Aspects of the Assessment and Intervention with Memory and Executive Functions in People with Neurological Conditions

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Thesis declaration form

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

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Overview

This thesis explored aspects of the assessment and intervention with memory and executive functions for people with neurological conditions.

Part one is a systematic review and meta-analysis of errorless learning (EL) a compensatory technique designed to facilitate learning for people with memory impairment resulting from neurological impairment. This study systematically reviewed and meta-analysed the reported treatments effects of EL from studies of patients with neurological conditions. In addition, the treatment effects for progressive conditions are reported separately from studies of non-progressive neurological conditions.

Part two is a service evaluation that explored the relationships between standardised tests of cognitive function and clinician-rated everyday decision-making. It aimed to identify tests within an existing assessment battery that contribute usefully to the assessment of decision-making capacity in specialist cognitive rehabilitation service for people with acquired brain injury (ABI).

Part three is a critical appraisal of the research process. It focused on the researchers experiences and learnings gained through the project completion. Identifying how prior experiences influenced the choice of project and further discusses some of the limitations of the project.

Impact Statement

This thesis examined two contemporary conundrums relevant to the practice of neuropsychology. Through systematic review and meta-analysis, the first project examined the treatment effects of errorless learning (EL) a compensatory technique designed to facilitate learning for people with memory impairment resulting from neurological conditions. This review of EL in the field of memory rehabilitation is timely. To date, there is only one meta-analysis of the treatment effects of EL, completed nearly twenty years ago which did not control for potential biases. Subsequently there has been a natural progression in the use of EL from well-controlled laboratory-based tasks to its integration into memory rehabilitation programmes. In addition to examining the overall effect of EL in people with amnesic disorders, this review was also the first to report the treatments effects from studies of patients with progressive conditions separately from studies of non-progressive neurological conditions. Results indicate that EL is an effective technique to help people with memory disorders learn new information. This informs clinicians of the appropriateness of its use in practice. However, potential publication bias was identified, along with variation in methodology and quality of the studies reviewed and analysed. Until steps are taken to produce studies which are suffice in size, well controlled and the publication of non-significant results are encouraged, caution must be applied to avoid over-estimating the clinical benefits of EL to patients.

The second element of this project aimed to investigate issues around long-reported concerns of a lack of correspondence between test performance on neuropsychological measures and everyday decision-making ability in patients with acquired brain injury (ABI). Reduced decision-making capacity is a common consequence of ABI. The results can have devastating consequences for an individual and the support systems around them. Accurate assessment of a person's decision-making ability is crucial to inform support needs. This

project examined this issue with a service evaluation in a specialist cognitive rehabilitation service. The evaluation explored the relationships between standardised tests of cognitive function and a custom clinician-rated measure of everyday decision-making. Results provide evidence towards the accuracy of the tests used in the service to assess the cognitive components of decision-making. The results also evidence how elements of the assessment battery employed by the service meet existing clinical standards. This evaluation suggests that at a group level, despite concerns in the literature around a lack of ecological validity, tests of executive function are more useful in the assessment of decision-making than those from broader cognitive domains. In addition, the results identify a specific measure of planning to be important in the assessment of decision-making. This work informs clinicians in the service on how to approach the cognitive assessment of decision-making and evidence some potential for modifications in their battery. These results could lead to increased accuracy of assessment, with increased potential for patient challenges in this domain to be identified. This review may also provide a framework for other services on how to approach evidencing their standard of cognitive assessment of decision-making, despite the lack of specific national guidelines.

Acknowledgements

This project would have not happened without the people who have inspired and supported me in my academic and clinical journey. I would like to acknowledge a leading figure in the field of neuropsychology, Professor Barbara Wilson, whose work has helped to improve the lives of countless people living with brain injuries and influenced the direction of my career.

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List of Abbreviations

ABI	Acquired Brain Injury
AD	Alzheimer's Disease
BADS	Behavioural Assessment of the Dysexecutive Syndrome
D-KEFS	Delis-Kaplan Executive Function System
DMQ	Decision-Making Questionnaire
EL	Errorless Learning
ELA	Errorless Learning Advantage
EF	Errorful Learning
FSIQ	Full-Scale Intelligence Quotient
GAD-7	Generalised Anxiety Disorder-7
GAI	General Ability Index
MCI	Mild Cognitive Impairment
MTL	Medial Temporal Lobe
NICE	National Institute of Clinical Excellence
PHQ-9	Patient Health Questionnaire-9
SET	Six Elements Test
SNST	Stroop Neuropsychological Screening Test
SR	Spaced Retrieval
TBI	Traumatic Brain Injury
TOMM	Test of Memory Malingering
TOPF	Test of Premorbid Functioning
VC	Vanishing Cues
WAIS-IV	Wechsler Adult Intelligence Scale- Fourth Edition

WMS-IV	Wechsler Memory Scale- Fourth Edition
ZM1	Zoo Map 1

Part 1. Literature Review

A Systematic Review and Meta-Analysis of the Efficacy of Errorless Learning in People with Memory Disorders

Abstract

Background: Errorless learning (EL) is a compensatory technique designed to facilitate learning by reducing interference from mistakes for people with memory disorders. EL has been trialled in numerous conditions and paradigms but with no recent meta-analysis. This study aimed to systematically review and meta-analyse the effects of EL in people with memory impairment and to report treatment effects from studies of patients with progressive conditions separately from studies of non-progressive neurological conditions.

Method: Studies had to meet the following main criteria (1) had an error minimising experimental condition (2) had a control group which employed no error minimising methods (3) reported quantitative behavioural outcomes. A database search in September 2020 used Medline, PsycInfo and Web of Science. Egger's tests of asymmetry were used to assess bias. Analyses were computed using the statistical package *R* and presented with forest plots.

Results: 49 studies were systematically reviewed, 33 studies with a total of 711 participants met criteria for meta-analysis. Analyses showed an advantage for EL over errorful(EF) learning. A medium effect (d=0.73) was found in within-subject designs and a large effect (d=1.12) was found in between-subjects design studies. Secondary analysis showed improved performance with EL for both progressive and non-progressive neurological disorders. Effects were attenuated when examining for potential publication bias.

Discussion: This analysis provides evidence that EL is an effective memory rehabilitation technique for people with memory disorders. In addition, this review is the first to document a disproportionate advantage of EL for people with non-progressive neurological conditions. However, there was a variation in methodology and quality of the studies reviewed and analysed and potential publication bias was identified which means caution should be applied when drawing conclusions about the results.

Introduction

2.1 **Background**

Memory dysfunction is a common consequence of different neurological conditions, including acquired brain injury (ABI) and dementia. Memory problems are the hallmark symptom of dementia which effects approximately 50 million people worldwide, with increasing prevalence in the population (Prince, et al 2015). Memory challenges are often a prominent difficulty for the 69 million people who experience a traumatic brain injury (TBI) and the 80 million survivors of stroke each year. (Dewan et al, 2018 & Gorelick, 2019). Memory impairments can be highly disabling and have been shown to chronically impact major domains of a person's identity and psychosocial functioning (Wilson, 1991 & Hoofien et al, 2001). Increased caregiver burden, depression and isolation are also common responses to caring for someone with memory impairment (Etters et al, 2008). It is therefore important to review and examine the efficacy of current rehabilitation techniques for people with memory impairments. The current work focussed on one such technique, 'Errorless learning' (EL).

2.2 **Approaches to Memory Rehabilitation**

Recommendations for the management of memory following TBI (Velikonja et al, 2014) stated there is weak evidence for the efficacy of restorative memory strategies. Despite media attention on 'brain training' interventions, to date they are known to have no clinically or functionally meaningful effects (Stanford Centre on Longevity, 2014; Simons et al, 2016). Fish and McKnight (2021) stated that in their current form restorative strategies are not suitable to implement in clinical practice and unless they advance the focus of memory rehabilitation must be on supporting learning and implementing compensatory strategies to enable a person to live well with their disability. Guidelines for rehabilitation of ABI (SIGN,

2013), also specify that learning techniques that reduce the likelihood of errors being made during the acquisition of information should be considered for people with moderate to severe memory impairment. Guidance for cognitive rehabilitation in dementia (NICE, 2018) states memory intervention should be considered for people with mild to moderate dementia, with the aim of the rehabilitation to improve or maintain functioning in everyday life, compensating for impairments and supporting independence.

2.3 **Errorless Learning in Memory Rehabilitation**

EL refers to a learning condition designed to prevent the participant, as far as possible, from making a mistake (Page et al, 2006). The term 'errorless' itself may be misleading. To create a condition which facilitates an absolutely error free set of responses over the course of learning trials is challenging. Clare and Jones (2008) proposed that although overt erroneous responses can be minimised in the experimental paradigm, the experimenter is unable to gauge and moderate non-verbal or covert errors a participant may be generating. Rather than a specific technique, EL is more an overarching principle used to reduce the likelihood of erroneous responses during learning and thereby avoid harmful effects of interference on learning. That said, EL is often achieved by employing specific techniques associated with error prevention (Page et al, 2006). A core technique of EL is to instruct a person not to guess their answers unless they are sure they are correct (Wilson et al, 1994). In addition, elimination of errors in the context of memory rehabilitation can be achieved by, the provision and eventual fading of cues, prompts, and the correct information, breaking down tasks into discrete steps, modelling the task to ensure the persons understanding (Sohlberg et al, 2005; Clare & Jones, 2008). Comparator conditions are often referred to as 'Errorful' (EF) or 'Trial and Error'. In EF learning, errors are allowed, actively promoted or even artificially induced, by encouraging participants to guess, and with incorrect responses subsequently corrected by the experimenter. 'Trial and Error' learning

when implemented as a control for EL refers to regular unstructured learning where a participant is encouraged to complete a task independently and when mistakes are made the participant is immediately corrected (Bourgeois et al, 2016).

Other methods have also been used either in conjunction with EL or as standalone techniques for promoting learning in amnesic individuals. Spaced retrieval (SR; i.e. distributed practice) involves the systematic increment of time intervals been trials and has been shown to promote the durability of learning (Landauer, 1978 & Wilson et al, 1994). Vanishing cues (VC) can be seen as a method of forward and backwards chaining that provides a participant with progressively weaker cues dependent on their successful recall of target information (Clare and Jones, 2008). For example, in a word list learning trial a participant would be presented with the full target word initially, such as PEACH and upon successful recall of that word the next presentation would be PEAC_ and so on. Both SR and VC have been described as procedures associated with error reduction, however the additional challenge of these conditions (i.e., they have a greater requirement for self-generation relative to 'pure' errorless learning procedures) mean that errors may not be completely eliminated, perhaps moderated by how fastidiously the encouragement not to guess has been implemented (Bourgeois et al, 2007).

2.4 **Neuroanatomy of Memory and Errorless Learning**

A large body of evidence has documented that people with memory disorders have deficits in the cortical networks responsible for explicit memory whilst implicit memory remains relatively intact (Milner, 1962; Cohen & Squire, 1980; Graf & Schacter, 1985; Roediger, 1990). Explicit or declarative memory, also subdivided into semantic and episodic memory (i.e., for facts and events respectively) is considered to be conscious and facilitated by attention and elaboration of the presented material (Stark, Stark & Gordon, 2005). Explicit

memory is considered to be reliant on the cortical structures in the medial temporal lobe (MTL: the hippocampal region and the entorhinal, perirhinal and parahippocampal cortices; Poldrack,et al, 2001). Implicit or non-declarative memory does not require conscious retrieval. Instead, implicit or procedural memory (e.g., for skills such as driving a car or riding a bike) influences behaviour and operates at an automatic level, facilitated by learning processes such as priming, conditioning and habituation, some of which involve subconscious processing, reliant on subcortical structures outside the MTL (Henson, 2010). A notable feature of implicit memory is its relative preservation in people with severe amnesia in comparison to explicit memory (Cohen and Squire, 1980).

2.5 **Errorless Learning Experimental Paradigms**

Baddeley and Wilson's (1994) seminal study first explored the use of EL for people with memory disorders following ABI. The researchers noted in the absence of explicit memory, implicit memory is highly susceptible to interference (Baddeley, 1992), and that given amnesic patients rely on implicit memory, they may be particularly susceptible to interference effects during learning, and particularly likely to benefit from learning approaches that minimise interference. Participants were taught two lists containing five, five letter words using a word stem completion task. The EL procedure involved the experimenter giving each participant the instructions; 'I am thinking of a five-letter word beginning with QU and the word is QUOTE, please write that down', whereas in the EF control condition participants were told 'I am thinking of a five-letter word beginning with QU. Can you guess what it might be?'. The study employed two healthy control groups, one with young participants and another with elderly participants. Results showed no significant effect of learning condition in either control group, however there was a significant effect of learning condition in the amnesic group, with amnesic patients learning significantly more words in the EL condition opposed to the EF condition.

2.6. **Use of Errorless Learning in Acquired Brain Injury**

Subsequent studies using similar experimental paradigms independently replicated Baddeley and Wilson's findings and further explored how EL might be applied in neuropsychological rehabilitation for people with ABI (Squires et al, 1997; Tailby & Haslam, 2003). An EL advantage (ELA) has been reported in a number of paradigms, including; word lists, object naming, verbal paired associates, face-name associations, skill learning (e.g. use of an electronic memory aid), general knowledge and event-based prospective memory (Wilson et al, 1994; Squires, 1996; Hunkin et al, 1998; Evans et al, 2000; Komatsu, 2000; Kalla, Downes & van den Broek, 2001; Page et al, 2006 & Fish et al, 2015). Evans et al (2000) found mixed results for the benefit of EL, with significant benefits found for face-name associations but not for a route learning. The authors suggested that this may have happened because their route recall task was essentially a task of explicit memory and did not rely on a procedural memory function.

2.7. **Use of Errorless Learning in Dementia**

Research has also shown the usefulness of EL in helping people with progressive neurological conditions of a dementia type to learn or re-learn information such as: face-name associations, personal information and using a memory aid (Clare et al 1999, 2000, 2001, 2002, 2003; Ruis & Kessels, 2005; Jean et al, 2007; Bier et al, 2008; Haslam, Moss & Hodder, 2010 & Laffan et al, 2010). Results from Clare et al (2000) were the first to highlight the feasibility and value of providing memory rehabilitation at an early stage of Alzheimer's disease. Participants in this study received individualised interventions for everyday memory challenges, such as learning the names of 11 members of a participant's social club. Memory recall was enhanced in the EL condition opposed to EF. Clare et al (2002) produced further evidence for the use of EL in early-stage Alzheimer's disease by identifying that EL-

associated memory gains largely remained 6 months after the intervention, despite the absence of practice. Jean et al. (2007) reported two case studies where people with dementia took part in a 3-week training programme using both EL and EF principles to relearn face-name associations of famous faces. Results again demonstrated the efficacy EL in people with dementia, noting improved recall in the EL opposed to EF condition.

2.8. **Current Applications of Errorless Learning**

There has been a progression from experimental studies establishing the concept and mechanisms of EL to attempts to replicate these findings in rehabilitation training programmes (Oudman, 2013; Thivierge et al, 2014; Bourgeosis et al, 2016 & Voigt-Radloff et al, 2017). However, there has only been one meta-analysis conducted to explore the treatment effects of EL. Kessels & de Haan (2003) analysed results from 168 participants with mixed progressive and non-progressive disorders from 8 studies, finding a large effect size of errorless learning (d=0.87; CI 0.10-1.64). This study provided a useful quantitative marker for the effectiveness of EL, close to a decade after Baddeley and Wilson's study. Their meta-analysis did not, however, investigate the efficacy of EL in separate patient groups, so it remains unclear whether EL is effective in progressive conditions as distinct from non-progressive neurological groups. The authors also noted a lack of studies with a sufficient control group or condition but did not incorporate formal quality appraisal. In addition, no account of publication bias was included within their analysis.

2.9. **Aims**

Almost 20 years has passed since the previous meta-analysis, and relevant studies have since been published. Similarly, methodology has progressed considerably in this time. It is hence timely to revisit the question of the efficacy of EL, whilst also investigating the quality of the evidence base and the treatment effects of EL in people with memory

impairment. Given ABI and dementia are very different clinical conditions we examined the effects of EL in these patient groups separately as well as in combination.

3. Methods

3.1. **Study Selection**

A search of peer reviewed journals was undertaken using the following databases: Web of Science, PsycINFO and Medline, from database inception to September 2020. The reference list of the only known systematic review and meta-analysis in the subject field was also searched (Kessels & de Haan, 2003). The following key terms derived from prior published research and the authors' knowledge were used; *Information to be learned, memory rehabilitation, errorless, memory impairment*. Alternative terms and synonyms encompassing both broad and narrow concepts based on key terms were also included (see Table 1 for full list of terms used in the search strategy). A pilot of the search strategy was conducted and the procedure was refined. Of note, a proximity operator was applied to '*error*' of two words adjacent to 'learning', to increase the precision of the results being found.

Table 1

Search Terms Used in Database Search

Key concepts:	"Information to be learned"	"Memory Rehabilitation"	"Errorless"	"Memory impairment"
Alternative terms / synonyms	"To be learned information" "Information" "Training" "Learning" "Relearning" "Everyday tasks" "Route learning" "Route training" "Way finding" relearning"	"Memory" "short term memory" "Rehabilitation" "Neurorehabilitation" "Neuropsychological rehabilitation" "Cognitive remediation" "Strategy training" "Compensatory strategy training"	"Trial and error learning" "Trial and error" "Trial-and-error" "Error minimi*" "Error minimisation" "Error reduc*" "Error-free"	"Memory Disorder*" "Cognitive impairment" "Amnes*" "Anterograde Amnesia" "retrograde amnesia" "Acquired memory impairment"

	"Computer training" "Computer learning" "Computer skill*" "Email training" "Email learning" (No papers) "Skill* learning" "Skill* training" "Skill* relearning" "List learning" "Verbal learning" "Paired-Associate Learning" "Face-name associations" "Name learning" "Name training" "Diary use*" "Whiteboard" "Learning strateg*" "Strategy" "Activities of daily living" "Memory aid*" "Semantic memory" "Episodic memory" "Prospective memory" "Retrospective memory"	"Cognitive rehabilitation" "Cognitive training" "Memory training" "Cognitive retraining" "Memory retraining" "Instrumental learning"	"Error free" "Error*" "Error based"	"Brain injur*" "TBI" "Head injur*" "Severe brain injur*" "Mild brain injur*" "Traumatic brain injur*" "ABI" "Diffuse axonal damage" "Diffuse brain injur*" "Diffuse head injur*" "Acquired brain injur*" "Stroke" "Cerebral Haemorrhage" "Cerbrovascular Accident*" Ischemi* Anoxia "Dementia" "Vascular Dementia' "Semantic Dementia" "Brain tumour" "Giloma*" "Hypoxi*" "Cerebral ataxia" "Encephalitis" "Alzheimer's dementia" "Alzheimer's d*" "Korsakoff's syndrome" "Korsakoff'*" "Neurogenic memory impairment*"

3.2. **Inclusion Criteria**

To warrant inclusion studies had to focus on memory rehabilitation for people with memory impairment (as indicated by prior performance on standardised cognitive

assessment), in human participants, with an experimental condition which employed error minimising methods, a control group or condition that used no error minimising methods, and to report quantitative behavioural outcomes from at least two conditions. In recognition of the genesis of EL from experimental paradigm to application in clinical practice, an acceptable EL condition was deemed to have stated the steps taken to prevent errors (e.g., encouragement to participants not to guess, availability of answers to prevent guessing, etc). Specific tasks were classified according to the learning material (e.g., word lists, route learning, face-name associations). The control condition was acceptable errors were allowed, actively promoted, or artificially induced. Further inclusion criteria relevant to the meta-analysis were that results were reported in sufficient detail for effect sizes to be extracted and calculated.

3.3. **Exclusion Criteria**

Studies were excluded from the review if: the participants were under the age of 18, the memory impairment originated from a psychiatric condition, they presented only secondary analysis of a primary analysis already included in the review, or published in languages other than English, the control condition used healthy participants. The question of how healthy controls perform under errorless learning conditions is not a focus of this review. Whether healthy control subjects show the same EL learning advantage as to memory impaired persons is a separate question which offers less clinical insight into the usefulness of EL applied in an impaired population. In addition, Squires (1997) described the challenge of using healthy controls "we have, of necessity, created learning conditions that would be very easy for controls". The nature of the tasks created for memory impaired persons would create low ceiling effects for the healthy controls and not create error generation, upon which the EL condition is designed to control. Single case studies were included in the systematic review but were not included in the meta-analysis.

3.4. **Main Outcome Measures**

The outcome measures used in this review measured a person's performance in each of the experimental conditions. Most studies measured performance by the number of correct responses given during an experimental trial in response to target stimuli. Some studies measured performance based on clinician ratings.

3.5. **Data Extraction and Analysis**

Authors were contacted where data was not available from the original published paper. Data were extracted by one author using a data extraction template. The method of intervention of each study was reviewed. In addition, information on aetiology, age and gender was also extracted.

When the study design included memory impaired persons and a healthy control with both EL and EF conditions, the data for just the memory impaired group was extracted. When participants were divided into groups based on severity of memory impairment (mild, moderate, severe) each group score was recorded. The time point of the data-extraction for the meta-analysis was the first measurement after both the invention and control conditions.

Methodological quality of all papers was reviewed using a standardised quality assessment tool with good inter-rater reliability of 73-100% per item agreement (Kmet et al, 2004; Appendix 1). A subset of 10 papers selected at random were also rated by an independent rater.

3.6. **Statistical Analyses**

For each study, effect sizes were calculated using standardised mean difference or Hedges g. Standardised mean difference was calculated by taking the mean difference between the intervention versus the control condition then dividing the pooled standard

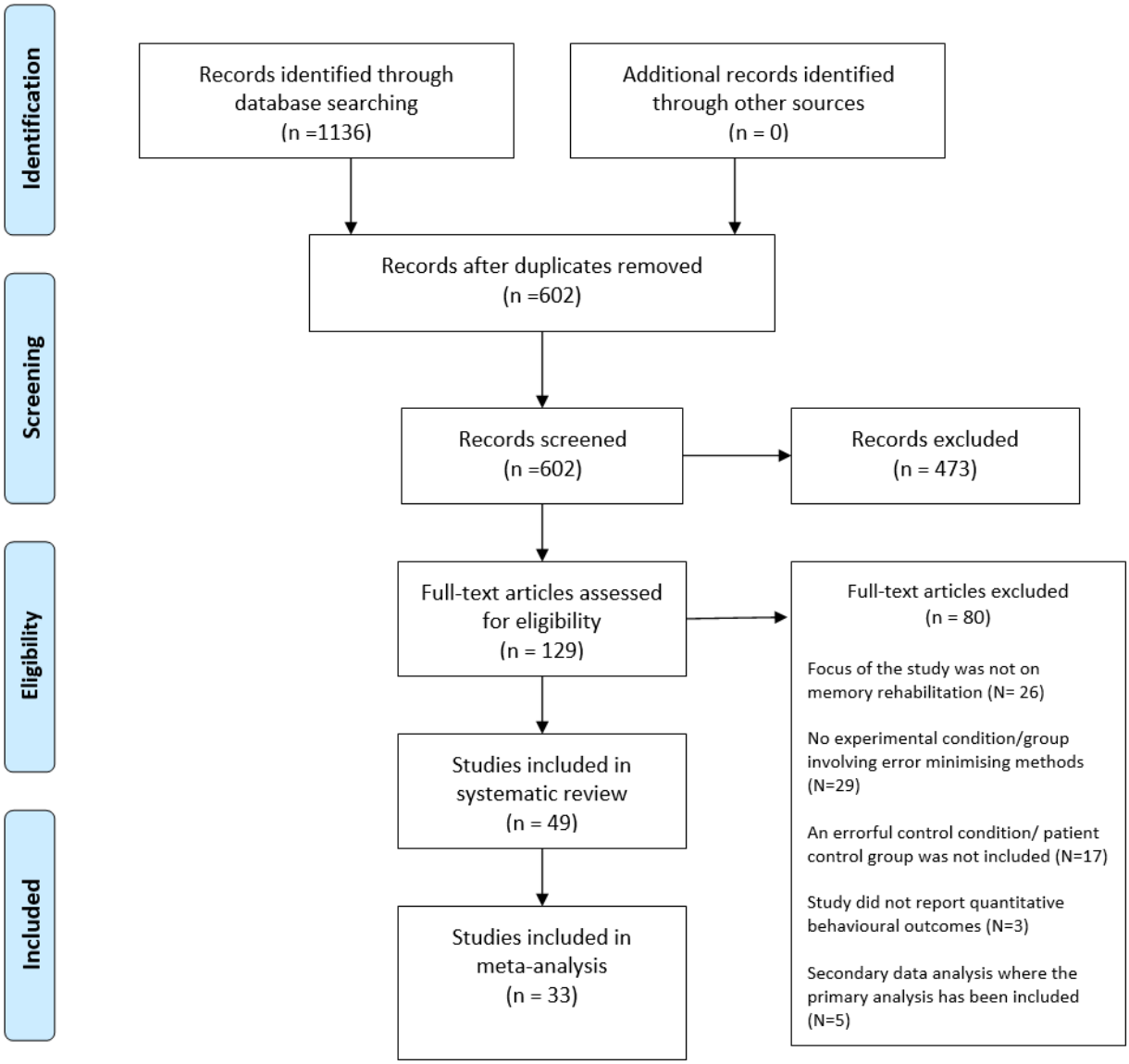
deviation between intervention and control performance (Lipsey and Wilson, 2001). The direction of the effect was deemed positive if the intervention score was higher than the control score. Heterogeneity was calculated using I^2 statistic (Higgins et al, 2003), using heterogeneity thresholds of <25% (low), 25-50% (moderate), and > 50% (substantial). Where significance was noted in the Heterogeneity calculation a Random Effects Model statistics were reported. All analyses were computed using the statistical package *R* (Team, 2013) using the *meta* package. Potential publication bias was examined in each statistical analysis using an Egger's test of asymmetry (Egger et al, 1997). Funnel plots were used to plot each trial's effect estimates against sample size to identify the presence of publication bias and other biases. Where potential publication bias was identified, the trim and fill data augmentation technique (Duval & Tweedie, 2000) was applied. This method can be used to estimate the number of studies missing from a meta-analysis due to the suppression of the most extreme results on one side of the funnel plot.

4. Results

A total of 602 studies were retrieved from electronic databases and reference searches after removing duplicates (see Figure 1 for PRISMA diagram). Of these, 472 studies were excluded during the initial screen of study title and abstract. One hundred and twenty-nine studies were read in full and 80 excluded (see Figure 1 for reasons), leaving 49 in the systematic review and 33 in the meta-analysis.

Figure 1

Prisma Flowchart of Study Selection



4.1. Systematic Review

4.1.1. **Quality Rating**

The quality of studies selected was assessed using Kmet et al (2004) appraisal tool for rating studies with a variety of designs. This tool used a 14-item checklist of criteria for which studies received a score of 0 (criteria not met), 1 (criteria partially met), 2 (criteria fully met) or 'N/A' if the criterion was not relevant. A full list of criteria and ratings are presented in Table 2. The total score was calculated from the sum of scores awarded to the study divided by the total possible sum for that study, resulting in values between 0 and 1.

Table 2

Quality Rating Criteria and Scores (Kmet et al, 2004)

	Question/ Objective sufficiently described?	Study design evident and appropriate?	Method of subject/comparison group selection described and appropriate?	Subject and comparison group characteristics sufficiently described?	Was random allocation described?	Was blinding of investigators reported?	Was blinding of subjects reported?	Outcome measures well defined and robust?	Sample size appropriate?	Analytic methods described and appropriate?	Some estimate of variance reported for the main results?	Controlled for confounding?	Results reported in sufficient detail?	Conclusions supported by the results?	Quality rating (total sum/total possible sum)
Ehlhardt et al (2005)	**	*	*	**		-	-	*	*	*		*	*	**	0.54
McKenna & Gerhand (2002)	*	**	*	**	-	-	-	**	*	*		*	*	*	0.59
Dou et al (2006)	**	*	**	*				*	**	**	*	**	**	*	0.64
Mimura & Komatsu (2010)	**	**	**	*	*		*	**	**	*		*	*	**	0.64
Roberts et al (2018)	**	*	*	**				**	*	**	**	*	**	**	0.64
Ueno et al (2009)	*	*	**	**				**	*	**	**	**	**	**	0.67
Rensen et al (2017)	**	*	*	**				**	**	**	**	*	**	**	0.67
Ruis & Kessels (2005)	**	*	**	**	*			**	*	**		**	**	**	0.68
Trevena-Peters et al (2018)	**	**	*	**		**	*	*	**	*	*	*	*	**	0.68
Baddeley & Wilson (1994)	**	**	*	**		-		**	*	**	*	*	**	**	0.69
Evans et al (2000)	**	**	*	*	-	-	-	**	*	*	*	**	*	**	0.69
Dunn & Clare (2007)	**	**	**	**			-		*	**		**	**	*	0.69
Komatsu et al (2000)	**	**	**	**	-	-		*	*	**		**	*	**	0.70
Thivierge et al (2008)	**	**	*	**	*	-	-	*	*	**	*	**	**	**	0.71
Lloyd et al (2009)	**	**	*	**				**	*	**	**	**	**	**	0.71
O'Neil-Pirozzi et al (2010)	**	**	*	**				*	**	**	**	**	**	**	0.71

Svoboda et al (2012)	**	**	*	*	*	-	-	*	*	**	*	**	**	**	0.71
Schmitz et al (2014)	**	**	*	**				**	*	**	**	**	**	**	0.71
Kalla et al (2001)	**	*	*	**	-	-	-	*	*	**	*	*	**	**	0.72
Clare et al (2002)	**	**	**	**	-	-	-	**	*	*		*	*	**	0.72
Oudman et al (2013)	**	**	**	**		-		**	*	**		**	**	**	0.73
Tailby & Haslam (2003)	**	**	**	*	*	*	*	**	*	**	**	**	**	**	0.75
Kessels et al (2007)	**	**	*	*	**			**	*	**	**	**	**	**	0.75
Lubinsky et al (2009)	**	**	*	**			*	**	**	**	*	**	**	**	0.75
Provencher et al (2008)	**	**	*	**	-	-	-	*	**	**	*	*	**	*	0.75
Laffan et al (2010)	**	*	*	**	*		-	**	**	**	**	**	**	**	0.75
Haslam et al (2011)	**	**	**	**				**	**	**	*	**	**	**	0.75
Jean et al (2010)	**	**	*	**	**	**	*	**	**	*	*	*	*	**	0.78
Callahan & Anderson (2019)	**	**	**	**			*	**	*	**	**	**	**	**	0.79
Squires (1996)	**	*	*	**	-	-	-	**	*	**	**	**	**	**	0.81
Haslam et al (2006)	**	*	*	**	-	-	-	**	*	**	**	**	*	**	0.81
Akhtar et al (2006)	**	**	**	*	*		*	**	**	**	**	**	**	**	0.82
Thivierge et al (2014)	**	**	*	**	*	*	*	**	*	**	**	**	**	**	0.82
Bourgeois et al (2016)	**	*	*	**	**	**	*	*	**	**	**	*	**	**	0.82
Squires et al (1997)	**	**	*	**	-	-		**	*	**	**	**	**	**	0.83
Page et al (2006)	**	**	**	**			-	**	*	**	**	**	**	**	0.86
Lee et al (2013)	**	**	*	**	**	**	*	**	*	**	**	*	**	**	0.86
Metzler-Baddeley & Snowden (2005)	**	**	**	**	*	-	-	**	*	**	*	**	**	**	0.88
Bourgeois et al (2007)	**	**	**	**	*	*	-	*	**	**	**	**	**	**	0.88
Haslam et al (2010)	**	**	*	**	*	-	-	**	*	**	**	**	**	**	0.88
Bertens et al (2015)	**	**	**	**	*	*	*	**	**	**	**	**	**	**	0.89

Fish et al (2015)	**	**	**	**	*	*	**	**	*	**	**	**	**	**	0.89
Clare et al (2003)	**	**	*	**	-	-	-	**	*	**	**	**	**	**	0.91
Bier et al (2008)	**	**	**	*	-	-	-	**	*	**	**	**	**	**	0.91
Dechamps et al (2011)	**	**	**	**	**	**	*	**	*	**	**	**	**	**	0.92
Ownsworth et al (2017)	**	**	**	**	**	**	**	*	**	**	**	*	**	**	0.92
Kerkhof et al (2020)	**	**	**	**	**	**	*	**	*	**	**	**	**	**	0.92
Kessels & Hensken (2009)	**	**	**	**	**	*	*	**	**	**	**	**	**	**	0.93
Voigt-Radloff et al (2017)	**	**	**	**	**	**	**	**	**	**	**	**	**	*	0.96

Note: ** = Criteria fully met, *= Criteria partially met, -= Criterion not relevant

4.1.2. **Participant Demographics**

The number of participants in selected studies ranged from single case designs to a randomised control design with 151 participants (Voigot-Radloff et al 2017). Most studies reported the ages of participants and ages ranged from 27 to 86 years, with a mean of 57 years. As one might expect, there was a different age profile for participants with progressive neurological conditions (M=74 years old) and non-progressive conditions (M=45 years old). Aetiologies of neurological conditions included those of a progressive type (Alzheimer's disease, Vascular dementia, dementia not otherwise specified and mild cognitive impairment) and conditions on non-progressive type (TBI, Stroke, Encephalitis, Korsakoff's syndrome, Tumour, Hydrocephalus, Anoxia).

4.1.3. **Study Design and Quality**

Quality ratings ranged from 0.54 to 0.94 (see Table 2) indicating wide variation. Overall, studies showed methodological strength in sufficiently describing the research objectives and the appropriate study design, controlling for confounding factors, describing the results in detail and linking them clearly to the conclusions. There was greater variation in reporting subject group selection and reporting of estimates of variance. Studies generally showed methodological weakness in their description of the process of selecting an appropriate sample size, with a number of studies recruiting a small sample size and not reporting estimates of variance.

4.1.4. **Characteristics of Selected Studies**

Full details of the studies can be found in Tables 3, 4 & 5. As these show, EL has been implemented in a wide range of experimental paradigms (Baddeley and Wilson, 1994; Tailby & Haslam, 2003; & Page et al, 2006) and incorporated in functional training programmes (O'Neil-Pirozzi et al, 2010; Lee et al, 2013; Bertens et al, 2015). Tasks ranged

from traditional face-name associations to practical tasks such as using external memory aids and completing/relearning activities of daily living such as dressing, cooking and washing laundry.

Table 3

Within-Subject Study Designs Included the Systematic Review and Meta-Analysis

Study	N	Type of patients	Age (+SD)	Task	Method of intervention	Control Condition	Test Format	Quality Rating
Squires et al, 1997. *(Experiment 1)*	16	CVA, TBI, ENC	44.5 (13.7)	Word-pair association (related)	Errorless learning; Asked not to guess, no time limitation with responses & when unable to make a link participants were helped	Errorful; Encouraged to guess, time limited responses	Cued recall	0.83
Kalla et al, 2001.	12	TBI, CVA	41.3 (11.5)	Face-name associations	Errorless learning: Participants were shown the face and name at the same time	Errorful; Participants shown the face and surname and asked to guess the first name. Correct response was shown after three incorrect guesses	Forced choice recognition	0.72
Tailby & Haslam, 2003. (Severe Memory impairment group)	8	TBI, CVA, AX, ENC	43 (17.2)	Word list	Errorless learning: Examiner led stem-completion. Participants given first two letters, as well as the full word and asked to write it down	Errorful; Participants given the first two letters of a 5 letter work and encouraged to guess what the word is. Participants got up to three time limited guesses before the correct response was given	Cued recall	0.75
Tailby & Haslam, 2003. (Moderate Memory impairment group)	8	TBI, CVA, AX, ENC	43.8 (13.1)	Word list	Errorless learning (Experimenter led)	Errorful (Encouraged to guess)	Cued recall	0.75
Ruis & Kessels, 2005.	10	AD	81.8 (1.84)	Face-name associations	Errorless learning; Experimenter provided correct name with the presentation of the face	Errorful: Subjects prompted to guess, after guessing the experimenter provides the correct name.	Free recall	0.68
Akhtar et al, 2006.	16	MCI	78.19 (5.67)	Word list	Errorless learning: Participants presented with word stem and full target word at the same time.	Errorful: Participants given a word stem and given a time limited opportunity to guess. Participants were then as to make a judgement	Free recall	0.82

					Participants were then as to make a judgement of learning as to how likely it would be that they would remember the word (0-100%)	of learning as to how likely it would be that they would remember the word (0-100%)		
Haslam et al, 2006 *(Experiment 1)*	3	AD	82.5 (2.08)	Face-name associations	Errorless learning: Provided with an initial letter and along with the full answer	Errorful: Participants told a persons name begins with a particular letter. Participants were then asked to guess either persons name or occupation. After a maximum of 3 incorrect guesses, participants were given the correct answer	Cued recall	0.81
Haslam et al, 2006 *(Experiment 3)*	7	AD, VD	78.3 (2.21)	Face-name associations	Errorless learning: As in experiment one	Errorful: As in experiment one	Cued recall	0.81
Page et al, 2006 Experiment 1 *(Severe memory impairment group)*	8	TBI, CVA, ENC, TUM, HYD. AX, VD	46 (12)	Word list	Errorless learning: Paticipants were presented with a word stem alongside the correct answer	Errorful: Participants were given a word stem and asked to guess the answer. Participants were also given an interference word when presented with the correct answer	Cued recall	0.86
Page et al, 2006 Experiment 1 *(Moderate memory impairment group)*	14	TBI, CVA, ENC, TUM, HYD. AX, VD	46 (12)	Word list	Errorless learning: As above	Errorful: As above	Cued recall	0.86
Kessels et al, 2007	10	KS	56.8 (8.9)	Route learning	Errorless learning: Experimenter told patients which direction to go.	Errorful: Experimenter asked the patient for directions, eliciting a guess until the correct response was made.	Cued visual recall	0.71
Bier et al, 2008	15	AD	78.3 (7.9)	Visual and verbal face name associations	Errorless learning with an effortful component: Picture and first name presented and then hidden. Picture then presented immediately without the	Trial and error method with implicit memory task instructions.	Free recall	0.91

					first name. If the participant did not provide the name after a short time it was provided to them .			
Kessels & Hensken, 2009 *(Severe memory impairment group)*	20	DNS	83.6 (8.1)	Skill learning (problem solving task)	Errorless learning: Cues were given to the participant before a sequence move is made	Errorful: Standard task instructions given to participants, Cues are only provided once a participant is unable to find and complete the next step	Free recall	0.93
Kessels & Hensken, 2009 *(Mild to moderate memory impairment group)*	20	DNS	76.5 (7.9)	Skill learning (problem solving task)	Errorless learning: As above	Errorful: As above	Free recall	0.93
Lloyd et al2009	20	TBI, CVA, TUM	42.5 (12.03)	Virtual route learning	Errorless learning: Participants were shown around the route for the demonstration trial and two learning trials, directed by the experimenter with the experimenter verbalising the route	Errorful: Participants were shown around the route for only the two demonstration trails. During the two learning trials participants were asked to direct the experimenter around the route	Free recall	0.71
Lubinsky et al, 2009	19	DNS	76.95 (7.33)	Word list	Errorless learning; Experimenter-provided condition. Word stem read aloud along with two sematic cues	Errorful: Experimenter displayed word stem and provided three options that could complete the stem. Target word subsequently provided with two sematic cues	Free recall	0.75
Ueno et al, 2009	13	TBI	27.8 (10)	Word list	Errorless learning: First letter of a 3-letter word provided along with the full word	Errorful: First letter of a three letter word provided then participants were asked to guess a maximum of 3 times before the correct word was given	Recognition	0.67
Laffan et al, 2010	20	AD	80.5 (6.3)	Face-name associations	Errorless learning: Picture of a famous name was presented and participants	Non-learning condition: Pictures presented to participants of famous people and participant were asked	Cued recall	0.75

					asked to name him/her only if they were certain they new the name. The target name was immediately provided	to guess. No feedback was provided		
Dechamps et al, 2011	14	AD	86 (5.7)	Skill learning (ADLs)	Errorless learning: At each step patient received verbal instruction before competition of the action sequence	Errorful: Participant were allowed up to 3 guesses or a maximum of 25 seconds before correction and cues were provided	Cued recall	0.92
Haslam, et al, 2011 *(Experiment 1)*	30	TBI, CVA, ENC, TUM, HYD	45 (14.17)	Face-name associations	Errorless learning: Participants were presented with the face together with the name at 3s intervals	Errorful: Participants were presented with a fash and dashes to represented the missing letters of the name. The correct name was given after four guess or ten seconds had passed	Free recall	0.75
Haslam et al, 2011 *(Experiment 2)*	15	DNS, AD, VD	77 (8.15)	Face-name associations	Errorless learning: Same as above	Errorful: As above	Cued recall	0,75
Svoboda et al, 2012	10	TBI, CVA, ENC, TUM	44.5 (N/A)	Skill learning (smartphone use)	Errorless principles combined with VC. Cues very withdrawn or faded based on a participants proficiency. Each application was broken down in its component steps	Multiple return to baseline: Participants told not to use the learnt device	Cued recall	0.71
Fish et al, 2015	14	TBI, CVA, SVD, IE , AX	53.93 (8.27)	Prospective memory task	Errorless learning: Participant asked to read out loud instruction sentence. Instruction sentence then displayed with the final word missing. Participants asked again to read instruction sentence and fill the gaps, but only if they knew they answer. Cues were also used to	Errorful: Forced error elicited by asking participants to guess the target word. Guessing encourage in the instructions	Force choice recall	0.89

					support a participant reaching a correct answer			
Roberts et al, 2018	19	MCI	76.79 (8.14)	Word list	Errorless learning: Presentation of word stem and full word. Participant asked to write the word down	Errorful: Word stem with initial letter of the word given, participants encouraged to guess. The examiner presented the correct word if the participant has not made a correct guess	Free recall	0.64
Callahan & Anderson, 2019	24	MCI	73.92 (5.82)	Word list	Errorless learning: Word stem presented and a target word presented that matched the word cue	Errorful: Word stem presented and participants allowed two guesses to complete the word before the target word was presented	Cued recall	0.79

Note: AD= Alzheimer's Disease; AX= Anoxia; CVA= Cerebrovascular accident; DNS= Dementia non-specified; ENC= Herpes simplex encephalitis; HYD= Hydrocephalus; IE= Idiopathic Epilepsy; KS= Korsakoff's Syndrome; MCI= Mild cognitive impairment; SVD= Small Vessel Disease; TBI= Traumatic Brain Injury; TUM= Intracranial tumour; VD= Vascular Dementia

Table 4

Between-Subject Study Designs Included the Systematic Review and Meta-Analysis

Study	N	Type of patients	Age (+SD)	Task	Method of intervention	Control Condition N	Control Group	Test Format	Quality rating
Baddeley & Wilson, 1994	16	TBI, CVA,ENC, AX, KS	44 (17.4)	Word list	Errorless learning: Word stem presented along with target word and participant asked to write the word down	16	Errorful: Participants given word stem and asked to guess. The correct response was given after 4 incorrect guesses	Cued recall	0.69
Bourgeois et al, 2007	22	TBI	43 (16.2)	Skill learning (strategy use)	Errorless learning principles combined with spaced retrieval. Established prompt and answer with participant. If participant appeared to struggle in their response the correction answer was provided	16	Errorful: Didactic strategy instruction. Discussion around common memory strategies. Participant goals were identified and participants were encouraged to try a memory strategy	Goal mastery scores	0.88
O'Neil-Pirozzi et al, 2010	53	TBI	47.3 (10.8)	Internal memory strategy use	12 session training programme with EL principles and VC	40	TBI Control group with no intervention	Free recall	0.88
Lee et al, 2013	6	TBI	N/A	List learning	12 Session memory training programme with errorless learning principles with vanishing cues and spaced retrieval. Learned task briken int component parts.	6	Waitlist	Free recall	0.86

					Provision of positive feedback				
Oudman et al, 2013	8	KS	58.9 (6.9)	Instrumental learning of ADLs	Errorless learning: Instructions, verbal cues and answer to the action provided immediately	8	Errorful: Unstructured learning. Participants are encouraged guess and errors are corrected	Cued recall	0.73
Schmitz et al, 2014	14	AD	79.4 (4.6)	Skill learning (Perceptual learning task)	Errorless learning: The target appeared before the response.	14	Errorful: When participants selected the wrong key, a beep sounded and the correct target appeared	Cued recall	0.71
Thivierge et al, 2014	9	AD	80 (6.14)	Skill learning (ADLs)	Errorless learning with spaced retrieval. Verbal instructions for each step of task	8	Block-randomised cross-over controlled study. Comparisons were made with trained and untrained groups	Cued recall	0.82
Bertens et al, 2015	30	TBI	49.7 (13.6)	Skill learning (ADLs)	Errorless learning with goal management training. Active guidance from the experimenter to prevent errors, verbal and written instructions. Practice sessions and gradual fading of cues after successful performance	30	Trial and error approach with goal management training. Experimenter did not prevent errors during the acquisition and application of the goal management strategy	Task mastery scores	0.89
Bourgeois et al, 2016	15	AD	83.67 (7.28)	Skill learning (ADLs)	Errorless learning: Participants provided with verbal and	21	Trial and error: Regular unstructured	Free recall	0.82

					visual cues. The therapist gave cues before the completion of each task		learning. After a mistake is made an experimenter corrects it immediately		
Ownsworth et al, 2017	27	TBI	37.86 (13.3)	Skill learning (Cooking)	Errorless learning: Therapists prevent participants from making mistakes by modelling each step and providing physical and verbal guidance	27	Error based learning: Therapists provide structured opportunities for participants to make errors, to learn, to self-correct with prompts and feedback	Cued recall	0.92
Rensen et al, 2017	51	KS	59.9 (6.3)	Skill learning (ADLs)	Errorless learning: Details not described	31	Waitlist: Care as usual but no EL	Observer rated measure	0.67
Voigt-Radloff et al, 2017	69	DNS	76.7 (8)	Skill learning (ADLs)	Errorless learning: Task broken into discrete steps. Therapist accompanied the patient's step performance by continuous verbal instruction. Upon error anticipation therapist demonstrated the next step	71	Trial and error learning: Patients asked to perform the task without instruction or demonstration. If a patient was unable to perform a step verbal instructions were given but not demonstrated	Observer rated measure	0.96

Kerkhof et al, 2020	6	AD & VD	68.9 (14)	Skill learning (Use of an app)	Training with EL principles: Task broken into smaller steps, task demonstrated and modelled for the patient to copy, step by step guidance provided for participants	4	Training without EL	Proficiency scores	0.92

Note: AD= Alzheimer's Disease; AX= Anoxia; CVA= Cerebrovascular accident; DNS= Dementia non-specified; ENC= Herpes simplex encephalitis; HYD= Hydrocephalus; IE= Idiopathic Epilepsy; KS= Korsakoff's Syndrome; MCI= Mild cognitive impairment; SVD= Small Vessel Disease; TBI= Traumatic Brain Injury; TUM= Intracranial tumour; VD= Vascular Dementia

Table 5

Studies Included in the Systematic Review but not the Meta-Analysis

Study	N	Type of patients	Age (+SD)	Task	Method of intervention	Control Condition	Test Format	Quality Rating	Reason for exclusion in meta-analysis
Squires, 1996	1	CVA	70 (N/A)	Notebook training	Errorless learning: Participants told not to guess and told the answer to the target	Errorful: Participants presented with the target and told they could guess three times. Correct answer was provided after three guesses	Cued recall	0.81	Single case design
Evans et al, 2000	18	TBI, CVA, ENC, KS	43.9 (14.53)	Face-name associations, route learning	Errorless learning using backward chaining and stem completion	Errorful: Participants encouraged to guess their responses to target material. After a maximum of five incorrect guesses participants were told the correct response	Cued recall	0.69	Means and standard deviations not reported
Komatsu et al, 2000	7	KS	60.6 (2.42)	Face-name paired associates	Errorless learning: Target shown with name. Participants were asked to say the name out loud	Errorful: Participants encouraged to guess	Cued recall	0.7	Means and standard deviations not reported
Clare et al, 2002	12	AD	71 (2.62)	Face- name associations	Errorless using spaced retrieval, mnemonic learning and VC	Control items where EL was not applied	Free recall	0.72	Means and standard deviations not reported
McKenna & Gerhand, 2002	1	ENC	40 (N/A)	Semantic memory Learning pictures	Errorless learning: Patient shown target photograph with target name to learn and asked to write the name down.	Participants wife acted as a control subject.	Cued recall	0.59	Single case design
Clare et al, 2003	1	AD	66 (N/A)	Name learning	Errorless- Repeated presentation and spaced rehearsal. Mnemonic method discussion photograph and generating associations	ABA maintenance	Cued recall	0.91	Single case design
Ehlhardt et al, 2005	4	TBI	38.44 (3.3)	Skill learning	Errorless Learning: Modelling target steps. Demonstration of correct step if an error occurs. Careful fading of support. High rates of correct practice. Task broken into discrete steps	ABA maintenance	Free recall	0.54	Maintenance condition, no proper control

Metzler-Baddeley & Snowden, 2005	4	AD	65.8 (1.87)	Paired associates	Errorless learning: Patietns presented with target and invited to unfold index card to reveal the name and then asked to write that name down	Errorful: Patients encourages to guess each time a photograph was presented	Free recall	0.88	Means and standard deviations not reported
Dou et al, 2006	26	TBI	39.46 (11.92)	Computer facilitated list learning	Errorless learning: Computer provided necessary information for patients to generate correct responses. Participants encouraged not to guess	Patient control	Cued recall	0.64	Means and standard deviations not reported
Dunn & Clare, 2007	10	AD, VD	80.7 (1.7)	Paired associates	Errorless learning, paired associates and vanishing cue. A face- name pair was shown. Participants were asked to say the name aloud and associate it with the face	Errorful: Participants encouraged to guess	Free recall	0.69	Means and standard deviations not reported
Provencher et al, 2008	1	AD	77	Route learning	Errorless learning &VC: Modelling the experimenter waled the entire room with the patient. Route broken down into discrete steps	ABA maintenance	Cued recall	0.77	Single case design
Thivierge et al, 2008	1	AD	66	Skill learning ADLs	Errorless learning: Task modelled by experimenter. Experimenter name each step being carried out whilst modelling. The experimenter asked the participant to name the steps whilst they completed the task. Participant told to seek help if required	ABA maintenance	Cued recall	0.71	Single case design
Haslam et al, 2010	22	AD	75.3 (7.3)	Face name associations	Errorless learning with vanishing cues. Participants provided with the target and surname association	Errorful: Participants provided with the target and first letter of the surname and encouraged to guess	Cued recall	0.88	Means and standard deviations not reported
Jean et al, 2010	11	MCI	68.55 (9.16)	Face name associations	Errorless with spaced retrieval: Participants presented with target material and answer. In the recall phase participants instructed not to guess their answer	Errorful without SR. Participants encourage to guess the responses and corrected after a certain amount of incorrect guesses	Cued recall	0.78	Means and standard deviations not reported

Mimura & Komatsu, 2010	18	AD	77 (4.9)	Paired associates	Errorless learning: Participants encouraged not to guess. Target material presented with answer	Errorful and effortful: Participants encouraged to guess answers	Cued recall	0.64	Means and standard deviations not reported
Trevena-Peters et al, 2018	49	TBI	49	Skill learning ADL retraining programme	Errorless and procedural training programme. Therapists provided sufficient support to promote task performance and avoidance of errors	TAU	Score on clinical rated measure of function	0.68	Means and standard deviations not reported

Note: AD= Alzheimer's Disease; AX= Anoxia; CVA= Cerebrovascular accident; DNS= Dementia non-specified; ENC= Herpes simplex encephalitis; HYD= Hydrocephalus; IE= Idiopathic Epilepsy; KS= Korsakoff's Syndrome; MCI= Mild cognitive impairment; SVD= Small Vessel Disease; TBI= Traumatic Brain Injury; TUM= Intracranial tumour; VD= Vascular Dementia

4.1.5. **Quality of Studies**

To give an overview of the methodological quality, the studies have been dived into three categories, indicating low (0.54-0.6), medium (0.6-0.8) or high quality scores (0.8-0.96). One study (Voigt-Radloff et al, 2017) received the highest rating (0.96). This study was an RCT, it controlled for confounding factors, adequately described participants and used blinded assessors. Lower ratings were typically associated with having omitted estimates of variance from the results, and from incorporating less rigorous controls related to the confounding of variables. Twenty-seven studies (Baddeley & Wilson, 1994; Evans et al, 2000; Komatsu et al, 2000; Kalla et al, 2001; Clare et al, 2002; Tailby & Haslam, 2003; Ruis & Kessels, 2005; Dou et al, 2006; Dunn & Clare, 2007; Kessels et al, 2007; Provencher et al, 2008; Thivierge et al, 2008; Lloyd et al, 2009; Lubinsky, Rich & Anderson, 2009; Jean et al, 2010; Laffan et al, 2010; Mimura & Komatsu, 2010; O'Neil-Pirozzi et al, 2010; Haslam et al, 2011; Svoboda et al, 2012; Oudman et al, 2013; Schmitz et al, 2014 Rensen et al, 2017; Roberts et al, 2018; Trevena-Peters et al, 2018 & Callahan & Anderson, 2019) were of medium quality. Generally these studies sufficiently described the research objective and applied appropriate methodology, however, subject and comparison selection were often only partially described. In addition insufficient data was provided to assess sample size, with the size often appearing small often with no mention of power. An additional 19 studies (Squires, 1996; Squires et al, 1997; Clare et al, 2003; Akhtar et al, 2006; Haslam et al, 2006; Metzler-Baddeley & Snowden, 2005; Page et al, 2006; Bourgeois et al, 2007; Bier et al, 2008, Kessels & Hensken, 2009; Haslam et al, 2010; Dechamps et al, 2011; Lee et al, 2013; Thivierge et al, 2014; Bertens et al, 2015; Fish et al, 2015; Bourgeois et al, 2016; Ownsworth et al, 2017; Kerkhof et al, 2020) were of high quality. These studies used a reasonable sample size, employed rigorous research designs, controlled for cofounding, and reported estimates of variance.

4.1.6. **Inter-Rater Agreement**

Ten studies were selected at random for a second reviewer to rate. Raw scores from both raters were converted into categorical data indicating the quality of the studies (low, medium, and high). Categorical inter-rater agreement for overall scores was 80%. Inter-rater agreement for overall scores is presented in Table 6. The overall scores assigned by the first reviewer ranged from 0.69 to 0.92 (mean 0.81, SD: 0.09). The overall scores assigned by the second reviewer ranged from 0.59 to 0.91 (mean 0.80, SD: 0.11). No papers were rated with the same overall score, discrepancies ranged from 0.01 to 0.20 (mean 0.04 SD: 0.9). Discrepancies reflected differences in the assignment of "yes" versus "partial" to the fulfilment of specific criteria in items specific to study design.

Table 6

Inter-Rater Agreement for Overall Scores

Research Paper	Rater 1 Overall Score	Rater 2 Overall Score
1	.68	.86
2	.96	.89
3	.68	.69
4	.86	.75
5	.91	.71
6	.81	.83
7	.68	.75
8	.89	.96
9	.89	.92
10	.77	.73

4.2. Meta-Analyses

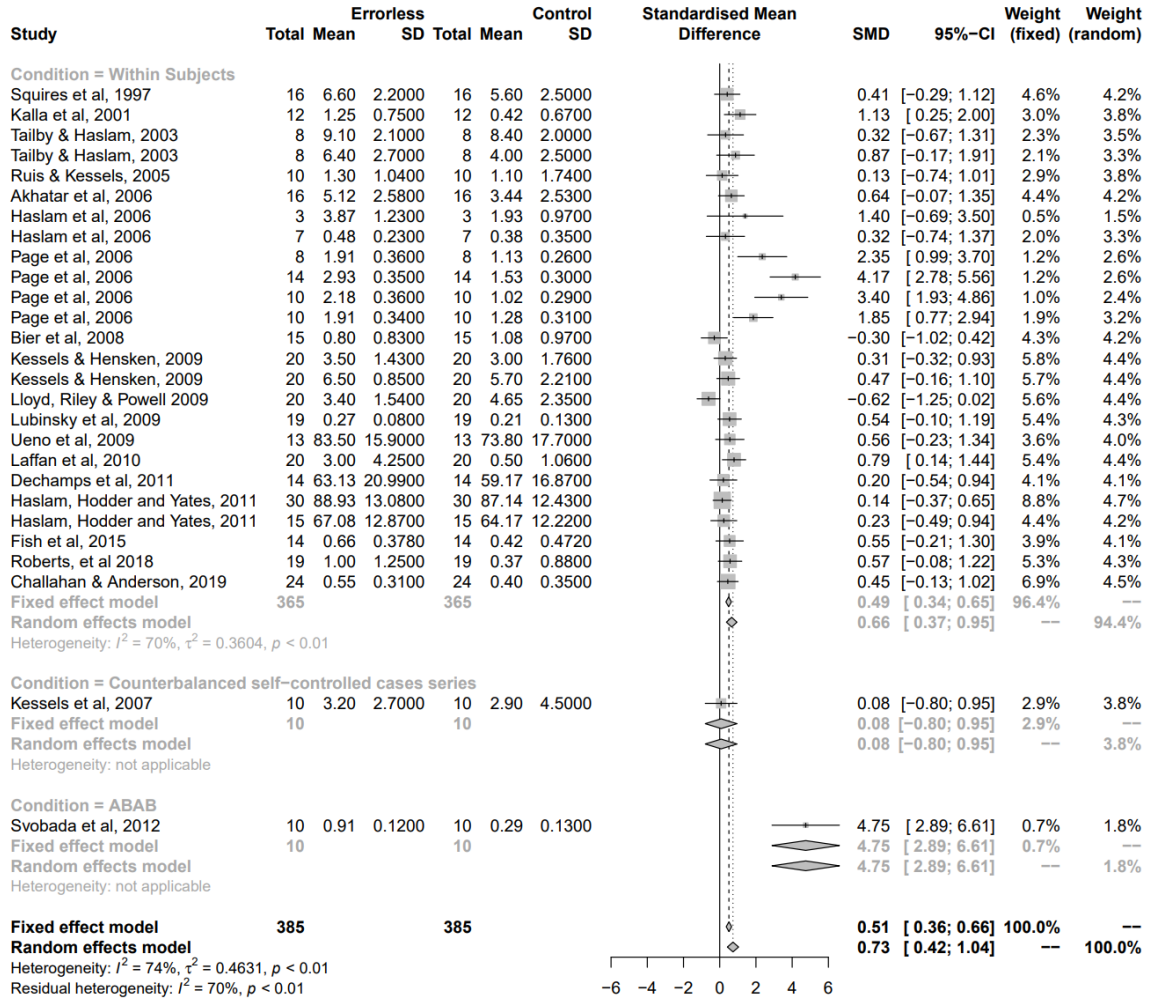
Sixteen of the 49 studies included in the systematic review were excluded from the meta-analysis. These excluded studies ranged in quality from 0.54 to 0.91. The overall quality of this subgroup of studies was scored as medium (0.73). Five studies were single case designs (Squires, 1996; McKenna & Gerhand, 2002; Clare et al, 2003; Provencher et al, 2008 & Thivierge et al, 2008). Ten studies did not report a condition/group mean and standard deviations (Evans et al, 2000; Komatsu et al, 2000; Clare et al, 2002; Metzler-Baddeley & Snowden, 2005; Dou et al, 2006; Dunn & Clare, 2007; Haslam et al, 2010; Jean et al, 2010; Mimura & Komatsu, 2010; Trevena-Peters et al 2018). One study used an ABAB design for four participants, however it did not have a sufficient control condition (Ehlhardt et al, 2005). Thirty-three studies were included in the meta-analysis (see tables 2 & 3 for included studies). Since it is not statistically advisable to directly compare studies with within-group and between-group designs separate meta-analyses were conducted for each (Wilson & Lipsey, 2001). The same approach was adopted to answer the secondary question exploring the EL advantage in progressive and non-progressive neurological conditions separately.

4.2.1. **Primary Within-Subject Design Meta-Analysis**

A total of 20 studies using within-subject designs with 385 participants with both progressive and non-progressive neurological conditions were analysed. The average quality rating in this subgroup of studies was “medium” (0.79), with a range from 0.67 to 0.9. Substantial heterogeneity was observed (I^2=74%, p<0.01) therefore a random effects model was used calculating an overall medium effect of errorless learning over control conditions (SMD 0.73; CI 0.42; 1.04), see Figure 2 for the forest plot. Squires et al, 1997 reported data from two separate experiments, each experiment had 16 participants, 14 of which took part in

both experiments. We selected the first experiment which used remotely linked word pairs as the target stimulus for the meta-analysis. However, if we were to include the second experiment teaching novel associations the overall estimate is largely unchanged (SMD 0.74; CI 0.43; 1.05).

Figure 2: A forest plot of studies using a within-subjects design.



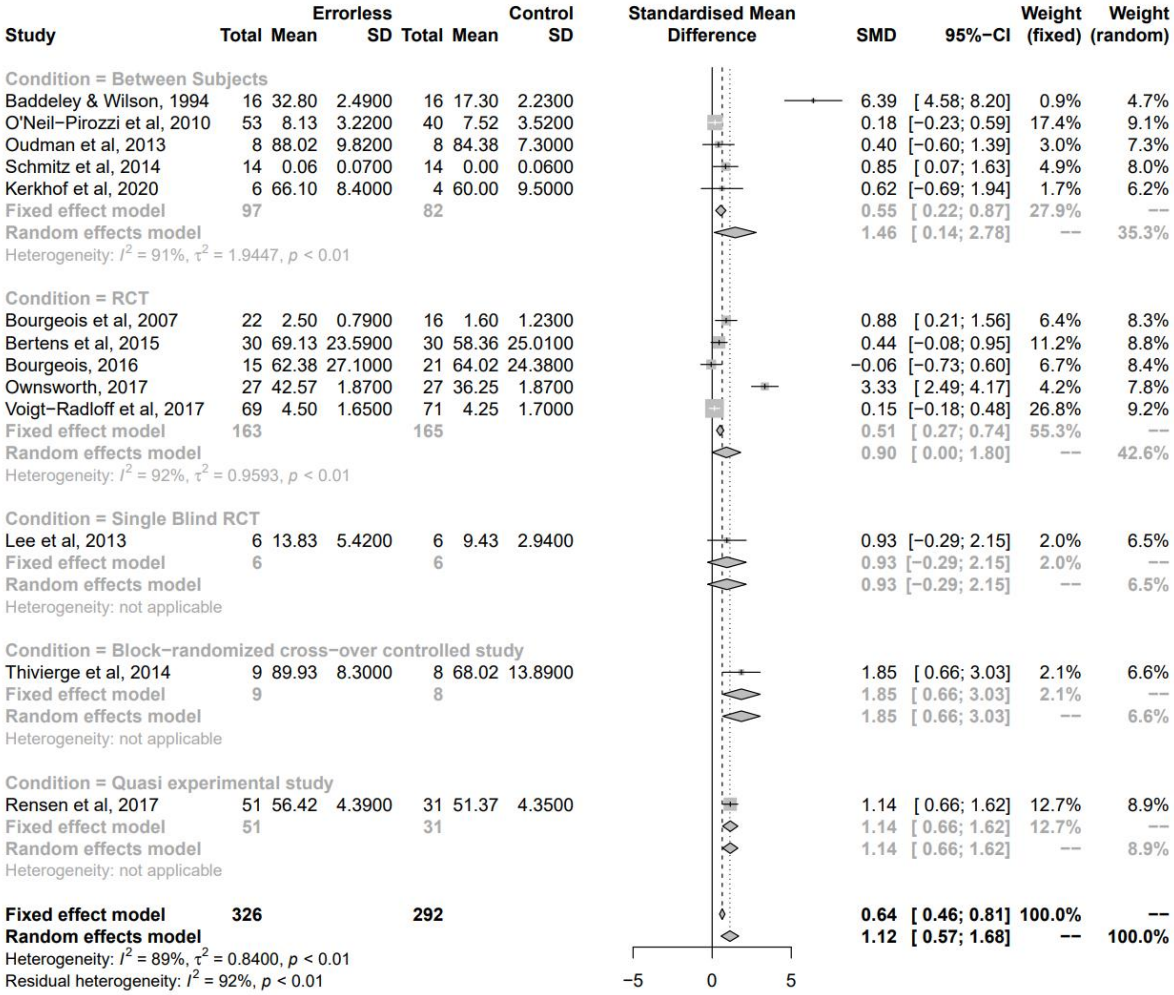
4.2.2. **Primary Between-Subject Design Meta-Analysis**

A total of 13 studies using between-subjects designs with 326 participants with memory impairment resulting from either progressive or non-progressive neurological conditions were analysed. On average, studies in this subgroup were rated as “high” (0.82)

with a range of 0.67 to 0.92. Substantial heterogeneity was observed (I^2=89%, p<0.01) therefore a random effects model was used calculating a large overall effect of errorless learning compared to control conditions (SMD 1.12; CI 0.57; 1.68), see Figure 3. In Lee et al (2013) there were two intervention arms; a therapist lead and a computer assisted EL condition. We selected the therapist led condition for the meta-analysis, as it represented the most similar experimental condition to other studies being analysed. However, if we were to include the computer assisted condition in place of the therapist lead condition the overall estimate is largely unchanged (SMD 1.07; CI 0.52; 1.63).

Figure 3

A Forest Plot of Between-Subject Studies



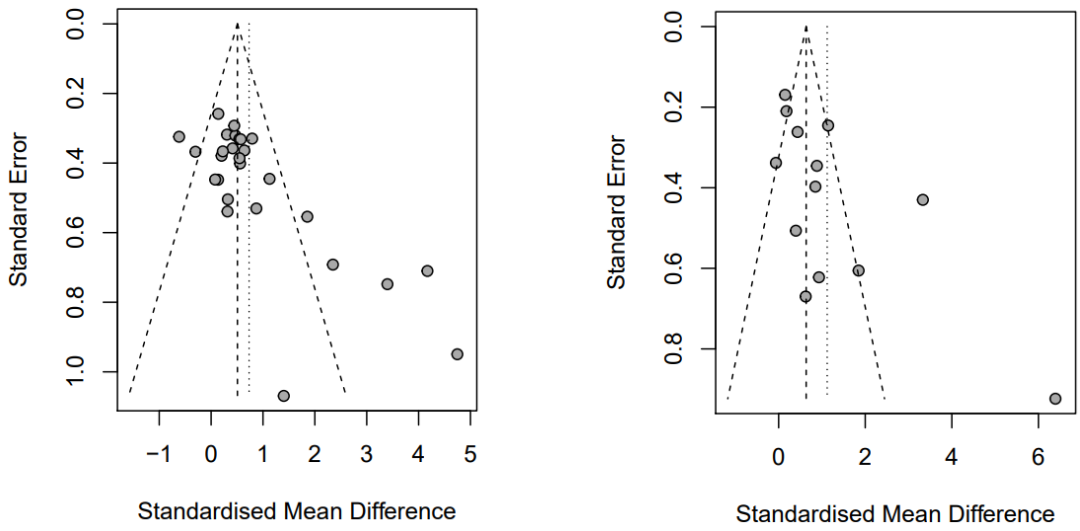
4.2.3. **Assessment of Potential Publication Bias**

Potential publication bias was tested in both meta-analyses using an Egger's test to identify asymmetry in the funnel plot (see Figure 4). Significance for asymmetry was found in both the within-subjects meta-analysis, p=<0.01, and the between-subject meta-analysis, p=0.02. A Trim-Fill analysis was completed to examine the sensitivity of the results to publication bias. It estimated that there are five studies missing in the between-subject dataset. After filling 5 studies the estimated ELA for studies using between-subject

methodology reduces from SMD 1.12 (CI 0.57; 1.68) to SMD 0.36 (CI -0.25; 0.98). A Trim-Fill analysis was also used for studies applying within-subject designs. It estimated that eight additional trials would need to exist in order to render the effect non-significant. After filling eight studies the ELA reduces from SMD 0.73; (CI 0.42; 1.04) to SMD 0.31 (CI -0.05; 0.66).

Figure 4

Funnel Plots for Within-Subject Studies (Left) and Between-Subject Studies (Right)



4.2.4. **Progressive Neurological Conditions**

Studies included in the primary meta-analysis which used participants with progressive neurological conditions were meta-analysed according to their study design (within-subject and between-subject). Ten studies with 261 participants with a range of progressive neurological conditions used a between-subjects design and 12 studies with 187 participants used a within-subjects design. Substantial heterogeneity was observed in the between subjects design (I^2=59%, r^2=0.438, p<0.01) but not in the within subjects design (I^2=0%, p=0.97) therefore a fixed effect model was used for within subjects and a random effects was used for between subjects. Both types of study reported an errorless learning

advantage of a medium effect size (between-subject design SMD 0.54; CI 0.22; 0.86; within-subject design SMD 0.46; CI 0.25; 0.66).

4.2.5. **Non-progressive Neurological Conditions**

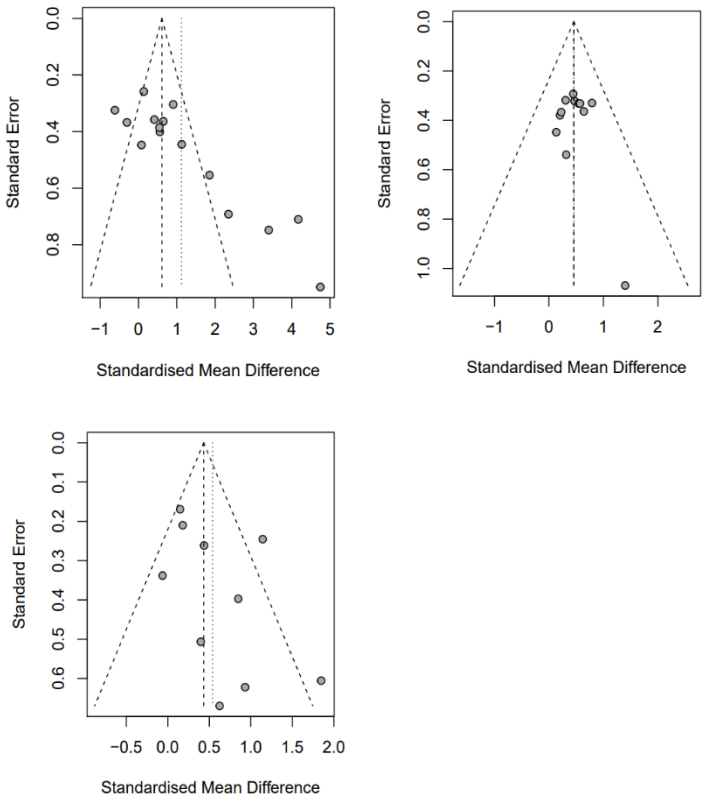
There were 222 participants included in the 17 studies of participants with non-progressive neurological conditions using a within-subject design. Significance in heterogeneity was identified (I^2=86%, r^2=1.01, p<0.01) therefore a random effects model indicated an ELA with a large effect size (SMD; 1.12; CI; 0.55; 1.68). The number of participants (N=56) in the three studies using a between-subjects design with participants with non-progressive neurological conditions was too small to meta-analyse.

4.2.6. **Secondary Meta-analysis Assessment of Potential Publication Bias**

Funnel plots were produced to test for potential publication bias (see Figure 5). An Egger's test was used to identify asymmetry in the funnel plots. Significance for asymmetry was found in the non-progressive within-subjects design funnel plot, p=<0.01. No asymmetry was found for the progressive within-subjects design funnel plot, p=0.65 or the between-subject design funnel plot, p=0.16. A Trim-Fill analysis was completed for the non-progressive within-subjects data, it estimated there are four missing studies in the data. After filling four studies the estimated ELA for non-progressive conditions in studies using within-subject methodology reduces from SMD; 1.12 (CI; 0.55; 1.68) to SMD; 0.44 (CI -0.21; 1.08).

Figure 5

Funnel Plots (Top Left; Non-Progressive Neurological Conditions Within-Subjects Study Design, Right; Progressive Neurological Conditions Within-Subjects Design, Bottom Left Progressive Neurological Conditions Between-Subject Study Design).



5. **Discussion**

5.1. **Main findings**

The goal of this study was to review an important memory rehabilitation technique, with the aim of providing further evidence for clinicians to make informed decisions about the application of EL in practice. This review both systematically and quantitatively analysed the treatment effects of EL, an approach widely applied in memory rehabilitation, versus EF learning for people with memory impairment resulting from progressive and non-progressive neurological disorders. To accomplish this in a methodically and statistically rigorous way, separate analyses were conducted according to study methodology. The overall results demonstrate that people with memory impairment benefit from EL in comparison with EF. That is, people with memory disorders are shown to have learnt, sufficiently stored and retrieved a wide range of material better in conditions where errors are minimised opposed to when they occur naturally or have been experimentally induced. This meta-analysis provides evidence that EL task performance is more accurate compared to EF methods, trial and error and treatment as usual. This finding is consistent with the theoretical view that errors interfere with the learning process for amnesic persons due to deficits in the domain of explicit memory, believed to be responsible for self-correcting errors (Baddeley and Wilson, 1994). An EL advantage was also consistently reported in studies that did not intentionally 'inject' errors into the control condition/group, but instead did not prevent erroneous responses from naturally occurring.

In relation to the secondary analysis, it was the first time the size of EL advantage in progressive or non-progressive conditions were explored separately. Results indicate both progressive and non-progressive neurological conditions benefit from EL relative to EF methods. Results suggest a larger effect size of EL in non-progressive conditions than

progressive conditions. One explanation for this finding could relate to the differing nature of cognitive deficits in people with memory impairment associated with a progressive versus non-progressive aetiology/condition. The ELA may differ because the populations differ. The people with memory impairment recruited for these studies differ in a number of ways; in the severity of their memory impairment, presence of attentional and/or executive function impairment, their age, and length of time with the condition.

One possibility for the potential additional benefits people with non-progressive conditions may acquire from a direct instruction method like EL, could be the scaffolding it provides for participants with dysexecutive and memory challenges (Ehlardt et al, 2005). Frontal cortical areas responsible for initiation, planning, organising and decision making are commonly implicated in TBI (McDonald, Flashman & Saykin, 2002). EL principles of breaking down a task into discrete steps and imparting clear directions may compensate for executive challenges that additionally interfere with the encoding and storing of information to memory. By encouraging erroneous responses, executive deficits such as decreased emotional regulation and increased impulsivity may in part explain some of the differences between performance in the two conditions. Frustration and confrontation with failure during learning may result in a lower retention rate in the EF condition and this may be more pronounced in non-progressive conditions (Schmeck & Grove, 1976). Fillingham et al (2010) found that participants had a preference for the EL condition over EF. In most of the progressive neurological conditions represented in the reviewed studies, neurological changes are initially mostly confined to the medial temporal areas, therefore executive deficits are less likely to be present at the relatively early stages of the disease, therefore the additional benefit of executive scaffolding EL offers may be less pronounced in this population. However, this generalisation of aetiologies may offer too simplistic an explanation. Clare et al (2002) identified the importance of individual differences, noting that although all participants had

significant memory impairments resulting from amnesia of a dementia type, their neuropsychological profiles differed.

It is interesting to consider how the severity of memory impairment could influence the success of EL. In particular, a series of studies focused on whether residual explicit memory explains the ELA. Hunkin et al (1998) and Tailby and Haslam (2003) propose that errorless learning advantage is attributable to explicit memory. Page et al (2005) challenged their position conceding that for some groups, performance following EL results from a mixture of both implicit and explicit memory, but the benefit of EL over EF conditions still result from the operation of implicit memory. Studies with memory impairment originating from a progressive neurological condition, predominantly recruit people with mild to moderate memory impairment. One such study, Meltzer-Baddeley & Snowden (2005), found no significant difference at an individual level between EF and EL conditions. They suggest EL may be most beneficial for participants with profound amnesia, whilst those with mild to moderate memory impairment may have significant residual explicit memory reserves which over-ride any additional benefits of EL. This current review has shown EL can be of benefit for people with non-progressive conditions, documenting larger effect size than progressive conditions. This may result from the larger proportion of studies recruiting participants with more severe memory impairment in the non-progressive than progressive conditions. However, debate exists as to whether a memory impairment following ABI can be considered truly amnesic (Clare & Jones, 2008) with a likelihood for elements of residual memory in most presentations. Severity of memory impairment and its influence on EL was not in the scope of this review, however it is an issue that remains warranting attention.

This meta-analysis along with the earlier meta-analysis of Kessels & de Haan's 2003 provides some evidence supporting the efficacy of EL in well-controlled laboratory tasks. Kessels and de Haan noted there had been promising early signs for the applicability of

EL in clinical practice. Clare et al, 2000 were the first to demonstrate how EL principles can be easily adapted for use in clinical settings, aimed at remediation of daily life memory dysfunction. Since Kessels and de Haan's meta-analysis a body of evidence has accrued reporting the efficacy of EL principles in memory rehabilitation programmes for re-learning activities of daily living for people with progressive disorders (Oudman et al, 2013; Thivierge et al, 2014; Bertens et al, 2015; Bourgrois et al, 2016; Kerkhof et al, 2020). However, the first adequately powered RCT examining EL as a method to teach persons with dementia ADLs found structured learning improved performance for participants with mild to moderate Alzheimer's, but EL had no additional effect over trial and error (Voigt-Radloff et al, 2017). It was suggested that structured learning (step-by-step approach, feedback and task engagement) in itself may provide fertile grounds for learning, independent of errors. In addition, the authors also noted motivational factors, such as the intervention being conducted in the participants own home for meaningful tasks. They thought this established an appreciation for the intervention which promoted learning and obscured the superior effect of error reduction. This study provides counter evidence to a body of lower powered studies. Future efforts to replicate Voigt-Radloff et al's study are warranted.

5.2 **Methodological Concerns in the Literature and Review Limitations**

As discussed, these results offer evidence indicating EL to be an effective memory rehabilitation technique. However, in the literature there exists a number of limitations which require cautious consideration when drawing an overall conclusion about the efficacy of EL.

It is important to address findings of asymmetry in funnel plots for both the primary analyses and the within-subject non-progressive neurological condition meta-analysis. Funnel plot asymmetry has been widely used to examine potential publication bias in the results of meta-analyses. Sterne et al (2011) warn of the frequent pitfalls of incorrectly

equating asymmetry with publication and other reporting biases through visual inspection alone. Considering the heterogeneity across samples may offer some explanation. There was a range of severity of memory disorder across the studies, it may be the case that the most benefit of EL is with the most amnesic people with memory disorders and these people may have been preferentially included in early small studies (Baddeley and Wilson, 1994.; Squires, 1996 & Page et al, 2006). As the clinical application of the technique has been further explored EL has been applied to those with milder memory impairment, perhaps eliciting less of an effect that earlier proof of concept studies. In addition, as the use of EL principles transitioned from highly controlled experimental paradigms to incorporation of EL into training programmes. It may be the case EL was implemented in a less 'pure' manner in larger studies, resulting in smaller effect sizes in comparison with smaller studies. However, this explanation may account for the primary analyses, but it would not account for the asymmetry captured in the within-subjects study design meta-analysis for non-progressive conditions, as there have been few studies incorporating EL into memory-rehabilitation in a large-scale manner. Beyond the proposed influence of heterogeneity, the biases of the research field must be considered. Similarly with the broader scientific landscape, there may be an ethos in neuropsychological rehabilitation that favours the publication of large effects. The employment of EL in active rehabilitation in healthcare settings may also be influenced by the lack of published replication studies, resulting from the competing demands of clinical priorities and a lack of protected time to research endeavours.

This review used a total summed proportion score for the quality appraisal, potentially resulting in some nuanced differences in quality across the studies being lost. Future studies could consider alternative approaches to understand the quality differences between study findings. The reviewed literature contained a large number of small studies, reflecting the origins of the field of neuropsychology in the study of single or small numbers of cases.

Commonly, small studies tend to report greater intervention effects than larger studies (Sterne, Gavaghan & Egger, 2000). So called 'small-study effect' may arise from reporting biases, where smaller studies are more likely to be selected for publication on the basis of statistical significance, or effects may arise in methodological flaws arising more frequently in small studies (Kjaergard, Villumsen & Gluud, 2001). Some researchers argue for the exclusion of small studies from meta-analysis to reduce the effects of publication bias (Stanley, Jarrell & Doucouliagos, 2010 & Turner, Bird & Higgins, 2013). Future research in field requires larger adequately powered, methodologically rigorous studies to target publication bias reduction.

There was a significant amount of heterogeneity across all studies in addition to the previously identified range in the severity of an individual's memory challenge. Principles of EL were applied to a wide range of task type, spanning a range of complexity from learning basic face-name associations to learning novel routes and multiple steps in task sequences. This review did not control and account for factors such as the number of learning trials in the studies, with some studies employing less the three sessions altogether and others employing four times weekly sessions over two months. It would be sensible to predict increased exposure to target material would result in increased potential for memory retention. Furthermore, the meta-analysis included a range of test format conditions, such as recognition, cued and free recall. Free recall conditions are evidenced to be more challenging than force-choice recognition (Hirst et al, 1988; Squire, 1992). It would be interesting to see under which test conditions EL may provide the greatest advantage. Additionally, the first post-test time point after a learning trial used for the meta-analysis was not standardised across studies, the effect of time and memory decay is well-documented. Also, this meta-analysis did not focus on the longevity of EL advantage. It was also not possible in this

review to answer some unresolved questions in the literature such as the generalisability of acquired memories and the durability of the learning over time and across environments.

5.3 **Conclusion**

This review and meta-analysis demonstrated evidence of an ELA in treating memory dysfunction in both progressive and non-progressive disorders over EF techniques. This review has also produced the first quantitative evidence exploring EL in progressive and non-progressive neurological conditions separately. Although speculative hypotheses are made in this review further attention is required in the field to understand the mechanisms behind the additional advantage seen in non-progressive neurological conditions. This review has also tracked the genesis of the use of EL principles in different tasks from well-controlled laboratory environments to its utility in clinical rehabilitation programmes. However, these results do need to be viewed cautiously. The small number of studies, significant heterogeneity, the low quality of some studies and potential publication bias issues makes an overall interpretation of the clinical utility of these results a challenge. Based on the promising nature of the results, it is our hope that future research will aim to address methodological shortcomings to provide clinicians with evidence for the applicability of EL in a range of clinical settings.

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Part 2: Empirical Paper

Improving the Assessment of Decision-Making: A Service Evaluation of Tests Used to Assess Decision-Making in Patients with Acquired Brain Injury

1. Abstract

Aims: Diminished decision-making ability is a common consequence of acquired brain injury (ABI). Accurate assessment of a persons's decision-making ability is crucial to inform support needs. This service evaluation aimed to explore the relationships between standardised tests of cognitive function and clinican-rated everyday decision-making ability. Within this, a secondary aim was to compare models of everyday decision-making based on multiple cognitive domains or executive function alone.

Method: This was a retrospective study using routinely collected data from a comprehensive neuropsychological assessment battery completed by 42 patients with ABI who attended an outpatient cognitive rehabilitation service in a 12-month period between 2018 and 2019. Multivariable linear regressions were used to examine associations between scores on a custom clinician-rated measure of everyday decision-making ability and selected neuropsychological tests of executive function, memory and intellect.

Results: BADS Zoo Map 1, a measure of planning ability had the most robust association and was the only significant individual predictor of overall score on the custom measure. Both multi-domain and executive-specific models significantly predicted clinician-ratings; however the executive-specific model predicted more variance (58.1%) than the multi-domain model (40.4%).

Conclusions: The results suggest that BADS Zoo Map 1 a measure of planning contributes usefully to the assessment of decision-making capacity ability in this service population and that any abbreviated assessment battery should retain this measure. Further, it suggests that at a group level, tests of executive function are more useful in the assessment of decision-making than those from broader cognitive domains, though at the individual level in clinical practice a broader assessment is still likely necessary.

2. Introduction

Acquired brain injury (ABI) refers to an injury or insult to the brain occuring after birth. Common causes of ABI are traumatic brain injury (TBI), stroke, tumor and infection. ABI is one of the leading causes of disability, with an estimated 1.4 million people living with this condition in the UK and yearly hospital admissions related to ABI averaging around 320,000 (The Neurological Alliance, 2019; Barber et al, 2019). The effects of ABI pose significant challenges to the individual and a significant burden to families and the health system (Ponsford et al, 2003; James et al, 2016). People with ABI are at greater risk of psycho-social difficulties such as poor mental health (Jorge et al, 2004; Hesdorffer et al, 2009 & Whelan-Goodinson et al, 2009), relationship breakdown (Wood & Yurdakul, 1997), social isolation (Salas et al, 2018), substance use (Caplan et al, 2015), unemployment (Andelic, 2011), homelessness (Oddy, 2012) and incarceration (Schofield et al, 2015).

After an initial period of rapid decline in cognitive function on sustaining the injury, followed by a period of recovery over the following days, weeks and months (depending on factors such as the severity of the injury; Green et al, 2008), for many people ABI results in a cognitive impairment characterized by difficulties in executive function (Stuss, 2011), memory (Arciniegas, Held & Wagner, 2002), communication (Behn et al., 2019) and attention and speed of processing (Mathias & Wheaton, 2007), with varying severity depending on the severity of the injury and the brain areas affected. While some or all these impairments may be observable, problems with planning and organising, problem-solving, self-awareness and decision-making may be subtle and can be difficult to detect, assess and understand (Clark-Wilson & Holloway, 2015 & Silver, McAllister & Arciniegas, 2018). As these executive functions are crucial in everyday life, people with undetected executive function impairment are at risk of their needs not being properly identified, increasing the likelihood of the aforementioned negative social outcomes.

Following an ABI, concerns are commonly raised about a person's autonomous decision-making (Marson et al, 2005). Impaired decisional capacity presents significant challenges for clinicians, who must frequently determine if a person has decisional capacity following an acute injury or if the person is able to resume autonomous decision-making during their rehabilitation (Dreer et al, 2012). Examples of decisions commonly faced by clinicians and patients post-ABI can be, but are not limited to, consent around medical interventions and hospitalisation, decisions around financial affairs around injury and handling everyday financial transactions (Dreer, 2008 & Gaudette & Anderson, 2002). The risk of not identifying the need for support can be catastrophic, for example people with TBI are shown to be at greater risk of financial and sexual exploitation from others (Colantonio et al, 2010 & Haag et al, 2016, Mccormick & Simberlund, 2020).

Impaired decision-making can contribute to the challenges faced by those with ABI and substantially impair everyday functioning and independence (Adshead et al, 2019 & Gaudette & Anderson, 2002). There are multiple sources of information and areas of knowledge relevant to understanding decision-making in people with brain injury in clinical practice which will be considered in turn. These include:

- A definition of 'decision-making'
- The legal frameworks relevant to decision-making
- How decision-making capacity is assessed and the types of decisions people face
- The cognitive and neuroanatomical basis for decision-making in neurologically healthy and impaired people
- The literature on decision-making after brain injury
- The particular complexities of the assessment of executive function after brain injury

2.1 **Definition of Decision-Making**

Decision-making has been described as a fundamental cognitive process "of human behaviour by which a preferred option or a course of action is chosen from among a set of alternatives" (Wang & Ruhe, 2007). An ABI can diminish a person's ability to make autonomous decisions and it is the responsibility of a person's clinical team to assess decision-making capacity.

2.2 **Legislation Relevant to Decision-Making Capacity**

The rights of people with disabilities to participate in decision-making are clearly stated in the 2006 United Nations (UN) Convention of the Rights of Persons with Disabilities (United Nations, 2006). Article 12 of the convention denotes the right of persons with disabilities to enjoy legal capacity on an equal basis with others in all aspects of life. The convention holds signatory nations responsible for developing measures to provide persons with a disability the access they may require to support in exercising their legal capacity. In the United Kingdom, clinicians apply a legal framework to guide the assessment of an individual's capacity to make decisions (Department of Health, 2005). The Mental Capacity Act , 2005 (MCA) has five statutory principles; a person 1) must be assumed to have capacity unless it is proven otherwise 2) must supported in making a decision by having all practical steps explored to help make that decision 3) must not be treated as lacking capacity on the basis of making unwise decisions 4) must have the decision made in their best interests, if it is deemed they do not currently possess capacity 5) must have the decision made on their behalf which is the least restrictive to their rights, if it is deemed they are currently not capacitous to make a decision.

2.3 **The types of decisions people typically need to make and the cognitive requirements of making them.**

Across the lifespan of a healthy adult, a person is assumed to be capable to autonomously approach a range of decisions from the perceived everyday mundane (e.g., choosing what colour socks to wear) to important decisions with wider implications (e.g., deciding to leave a job). When assessing a person's capacity to make a decision, a clinician will be guided by the MCA, which states capacity to make a decision requires the ability to understand information relevant to the decision, to retain information, to weigh up and use that information to make the decision, and to communicate their wishes. An example of this may be acquiring the consent of a patient to have a surgical intervention; does the person understand the procedure, can they retain that information in order to facilitate a decision, are they able to weigh up the risks of the procedure in relation to the proposed benefits in order to reach a decision, and can they then communicate their wishes.

2.4 **The Neuroanatomical and Cognitive Basis for Decision-Making**

2.4.1 **Models of Decision-Making in Healthy People**

Decision-making has been intensely studied by range of disciplines from cognitive psychology, economics to computer science (Baron, 1994; Kahneman et al, 1982; Lipshitz et al, 2001 & Sterling, 2003). Fellows' (2004) literature review on the cognitive neuroscience of human decision-making offers a synthesis and conceptual framework based on existing literature. Fellows described decision-making to be "like other executive processes, it involves the synthesis of a variety of kinds of information: multimodal sensory inputs, automatic and emotional responses, past associations, and future goals". Fellows identified three component processes of decision-making in a conceptual framework;

1. Identification of options; generating or recognising options and identifying when enough options have been considered, particularly crucial in relatively unstructured situations.
2. Assessing value; considered to be the subjective property of a stimulus dependent on external factors such as the availability of other options, hedonic assessment (liking), reward anticipation, time/delay of said reward, probability and risk of choice, weighing up the value of options with pros and cons.
3. Decision in action; the link between preferences and choices and a response based on value.

Fellows' conceptual model is highly relevant to this service evaluation as it identifies a number of processes that overlap with the MCA framework.

2.4.2 **Neuroanatomy of Decision-Making following Acquired Brain Injury**

Lesion studies have informed understanding of decision-making by exploring how damage related to TBI, stroke, tumour) in the frontal lobes could be associated with strikingly poor decision-making (Eslinger & Damasio, 1985; Harlow, 1999 & Ackerly, 2000). Key neural areas identified to be involved in decision-making are found in highly inter-connected areas of the prefrontal cortex (PFC); the ventromedial frontal lobe (VMPFC), orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (DLPFC) (Stuss & Levine, 2002 & Mesulam, 2003). Influential laboratory studies focused on how participants with PFC damage engage in risky decisions whilst completing a card-based gambling task (Bechara et al, 1994, 1997 & 2005). Referred to as the Iowa Gambling Task (Bechara et al, 1994), participants are required to repeatedly choose from four desks of cards with the goal of winning as much virtual money as possible. Each deck is associated with wins and losses to varying degrees. As healthy control participants progressed through trials they gradually learnt to avoid riskier

decks by choosing the decks with lower stakes, and this learning was thought to be implicit and emotion-based. Participants with VMPFC damage persistently selected the disadvantageous decks compared to controls indicating they failed to use their emotional response to losses to guide their decision-making. These identified cortical areas are closely connected to limbic structures such as the amygdala (Phelps et al, 2004). The amygdala has been shown to be important for decision-making by triggering automatic responses to emotional stimuli, including reward and punishment. Patients with amygdala damage have been shown to lack these automatic responses and therefore are not guided by 'somatic markers', resulting in deficits in decision making (Gupta et al, 2011). However, decision-making does not have to involve risk to pose a challenge. Fellows (2006) found VMPFC damage can fundamentally affect how decisions are made even in the absence of risk, uncertainty, or the need to consider future outcomes.

2.5 **Decision-Making Following Brain Injury**

As discussed previously in relation to the MCA decision-making involves a number of steps. The opportunity will now be taken to discuss the cognitive and emotional domains involved in these steps within a literature evidencing their implication in ABI.

2.5.1 **Executive Functions**

The importance of executive functions in successful adaptive living has been increasingly recognised (Duncan et al, 1996; Perna et al, 2012; Wilson & Betteridge, 2019). Theoretically, executive functions (EFs) are considered responsible for the co-ordination and regulation of other areas of cognitive function, for example those concerned with general mental abilities such as memory, attention, language. Damage to the frontal lobes and their connections may lead to changes in cognition, behaviour and personality. Executive dysfunction can disrupt other cognitive domains important for decision making such as

memory and attention. In order to generate the options for a decision, to then evaluate options, to inform choice a combination of memory and executive functions is required. Frontal lobe damage can also lead to disorganised memory encoding (Rabinowitz & Levin, 2014), increasing the risk a patient could conflate, misremember and misattribute the information informing the basis of a decision.

2.5.2. **Memory and Learning**

As referenced in the MCA, a person must understand and remember information necessary to the decision being made. Stored representations of memory have been shown to influence a person's value-based choices (Biele et al, 2009; Gluth et al, 2015 & Shadlen & Shohamy, 2016). The frontal and temporal lobes and related neural pathways, though not exclusively, are responsible for number of important memory processes. These areas are susceptible to damage in ABI (Wallesch, 2001 & Warren et al, 2009). With ABI there can often be pronounced implications on 'working-memory' (McHugh et al, 2008) the multi-component model of the cognitive system used to simultaneously process and store information over the short term (Baddeley & Hitch, 1974). In a TBI population, Dreer et al (2008) identified that impairment with short-term verbal memory was strongly associated with reduced medical consent capacity at the acute phase of hospitalisation. Dreer and colleagues noted how improvement in the domain of working memory during recovery predicted an individual capacity-making at 6-month follow up compared to acute phase of an ABI.

2.5.3 **Intellectual Functioning**

The concept of 'fluid' and 'crystallised' intelligence are two components of general intelligence identified by Cattell (1971 & 1987). Fluid intelligence encompasses a person's reasoning ability, their ability to generate, manipulate and transform different types of

information (Zaval et al, 2015). Crystallised intelligence refers to the experience-based knowledge a person acquires over the course of a lifetime of environmental interactions (Salthouse, 2004). Research has identified the integral role of intellectual functions and decision-making ability. In healthy adult populations correlations have been demonstrated with decision-making competence and both general intelligence (Bruine de Bruin, 2007) and fluid intelligence (Roman et al, 2019). Skagerlund et al, (2021) argue some researchers believe that as a construct decision-making is so intertwined with general intelligence that individual differences on measures of decision-making competence are just tapping into general intelligence (Blacksmith et al, 2019). A meta-analysis by Königs et al (2016) quantified intellectual impairments in a TBI populations. Severity of the injury and phase of recovery were moderate to strong predictors of full-scale performance and verbal IQ. People with moderate to severe TBI had medium to large impairments in intellectual functioning. Although no one study has focused singularly on the role of impaired intellectual functioning on decision-making in ABI, it makes logical sense that changes in intellectual functioning following ABI contribute to reduced decision-making capacity (i.e. impairing a person's ability to understand information).

2.5.4 **Mood and Emotionally Based Decision-Making**

Research has shown that emotional states such as anxiety and depression, can impede a person's reasoning (Forgas, 1989; Hockey et al, 2000; Hockey et al, 2000; Pham, 2007 & Lerner et al, 2015). Evidence suggests that people make decisions not only by evaluating the consequences and their probability of occurring, but also at a gut or emotional level. In healthy adults, people who meet clinical cut-offs for depression have also been shown to have slowed decision-making over controls (Lawlor et al, 2020). It is important to consider and screen for mood disorders when assessing decision-making capacity. It is not uncommon for people to experience mood and anxiety disorders following ABI (Bowen et al, 1998 & Jorge

et al, 2004). For example, depression occurs in approximately one third of stroke survivors (Towfighi et al, 2016).

2.6 **Assessment of Cognitive Domains Relevant to Decision Making**

Accurate assessment of an individual's challenges related to decision-making is essential to inform rehabilitation care plans. One of the most significant challenges in relation to assessment of decision-making capacity is the ecological assessment executive function.

2.6.1 **Challenges in the Assessment of Executive Function**

Given the central role of EFs in a person's independent functioning, it is crucial that clinicians have valid tools to accurately assess cognitive abilities of people with brain injuries. Accurate estimation of post injury executive functioning can inform future rehabilitation, in the type and level of required support an individual needs, and the degree to which a person may struggle to make everyday decisions. As previously described, it is often the case that people's needs are not sufficiently recognised, resulting in patients not receiving the appropriate support they require (Holloway & Fyson, 2016).

Clinicians and researchers have long reported concerns regarding a lack of ecological validity with the current available tests of executive functions (Teuber, 1964; Mesulam, 1986; Burgess et al, 2000 & 2009). The lack of correspondence between test performance and everyday decision-making has long been recognised and referred to as the 'knowing doing dissociation' and 'the frontal paradox' (Walsh, 1985). Someone with an ABI may well possess the intellectual awareness of some or all of their changes in ability and functioning, whilst even acknowledging compensatory strategies to manage these challenges. However, this knowledge may not manifest itself in naturalistic settings with the decisions they make (Holloway & Fyson, 2016). Different ideas have been suggested to understand the weak relation between everyday ability and tests that typically assess a range of executive

functions. Previous research has highlighted the conditions of 'office based' tests and question whether they can accurately capture the cognitive demands placed on EFs during everyday situations (George & Gilbert, 2018; Worthington, 2019). 'Office-based' tests rarely have any strong emotional component. They also differ from real life in generally having clear rules, involving one task at a time. Burgess (1997) argued that it is difficult to assess EFs using typical neuropsychological tasks because executive operations rely on novelty and lower-order functions and cannot be tested in isolation. Further, Burgess (2009) highlighted how the historical approach of identifying isolated components of cognitive function and attempting to measure them alone rather than in combination with other abilities has been problematic, citing the weak to moderate relationship between tests typically administered and people's everyday behaviour as evidence that new tests are required.

2.7 **Service Evaluation Context**

This service aimed to use this evaluation to help evidence the standard for elements of its comprehensive cognitive assessment in relation to decision-making. The existing guidance on the conduct of complex assessment of decision-making is sparse and too generic (The British Society of Rehabilitation Medicine, 2015). When patients are initially assessed in this inner-city outpatient cognitive rehabilitation service they complete an extensive battery of neuropsychological tests. This battery includes a range of tests of executive function as well as tests examining multiple cognitive processes involved in decision making. Clinicians at this service also complete various rating scales about the patient's likely level of ability in a variety of domains. The assessment of decision-making ability still requires a significant amount of clinical judgement. Burgess et al (2009) stated that at least in principle, rather than the 'office-situation' being the constraining factor, the issue for neuropsychologists is that they only have well-established tools for a fraction of the full range of executive function abilities implicated in decision making. This raises the challenge of treating problems that

one cannot first measure and highlights the need to create new tools as a priority. Therefore, we developed a pilot clinician rated measure of decision-making to see if we can identify tests used by this service which are strongly associated to common clinical concerns with a person's potential challenges in everyday decision-making.

2.8 **Service Evaluation Aims**

This service evaluation aimed to address the following questions, in a sample of patients referred to a service specialising in rehabilitation for people cognitive and/or behavioural disability resulting from acquired brain injury:

- Which model (multi-domain & executive-specific) has the greater associations with everyday decision-making ability measured by the service custom measure?
- Which of the selected tests of executive function used by the service as part of an assessment battery has the most robust associations with everyday decision-making ability as measured by a custom clinician rated measure of a patient's decision-making capacity?
- Does a composite measure of executive tests have a stronger association with everyday decision-making abilities as rated by a custom clinician measure than any single existing test?
- To assess the internal consistency of a pilot custom-clinician measure of decision-making created for this service evaluation.

We used a database of routinely collected data and performed statistical analyses using multivariable linear regression models to identify answers to the above questions. In answering these aims the service will be able to establish the standard of assessment it is achieving. If more is understood about the relationships between the scores from each test and everyday decision-making ability, this could translate to service improvement, for

example by being better able to estimate everyday function in future cases, and/or to refine the service assessment battery to make it faster and more cost-efficient to complete.

3. Method

3.1 **Design**

This project was a retrospective service evaluation. University College London and University College London Hospitals Joint Research Office agreed that it did not meet the definition of research. This service evaluation was registered with the NHS Foundation Trust the outpatient Cognitive Rehabilitation Service was based (REF; AUD1000486; 24/02/2020). An honorary contract with the NHS Trust was obtained for the lead author to extract data into an anonymised database using anonymised neuropsychological test proformas.

3.2 **Service Context**

This evaluation was conducted in a cognitive outpatient service. The service provides specialist neurorehabilitation to patients who require intensive therapy following ABI. Neurological presentations rehabilitated include: TBI, stroke, anoxia, diseases or infections to the brain, tumours and multiple sclerosis. Patients attend an initial interview, then one full day of cognitive testing, followed by four days of assessment as preparation for a bespoke intensive rehabilitation programme ranging in length from weeks to months dependent on the needs of the individual.

3.3 **Sample Characteristics**

3.3.1 **Demographics**

The database sample comprised of forty-two people (29 males 69%, 13 females 31%), with a mean age of 30.40 years (SD 15.17, range 19-78). The group had an average of 14.50 years of education (SD 2.57, range 10-18). Ten people had received a primary-level

education, eleven had obtained A-levels or equivalent, seventeen had degree-level education and four had post-graduate education. Occupational classifications from the Office for National Statistics (ONS) categorised nine people as having engaged in higher managerial and directorial roles, seven in professional roles, five in associate professional occupations, five in skilled trade occupations and two in process, plant and machine operations. An additional five were students and three were unemployed prior to their injuries. Post injury, twenty-seven people were unable to work/unemployed, six were on sick leave, five worked reduced hours or part-time, two had retired, one person had become a full-time parent, one person remained in education. According to ONS ethnicity classifications, twenty-six people were White British, ten were Black/African/Caribbean/Black British, three were Asian/Asian British, three were White Other. Thirty-seven people described English as their native language and five described themselves as having an alternative native language but having fluency in English. To further characterise the sample the English indices of deprivation (Ministry of Housing, Communities & Local Government, 2019) was calculated for each participant. This tool provides a relative measure of deprivation based on a person's locality using seven domains of deprivation: 1) income deprivation 2) employment deprivation 3) education, skills and training deprivation 4) health deprivation and disability 5) crime 6) barriers to housing and services 7) living arrangements. Index decile rankings are scaled: 1 for most deprived to 10 for least deprived. People in this sample had a mean of 5.98 (SD 2.70). The modal decile for the group was 4 (range 1-10, IQR 4.5). Scores on the DMQ within this sample had a mean of 64.21 (SD 29.29, range 5-109).

3.3.2 **Aetiology**

The people included in the database had a diagnosis of acquired brain injury corroborated by neurology reports and had been seen in the service between October 2018 and October 2019. This database included patients with ABI of varied aetiology; eighteen people (42%) had a traumatic brain injury, eleven people (26%) had cerebrovascular disease (twelve strokes and one small vessel disease), six people (14%) had a hypoxic injury second to a cardiac arrest, three people had encephalitis (7%), two people (5%) had a resected brain tumour, one person (2%) had injuries resulting from hydrocephalus and one person (2%) had multiple sclerosis (for more detail see Table 1). The mean duration of the neurological disorder was 24.62 months (SD 45.04, range 1-236).

3.4 **Procedure**

This study used a database created through the extraction of stored test scores of proformas from the routinely administered neuropsychological battery patients completed at an inner-city cognitive rehabilitation service for an assessment. All patients attended a four-day assessment. Prior to their admission they completed an extensive battery of neuropsychological tests. The tests were administered by a trained assistant psychologist and included breaks for patients when appropriate. In some circumstances tests were administered over a number of sessions rather than on a single day, or if a patient had recently completed tests, those test scores were included rather re-administering the test. Personally identifiable data was only viewed by clinicians onsite and patient details were not identifiable to the researcher. The data were securely transferred in anonymous format to UCL servers for the purposes of analysis.

Ratings on the custom clinician measure the ‘Decision Making Questionnaire’ (DMQ) were completed by a Clinical Psychologist in the WOCRS team. Ratings were completed

based on a minimum of four hours of face-to-face contact and four multi-disciplinary team meetings where the patient's assessment was discussed to develop a care-pathway and treatment plan.

3.5 **Measures**

People attending this inner-city cognitive rehabilitation service all completed the following measures:

3.5.1 **Test Battery**

- Test of Memory Malingering (TOMM; Tombaugh, 1996)
- Test of Premorbid Functioning (TOPF; Wechsler, 2011)
- Wechsler Adult Intelligence Scale- Fourth Edition (WAIS-IV; Wechsler, 2008)
- Graded Naming Test (GNT; McKenna & Warrington, 1983)
- Rey-Osterrieth Complex Figure Test (ROCFT; Osterrieth, 1944; Rey, 1941)
- Line orientation subtest of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998)
- Wechsler Memory Scale- Fourth Edition (WMS-IV; Wechsler, 2009)
- Zoo Map and Six Elements Test subtests of the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al, 1997)
- Trail Making Test, Sort Test and Verbal Fluency subtests of the Delis-Kaplan Executive Function System (D-KEFS; Delis et al, 2001)
- Stroop Neuropsychological Screening Test (SNST; Trenerry et al, 1989)
- Patient Health Questionnaire (PHQ-9; Kroenke et al, 2001)
- Generalised Anxiety Disorder Questionnaire (GAD-7; Spitzer et al, 2006)

3.5.2 **Decision-Making Questionnaire (DMQ)**

A review of existing questionnaire measures was completed by the lead researcher to develop a novel measure featuring the component cognitive processes important to decision making for the purposes of this service evaluation. Single items related to processes which might interfere with everyday decision-making (impulsivity, reward responsivity, attention, initiation, insight, mood/motivation) were extracted from multiple measures (7 items) or created specifically for this measure (17 items), for more detail see Table 1 for the development of the scale and Appendix 2 for the questionnaire. Clinician expertise in the service was used in consultation at each stage of the development of the measure. The DMQ consists of twenty-four questions, with each item rated between 0-6, with an overall score out of 144. One item (Q1) was reversed scored. High scores on the DMQ indicate a clinician's concerns regarding a person's decision-making abilities. Scoring was completed by a single psychologist who based their retrospective ratings of the patients based on their memory of prior contact with the patients during the four day assessment phase and previous multi-disciplinary team meetings where the patient's assessment was been discussed.

Table 1

Origins and Development of the Decision-Making Questionnaire (DMQ)

Item number	Origin of item	Original version of item	Revised final version of item
1	'Problem-Solving Inventory' (PSI; Heppner & Peterson, 1982)	Do you have confidence the patient can handle novel problems e.g. when the patient is faced with an unfamiliar problem outside of their routine, or their normal contexts?	They can solve novel problems, i.e. when faced with an unfamiliar problem outside of their routine, or their normal contexts
2	Original item	N/A	They struggle to get started with a task, particularly if it is difficult
3	Original item	Do you have any concerns with this patient's susceptibility to distractions whilst making a decision?	They are susceptible to distraction
4	Original item	Do you believe this patient lacks insight into their cognitive challenge adversely impacting on their ability to make important decisions e.g about their care, finances, relationships?	They lack insight into any cognitive challenges they have
5	'The Moss Attention Rating Scale' (Whyte, Bode & Malec, 2003)	Do you believe the patient is able to detect errors in their own performance?	They are unable to detect errors in their own performance
6	Original item	Do you believe the patient lacks the ability to sustain their attention when making decisions?	They lack the ability to sustain their attention
7	'The Awareness Questionnaire' (Sherer et al, 1998)	How well organised is the patient now as compared to before his/her injury?	They have difficulties with planning and organising

8	Original item	Does the patient struggle to follow through on decisions?	They do not or are inconsistent in the extent to which they follow through on their decisions
9	Original item	N/A	They are able to update their opinions when new information comes to light
10	Original item	N/A	They are able to appreciate more than one perspective on a situation
11	Original item	N/A	They tend to jump to conclusions rather than thinking things through step by step
12	The 'Apathy Evaluation Scale' (Fisk et al, 1994)	S/he is less concerned about her/his problems than s/he should be	They are less troubled about their problems than they should be
13	The 'Fatigue Impact Scale' (Fisk et al, 1994)	I am less motivated to do anything that requires thinking	They do not seem motivated to do things that require effortful thought
14	The 'Fatigue Impact Scale' (Fisk et al, 1994)	Minor difficulties seem like major difficulties	They become overwhelmed when faced with minor decisions
15	Original item	N/A	They avoid making decisions even to their detriment
16	Original item	Do you have any concerns the patient is prone to acting in an impulsive manner?	They are prone to acting in an impulsive manner
17	Original item	N/A	They make decisions that are 'out of character', i.e. not congruent with their reported values, identity or beliefs
18	'The Moss Attentional Rating Scale' (Whyte, Bode & Malec, 2003)	Fails to notice situations affecting current performance	They can recognise when contextual factors (e.g. being tired, hungry, upset) might adversely impact their decision making
19	Original item	N/A	They are overly influenced by other people's opinions (i.e. they are suggestible)

20	Original item	N/A	They are highly influenced by incentives or rewards
21	Original item	N/A	They recognise when they need assistance and/or additional information in order to solve a problem
22	Original item	N/A	They have challenges making minor everyday decisions such as deciding meals, routes and what to wear.
23	Original item	N/A	I have concerns about their ability to make important decisions e.g. about their care, finances, relationships
24	Original item	N/A	I have concerns about their engagement in risky decision making e.g. decision that lead to the increased possibility of physical harm

3.6 **Neuropsychological Measures**

From the neuropsychological battery previously described. The following measures were selected for the analysis:

3.6.1 **Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al, 1996)**

The BADS was designed to assess the skills and demands involved in everyday life, and to predict 'everyday problems arising from the dysexecutive syndrome' (Wilson et al, 1996). This service evaluation used scores on two BADS subsets: Zoo Map 1 (ZM1) and Modified Six Elements Test (SET). Both subsets require planning, problem solving and monitoring of behaviour, but the SET is typically characterised as measuring multitasking and the ZM1 planning (Wilson et al, 1998). In the SET subtest, patients were required to carry out 3 different tasks (geometrical figures to be copied, picture naming and arithmetic), divided into two parts, in a 10-minute time limit whilst adhering to certain rules. On The ZM1 subtest participants were required to show how they would plan a route to visit six out of a possible twelve locations, whilst planning the route they had to adhere to certain rules. The BADS has a high inter-rater reliability (range 0.88- 1.00), and adequate construct validity (63.9%) when compared to other validated executive tests, with the strongest predictor of group membership being the SET (z=4.89, *P*-.027; Norris & Tate, 2000). When Wilson et al (1998) measured the ecological validity of the subtests in the BADS, Zoo Map had the strongest correlation with a measure of executive dysfunction based on informant ratings of everyday behaviour. (-.46).

3.6.2 **Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Kramer 2001)**

The D-KEFS comprised nine tests which have shown to be sensitive to the assessment of executive-function deficits. This evaluation used scores from two subtests relevant to the

processes relied on in decision-making: D-KEFS Sort Test, measured concept-formation and problem solving (verbal/nonverbal) and D-KEFS Verbal Fluency Test (phonemic) measured letter fluency and D-KEFS Verbal Fluency Switching measured category switching. The clinical utility of the D-KEFS has been demonstrated with the criterion validity of the Verbal Fluency subtest in TBI (Jurado et al, 2009 & Anderson et al, 2017) and with the Sort Test in Multiple Sclerosis (Parmenter et al, 2007) and TBI (Heled et al, 2011). The Sort Test required subjects to sort cards according to target rules, including perceptual or non-verbal rules and primarily verbal rules (Delis et al, 2001). Performance was evaluated both in terms of the total number of correct target concepts in the participants sorts as well as the accuracy and level of abstraction of sort descriptions. The Verbal Fluency Test contained three subtests which required verbal response generation with a one-minute time limit. Letter Fluency required verbal generation of words beginning with a certain letter. Category Switching was a single trial requiring the participant to alternate between two different semantic categories.

3.6.3 **Wechsler Adult Intelligence Scale- Fourth Edition (WAIS-IV; Wechsler, 2008)**

The WAIS-IV is comprised of ten core subtests and five supplemental subtests, with the ten core subtests yielding scaled scores that sum to derive the Full-scale IQ. The scale is well established, with good psychometric properties with very high inter-rater reliability (range .90- 1.), and test-retest reliability over a 12-week period (range .70- .90) and correlates highly with the Stanford-Binet intelligence scale (0.88) (Benson et al, 2010). Here, the General Ability Index (GAI) was used to examine reasoning processes relatively distinct from processing speed and working memory. The GAI consists of the Similarities, Vocabulary and Information Subtests for the Verbal Comprehension Index and the Block Design, Matrix Reasoning and Visual Puzzles subtests from the Perceptual Reasoning Index. The index measures skills such as verbal abstraction and inductive reasoning, perceptual problem solving, vocabulary and word knowledge.

3.6.4 **Wechsler Memory Scale- Fourth Edition (WMS-IV; Wechsler, 2009)**

The WMS-IV is comprised of seven subtests measuring different memory functions. The WMS-IV has demonstrated excellent reliability and validity (Wechsler, 2009) and construct validity for individuals with TBI (Carlozzi, Grech & Tulsky, 2013). Here, the Logical Memory subtest was used, a measure of contextual learning and memory, both processes which are evidenced to be important for decision-making. The subtest consisted of three parts: immediate recall, delayed recall and delayed recognition. Participants were immediately required to recall details of two short passages, then after a 20–30-minute delay asked to recall the same passages. Participants are then given a forced choice 'Yes/No' recognition trial regarding the passages.

3.6.5 **Stroop Neuropsychological Screening Test (SNST; Trenerry et al, 1989)**

The SNST is concerned with cognitive interference and inhibitory control. The Stroop paradigm has been shown to be sensitive with neurological conditions associated with executive dysfunction, such as TBI (Larson et al, 2007) and has shown to have satisfactory overall reliability (Strauss et al, 2006). In the Colour-Word Task, the participant was required to view a list of words that are printed in a different colour to the meaning of the word. The participant was then asked to name the ink colour in which the colour names are printed, requiring inhibition of an incorrect response.

3.6.6 **Test of Memory Malingering (TOMM; Tombaugh, 1996)**

The TOMM is a performance validity test which takes the form of a forced-choice visual recognition memory test. The TOMM has been shown to have high sensitivity and specificity for identifying incomplete of invalid performance in TBI (Haber & Fichenberg, 2006; Bauer et al, 2007). The test comprises three trials, however, conventionally a score of 45 or less on Trial 2 is considered to be indicative of an invalid performance (Tombaugh,

1996). At this cut-off, more than 90% of neurologically impaired patients are correctly classified as 'not malingering' (Tombaugh, 1996).

3.7 **Psychological Measures**

3.7.1 **Patient Health Questionnaire (PHQ-9; Kroenke, Spitzer & Williams, 2001) & Generalised Anxiety Disorder Questionnaire (GAD-7; Spitzer et al, 2006)**

The PHQ-9 and GAD-7 are two widely used instruments to screen patients for depression and anxiety. The PHQ-9 items are based on DSM-V criteria and demonstrate sensitivity and specificity to detect depression (Kroenke & Spitzer, 2002). Similarly, the GAD-7 items are based on DSM-IV criteria and have displayed high specificity and sensitivity in the identification of anxiety disorders (Spitzer et al, 2006). Both instruments have been successfully used with individual with neurological disorders (Fann et al, 2005). Fann et al (2005) found the PHQ-9 had a test-retest reliability for total score of r= 0.76 (P <.001) in a TBI population.

3.8 **Statistical analyses**

The planned statistical analyses aimed to: (a) examine which of the existing tests of executive function had the most robust associations with everyday decision-making ability, (b) examine whether a model encompassing multiple cognitive domains had a stronger association with everyday decision-making ability than a model comprised of tests of executive function, (c) examine if a composite measure of selected subtests of the BADS had a stronger association with everyday decision-making abilities than any single existing test, (d) to examine the internal consistency of a clinician rated pilot measure of decision-making.

Multivariable linear regressions were used with total DMQ score as the outcome in two separate analyses.. To increase statistical power both models were limited to six predictor variables. The approach was taken to initially inspect the distributions of raw data for all

predictors and variance estimates. Linearity, homoscedasticity and normality of distribution of the scores and the relationship between the predictors were inspected. Outliers beyond three standard deviations were excluded. Missing data was approached using the 'Exclude cases pairwise' function in SPSS, which excludes a case only if the data is missing for a specific analysis, but the case will still be included in any of the analysis for which that case has the necessary information.

Within the statistical analysis neuropsychological measures of interest were grouped in two models of decision-making:

1) Multi-domain model of decision-making: As evidenced, the decision-making is reliant on a number of interlinked cognitive processes. This model included measures of intellect (WAIS General Ability), memory (WMS-IV Logical Memory) and executive function (DKEFS Phonemic Verbal Fluency, DKEFS Sort Test, Stroop Trial B and a BADS Composite) The BADS composite used scores two subtests which are conceptually linked and equally weighted: ZM1 and the SET.

   Executive-specific model of decision-making: As evidenced, executive functions are considered to be a crucial component of decision-making. This model will examine the following measures: ZM1, SET, Stroop Trial B, DKEFS Sort Test Free Sorting, DKEFS Phonemic Verbal Fluency and DKEFS Verbal fluency Switching.

3.8.1 **Sensitivity Analysis**

This was an existing data set therefore a sensitivity analysis was conducted using the computer software package 'G-Power' (Faul et al, 2007), specifying alpha at 5% and power

at 80%. Using 6 predictor variables a resulting minimum detectable F^2 effect size of 0.386 was calculated in the sample size parameters of 42 participants.

4. Results

4.1 **Sample Characteristics**

4.1.1 **Depression and Anxiety Scores.**

Thirty-nine people completed measures of depression and anxiety; three sets of data were missing. The mean score on the PHQ-9 was 9.72 (SD 6.13, range 1-24) and the mean score on the GAD-7 was 7.10 (SD 5.6, range 0-20). See table 2 for the distribution of scores in clinical classifications.

Table 2

PHQ-9 and GAD-7 patient scores

PHQ-9 Symptom Classification	*N Patients*	*GAD-7 Symptom Classification*	*N Patients*
None	9	None	19
Mild	12	Mild	12
Moderate	9	Moderate	5
Moderately Severe	6	Severe	3
Severe	3		

4.1.2 **Performance Validity Measures**

Forty people completed the TOMM of which thirty-six scored above the second trial cut off and provided a performance considered to be effortful. Four people scored below the cut-off providing a performance indicative of a suboptimal effort. Two patients did not complete the TOMM, one as they were registered blind, and one for unclear reasons.

4.2 **Preliminary Analyses**

4.2.1 **Internal Consistency of the Decision-Making Questionnaire**

Internal consistency assesses the degree to which items on a test are interrelated (Tavakol & Dennick, 2011). Internal consistency was measured using Cronbach's alpha. Alpha varies from 0 to 1, high alpha values indicate a high degree of interrelatedness among items on a test. The DMQ displayed a good internal consistency, the Cronbach alpha coefficient was .94. As the scale was in development an examination of individual items was conducted. The corrected item- total correlation table was examined; this gives an indication of the degree to which each item correlates with the total measure. Low values (less than .3) indicate that an item may be measuring something different from the scale as a whole (Pallant, 2020). Items, Q14 (.19), Q.15 (.22) and Q19 (.27) were identified to be below threshold, therefore the impact of removing each item on the scale was examined. Results noted a marginal increase in the Cronbach alpha coefficient to .95 for each item respectively. This marginal increase was not deemed sufficient to remove the items from the scale due to the value these questions were subjectively thought to provide, alongside the preliminary and service specific nature of the scale. Q14 & Q15 explore emotional factors in decision making, Q19 assesses interpersonal factors in decision-making. We know that these factors are important to decision-making, and they are not considered elsewhere in the measure.

4.2.2 **Distribution of Scores on the Decision-Making Questionnaire**

The normality of the distribution of the scores on the total DMQ score was assessed using the Kolmogorov-Smirnov statistic. A non-significant result was obtained (.20) indicating normality in the distribution of scores. The DMQ had a total score of 144, this evaluation had a mean score of 64.21 (range 5- 109, SD 29.29). No items were scored with 'n/a', therefore total scores were used, otherwise a proportionate score would have been calculated.

4.3 **Primary Analyses**

4.3.1 **First Linear Regression: Using a Multi-Domain Model of Decision-Making**

A multivariable linear regression was performed with the total DMQ score as the outcome and a multi-domain model of decision making with the following six predictors: WAIS General Ability Index Score, WMS-IV Logical Memory 1 Standard Score, DKEFS Phonemic Verbal Fluency Standard Score, DKEFS Sort Test Free Sorting Correct Sorts Standard Score, Stroop Trial B Percentile and a BADS Composite (ZM1 Overall Standardised Score and SET Overall Score).Table 3 displays the correlations between variables, the unstandardised regression coefficients (β) and *R* (.740), R^2 (.547) and R^2 adjusted (.404). *R2* for the regression model was significantly different from zero, $F(6,19) = 3.830$, $p < 0.1$.

Table 3

Linear Regression Analysis Summary Predicting Total Score on the DMQ Using a Multi-Domain Model of Decision-Making

Variable	*B*	*SE B*	*Beta*	*T*	*Sig.*
Constant	137.44	22.43	-	-	-
BADS Composite	-2.47	2.30	-.26	-1.08	.296
WAIS GAI (IS)	-.25	.368	-.19	-.69	.500
WMS-IV Logical Memory 1 (SS)	-.41	1.48	-.06	-.28	.526
DKEFS Verbal Fluency Phonemic (SS)	-2.45	1.61	-.34	-1.52	.144
DKEFS ST Free Sorting Correct Sorts (SS)	-1.02	1.48	-.137	-.69	.502
Stroop Trial B (Percentile)	-.05	.16	-.07	.34	.38

Note: *IS= Index score, SS= Standardised Score*

Using a conservative estimate (R^2 adjusted) due to the small sample size, altogether 40.4% of variability in the DMQ total score was predicted by the six predictors. No single predictor coefficient made a uniquely significant contribution to the model. The DKEFS

Verbal fluency test (*R*= -.62) produced the largest correlation followed by the BADS composite (*R*= -.592), the WAIS GAI (*R*= -.592), WMS-IV Logical memory (*R*= -.526), DKEFS Sort Test (*R*=-.511) & Stroop Trial B (*R*= -.380). Table 4 reports all correlations in the analyses.

Table 4

Correlation Table Reporting the Two Separate Regression Analyses of Models of Decision-Making

		Multi-Domain Model of DM	Executive Specific Model of DM
Variable	*N*	*R*	*R*
BADS Composite	37	-.592	
WAIS GAI (IS)	31	-.592	
WMS-IV Logical Memory 1 (SS)	40	-526	
DKEFS Verbal Fluency Phonemic (SS)	40	-.623	-.623
DKEFS Sort Test Free Sorting Correct Sorts (SS)	40	-.511	-.511
Stroop Trial B (%ILE)	33	-.38	-.38
BADS Zoo Map 1 Overall Score (SS)	38		-.667
BADS Six Elements Overall (SS)	38		-.275
DKEFS Verbal Fluency Switching (SS)	40		-.638

Notes: *IS= Index Score; SS= Standardised Score; %ILE= Percentile*

4.3.2 **Second linear regression; Using an Executive-Specific Model of Decision-Making**

A multivariable linear regression was performed between total DMQ score as the outcome and an executive-specific model of decision-making, with the following six scores as predictors: ZM1 Overall Standardised Score; SET Overall Standardised Score; Stroop Trial B Percentile; DKEFS Sort Test Free Sorting Correct Standard Score; DKEFS Phonemic

Verbal Fluency Standard Score; DKEFS Verbal fluency Switching. Table 5 displays the correlations between variables, the unstandardised regression coefficients (β) and *R* (.814), R^2 (.662) and R^2 adjusted (.581). *R2* for the regression model was significantly different from zero, F (6,25)= 8.154, p <0.001.

Using a conservative estimate (R^2 adjusted) due to the small sample size, altogether 58.1% of variability in the DMQ total score was predicted by the six predictors. ZM1 was the only predictor to contribute significantly to prediction of the DMQ total score (β=.501, R^2=.-667, p <.001). ZM1 had the most robust association with the DMQ total score, with the DKEFS subtest scores also showing a strong association; Verbal Fluency Switching (*R*=.638), Phonemic Verbal Fluency (*R*=-623) and the Sort Test (*R*=-0.511). The SET overall score had the smallest association with the DMQ total score (*R*=.-275).

Table 5

Linear Regression Analysis Summary Predicting Total Score on the DMQ Using an Executive-Specific Model of Decision-Making

Variable	*B*	*SE B*	*Beta*	*T*	*Sig.*
Constant	127.19	11.68	-	-	-
BADS Zoo Map 1 (ZM1) (Overall SS)	-6.6	1.85	-.46	-3.58	.001*
BADS Modified Six Elements (Overall SS)	.39	1.97	.026	.198	.845
DKEFS Sort Test- Free Sorting Correct (SS)	-.607	1.125	-.082	-.539	.595
DKEFS Verbal Fluency Phonemic (SS)	-1.168	1.45	-.161	-.801	.430
DKEFS Verbal Fluency Switching (SS)	-2.127	1.25	-.308	-1.696	.102
Stroop Trial B (SET) (%ILE)	-.046	.108	-.059	-0.421	.677

Notes: *SS= Standardised Score; %ILE= Percentile*

5. Discussion

5.1 **Summary of Findings**

This project aimed to evaluate routinely administered tests to assess decision-making following an ABI. To achieve this goal, an anonymised sample of scores from patients who previously completed a neuropsychological assessment battery were analysed. Scores on existing validated neuropsychological measures were grouped into two theoretical models of decision-making. Results indicated a model using tests of executive function explained more of the variance in overall scores on a clinician rated measure of everyday decision-making after ABI, than a model using tests which measured a broader array of cognitive functions. This indicates the importance of focusing on tests of executive function in the assessment of decision-making in people with ABI. Of the existing tests of executive functions, three tests; ZM1 (*R*= .667), D-KEFS Verbal Fluency Switching (*R*= .638) and D-KFES Verbal Fluency Phonemic (*R*= .623) showed the strongest relationship with the overall DMQ score. Despite the overall significance of each model in predicting scores on the DMQ, no variables other than ZM1 individually made a statistically significant unique contribution to the prediction of the DMQ. A composite variable including two related measures of planning and multi-tasking from the same battery of executive function tests did not have a stronger association with everyday decision-making ability than any single existing test.

5.2 **Relating the Findings to the Literature**

In this section, the findings are discussed in relation to the models of decision-making and the literature evidencing the impact of ABI on cognitive processes responsible for everyday decision-making.

5.2.1 **The Results in Relation to a Multi-Domain Model of Decision Making**

To date particular attention has been paid in the literature to the role executive functions in everyday decision-making, despite the evidence of the importance of cognitive functions such as general intelligence (Bruine de Bruin et al, 2007) and memory (Del Missier et al, 2013). The implications on cortical areas responsible for these processes in ABI is well-established (Rabinowitz & Levin, 2014). Therefore, a logical hypothesis is that impairment resulting from ABI in these functions will result in impaired decision-making. The multi-cognitive domain model of decision-making predicted a moderate 40.4% of the variance of total scores on the DMQ. Both the WAIS-IV GAI and WMS Logical Memory subscales had moderate associations with the DMQ, along with tests of executive function. These results suggest we can attribute these tests with some overall explanation of the DMQ scores. The WAIS-IV GAI incorporates subtests from both verbal and perceptual subtests, both conceptually related to the generation and identification of options in Fellows' (2004) theoretical model of decision-making, and the understanding of information criteria in the MCA. The WMS Logical Memory can be conceptually linked to Fellows' model of assessing the value of options over a time delay, and the MCA, in relation to being able to retain the information. The two delayed time points (immediate and delayed) and different forms in which memory was accessed (recall and recognition) may represent some of the varied demands placed on the role of memory in everyday decision-making.

These results suggest the stronger predictor of everyday decision-making following ABI is not one which takes into broad account of an array of cognitive functions. Despite the model being associated with score on the DMQ, it is somewhat surprising the degree of the association was not stronger. One explanation could potentially lie with the ecological validity of individual tasks. With memory for example, the nature of the tasks might not represent the conditions which place demands on component processes such as working memory in in everyday decision-making. For example, Del Misser et al (2012 & 2013) stated

that working memory processes appear to be less involved in decision-making when the decision can be carried out by using simple strategies. Although participants with severe memory impairments will likely have a low threshold for failing on a memory task, it could that people with moderate to mild impairments will perhaps not have a significant enough load placed upon their working-memory due to the nature (use of structure) of the tests.

5.2.2 **The Results in Relation to an Executive-Specific Model of Decision Making**

A model using tests of executive functioning predicted 58.1% of the variance of final scores on the DMQ. These results suggests that executive functions play more prominent role in everyday decision-making than other cognitive component processes combined following ABI. This may be explained by the nature and mechanisms of injury in ABI, especially TBI, which half of this sample had experienced, and the common implications to the frontal lobes (Levin & Kraus, 1994). Skagerlund et al (2021) described superior decision-making competence is supported "by a complex orchestration" incorporating and general oversight of other domains. Incorporating Skagerlund's language into a metaphor, it may that handicapping the conductor of an orchestra is likely to have more detrimental effect on its output than implicating any one component part.

Of the tests of executive function one subtest of the BADS (ZM1) made a unique statistical contribution to the prediction of overall scores on the DMQ. This subtest examined specific abilities grouped under executive functions highly related to problems in everyday decision-making. The ZM1 is designed to assess planning ability, which is understood as the ability to identify and organise steps required to meet a goal (Lezak, et al, 2004). The evidence for the validity of the Zoo Map Test is mixed, Norris and Tate (2000), Bennet et al (2005) and Wood and Liossi (2006) found no significant correlations between Zoo Map and other measures of executive function. However, Wilson et al (1998), Knight et al (2002)

provide evidence for the test validity along with Oosterman et al (2013) who found Zoo Map was significant predictor of planning performance when other cognitive domains (working-memory and processing speed) were controlled. The ABI populations in both Wilson & Knight's studies respectively were representative the sample in this evaluation. Despite the bulk of the population of the Oosternman's study being representative of this sample (i.e. TBI, stroke, tumour) it did contain progressive neurological conditions (Parkinson's disease, Alzheimer's disease) and psychiatric disorders (e.g., major depression and anxiety) not in this sample. Therefore, with a lack of conclusive evidence, we can only tentatively say BADS Zoo Map is a valid measure of planning ability in this sample.

Interestingly, the relationship between the overall DMQ score and the SET was non-significant and weak. This is curious as the SET has been shown to predict problems with planning and goal-directed behaviour (Burgess et al, 1998 & Alderman et al, 2003) and has been found to be one of the most sensitive subtests of the BADS battery (Burges et al, 1998; Bennett et al, 2005; Bertens et al, 2015). Although the evidence does not relate directly to everyday decision-making ability, it does suggest ecological validity for this test in the measurement of executive functions, which as discussed is shown to be strongly related to decision-making. The results of this evaluation could demonstrate that opposed to ZM1 which is considered to measure planning ability, The SET taps into wider multitasking abilities (working memory, rule learning, strategy application and response) which combined are less relevant to everyday decision-making ability following ABI. Results suggest The Stroop Test, considered to be a measure of selective attention and response inhibition may also have less of an influence on challenges with everyday decision making following an ABI. However, response inhibition is associated with frontal-subcortical areas that are frequently damaged after a TBI (Levin & Kraus, 1994), and therefore we would expect people with this type of damage to show high levels of impulsivity and response inhibition,

both of which have been identified to result in costly decision-making (Bechara & Van Der Linden, 2005 & Rochat et al, 2013). The Stroop may provide a neutral condition which does not illicit an emotionally salient response reflective of challenging everyday decision making, in line with Bechara and Damasio's (2005) 'Somatic Market Hypothesis'. The central feature of the theory states that emotion-related markers influence cognitive processes which influence decisions and bias behaviour in ways a person might not be aware of. The inclusion of a test such as the Iowa gambling task as mentioned in the introduction, may have provided a more ecologically valid examination of the influence of inhibition in everyday decision-making.

5.3 **The Development of a Pilot Measure of Decision-Making**

This service evaluation developed a clinician rated measure of decision-making to see which model of decision-making and executive tests have the most robust associations with everyday decision-making. It is recognised that the assessment of decision-making following ABI requires a significant amount of clinical judgement (George and Gilbert, 2018). The inclusion of clinical knowledge in creating new items on a pilot measure, plus the adaption of existing items from measures related to decision-making created a measure which provided informative results for this evaluation. The high internal consistency of the measure allows some confidence that the construct being broadly measured was everyday decision-making, therefore relationships measured between the DMQ and the battery of tests have clinical utility.

5.4 **The Service Standard in Relation to Clinical Guidelines**

Consideration will now be made in respect to the standard this service is currently achieving in the assessment of decision-making in respect to relevant clinical guidelines before the general limitations and practical application of the results are discussed.

5.4.1 **Service Standards**

A challenge faced in this evaluation was the lack of relevant existing clinical guidelines and standards for the assessment of cognition in ABI. In fact, there are no existing specific guidelines that provide standards for assessment of decision-making. Standards quoted are generic, and by virtue of assessing cognition for severe ABI this service already achieves the generic standard outline by the BSRM (2015). As discussed, these results evidence significant associations with a measure of everyday decision-making across both groupings of tests used in the comprehensive assessment battery in the service. Therefore, this provides evidence to support that these measures are 'valid, reliable, and extensive' (Nice, 2013). Subsequently we can say the assessment measures included in this evaluation and employed by the service are providing a high standard of assessment of functions important to decision-making. In addition, these results are also able to support the use of these measures within a TBI population, where existing standards do not exist.

However, as previously outlined there have long been questions regarding a lack of ecological validity with the current available tests of executive functions (Teuber, 1964; Mesulam, 1986; Burgess et al, 2000 & 2009). Indeed, two executive function tests evaluated (SET and Stroop) have shown a low association with everyday decision-making. However, when grouped together in an executive battery they contributed to a significant relationship with everyday decision-making, thus further providing evidence that current assessment tools used by the service have an adequate level of validity, reliability and responsivity thereby meeting clinical standards. However, the results of this evaluation require scrutiny before the practical applications of the results which aimed to improve clinical practice can be discussed.

5.4.2 **Limitations**

A number of limitations of this evaluation will now be discussed, all of which suggest caution is required in relation to this service adopting these results to inform the refinement of its assessment battery. The development of the DMQ lacked a number of steps that would have been considered in a broader research project as outlined by Boateng et al (2018) for the validation of psychometric scales. For example, in the scale development no pre-testing of questions, sampling or surveying was completed. A larger sample size would have allowed an exploratory factor analysis of the DMQ to be completed (de Winter et al, 2009). One clinical psychologist rated 42 people they had assessed in a specialist interdisciplinary team assessment. The psychologist who completed the ratings of the DMQ was not blinded to patient performance on the cognitive measures. It is reasonable to believe additional raters would have reduced potential biasing which is likely to appear when results are based on one clinician rating. In addition, scoring of the DMQ was retrospective and purely based on clinician memory of the patients. This is likely to have resulted in less-than-optimal accuracy of the clinician rating of patient challenges everyday decision-making. Considerations are required in the service as to whether further development and validation of the DMQ is warranted to improve the robustness of future results.

In addition, this evaluation only identified one measure to be a predictor of outcome. But it may be the case there are other individual predictors which genuinely are significantly associated with the overall score on the DMQ, however the statistical power delivered by this sample resulted in significance being undetected. Therefore, we are unable to say there are no other significant predictors with great confidence. A larger sample with increased statistical power to identify other potential predictors would be advisable before decisions are made for the refinement of the service assessment battery.

The type of overall scores used in analysis should also be considered. Where possible the standardised score of a test was analysed, with the benefit of seeking to reduce multicollinearity (Shrestha, 2020). However, when scaled scores are applied, it could be argued that rather than the persons score on the test predicting the overall score on the DMQ, it is the differences from the average performance of that person's age that is predicting the relationship with the DMQ. A future alternative approach to analysing this secondary data to inform service improvement could involve using raw scores and age as a predictor variable.

5.4.3 **Practical Applications**

This evaluation aimed to increase the understanding between test scores and everyday decision making. The aim was to translate this understanding into suggested improvements in clinical practice thus improving the standard the service provides for the assessment of decision-making. Results identified ZM1 to have the most robust association with everyday day-decision making ability. This evaluation therefore provides preliminary evidence that any abbreviated battery should retain this measure. More broadly ZM1 has been shown to be strongly associated with planning abilities, therefore clinicians in the service should pay particular attention to this domain in their assessments. Along with the ZM1, these results suggest clinicians should consider the value of using the letter fluency and category switching subtests from the D-KEFS as part of their assessment. This service evaluation found a weak relationship with the DMQ overall score and the SET and Trenerry Stroop, the usefulness of both tests should be considered by clinicians in their assessment, and caution is advised for their use within an abbreviated battery. The tests selected for the service assessment battery may not contain an ecologically valid measure of selective attention and response inhibition. This evaluation proposes trialling the use of the Iowa gambling task in replacement for the Trenerry Stroop to improve clinical practice. At a group level, tests of executive function were evidenced to be more useful in an assessment of decision-making than those from

broader cognitive domains. Though at the individual level in clinical practice a broader assessment is still likely necessary. This is due to the heterogeneity of cognitive presentations following ABI and the requirements of assessing domains such as memory and intellect for the MCA. Overall, these preliminary results increase provide evidence for the potential refinement of the selection of tests used in the assessment battery which could translate to improvement in clinical practice (i.e., selecting tests for abbreviated assessment battery), and lead to improved estimations of everyday function in future cases.

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Part Three

Critical Appraisal

This project has been conducted in a challenging context. This backdrop irrevocably changed this research project from its original genesis. For this reason, I shall present this critical appraisal in a manner that takes a chronological perspective towards the development, challenges and learnings in this body of work.

1.1 **The Beginnings of this Project: My Motivation and Identifying a Focus for Research**

Both elements of this thesis were informed by my clinical experience. Prior to embarking on a clinical psychology doctorate my experience had been based within a neuropsychological rehabilitation unit for people with acquired brain injury (ABI). I was part of a multi-disciplinary team applying a holistic model of neuropsychological rehabilitation to service users who had experienced an ABI. The centre used a biopsychosocial model for assessment and formulation in clinical intervention, and for the planning of care provision (Wilson et al, 2009). Patients were seen in an outpatient setting, attending the specialist centre for intensive neuropsychological rehabilitation programme, then followed by integration phase where they were supported to generalise strategies within community settings.

It was during this time I first became aware of the challenges faced by clinicians in accurately assessing a person's cognitive function in part due to concerns around the ecological validity of routinely administered tests of executive function (Burgess et al, 1998). I experienced first-hand how some patients with ABI performed well in interview and test settings, despite notable impairments in everyday life functioning and became interested in the literature around the 'knowing and doing association' (Teuber, 1964) otherwise known as the 'frontal lobe paradox' (Walsh, 1985). The literature suggests tests, their method of administration and the setting in which they are administered may introduce sufficient external structure to suppress some of the behavioural and cognitive challenges observed in

naturalistic settings (Burgess et al, 2009). This was concordant with some of my own experience in the administration of neuropsychological tests within a structured 'office-based' environment setting. Furthermore, I saw how establishing an accurate picture of someone's decision-making ability was essential for clinicians within the framework of the Mental Capacity Act (MCA). This installed an interest to examine the utility of both commonly used tests, and those not commonly used in the assessment of executive functions and decision-making, to further progress the evidence-base with a hope it would benefit clinical practice.

I also gained experience of applying evidence-based interventions for people with memory impairments. I was able to support profoundly amnesic patients to learn to use external memory aids through applying the principles of 'Errorless learning' (EL; Wilson et al, 1994). This was a defining moment in my early career, which shaped both my research interests and desire to continue working in the field following training. I was both intrigued and impressed to see how applying these principles were able to support profoundly amnesic individuals learn new skills. Often it would be the case that the individuals I extensively worked with over a substantial period had no explicit recollection of our sessions, however held the implicit knowledge gained from the content of the sessions and were able to achieve goals around increasing independence and reducing their distress in relation to their memory impairment. Running these sessions helped me to appreciate elements that facilitated learning: therapist patient rapport, a sense of mastery and the working toward meaningful individualised goals. However, I was aware of the limitations in the evidence-base around the use of errorless learning, evidenced by the fact there existing only one systematic review and meta-analysis on the technique (Kessels & de Haan, 2003). I also noted how as a clinician, after referring to the evidence-base I was unable to identify which patient group might receive the most benefit from EL. My aim for the meta-analysis and systematic review was to

contribute to the understanding of EL and to provide clinicians with more direction in its use by examining its utility within ABI.

1.2 **The Original Project and Changes and Changes Resulting from COVID-19**

The empirical element of this project changed because of the COVID-19 pandemic. The challenges and uncertainty arising from the pandemic fundamentally impacted the outpatient service I had intended to recruit from. This was a microcosm of the wider challenges faced by the NHS within clinical research more generally during this period (Iacobucci, 2020). The planned original empirical project was a single site interventional study aimed at identifying processes that might interfere with everyday decision-making processes, and to incorporate these into a test battery. I aimed to recruit 29 participants with ABI to the pilot study in order to achieve sufficient statistical power. It was planned participants would complete an hour and a half session and be administered a brief battery of cognitive tests. The battery of cognitive tests selected to be used were theoretically driven tests not commonly used in clinical practice. These tests targeted processes that can interfere with everyday decision-making, including emotional factors (drive/reward), presence of distractions, use of cognitive heuristics (mental problem-solving shortcuts), integration of different cognitive functions, and lack of awareness of cognitive deficits. The aim was to identify which tests would be most useful to incorporate into a test battery to improve the ecological validity of the assessment of decision-making.

The study in its original form required NHS ethics approval. In gaining ethical approval, came to I appreciate how much a of scrutinous and involved a process acquiring NHS ethical approval was, certainly with a cost in terms of a time commitment. Protecting the rights of research patients through ethical legislation such as The Declaration of Helsinki is of course paramount to the process of clinical research. Importantly so, because within the

field of neuropsychology we work with patients who are to all intent and purposes highly vulnerable due to their neurological limitations (i.e., lack of insight, memory and information processing difficulties). However, Janasari et al (2015) suggested that "neuropsychologists have been saddled with working in a system that is largely irrelevant and unnecessary" since most of the research activity in the field is non-invasive and consists of behavioural studies with paper-and-pencil tasks, where there is a negligible risk to patients. They believed the current NHS ethical system acts as a disincentive to clinicians engaging in research which they are passionate about, due to the required elaborate justification of the minutia of non-relevant details within a proposed study. They argued the NHS ethical process in its current guise protracts the research process and slows scientific progression and possibly does not even lead to safer outcomes. As a clinician in the early stages of my career, I do understand the argument Janasari and colleagues are making. I believe establishing protected research time in a clinical role can be challenging and a significant proportion of that limited time could be consumed by the NHS ethical process. However, I did find immense value in going through the process, and it supported the rigorous development of the methodology of the study. Had the study run, I believe the thought and consideration given in its conception resulting from the NHS ethics process would have provided fertile ground for robust results. Overall, it gave me an idea of the practical application of research within the NHS and the practical demands placed on the 'practitioner-scientist' role that I aim to embody throughout my career.

By far the most significant challenge throughout this thesis was the loss of interventional arm to the project. Over a short amount of time it became clear that the interventional arm of the project would not be able to commence. Local NHS research offices placed a halt on all active research, bar Covid-19 related research. In addition, the service I intended to recruit from stopped seeing outpatients for an indeterminant amount of time.

Therefore, in discussion with my project supervisors, the interventional arm of this project was removed. I found this a tremendously challenging loss to navigate. Partly because of the large amount of work I had lost, including the NHS ethics application, but also because it was in a context of wider losses, both on training and in my personal life resulting from the pandemic. Within hindsight, this loss perhaps has prepared me for the fact there are no guarantees in research, for example it is all too common to have grant bids rejected. I was able to learn from my supervisors who calmly and skilfully supported me to renavigate towards another project feasible for the circumstances and importantly still offering potentially informative insights to researchers and clinicians in the field of neuropsychology. In lieu of an interventional arm to the study, it was decided that alongside the meta-analysis and systematic review the focus of the empirical paper would be a service-evaluation, analysing routinely collected data.

1.3 **Reflections on Conducting a Systematic Review and Meta-Analysis**

I had not conducted a systematic review or a meta-analysis before. The process of completing both involved a significant learning curve. Exploring the literature and endeavouring to cover all the correct search terms and combinations was a challenge, especially in a literature which was heterogeneous in its terms for both the name of the intervention, but also the patient group, the target material, the method of delivery and length of delay before measurement in intervention groups. To manage this heterogeneity, I found it important to have clear research questions which helped contained the scope of the review and enabled me to have a clear inclusion and exclusion criteria. The PICO tool (Richardson et al, 1995) helped formulate this research question by breaking it into four parts: patient or the problem to be addressed, the intervention or exposure, the comparison or intervention of exposure, the clinical outcome of interest, and the study type to be included. Placing this structure upon the research question helped develop my search strategy. However, I was

conscious of implementing a tool where there had been very little evidence assessing the effect of using the PICO method versus other available models or unguided searching on the quality of the literature search results (Eriksen & Frandsen, 2018). Frandsen et al 2020 also suggest not to search for outcomes due to a low retrieval of results from major databases. The outcome search in this review did not impact the number of retrieved studies, and instead offered a helpful refinement of important papers in the field of EL.

As previously described, I embarked on this project having experienced the advantageous clinical use of EL. I was aware of important issues that this review was not able to examine. These issues were outlined by Clare and Jones (2008) in their critical review identifying the need for further research examining the longevity and the generalisability of the acquired knowledge gained from EL. Issues which are important and deserving of their own systematic review and meta-analysis. Conducting a systematic review also provides an opportunity to note gaps in the literature. Due to approaching this research from a scientist practitioner position, I became aware of limited reports of patient experience within the EL conditions. Understanding and using patient and caregiver experience is known to help contextualise the reported effects of a treatment (Rand et al, 2019).

In respect to my own learning and development of research skills this was the first time I was confronted by and attempted to take stock of the issue of bias in research. I recognise that I carried my own bias into this research endeavour. I was unsurprised to the observe the strong initial effect-sizes reported from this meta-analysis. It chimed with my own clinical experience of using EL. However, my own biases were challenged when exploring potential publication bias as recommended by the PRISMA statement for reporting systematic reviews and meta-analyses (Liberati et al, 2009). By conducting multiple Egger's tests of asymmetry, I was able to view the presence of potential bias in the studies included in this analysis which undoubtedly moderated the potential conclusions which could be drawn

from the results. Sedgwick (2015) stated that publication bias can result from the publication or non-publication of relevant trails dependent on the nature and the direction of the results. Publication bias may result from non-significant results from studies not being included in the meta-analysis because they were not published in the first place, due to a favouring of significant results for publication. Although identified within this body of neuropsychological literature, it is true that it is a substantial problem for the credibility of research and meta-analyses in general (Van Art et al, 2019). Although we can only postulate what we are seeing is 'potential' publication bias, as there is currently no method to examine the issue which provides a definitive answer. To this authors knowledge, there are to date no studies reviewing the prevalence of publication bias within the field of neuropsychology. From the proposed sources of publication bias made by Egger at al (1997) there are some reasons which appear relevant to this literature, beyond the already identified favouring of statistically significant results. Egger and colleagues proposed one of the causes prosed asymmetry in funnel plots was true heterogeneity, in particular the size of effects differing according to study size and intensity of intervention. The studies within the meta-analysis ranged greatly in both the number of participants per interventional arm but also in the intensity of the EL intervention with some interventions lasting weeks to other participants only having a limited number of sessions. An alternative theory may be that these results evidence true effect-sizes. To bring credibility to this proposal the methodology of the studies need to be robust. It is certainly the case that in some of the smaller conceptual studies, rigorous approaches to methodology were taken, however the systematic review evidenced that there was a notable range of quality in study methodology.

1.4 **Reflections on Conducting a Service Evaluation**

Conducting a service evaluation provided another learning curve. This is my first experience of using anonymised existing data. The results of this project were able to provide

clinically useful information in relation to the standard the service was providing and recommendations for improvement of clinical practice. However, in its preliminary design the evaluation had methodological weaknesses. Also, compromises were made to balance the requests and needs of the service with the rigour of the analysis. Thoughts around using this data and addressing challenges which arose will now be made.

Since I had not collected the existing data used in the analysis, it was important for me to become familiar with the dataset. I targeted familiarisation with the original data collection processes, in terms of the understanding the population assessed, the length of the assessment sessions, which tests were used and what questions did they serve to answer. Speaking to clinicians in the service helped me understand the rationale behind the assessment and how the results informed rehabilitation and care planning. I was also able to draw on my own expertise in this area, having administered all these tests in other services and being familiar with the score profiles and what they indicate. Hox and Boeije (2005) outline some of the known advantages and disadvantages to secondary data use. Of note the authors highlight the importance of closely evaluating the quality of the existing data. This data set was collected by a service that used trained and skilled staff to administer valid and established measures in a standardised manner. In addition, the service applied the Test of Memory Malingering (TOMM: Tombaugh, 1996) which provided important information about the validity of participant performance. It is reasonable to assume that the dataset was of a high standard. However, as a researcher using existing data, I will never exactly how well the data collection was executed.

Balancing the rigors of the analysis with aims and requests of the service was at times challenging. One issue I faced was in response to the number of predictors used in the multivariable linear regression. Given the sample size and having completed a sensitivity analysis I was aware that including six predictors reduced the statistical power of the each of

the group analyses. This was something that I broached with the service who decided they wanted the analyses to approximate the clinical assessment more broadly, therefore they required a larger number of predictor variables and accepted the limitations of the statistical power contained within a model of six predictors.

In addition, there were challenges in identifying suitable clinical guidelines from which to reference the service standard against. Although not essential to a service evaluation (Health Research Authority, 2017) using relevant guidelines is a helpful benchmark to evaluate the standard the service delivered to patients. The service was a specialist cognitive rehabilitation unit and the most relevant existing standards (National Institute for Health and Care Excellence, 2013 & British Society for Rehabilitation Medicine, 2015) could be broadly applied to the service, but lacked specificity, especially within the realm of the cognitive assessment of decision-making. The lack of clinical guidelines for cognitive assessment in traumatic brain injury (TBI) population also provided a strong rationale for the service to evaluate and evidence the standard of selected tests from their battery.

1.5 **Conclusions of the work**

This thesis was the result of nearly three years of work conducted during an extremely challenging context. While the finished product is significantly different to what I had envisaged and planned for in early 2019, I have found both elements of this thesis extremely interesting. I believe that through producing both elements of this project I have developed advanced skills in the evaluation research, and how to conduct a service evaluation drawing on existing literature to support the improvement clinical standards. I hope the work presented here can provide researchers and clinicians with helpful direction and insights around aspects of the assessment and intervention of memory and executive functions, upon which to inform their clinical practice.

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Appendix

Appendix 1

Kmet (2004) Quality Appraisal Tool for Quantitative Studies

Criteria		YES (2)	PARTIAL (1)	NO (0)	N/A
1	Question / objective sufficiently described?				
2	Study design evident and appropriate?				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate?				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				
5	If interventional and random allocation was possible, was it described?				
6	If interventional and blinding of investigators was possible, was it reported?				
7	If interventional and blinding of subjects was possible, was it reported?				
8	Outcome and (if applicable) exposure measure(s) well defined and robust to measurement / misclassification bias? Means of assessment reported?				
9	Sample size appropriate?				
10	Analytic methods described/justified and appropriate?				
11	Some estimate of variance is reported for the main results?				
12	Controlled for confounding?				
13	Results reported in sufficient detail?				
14	Conclusions supported by the results?				

Appendix 2

Final Version of the Decision-Making Questionnaire (DMQ)

Item	We would like your opinion on _____'s decision making abilities. Based on your experience of them, please indicate your level of agreement or disagreement with each of the following statements:	Strongly disagree			Neutral			Strongly agree	N/A or unable to comment
1	They can solve novel problems, i.e. when faced with an unfamiliar problem outside of their routine, or their normal contexts	6	5	4	3	2	1	0	
2	They struggle to get started with a task, particularly if it is difficult	0	1	2	3	4	5	6	
3	They are susceptible to distraction	0	1	2	3	4	5	6	
4	They lack insight into any cognitive challenges they have	0	1	2	3	4	5	6	
5	They are unable to detect errors in their own performance	0	1	2	3	4	5	6	
6	They lack the ability to sustain their attention	0	1	2	3	4	5	6	
7	They have difficulties with planning and organising	0	1	2	3	4	5	6	
8	They do not or are inconsistent in the extent to which they follow through on their decisions	0	1	2	3	4	5	6	
9	They are able to update their opinions when new information comes to light	0	1	2	3	4	5	6	
10	They are able to appreciate more than one perspective on a situation	0	1	2	3	4	5	6	
11	They tend to jump to conclusions rather than thinking things through step by step	0	1	2	3	4	5	6	
12	They are less troubled about their problems than they should be	0	1	2	3	4	5	6	
13	They do not seem motivated to do things that require effortful thought	0	1	2	3	4	5	6	
14	They become overwhelmed when faced with minor decisions	0	1	2	3	4	5	6	
15	They avoid making decisions even to their detriment	0	1	2	3	4	5	6	
16	They are prone to acting in an impulsive manner	0	1	2	3	4	5	6	
17	They make decisions that are 'out of character', i.e. not congruent with their reported values, identity or beliefs	0	1	2	3	4	5	6	
18	They can recognise when contextual factors (e.g. being tired, hungry, upset) might adversely impact their decision making	0	1	2	3	4	5	6	
19	They are overly influenced by other people's opinions (i.e. they are suggestible)	0	1	2	3	4	5	6	

20	They are highly influenced by incentives or rewards	0	1	2	3	4	5	6	
21	They recognise when they need assistance and/or additional information in order to solve a problem	0	1	2	3	4	5	6	
22	They have challenges making minor everyday decisions such as deciding meals, routes and what to wear.	0	1	2	3	4	5	6	
23	I have concerns about their ability to make important decisions e.g. about their care, finances, relationships	0	1	2	3	4	5	6	
24	I have concerns about their engagement in risky decision making e.g. decision that lead to the increased possibility of physical harm	0	1	2	3	4	5	6	