversely, QuickSort scores of 17 or greater, which were common in cognitively healthy adults (63%), reduce the likelihood of impairment by a factor of 0.16.

The use of a nomogram[29] or online calculator[30] to estimate a person's posttest probability of impairment—based on their QuickSort score and the prevalence of impairment in that clinical setting—further enhances its clinical utility. For example, a patient who gets a QuickSort score of 5 in a clinical setting where approximately 50% of patients are cognitively impaired has an 85% likelihood that they will be impaired on lengthier cognitive screens, suggesting they need to undergo further investigations into the presence of cognitive decline.

A limitation of this study relates to the sample sizes. Test-retest reliability was assessed using a small convenience sample of inpatients and now needs to be evaluated in a community-dwelling sample. Administration time was only recorded for a subset of participants and needs to be assessed further. Although the QuickSort normative sample is larger than those originally reported for the MMSE and FAB,[31,32] larger normative data sets, stratified by age and education, are now available for these measures,[20,33-36] suggesting the QuickSort norms should be expanded. Last, cumulative frequencies above and below cut-scores were reported because the small samples precluded multiple-level LRs and interpretation of stand-alone scores.

Future research should examine patients who have more overt cognitive impairments, such as adults with dementia. The QuickSort-e also needs to be developed further by integrating decision-making algorithms that instantaneously provide posttest probabilities in response to clinical questions that are relevant to specific settings (e.g., the likelihood the patient is cognitively impaired, has a neurodegenerative disorder, or will be readmitted to hospital). Finally, the QuickSort-e may be suitable for telehealth assessments, which are in much greater demand as a result of COVID-19, but additional reliability and validity studies are needed to support this type of use.

Overall, the QuickSort assesses the cognitive decline associated with various neurodegenerative disorders of older age.[15] It provides a quick, easy, reliable, and valid cognitive screen that is suitable for use in busy clinical settings. Importantly, the QuickSort provides a viable alternative to lengthier screens, such as the MMSE and FAB. Clinicians are encouraged to customize it to their clinical setting, using posttest calculators, to improve the accuracy and efficiency of their cognitive screening.

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Author Contributions: A. M. Foran designed and created the QuickSort, and was responsible for study inception and execution, data collection and coding, data analysis and reporting, and final manuscript preparation. J. L. Mathias supervised all aspects of this research, particularly the study design, data analysis, and preparation of both the QuickSort manual and study manuscript. S. C. Bowden also contributed throughout all stages of the study, and was particularly involved in providing statistical advice and oversight.

Sponsor's Role: A M Foran was employed as the Senior Clinical Neuropsychologist for the RAH during the data collection phase of the study.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Supplementary Table S1: Demographic and Test Data for the Cognitively Healthy Normative Subsample, with Additional Data Showing the Distribution of Scores

Supplementary Table S2: Results of Linear Regression Analyses Examining the Influence of Demographic Variables on the QuickSort Total and Sorting Scores in the Normative Subsample

Supplementary Table S3: Summary Demographic and Test Scores for the Impaired and Nonimpaired Diagnostic Groups, Formed Using MMSE Scores (n = 258)

Supplementary Table S4: Summary Demographic and Test Scores for the Impaired and Nonimpaired Diagnostic Groups, Formed Using the FAB (n = 256)

Supplementary Table S5: Summary Demographic and Test Score for the Impaired and Nonimpaired Diagnostic Groups, Formed Using either the MMSE or FAB, or both (n = 260)

Supplementary Table S6: ANCOVA Investigating the Influence of Age and Education when Predicting Impairment on the MMSE, FAB, and either the MMSE or FAB, or both

Supplementary Table S7: Diagnostic Data for QuickSort Sorting Scores, when Predicting Impairment on the MMSE, FAB and either the MMSE or FAB, or both

Supplementary Appendix S2: QuickSort Manual and Test Stimuli

Appendix B.2: Supplementary tables and figures for Study 4 (Chapter 6)

Supplementary Table B.2.1: Demographic & test data for the Cognitively-Healthy normative subsample, with additional data showing the distribution of scores

	n	*M*	*SD*	*Median*	*Q1*[1]	*Q2*[2]
Age	115	71.2	7.70	70	65	77
Male	53					
Female	62					
Education (years)	115	11.7	2.84	11	10	13
MMSE Total score (range: 0-30)[3]	115	28.5	1.29	29	28	29
FAB Total score (range: 0-18)[4]	115	15.6	1.99	16	14	17
QuickSort						
Sorting score (range: 0-12)[5]	115	10.4	2.66	12	9	12
Explanation score (range: 0-6)[6]	115	5.4	1.14	6	5	6
Total score (range: 0-18)	115	15.8	3.37	18	15	18
Administration time[7]	19	1_{min} 43_{s}	51_{s}	1_{min} 58_{s}	1_{min}	2_{min} 3_{s}
Repetition errors (range: 0-5)[8]	115	0.3	0.53	0	0	0
Concrete responses (range: 0-3)[9]	115	0.4	0.74	0	0	1
DASS-21[10]						
Depression (range: 0-21)	115	2.3	3.35	1	0	3
Anxiety (range: 0-21)	115	2.6	2.83	2	2	4
Stress (range: 0-21)	115	4.3	3.88	4	4	7

[1]*Q1* = 25th percentile; [2]*Q2* = 50th percentile; [3]Mini Mental Status Examination Total score; [4]Frontal Assessment Battery Total score; [5]only 6% made more than one sorting error; [6]68% attained a perfect Explanation score, [7]min = minutes, s = seconds; [8]21% repeated a sort, [9]29% provided a concrete response; [10]Depression, Anxiety and Stress Scale-21

Supplementary Table B.2.2: Results of linear regression analyses examining the influence of demographic variables on the QuickSort Total and Sorting scores in the normative subsample

QuickSort	Demographic variable	B	SE	β	*t*	*p*
Total score	age	-0.14	0.05	-0.18	-3.04	<.01
	education (years)	0.56	0.11	0.30	4.98	<.01
	gender	-0.27	0.76	-0.02	-0.35	0.72
Sorting score	age	-0.10	0.03	-0.18	-2.94	<.01
	education (years)	0.38	0.08	0.29	4.85	<.01
	gender	-0.15	0.54	-0.02	-0.23	0.78

Supplementary Table B.2.3: Summary demographic & tests scores for the impaired and non-impaired Diagnostic groups, formed using MMSE scores (*n* = 258)

	Impaired (MMSE<24)		Non-impaired (MMSE≥24)				
	n	*M (SD)*	*n*	*M (SD)*	*t*	χ^2	*p*
Age	34	76.4 (8.33)	224	71.7 (7.70)	3.23		<.01
Education (years)	33	10.2 (3.80)	221	11.6 (3.12)	2.32		0.02
Gender							
Male	21		119			0.89	0.35
Female	13		105				
Participant source							
Community sample	3		184			79.56	<.01
Inpatient sample	31		40				
QuickSort							
Total score (range: 0-18)	34	5.9 (5.43)	224	13.3 (5.56)	7.21		<.01
Sorting score (range: 0-12)	34	3.7 (3.25)	224	8.6 (4.03)	6.82		<.01
Explanation score (range:0-6)	34	2.1 (2.21)	224	4.6 (1.80)	7.37		<.01
Repetition errors (range: 0-5)	34	2.1 (1.55)	224	0.7 (1.11)	6.56		<.01
Concrete responses (range: 0-3)	34	0.2 (0.50)	224	0.4 (0.66)	1.19		0.24
Administration time	10	6_{min} 0_{s} (2_{min} 28_{s})	32	2_{min} 26_{s} (1_{min} 33_{s})	4.85		<.01
DASS-21							
Depression (range: 0-21)	5	2.2 (2.49)	186	2.4 (3.39)	0.13		0.90
Anxiety (range: 0-21)	5	1.6 (1.82)	186	2.7 (2.99)	0.85		0.40
Stress (range: 0-21)	5	1.2 (1.64)	186	4.3 (3.97)	1.76		0.08

MMSE = Mini Mental Status Examination; min = minutes, s = seconds; DASS-21 = Depression Anxiety and Stress Scale -21

Supplementary Table B.2.4: Summary demographic & tests scores for the impaired and non-impaired Diagnostic groups, formed using the FAB (*n* = 256)

	Impaired (FAB<11)		Non-impaired (FAB≥11)				
	n	*M (SD)*	*n*	*M (SD)*	*t*	χ^2	*p*
Age	34	75.3 (8.54)	222	71.6 (7.68)	2.56		0.01
Education (years)	33	9.6 (3.09)	222	11.7 (3.19)	3.63		<.01
Gender							
Male	20		118			0.38	0.54
Female	14		104				
Participant source							
Community sample	11		176			32.98	<.01
Inpatient sample	23		46				
QuickSort							
Sorting score (range: 0-12)	34	3.0 (2.90)	222	8.8 (3.93)	8.15		<.01
Explanation score (range: 0-6)	34	2.0 (1.92)	222	4.7 (1.85)	7.68		<.01
Total score (range: 0-18)	34	5.0 (4.51)	222	13.5 (5.51)	8.51		<.01
Repetition errors (range: 0-5)	34	1.9 (1.67)	222	0.7 (1.11)	5.40		<.01
Concrete responses (range: 0-3)	34	0.3 (0.57)	222	0.4 (0.65)	0.93		0.35
Administration time	4	3_{min} 30_{s} (1_{min} 43_{s})	37	3_{min} 3_{s} (2_{min} 15_{s})	0.39		0.70
DASS-21							
Depression (range: 0-21)	11	3.2 (4.33)	180	2.3 (3.31)	0.80		0.42
Anxiety (range: 0-21)	11	4.1 (4.01)	180	2.6 (2.88)	1.60		0.11
Stress (range: 0-21)	11	5.0 (5.06)	180	4.2 (3.89)	0.64		0.52

FAB = Frontal Assessment Battery; min = minutes, s = seconds; DASS-21 = Depression Anxiety and Stress Scale -21

Supplementary Table B.2.5: Summary demographic & tests scores for the impaired and non-impaired Diagnostic groups, formed using either the MMSE or FAB, or both (*n* = 260)

	Impaired (either the MMSE<24 or FAB<11 or both)		Non-impaired (either the MMSE≥24 or FAB≥11 or both)				
	n	*M (SD)*	*n*	*M (SD)*	*t*	χ^2	*p*
Age	51	74.8 (8.43)	209	71.6 (7.71)	2.59		0.01
Education (years)	44	10.4 (3.88)	205	11.7 (3.12)	2.45		0.02
Gender							
Male	31		110			1.01	0.29
Female	20		99				
Participant source							
Community sample	12	74.8 (8.43)	175			73.58	<.01
Inpatient sample	39		34				
QuickSort							
Sorting score (range: 0-12)	51	3.5 (3.21)	209	9.0 (3.83)	9.47		<.01
Explanation score (range: 0-6)	51	2.2 (2.13)	209	4.8 (1.70)	9.40		<.01
Total score (range: 0-18)	51	5.7 (5.20)	209	13.8 (5.24)	9.86		<.01
Repetition errors (range: 0-5)	51	1.9 (1.57)	209	0.6 (1.03)	7.32		<.01
Concrete responses (range: 0-3)	51	0.2 (0.51)	209	0.4 (0.66)	1.41		0.16
Administration time	10	5_{min} 36_{s} (2_{min} 27_{s})	32	2_{min} 26_{s} (1_{min} 33_{s})	4.85		<.01
DASS-21							
Depression (range: 0-21)	14	3.1 (3.98)	177	2.3 (3.32)	0.87		0.39
Anxiety (range: 0-21)	14	3.6 (3.76)	177	2.6 (2.90)	1.13		0.26
Stress (range: 0-21)	14	4.0 (4.88)	177	4.3 (3.89)	0.25		0.81

MMSE = Mini Mental Status Examination; FAB = Frontal Assessment Battery; min = minutes, s = seconds; DASS-21 = Depression Anxiety and Stress Scale -21

Supplementary Table B.2.6: ANCOVA investigating the influence of age & education when predicting impairment on the MMSE, FAB, and either the MMSE or FAB, or both

QuickSort score	Diagnostic grouping variable	SS	*df*	MS	*F*	*p*
Total	MMSE					
	Age	0.27	1	0.27	3.14	.08
	Education (years)	0.01	1	0.01	0.15	.67
	QuickSort Total score	7.08	17	0.42	4.82	<.01
	FAB					
	Age	0.12	1	0.12	1.44	.23
	Education (years)	0.28	1	0.28	3.38	.07
	QuickSort Total score	7.81	17	0.46	5.58	<.01
	Either the MMSE or FAB, or both					
	Age	0.11	1	0.11	1.03	.31
	Education (years)	0.05	1	0.05	0.44	.51
	QuickSort Total score	12.83	17	0.76	6.99	<.01
Sorting	MMSE					
	Age	0.28	1	0.28	3.05	.08
	Education (years)	0.01	1	0.01	0.13	.72
	QuickSort Sorting score	5.52	11	0.50	5.52	<.01
	FAB					
	Age	0.19	1	0.19	2.31	.13
	Education (years)	0.28	1	0.28	3.46	.06
	QuickSort Sorting score	7.44	11	0.68	8.27	<.01
	Either the MMSE or FAB, or both					
	Age	0.12	1	0.12	1.09	.30
	Education (years)	0.06	1	0.06	0.56	.46
	QuickSort Sorting score	11.31	11	1.03	9.21	<.01

The results of the ANCOVA may be less reliable because age and years of schooling were correlated (r = 0.19, p <.01), and the assumptions were not met relating to the homogeneity of variance (F = 18.00 (17,238), p<.01) and normally distributed residuals (D = 0.25 (256) p <.00; W = 0.90 (256), p <.01); MMSE = Mini Mental Status Examination; FAB = Frontal Assessment Battery; SS = sum of squares; MS = mean square

Supplementary Table B.2.7: Diagnostic data for QuickSort Sorting scores, when predicting impairment on the MMSE (left columns), FAB (centre columns) and either the MMSE or FAB, or both (right columns)

QuickSort Sorting cut score	Impaired MMSE (<24) (*n* = 258)				Impaired FAB (<11) (*n* = 256)				Impaired on either the MMSE or FAB or both (*n* = 260)			
	Se	Sp	LR+	LR-	Se	Sp	LR+	LR-	Se	Sp	LR+	LR-
<1	0.06	0.98	3.29 (0.63 – 17.30)	0.96 (0.88 – 1.04)	0.15	0.99	16.32 (3.30 – 80.82)	0.86 (0.75 – 0.99)	0.10	0.99	9.80 (2.05 – 51.31)	0.91 (0.83 – 1.00)
<2	0.18	0.95	3.29 (1.32 – 8.19)	0.87 (0.74 – 1.02)	0.29	0.96	7.25 (3.18 – 16.56)	0.74 (0.59 – 0.92)	0.24	0.96	6.18 (2.65 – 14.25)	0.80 (0.68 – 0.92)
<3	0.50	0.88	4.15 (2.55 – 6.76)	0.57 (0.40 – 0.80	0.47	0.87	3.73 (2.27 – 6.13)	0.61 (0.44 – 0.83)	0.47	0.90	4.49 (2.74 – 7.30)	0.59 (0.46 – 0.77)
<4	0.65	0.81	3.37 (2.34 – 4.86)	0.44 (0.28 – 0.69)	0.76	0.83	4.47 (3.17 – 6.30)	0.28 (0.15 – 0.52)	0.67	0.85	4.48 (3.10 – 6.48)	0.37 (0.25 – 0.56)
<5	0.82	0.75	3.29 (2.50 – 4.34)	0.24 (0.11 – 0.49)	0.88	0.77	3.73 (2.88 – 4.92)	0.15 (0.06 – 0.39)	0.82	0.79	3.91 (2.92 – 5.24)	0.22 (0.12 – 0.41)
<6	0.93	0.72	3.37 (2.67– 4.25)	0.09 (0.02 – 0.35)	0.91	0.74	3.55 (2.77 – 4.55)	0.12 (0.04 – 0.32)	0.84	0.78	3.60 (2.24 – 4.72)	0.21 (0.11 – 0.39)
<7	0.82	0.71	2.88 (2.22 – 3.73)	0.25 (0.12 – 0.51)	0.91	0.73	3.43 (2.69 – 4.37)	0.12 (0.04 – 0.36)	0.84	0.76	3.46 (2.65 – 4.51)	0.21 (0.12 – 0.39)
<8	0.85	0.65	2.44 (1.94– 3.06)	0.23 (0.10 – 0.51)	0.91	0.67	2.74 (2.21 – 3.39)	0.13 (0.04 – 0.39)	0.86	0.69	2.78 (2.21 – 3.49)	0.20 (0.10 – 0.40)
<9	0.85	0.65	2.45 (1.93 – 3.03)	0.23 (0.10 – 0.51)	0.91	0.66	2.70 (2.18 – 3.34)	0.13 (0.05 – 0.39)	0.86	0.68	2.73 (2.18 – 3.43)	0.20 (0.10 – 0.40)
<10	0.91	0.50	1.84 (1.55 – 2.18)	0.17 (0.06 – 0.52)	0.94	0.51	1.93 (1.65 – 2.27)	0.11 (0.03 – 0.44)	0.92	0.54	1.99 (1.68 – 2.35)	0.15 (0.06 – 0.38)
<11	0.91	0.50	1.84 (1.55 – 2.18)	0.17 (0.06 – 0.52)	0.94	0.51	1.93 (1.65 – 2.27)	0.11 (0.03 – 0.44)	0.92	0.54	1.99 (1.68 – 2.35)	0.15 (0.06 – 0.38)
<12	0.94	0.50	1.90 (1.62– 2.22)	0.12 (0.03 – 0.45)	0.94	0.51	1.92 (1.64 – 2.25)	0.12 (0.03 – 0.45)	0.94	0.54	2.03 (1.73 – 2.35)	0.11 (0.04 – 0.33)

The QuickSort Sorting score was able to discriminate between participants who were intact verses impaired on the MMSE $t(256) = 6.82$, $p < .0001$, on the FAB $t(254) = 8.15$, $p < .0001$, and either the MMSE or FAB or both, $t(258) = 9.47$, $p < .0001$; MMSE = Mini Mental Status Examination; FAB = Frontal Assessment Battery; Se = sensitivity; Sp = specificity; LR+ = positive likelihood ratio (& 95% Confidence intervals), LR- = negative likelihood ratio (& 95% Confidence Intervals)

Appendix C Supplementary information for Study 5 (Chapter 7)

Appendix C.1: Not permitted to reproduce the published Article for Study 5

Appendix C.2: Supplementary tables and figures for Study 5 (Chapter 7)

Supplementary Table C.2.1 : Total score categories for the MMSE when predicting inpatients who lacked/did not-lack lifestyle decision-making capacity

MMSE Total Score[a]	Inpatients		LR (95% CI)	Pre-test probability of lacking LS-DMC 58%[b]	25%[c]	10%[d]
	Lacking LS-DMC	Not-lacking LS-DMC		Post-test probability of lacking LS-DMC		
0 - 17	%	2[e]	5.42 (0.22 – 134.72)	88%	64%	38%
18 - 27	84%	70%	1.21 (0.91 – 1.62)	63%	29%	12%
28 - 30	7%	29%	0.23 (0.07 – 0.82)	24%	7%	3%

MMSE = Mini-Mental Status Examination; LS-DMC = life-style decision-making capacity; LR = likelihood ratio; 95% CI = 95 percent confidence interval; [a]three score categories were created to facilitate comparison to the QuickSort score categories for informing LS-DMC; [b]pre-test probability of inpatients lacking LS-DMC who were referred to the Neuropsychology service was estimated to be 58%, based on the Retrospective-inpatients group; [c]25% hypothetical prevalence of LS-DMC; [d]10% hypothetical prevalence of LS-DMC; [e]no inpatient who did not-lack LS-DMC scored <18 on the MMSE, therefore a nominal value of 0.4 was used to compute the multi-level likelihood ratios

Supplementary Table C.2.2 : The MMSE Total scores within the QuickSort Total score categories that inform LS-DMC

QuickSort Total score category	MMSE			
	n	***range***	***M***	***SD***
0-1	11	13 - 27	22.5	4.1
2-12	43	15 - 30	23.7	3.8
13-18	15	20 - 30	25.2	3.5

MMSE = Mini-Mental Status Examination; LS-DMC = life-style decision-making capacity