Exploration of the effectiveness of computerised cognitive retraining of executive functioning and the neuropsychological mechanisms of working memory training

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Declaration

This thesis is submitted for a Doctorate of Clinical Psychology at the University of Sheffield. It has not been submitted for any other qualification or to any other institution.

Structure and Word Counts

Both the literature review and research report have been prepared in accordance with guidelines for authors submitting articles to the British Journal of Clinical Psychology. Writing style and formatting conform to the Publication Manual of the American Psychological Society (Sixth Edition).

Literature Review:

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Including References	9249

Research Report:

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Including References	12178

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Main Abstract

Executive dysfunction, the impairment of high-order cognitive functioning, has a detrimental effect on recovery following acquired brain injury (ABI). Computerised cognitive retraining (CCR) is an emerging rehabilitation technique, based on the theory that repeated completion of increasingly challenging tasks can induce neural changes, leading to restitution of functions. The CCR of high-order cognitive functions has been revealed to benefit other areas of cognition, due to training stimulating high-order processes that support a range of functions.

A systematic review examined whether CCR is an effective method of rehabilitating executive functioning in an ABI population. However, insufficient evidence was obtained as only a small number of predominantly poor quality studies were identified. Tentative findings suggest that working memory (WM) abilities can be improved through retraining and that CCR of WM has the potential to trigger wider improvements in patients' cognition. However, further investigation of these findings is warranted.

An empirical study aimed to investigate whether training patients' WM, through repeated completion of simple WM tasks, could improve their attention and/or executive functioning. Participants' scores on backwards digit span (DS; a task involving recall of digits in reverse, requiring manipulation of digits in WM) were demonstrated to significantly predict their attention and inhibition scores, whilst their performance on forwards DS did not significantly predict their attention and inhibition scores (a task involving forwards recall of digits, only requiring storage of digits in WM). Consequently, CCR exercises that require manipulation of information in WM could potentially trigger improvements in patients' attentional and inhibitory abilities.

Acknowledgements

I would first like to thank the Neuropsychology Service at the Royal Hallamshire Hospital for granting me assess to their neuropsychological assessment data, enabling this study to go ahead. Many thanks to Dr Claire Isaac my research supervisor for her support, particularly her guidance and reassurance when things have not gone to plan. Thanks also to David Saxon whose statistical expertise has been invaluable. Lastly, I would like to thank my friends and family for supporting me and keeping me going throughout this project.

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Literature Review

Computerised cognitive retraining of executive functioning following acquired brain injury: A review of the literature

Abstract

Executive dysfunction is one of the most debilitating cognitive impairments following acquired brain injury (ABI), due to its pervasive effect on functioning. Computerised cognitive retraining (CCR) is an innovative technique for rehabilitating cognitive functioning following ABI. This review examined the role CCR may have in rehabilitating aspects of executive functioning in an ABI population and aimed to ascertain how the effectiveness of CCR is being assessed. A systematic review of the literature was performed. Eleven studies were reviewed and their methodological quality assessed. Due to the small number and poor quality of the studies there was insufficient evidence to evaluate whether CCR is an effective method of rehabilitating executive functioning in patients with ABI. Findings of three high quality studies tentatively suggest that patients' working memory (WM) abilities can be improved through CCR and indicate that CCR has the potential to trigger wider improvements in patients' cognition. Further investigation of the utility of CCR in the rehabilitation of executive functioning is warranted. This review highlighted that a limited range of outcome measures are being utilised to assess the effectiveness of CCR, therefore wider assessment of the benefits of CCR is necessary.

Practitioner points:

- Evidence tentatively suggests that patients' WM abilities can be improved through CCR.

- The restitution of cognitive abilities may be possible following ABI.
- A small number of poor quality studies were identified, a reflection of the state of the current CCR evidence base which is in need of further exploration.

Acquired brain injury (ABI) is damage caused to the brain after birth, either due to a sudden blow to the head or a non-traumatic event, for example an infection. Following ABI individuals typically experience a wide range of cognitive impairments, which can have devastating effects on their functioning (Holmqvist, Kamwendo & Ivarsson, 2009) and quality of life (Cumming, Brodtmann, Darby & Bernhardt, 2014). An area of cognition commonly impaired following ABI is executive functioning (Headway, 2012); a range of high-order cognitive processes hard to definitively define. Current definitions of executive functioning include abilities such as planning, multi-tasking, problem solving, reasoning, inhibition, sustaining attention and manipulating information in working memory (WM; Chan, Shum, Toulopoulou & Chen, 2008; Cicerone, Levin, Malec, Stuss & Whyte, 2006). Dysfunction of executive functioning is considered one of the most debilitating cognitive impairments as it pervades a wide range of cognitive functions (Wheeler, 2014). Impairments of executive functions such as attention and WM have been demonstrated to have a significant impact on return to functioning following traumatic brain injury (TBI; Spitz, Ponsford, Rudzki & Maller, 2012), because the ability to attend to and remember information underlies the majority of cognitive abilities.

Attention can be defined as the selection of stimuli for further processing; it is not a unitary construct, but a collection of components. There are numerous theoretical models of attention, however Sohlberg and Mateer's (2001) model is the most applicable to the present review as it has been readily utilised in the assessment and rehabilitation of neurology patients. It identifies five discrete components of attention: (a) focused attention; directing attention to stimuli, (b) sustained attention/vigilance; maintaining a consistent response to stimuli, (c) selective attention; selecting specific stimuli to attend to, (d) switching/alternating attention; shifting focus from one stimuli to another, and (e) divided attention; simultaneously responding to multiple stimuli. In subsequent research Sohlberg and Mateer (2010) have included (f) suppression; ignoring distractors and (g) working attention; the maintenance of information in short-term memory (STM), as additional components. The term ‘executive attention’ is often used to describe the aspects of attention effective in managing multiple, novel and conflicting stimuli (Sohlberg & Mateer, 2010).

Traditionally WM has been defined as the ability to temporarily hold and manipulate information in STM (Baddeley, 1992). However, more recent research has indicated that WM is a complex construct that deploys executive attention to manage competing sources of information, manipulate information and ignore irrelevant information in STM (Morrison & Chein, 2011). Baddeley and Hitch’s (1974) WM model is the most influential of the theoretical models, it identifies the central executive as the sub-system responsible for employing executive attention, in order to coordinate information from two STM storage sub-systems: the phonological loop (auditory stimuli) and visuospatial sketchpad (visual stimuli). The central executive is thought to supervise not only WM, but other high-order processes, for example attentional control, arithmetic and reasoning (Baddeley & Logie, 1999).

Consequently, effective rehabilitation of attention and WM is vital, as these high-order abilities are required to successfully recover and return to everyday functioning. Specifically, attentional control and WM are necessary to successfully complete physical and cognitive rehabilitation programmes e.g., following and learning rehabilitation strategies (Westerberg et al., 2007).

Cognitive Rehabilitation

It is recommended that individuals with ABI receive a period of rehabilitation, designed to promote recovery of impaired functions and improve functioning (Cicerone et al., 2000). Although a number of recent systematic reviews have revealed encouraging evidence indicating that rehabilitation can improve the cognition of individuals with ABI (Cappa et al., 2011; Cicerone et al., 2011; Rohling, Faust, Beverley & Demarkis, 2009). There have been criticisms of the cognitive rehabilitation evidence-base, first because traditionally it has been guided by collective expert opinion rather than research (NINDS, 2004) and second because recommendations have been based on evidence which has not been thoroughly critiqued (Cicerone, Azulay & Trott, 2009). In terms of methodological quality, all three reviews mentioned above only comment on study design, they do not perform further critique.

Cicerone and colleagues (2009) sought to resolve this by thoroughly appraising a sample of cognitive rehabilitation studies against methodological quality criteria. Encouragingly, this review revealed patients' attention and executive functioning can be effectively rehabilitated, following both compensatory techniques; adapting to the presence of cognitive deficits by circumventing them (das Nair & Lincoln, 2012), and restitutory methods; repeated completion of increasingly demanding cognitive tasks which induces a change of neural pathways and restoration of lost functions (Kimberely, Samargia, Moore, Shakya & Lang, 2010; Rabipour & Raz, 2012). However, researchers have also been criticised for how they are evaluating the effectiveness of cognitive rehabilitation, Wilson (2007) called for the effectiveness of rehabilitation to not just be based on cognitive improvement, but also on improvements of patient functioning and quality of life, however this evidence is sparse in the literature.

Computerised Cognitive Retraining (CCR)

Until relatively recently the idea of restitution had been losing support, but with the surge of technological advances such as functional imaging providing evidence that the brain remains plastic, such techniques have been revisited. Similarly, technological advancements have been successfully applied to the development of restitutory rehabilitation techniques and are responsible for the emergence of CCR programmes.

CCR typically involves individuals repeatedly completing onscreen tasks of increasing difficulty aimed at enhancing their cognition. Available commercial CCR programmes either simultaneously retrain a broad range of cognitive functions or intensively retrain a specific cognitive construct. However, there is currently no standardised CCR protocol, thus implementation can vary widely. The effectiveness of CCR programmes has been predominantly assessed through the use of trained, near-transfer and far-transfer tasks. Trained tasks consist of individuals' performances on onscreen training exercises i.e. training scores. Near-transfer tasks include individuals' performances on assessments or questionnaires measuring the cognitive function being targeted by the training, for example WM scores following WM CCR. Far-transfer tasks consist of individuals' performances on assessments or questionnaires measuring an unrelated cognitive function not being trained, for example executive functioning scores following attention CCR. Consistent with the holistic aims of cognitive rehabilitation, some researchers also monitor changes in individuals' functioning and quality of life following CCR.

A systematic review examining the CCR literature has not been conducted; two narrative reviews exploring computer-assisted cognitive rehabilitation were published in 2002 prior to the recent growth of commercial CCR programmes (Gontkovsky, McDonald, Clark and Ruwe, 2002; Lynch, 2002). More recently Cha and Kim (2013) reviewed 12 studies investigating computer-based rehabilitation in patients with stroke, demonstrating an improvement of general cognitive functioning post-training. However, in the abovementioned reviews CCR was delivered alongside other rehabilitation techniques so it is not clear what if any contribution CCR made. Due to the frequency at which executive functions are impaired following ABI and their significant impact on recovery, the present review focussed on establishing whether CCR is an effective method of improving the executive functioning of patients with ABI.

Aims

The primary aim was to evaluate whether CCR is an effective method of rehabilitating aspects of executive functioning in an ABI population. The secondary aims were to ascertain first how researchers are evaluating the effectiveness of CCR, second at what point during rehabilitation CCR has been demonstrated to be effective, and third how many CCR sessions are required to replicate findings; questions pertinent to evaluating the validity of the evidence-base and its applications to clinical practice.

Method

A systematic review of the CCR literature for adults with executive dysfunction post-ABI was conducted.

Search Strategy

Three electronic databases; Medline, Cinahl and PsycInfo were searched using the following terms: *rehabilitation, retraining, training, remediation, restitution, cognitive, cognition, working memory, attention, executive function, problem solving, reasoning, brain injury, traumatic brain injury, acquired brain injury, head injury, stroke, computer, computerised and computerized*. The last reviews of CCR were published in 2002 (Gontkovsky et al., 2002; Lynch, 2002), therefore literature published between January 2000 and February 2014 was searched. Reference lists of recent cognitive rehabilitation review articles (Cappa et al., 2011; Cha & Kim, 2013; Cicerone et al., 2005; Cicerone et al., 2006; Cicerone et al., 2009; Cicerone, 2011; Rohling et al., 2009) were scanned for studies that may have been missed. This search strategy, performed on 22nd and 23rd February 2014, identified 347 studies.

Studies were screened for relevance by abstract content, before a more thorough review of full-text articles was performed (see Figure 1). Those studies included for further examination were: (a) original research reports, (b) of CCR, (c) with an adult population, (d) who had sustained an ABI, (e) with executive dysfunction and (f) that reported cognitive outcomes. Studies were only included if it was clear that the CCR intervention fulfilled a definition of retraining i.e. repeated completion of cognitively stimulating exercises over multiple sessions. Studies were excluded if they: (a) were not available in English, (b) assessed non-cognitive forms of rehabilitation, (c) were not empirical, (d) evaluated a compensatory, invasive or non-computerised intervention and (e) were secondary sources.

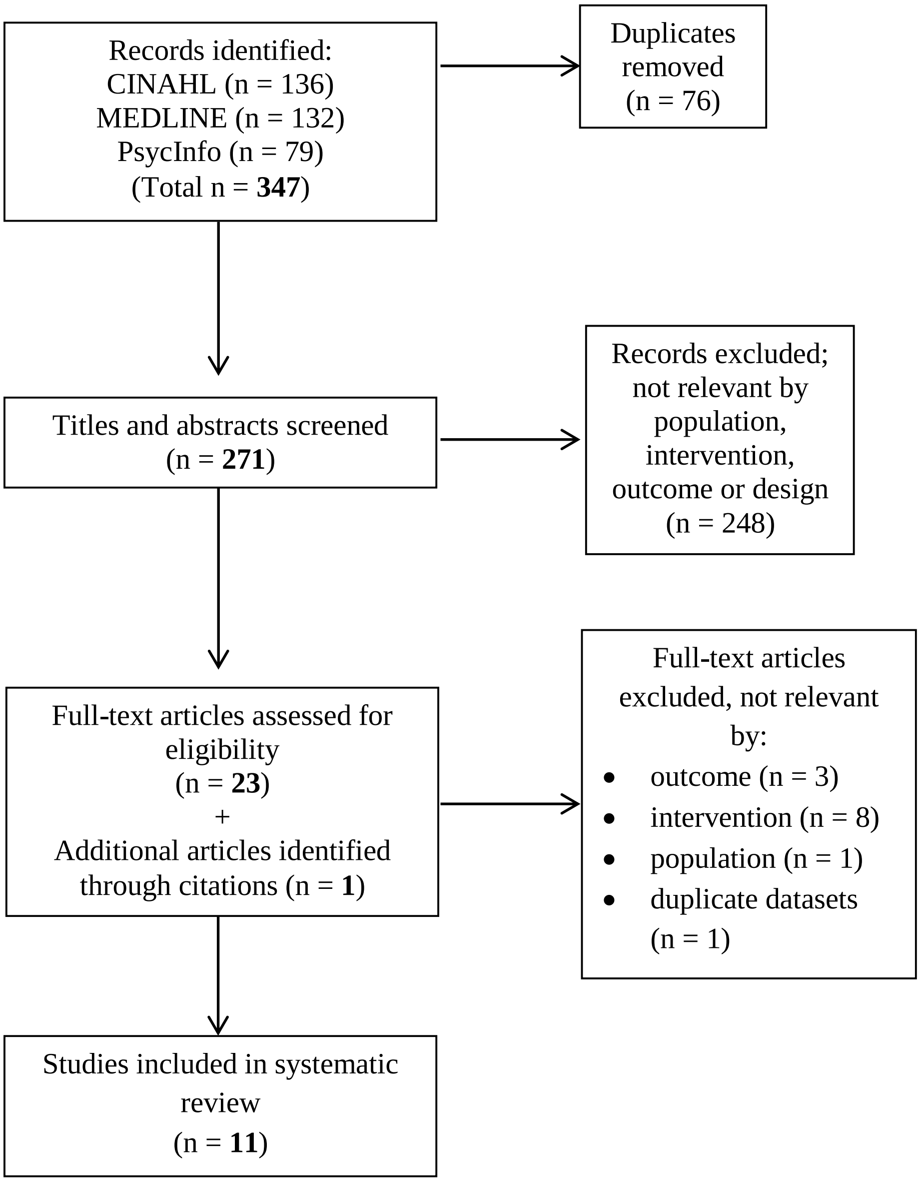

Figure 1. Search strategy

Forward and backward citations of included studies were scanned identifying one study that had been missed. No additional studies were identified through the scanning of reference lists of cognitive rehabilitation review articles. Lastly, two studies utilised the same dataset, therefore the most relevant study reporting cognitive outcomes was included. This search strategy yielded 11 studies.

Methodological Quality

The methodological quality of the studies was assessed using a comprehensive methodological quality measure, the Downs and Black checklist (Downs & Black, 1998; see appendix A). This checklist was designed to assess the quality of randomised and non-randomised studies of healthcare interventions, consisting of 27 dichotomous items (scored 0 for absence, 1 for presence). Four sub-scales are calculated relating to levels of reporting i.e. whether sufficient information was provided to assess the study findings (10 items), external validity (3 items), bias (6 items) and confounding (6 items), generating a profile of a study's strengths and weaknesses. The checklist has an additional item relating to statistical power, which was adapted to also be dichotomous for absence or presence of a power calculation. The methodological quality of all studies was assessed by the first author and an independent rater (doctoral student), who rated a random sub-sample of three studies. Inter-rater reliability was calculated using Cohen's Kappa statistic and substantial agreement was established ($\kappa = .742$, $n = 81$). Disagreements between the two raters were resolved through verbal discussion of the evidence until agreement was met, as the first author had more familiarity with the literature their decision stood when agreement could not be achieved.

Four studies scoring considerably above the median quality score of 16 were classified as high quality, five studies scoring at and around the median as medium quality and two studies scoring considerably below the median as low quality. Studies are summarised in Table 1, organised into three categories by the cognitive functions targeted by CCR programmes; attention, attention and other cognitive functions (attention plus) and WM studies, ordered from high to low quality.

Table 1

Description of CCR studies

Attention studies						
Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Sturm et al., 2004 (Germany)	Non-independent groups Pre and post + baseline	Intervention = 4 Control = 4	5–21 (13)	AIXTENT alertness training; 14 sessions, 45 minutes, over 4 weeks	Near-transfer: TAP	Medium 15
Zickefoose, Hux, Brown & Wulf, 2013 (USA)	Single-group Pre and post	4	36–420 (210)	APT-3 (selective, sustained, working and alternating attention, and suppression) and Lumosity attention training; 20 sessions, 30 minutes, over 1-month period, for each programme	Trained: Accuracy scores on APT-3 and Lumosity training programmes, adapted number and letters subtests from the NAB Near-transfer: TEA	Medium 14

Attention studies continued

Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Hauke, Fimm & Sturm, 2011 (Germany)	Single case Pre and post + baseline and follow-up	1	60	Alertness subprogram of Attention Training CogniPlus program (developed from AIXTENT); 15 sessions, 45 minutes, over three weeks	Near-transfer: Alertness, vigilance and focused attention subtests from the VTS, divided attention subtest from the TAP, FEDA	Low 12
Sturm et al., 2003 (Belgium, France, Germany, Italy)	Four single groups Pre and post + baseline	33 (9, 7, 11 and 6)	3-128	AIXTENT alertness, vigilance, selective attention and divided attention training (a group completed each programme); 14 sessions, 60 minutes, over three weeks	Near transfer: TAP	Low 11

Attention plus studies						
Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Prokopenko et al., 2013 (Russia)	Independent groups Pre and post	Intervention = 24 Control = 19	Unknown range 2 weeks	Computerised Schulte's tables attention training and computerised figure-background visuospatial training; 14 sessions, 30 minutes, for 2 weeks	Trained: Schulte's tables Far-transfer: MMSE, MoCA, FAB, IADL, SS-QOL-2, PGIS, HADS	High 22
Li, Robertson, Ramos & Gella, 2013 (USA)	Single-group Pre and post	11	48–600 (255)	Parrot Software, attention and memory training 8 session, 60 minutes, over 2 - 8 weeks	Near-transfer: Cognistat Assessment subtests assessing attention and memory	Medium 16

Attention plus studies continued						
Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Łojek and Bolewska, 2013 (Poland)	Non-independent groups Pre and post	Intervention = 9 Control = 6	18–240 (78)	RehaCom, attention and memory training; 30 sessions, 60 minutes, over 15 weeks	Trained: Difficulty level on RehaCom Near transfer: TMT, RFFT, RAVLT, CFT, Digit Span and Digit Symbol subtests from WAIS Far-transfer: SWLS	Medium 16
Fernandez et al., 2012 (Cuba)	Single-group Pre and post	50	12-60 (50% of participants)	RehaCom, attention and memory training; 60 sessions, 50 minutes, over 12 weeks	Near-transfer: TMT	Medium 14

WM studies						
Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Åkerlund, Esbjornsson, Sunnerhagen & Bjorkdahl, 2013 (Sweden)	Independent groups (cross over) Pre and post + follow-up	Intervention 1 = 20 Control = 18 / Intervention 2 = 8	3–115 (7.5)	Cogmed; 25 sessions, 30-45 minutes, over 5 weeks	Near-transfer: Digit Span, Span Board, Arithmetic and Letter-number Sequencing subtests of the WAIS-III Far-transfer: BNIS, DEX, HADS	High 20
Lundqvist, Grundstrom, Samuelsson & Ronnberg, 2010 (Sweden)	Independent groups (cross over) Pre and post + follow-up	Intervention 1 = 10 Control = 11 / Intervention 2 = 11	Unknown range (46.4)	Cogmed; 25 sessions, 45-60 minutes, for 5 weeks	Trained: Index scores on Cogmed Near-transfer: Digit Span and Block Span Board subtests from the WAIS, Listening task (unknown), Picture Span (unknown) Far-transfer: PASAT, CWIT, COPM, EQ-5D, Health status rating	High 20

WM studies continued

Author, year (country)	Design	Sample size (N =)	Months post-injury (mean)	Intervention	Outcome measures	Methodological quality
Westerberg et al., 2007 (Sweden)	Independent groups Pre and post	Intervention = 9 Control = 9	12–36 (20)	RoboMemo (an early version of Cogmed); 25 sessions, 30-45 minutes, for 5 weeks	Near-transfer: Digit Span and Span Board subtests from WAIS-R. Far-transfer: PASAT Version A, Stroop, Claeson-Dahl Word List Recall Test, Raven's Progressive Matrices (modified for study), RUFF 2&7 Selective Attention Test, CFQ (duration adapted)	High 20

Note. Attention Process Training-3 (APT-3); Barrow Neurological Institute Screen for Higher Cerebral Functions (BNIS); Canadian Occupational Performance Measure (COPM); Colour Word Interference Test (CWIT); Cognitive Failures Questionnaire (CFQ); Dysexecutive Questionnaire (DEX); EuroQoL Questionnaire (EQ-5D); Frontal Assessment Battery (FAB); Activities of Daily Living Scale (IADL); Hospital Anxiety and Depression Scale (HADS); Mini Mental State Examination (MMSE); Montreal Scale of Cognitive Assessment (MoCA); Neurological Assessment Battery (NAB); Paced Auditory Serial Attention Test (PASAT); Patient Global Impression Scale (PGIS); Questionnaire of Experienced Attention Deficits (FEDA); Rey Osterrieth Complex Figure Test (CFT); Rey Auditory Verbal Learning Test (RAVLT); Ruff Figural Fluency Test (RFFT); Satisfaction with Life Scale (SWLS); Stroke Specific Quality of Life (SS-QOL-2); Test of Attentional Performance (TAP); Test of Everyday Attention (TEA); Trail Making Test (TMT); Vienna Test System (VTS); Wechsler Adult Intelligence Scale – Third Edition (WAIS-III).

Results

Description of Studies

Design. Studies utilised designs of varying robustness; six recruited two comparative groups (four independent groups and two non-independent groups), four recruited single groups and one a single-case. Two group studies employed a cross-over design whereby both groups completed the CCR non-concurrently. All studies measured pre-training and post-training scores, additionally three studies monitored a baseline and three studies utilised a follow-up.

Participants. Across the 11 studies 211 participants were recruited to complete CCR, whilst four studies recruited 38 control participants. All studies recruited adults, with an average age of 46.7 years. In three studies participants had sustained a stroke, in one study participants had experienced TBI, the single case participant had suffered brain stem encephalitis and in six studies participants had a variety of ABIs.

Programmes. Ten studies utilised commercially available CCR programmes; AIXTENT (Sturm, Hartje, Orgass & Willmes, 1993), Cogmed (Klingberg, Forssberg & Westerberg, 2002), RehaCom (Schuhfried, 2003), APT-3 (Sohlberg & Mateer, 2010), Lumosity (Lumos Labs, 2010) and Parrot Software (Weiner, 1985-2011), whilst one study developed their own CCR programme. Further details of each CCR programme are provided subsequently.

Quality. Between 82% and 41% of the Downs and Black quality criteria were fulfilled by the 11 studies, highlighting the variability of study quality (see appendix B for study quality scores). Level of reporting was generally high across the studies with almost all studies describing the aims, participants, intervention and outcomes, whereas only two studies (Lundqvist et al., 2010; Westerberg et al., 2007) performed a power calculation. Items regarding measurement bias were well evidenced with the majority of studies administering valid and reliable outcome measures, and appropriate statistical analyses, whereas items pertaining to confounders and external validity were poorly evidenced.

External validity was poorly evidenced due to ambiguity over which population participants were recruited from (Prokopenko et al., 2013; Sturm et al., 2003; Zickefoose et al., 2013), whether the whole population was approached to participate (all studies except Li et al., 2013) and the proportion who consented/declined to participate (all studies). Items assessing confounders were unfulfilled due to adjustments not being made for confounding variables (Fernandez et al., 2012; Lojek & Bolewska, 2013; Lundqvist et al., 2010; Sturm et al., 2004; Sturm et al., 2003; Westerberg et al., 2007; Zickefoose et al., 2013) and drop outs (Akerlund et al., 2013; Westerberg et al., 2007), and lack of clarity over concurrency of recruitment (Lojek & Bolewska, 2013; Lundqvist et al., 2010; Prokopenko et al., 2013; Sturm et al., 2003; Westerberg et al., 2007).

Table 2 demonstrates the proportion of quality classifications for each study category and Table 3 illustrates overall and sub-scale quality scores for each study category. Study quality will be considered throughout the review to evaluate the validity of each study's findings.

Table 2

Study quality classifications based on Downs and Black checklist scores

Study category	**Quality classifications**		
	High	Medium	Low
Attention	0	2	2
Attention plus	1	3	0
WM	3	0	0

N = 11

Table 3

Percentage of Downs and Black quality criteria achieved

Study category	**Quality score (%)**					
	Reporting	External validity	Bias	Confounders	Power	Overall score
Attention (n = 4)	75	16.7	66.7	20.8	0	49.1
Attention plus (n=4)	90	16.7	83.3	41.7	0	63
WM (n = 3)	96.7	44.4	83.3	55.6	66.7	74.1
Mean (*N* = 11)	86.4	24.2	77.3	37.9	18.2	60.9

Study Outcomes

Evidence concerning each of the review's aims will be discussed in turn, first whether CCR is an effective method of rehabilitating aspects of executive functioning in an adult ABI population. Studies investigating the CCR of attention will be described and critiqued, followed by WM studies.

Attention. Eight studies attempted to retrain attention; four exclusively targeted attention and four targeted attention alongside another cognitive function; memory (Fernandez et al., 2012; Li et al., 2013; Lojek & Bolewska, 2013) and visuospatial skills (Prokopenko et al., 2013). One study was of high quality, five of medium quality and two of low quality, demonstrating variation in methodological quality.

The aspects of attention targeted for retraining were: alertness, suppression, switching (alternating) of attention, divided, focused, selective, sustained (vigilance) and working attention. Two studies did not define the aspects of attention being retrained, thus these studies are described as targeting ‘undefined attention’, whereas one study simultaneously targeted/assessed numerous attentional components, described as targeting ‘combined attention’.

A variety of CCR programmes were utilised:

- AIXTENT had a video-game format. It included alertness (reacting to obstacles whilst driving), vigilance (responding to changes in targets moving across the screen), divided (monitoring three controls on a flight simulator) and selective attention exercises (shooting specific pairs of targets in a safari scene).
- APT-3 included exercises of suppression, alternating, selective, sustained and working attention. Training entailed intensive repetition of exercises of increasing difficulty, however no further details were provided.
- Parrot Software included numerous attention sub-programs, however only details of a visual attention training task were given (reacting to appearance of a stimuli, task difficulty increased with introduction of increasing distractors).
- RehaCom included a variety of attention exercises, but only details of a pattern comparison task was provided (choosing a matching picture from a group of similar pictures).
- Schulte’s tables targeted alternating, divided, selective and sustained attention. Participants had to quickly select numbers 1-25 in ascending order, randomly distributed in a 5x5 grid.

Evidence for the CCR potential for each component of attention will be described, starting with basic attention processes and then executive attention processes (based on Sohlberg and Mateer's (2010) model), demonstrating the trained and near-transfer effects; discussion of far-transfer effects will follow separately.

Basic attention processes.

Alertness. In three studies (low and medium quality) participants completed fourteen to fifteen 45-60 minute AIXTENT alertness training sessions (Hauke et al., 2011; Sturm et al., 2003; Sturm et al., 2004), with improvements assessed on near-transfer tasks; TAP and VTS alertness subtests. Hauke et al's participant had significantly impaired alertness throughout the four-year baseline, but following three sessions demonstrated significantly improved alertness, which persisted six months post-training. Similarly, Sturm et al., (2003) established significant improvements in their nine participants' alertness, whilst Sturm et al., (2004) demonstrated significantly improved alertness for three participants, whilst their fourth participant with severely impaired alertness did not benefit.

Focused attention. Only Hauke et al's (2011) low quality study assessed the impact of CCR on participants' focused attention, demonstrating significantly improved focused attention subtest scores on the VTS (near-transfer task) following six days of the abovementioned AIXTENT alertness training, which persisted six months post-training. However, a stable baseline was not achieved as it was demonstrated that the participant's focussed attention was already improving prior to training.

Sustained attention (vigilance). Four studies (low and medium quality) investigated the retraining of sustained attention, Hauke et al's (2011) participant completed fifteen 45-minute AIXTENT alertness training sessions, Sturm et al's

(2003; 2004) fourteen 45-60 minute AIXTENT vigilance training sessions, and Zickefoose et al's (2013) forty 30-minute APT-3 and Lumosity attention training sessions. Improvements were assessed on trained tasks; APT-3 performance and near-transfer tasks; TAP, VTS and TEA subtests. Although Zickefoose et al., demonstrated significant improvements in their four participants' sustained attention scores on the APT-3, inconsistent performances were established on their sustained attention TEA subtest scores. Hauke et al., reported significant improvements in vigilance after six days of training, which persisted six months post-training, however a stable baseline was not achieved as the participant's vigilance was already improving prior to training. Sturm et al., (2003) demonstrated significant improvements on one measure of vigilance (number of omissions) but not on another (number of errors), whereas Sturm et al., (2004) only demonstrated significantly improved vigilance for one of their four participants; two participants with severely impaired vigilance did not benefit.

Summary. Promising improvements in alertness were revealed following CCR, whilst the evidence indicated focused and sustained attention may be less responsive to CCR. Sturm et al's (2004) findings also implied that severity of attention deficits may influence responsiveness to CCR, as their severely impaired participants did not improve. However, these findings are undermined by the low quality of the studies, particularly poor fulfilment of external validity i.e. recruitment of non-representative small sample sizes by all four studies. Furthermore, the lack of control groups and baseline measurement by Sturm et al., (2003) and Zickefoose et al., (2013) indicate poor accountability of confounders such as test re-test and spontaneous recovery, which Hauke et al's (2011) study demonstrated does occur in an ABI population.

Executive attention processes.

Divided attention. Two low quality studies (Hauke et al., 2011; Sturm et al., 2003) investigated the CCR of divided attention; training format described previously. Improvements were assessed on near-transfer tasks; TAP divided attention subtest scores. Sturm et al., established significant improvements in their six participants' divided attention, similarly after six sessions Hauke et al., demonstrated significant improvements in their participant's divided attention, which persisted for six months, however a stable baseline was not achieved as the participant's divided attention was already improving prior to training.

Selective attention. Two studies (low quality; Sturm et al., 2003 and medium quality; Zickefoose et al., 2013) explored the impact of CCR on selective attention; training format described previously. Zickefoose et al., reported mixed findings; despite participants' scores on the selective attention domain of APT-3 significantly improving, similar improvements were not demonstrated in participants' scores on selective attention subtests of the TEA. Similarly, Sturm et al., established no significant improvements in their 11 participants' scores on selective attention subtest of the TAP.

Switching attention. Two medium quality studies (Fernandez et al., 2012; Zickefoose et al., 2013) explored the CCR of switching attention. Zickefoose et al's training format has been described previously, whilst Fernandez et al's participants' completed sixty 50-minute RehaCom attention and memory training sessions that did not specifically target a particular attention component. Although Zickefoose et al's participants improved on APT-3 switching attention tasks, no such improvements were demonstrated on their switching attention TEA scores, furthermore Fernandez et al., demonstrated no improvements on the TMT Part B; near-transfer task of switching attention.

Suppression and working attention. Only Zickefoose et al's (2013) medium quality study evaluated whether suppression and working attention can be retrained; training format described previously. Due to the TEA not having corresponding subtests improvements in participants' suppression and working attention were only demonstrated on their corresponding APT-3 training scores; all four participants' suppression and working attention scores significantly improved.

Summary. The evidence did not reveal any encouraging improvements in selective attention and switching of attention following CCR. The inconsistent outcomes of Zickefoose et al., (2013) are further undermined by their failure to control for spontaneous recovery by not utilising a baseline or control group. In contrast, some promising findings were demonstrated in the retraining of suppression, divided and working attention. However, Hauke et al's (2011) participant's improved divided attention is confounded by the detection of some spontaneous recovery during baseline, and the improvements of Zickefoose et al's participants' suppression and working attention are only based on trained APT-3 scores and were not assessed on any near-transfer tasks.

Combined attention. One high quality study attempted to retrain participants' attention alongside visuospatial functioning and evaluated CCR by assessing combined attention. Prokopenko et al., (2013) demonstrated significant improvements in participants' performance on Schulte's tables (an exercise of sustained, selective, divided and alternating attention) after training on this task for fourteen 30-minute sessions. Prokopenko et al., was the only study of attention to compare participants' performance with a control group, however they only did this on a trained attention task, and therefore significant improvements may be due to practice effects.

Undefined attention. Two medium quality studies retrained undefined components of attention. Lojek and Bolewska (2013) established improved performance on participants' RehaCom training scores, following thirty 60-minute undefined RehaCom attention and memory sessions, however they did not demonstrate similar improvements on a range of near-transfer tasks. Li et al., (2013) demonstrated significant improvements in participants' scores on near-transfer Cognistat attention subtests following eight 60-minute sessions of Parrot Software attention and memory training. However, as Lojek and Bolewska's only positive findings were on trained attention task which their control group did not complete, none of the significant findings were compared with a control group consequently it is not clear whether CCR can result in improvements of undefined attention. Furthermore, it was not clear which components of attention were retrained limiting replicability.

Far-transfer effects. The majority of attention studies evaluated participants' performance on trained and near-transfer tests, only two studies explored the wider training effects of CCR of attention on other cognitive functions and/or participant functioning. One high quality study, Prokopenko et al., (2013) explored the impact of Schulte's tables training sessions on general cognitive and executive functioning, and numerous measures of participants' functioning and wellbeing (e.g. mood, ADLs, quality of life). Although Prokopenko et al., demonstrated significant improvements in participants' executive functioning and in self-reported functioning they also trained visuospatial skills so any transfer effects cannot be attributed to attention retraining alone. Low quality study Hauke et al., (2011) demonstrated significant improvements in self-reported drive, distractibility and speed of processing following AIXTENT alertness training, however this is based on a single participant. Overall there was an absence of evidence for far-transfer effects, thus no conclusions can be drawn on the wider benefits of CCR of attention.

WM. Three high quality studies investigated the retraining of WM (Akerlund et al., 2013; Lundqvist et al., 2010; Westerberg et al., 2007), their participants completed twenty-five 30-60 minute Cogmed or RoboMemo (an earlier version of Cogmed) training sessions. Cogmed training entails repeated completion of verbal and visuospatial WM exercises, for example requiring participants to remember positions of stimuli in an onscreen grid in the same order, reverse order or after rotation of the grid, or remembering sequences of digits and letters in the same or reverse order. All training tasks are said to involve simultaneous maintenance of numerous stimuli and temporary storage of stimuli characteristics, location and sequencing; difficulty level is automatically adjusted so participants are always performing close to their WM capacity.

Lundqvist et al., (2010) were the only study to analyse changes in participants' scores on Cogmed tasks, demonstrating significant improvements in participants' scores on Cogmed tasks over time. All three studies demonstrated significant improvements on near-transfer WM tests i.e. digit span (Akerlund et al., 2013; Westerberg et al., 2007) and spatial span (Lundqvist et al., 2010; Westerberg et al., 2007), however conflictingly Akerlund et al., (2013) established no significant improvements in spatial span. Significant improvements were also established on other WM tests i.e. picture span, listening span (Lundqvist et al., 2010) and WM subtests from the WAIS (Akerlund et al., 2013)

All three studies also demonstrated far-transfer effects, establishing significant improvements in general cognitive functioning (Akerlund et al., 2013) attention (Westerberg et al., 2007; Lundqvist et al., 2010) and inhibition (Lundqvist et al., 2010). In contrast Westerberg et al., (2007) found no significant improvements in participants' inhibition, non-verbal reasoning or declarative memory. Lastly, significant improvements in mood (Akerlund et al., 2013), occupational functioning (Lundqvist et al., 2010) and health status (Lundqvist et al., 2010) were established, along with reduction in cognitive symptoms (Westerberg et al., 2007). However, no significant improvements were demonstrated in participants' self-reported executive functioning (Akerlund et al., 2013) or quality of life (Lundqvist et al., 2010).

The three studies revealed promising trained, near-transfer and far-transfer effects following WM retraining, however these were not consistently demonstrated across all three studies. As these studies are of equivalent methodological quality and utilised the same CCR programme this calls into question the positive findings demonstrated and whether they would be replicated.

Outcome Measures

Examination of the outcome measures administered across the 11 studies was performed to ascertain how researchers are currently evaluating the effectiveness of CCR. Studies employed a range of outcome measures, with an average of five outcome measures per study, ranging from one to 10. The use of trained, near-transfer and far-transfer tasks is explored.

Trained. Four studies utilised changes in participants' CCR scores as evidence of cognitive improvement, namely changes in participants' scores over time on APT-3, Lumosity, Cogmed, RehaCom and Schulte's tables were utilised in the respective studies.

Near-transfer. All studies utilised cognitive assessments and/or questionnaires that assessed the same cognitive functions as that being targeted by CCR; near-transfer effects. The attentional studies utilised attention-focused test batteries, subtests and stand-alone tests, as well as an attention deficit questionnaire, whilst the WM studies utilised WM subtests and stand-alone WM tests.

Far-transfer. Five studies utilised cognitive assessments and/or questionnaires that assessed unrelated cognitive functions; far-transfer effects. Studies assessed a range of different untrained cognitive functions, for example two studies assessed general cognitive functioning, two tested participants' inhibition, one study assessed participants' executive functioning and another their reasoning ability. Two studies assessed changes in participants' cognition through questionnaires; one study of general cognitive functioning and another of executive functioning. Additionally, four studies used self-report functioning/wellbeing questionnaires to assess wider training effects on participants' functioning, for example evaluating mood and quality of life.

In conclusion five studies utilised only near-transfer tasks, and one study utilised only trained and near-transfer tasks when evaluating the effective of CCR, thus six studies did not explore far-transfer effects. Only two studies utilised trained, near-transfer and far-transfer tasks, exploring the full array of training effects.

Timing of CCR

To ascertain at what point during rehabilitation CCR has been demonstrated to be effective, time post-ABI was examined across the 11 studies. Participants from the 10 studies with adequate reporting (Lundqvist et al., 2010 did not provide inadequate information about time post-ABI) were in either the post-acute (i.e. less than 12 months post-ABI) or chronic (i.e. more than 12 months post-ABI) stage of recovery, ranging from two weeks to 50 years post-ABI. Six studies recruited participants in the post-acute stage, however only one of these studies only recruited participants in this stage (Prokopenko et al., 2013), whilst the remaining five studies (Akerlund et al., 2013; Fernandez et al., 2012; Sturm et al., 2003; Sturm et al., 2004; Westerberg et al., 2007) also recruited participants in the chronic stage. In contrast four studies exclusively recruited participants in the chronic stage, with three of these studies recruiting participants over 240 months post-ABI (Li et al., 2013; Lojek & Bolewska, 2013; Zickefoose et al., 2013).

Although eight studies recruited participants in both post-acute and chronic stages, no studies compared the effectiveness of CCR across these stages. Furthermore, no studies discussed the confounding effects of natural recovery, which is likely to be greater in the post-acute phase. Two studies investigated whether time post-ABI had an influence on CCR outcome; Li et al., (2013) recruited participants from 4 to 50 years post-ABI and demonstrated that years post-ABI was not significantly correlated with improvement on Cognistat attention subtests; near-transfer tasks. Similarly, Westerberg et al., (2007) established that time post-stroke was not significantly correlated with performance on a range of WM, inhibition, abstract reasoning and memory tests; near and far-transfer tasks. As these two studies were of high and medium quality, their combined findings suggest that time post-ABI may not have a significant influence on CCR outcome. Furthermore, the small number of reported drop outs in only two studies; nine in Akerlund et al., (2013) and three in Westerberg et al., (2007), demonstrates that participants in varying stages of recovery were able to complete CCR.

Amount and Intensity of CCR

To ascertain how many CCR sessions have been demonstrated to be effective in improving participants' cognition, the amount and intensity of CCR completed in each study was examined. All studies provided details on the length and number of training sessions, and number of weeks trained, enabling calculation of the total minutes trained and minutes trained per week (summarised in appendix C**).**

Amount. A large variation in the amount of CCR completed by participants was demonstrated across the 12 studies; length of training sessions varied from 30 to 60 minutes, number of training sessions from 8 to 60 and total minutes trained from 420 to 3000. Fernandez et al., (2012) trained participants significantly longer than any other study (3000 minutes), whereas Prokopenko (2013) only trained participants for 420 minutes, significantly less than most studies. Fernandez et al's longer training time cannot be accounted for by their training including both memory and attentional exercises, as Prokopenko et al., included visuo-spatial and attention retraining exercises over a shorter time period.

Due to differences in methodological quality of the two studies and because Fernandez et al., only utilised near-transfer tasks, whereas Prokopenko et al., only utilised trained and far-transfer tasks, it was not appropriate to compare and contrast the findings of the two studies to evaluate whether training participants for longer influenced CCR outcome. However, the large variation in the amount of CCR completed by participants does indicate that exploration of optimal training time would be possible.

Intensity. Similarly, a wide variation in the intensity of CCR training was established; number of weeks trained varied from 2 to 15 and number of minutes trained per week varied from 96 to 280. Three studies (Fernandez et al., 2012;

Lundqvist et al., 2010; Sturm et al., 2003) trained participants intensively for 250, 262.5 and 280 minutes per week, whereas two other studies (Li et al., 2013; Lojek & Bolewska, 2013) only trained participants for 96 and 120 minutes per week.

However, due to the ‘intense’ and ‘less intense’ studies being of varying methodological quality, employing varying trained, near-transfer and far-transfer tasks and covering attention and WM CCR, it was not appropriate to compare and contrast their findings to evaluate whether training participants more intensively influenced CCR outcome. However, the variation in the intensity of CCR completed by participants does indicate that exploration of optimal training intensity is possible.

Discussion

The present review described the evidence from 11 CCR studies that aimed to retrain aspects of executive functioning of individuals with ABI. Only studies exploring the CCR of attention and WM were identified in this search of the current CCR literature, indicating that CCR of other aspects of executive functioning may yet need to be investigated.

Study Findings

Attention. Eight studies investigated the CCR of attention, however as two studies did not define which components of attention they retrained and one study simultaneously retrained a collection of attention components, only five studies attempted to discretely retrain theoretically defined components of attention. Consequently, the retraining of each attentional component was inadequately explored by only one or two studies. Furthermore, the majority of studies only examined the effectiveness of CCR on participants’ scores on trained and/or near-transfer tasks, only two studies explored far-transfer effects thus any conclusions regarding the utility of attention retraining were limited to direct training and near-transfer effects.

Despite a few studies demonstrating promising improvements of a few attention components following CCR (i.e. alertness, focused and divided attention), such findings were undermined by the poor methodological quality of the studies, detection of spontaneous recovery during baseline and inconsistencies in outcomes (improvements revealed on only some outcome measures, not all). Consequently, it was not possible to make any conclusions about whether CCR is an effective method of rehabilitating attention post-ABI.

WM. Three high quality studies investigated the retraining of WM and their findings carry more weight as they presented fewer methodological limitations. The three studies all employed the same CCR programme indicating that the same aspects of WM were targeted in each study, enabling direct comparison of findings. Furthermore, all three studies evaluated outcome of CCR on near-transfer and far-transfer tasks, enabling a more comprehensive investigation of the cognitive and functional improvements following CCR of WM.

The three studies demonstrated significant improvements on a variety of measures following CCR; all revealing significant improvements on near-transfer tasks (tests of WM), two studies demonstrated significant improvements in participants' attention and single studies demonstrated improvements in participants' general cognitive functioning, self-reported cognitive functioning, mood, occupational functioning and health status. However, on two occasions significant findings were not consistently achieved i.e. one study did not reveal significant improvements in spatial span whilst the other two studies did, and one study revealed significant improvements in participants' inhibition whilst another study did not. Such inconsistencies indicate that positive findings may not be replicable.

Overall, the three studies demonstrated promising findings that WM can be retrained following ABI and that training may positively impact participants' wellbeing and functioning, however these findings are only based on three small studies and will need replication.

Evaluating the effectiveness of CCR. Examination of the outcome measures utilised across the 11 studies revealed that researchers are currently deploying a wide range of reliable and valid cognitive assessments and self-report questionnaires to evaluate CCR outcome. However, the majority of these outcome measures are measuring changes in participants' performance on near-transfer tasks; over half of the researchers did not deploy any measures of far-transfer effects. Only two studies utilised the full range of measures (trained, near-transfer and far-transfer) enabling comprehensive evaluation of CCR outcome. Given Wilson's call for quality of life to be monitored following rehabilitation (2007), surprisingly only three studies assessed participants' functioning and/or quality of life following CCR. Wider assessment of the benefits of CCR appears needed.

Timing of CCR. Despite participants from both post-acute and chronic stages of recovery being recruited across the 11 studies, no studies directly compared the outcomes of these two populations. Two studies of high and medium quality did explore the impact of time post-ABI on cognitive outcomes, tentatively suggesting time post-ABI does not have an effect on outcome. Furthermore, low dropouts across the 11 studies suggest that participants of varying stages of recovery can successfully complete the training and therefore potentially benefit. However, further investigation is required to enable better awareness of what point during rehabilitation CCR programmes are the most beneficial for patients.

Amount of CCR. None of the 11 studies explored whether the number of CCR sessions or the intensity of these sessions had an impact on outcome. Across the 11 studies a wide range of training protocols were being implemented with little explanation as to why, in order for clinicians to design treatment regimes more detailed explanations are required.

Clinical Implications

Many questions remain about the utility of CCR in the rehabilitation of executive functioning. Evidence from three WM studies suggests that WM can be improved through CCR and possibly trigger wider cognitive improvements. If such findings can be replicated this would first suggest that it may be possible to improve the cognition of individuals with ABI by implementing a computerised intervention that involves less clinician input than traditional interventions. Second, if CCR is demonstrated to be an effective rehabilitation technique this would also reinforce the idea that restitution of cognitive abilities is possible following an ABI, and would support the theory of neural plasticity.

Recommendations

Studies of high methodological quality are required to further investigate whether CCR is an effective method of rehabilitating executive functioning in an ABI population. Specifically studies with larger sample sizes, utilising random sampling and randomisation to intervention or control group. One methodological limitation that affected the majority of the included studies was the lack of control for spontaneous recovery and test-retest effects, which could be accounted for by monitoring a stable baseline period or recruiting an active control group.

To enable better understanding of the clinical utility of CCR programmes future CCR studies should first include analyses of the effect of time post-ABI, possibly comparing the outcomes of patients in the early stages of recovery with patients many years post-ABI. This would enable clinicians to better ascertain whether CCR programmes would be appropriate for their patients. Second, investigation of whether the intensity of CCR influences training outcome would be useful, by comparing intense and less intense CCR programmes. This would enable design of evidence-based CCR training protocols.

Third, future studies should explore whether the severity of a patient's cognitive difficulties will influence their ability to engage with CCR programmes. There was no exploration as to whether participants needed a specific level of cognitive functioning to engage with or benefit from CCR. This could be explored in future studies by recruiting patients of varying levels of impairment and examining their respective gains from CCR. Lastly, if CCR packages are to be worthwhile and cost effective they need to be demonstrated to have far-transfer effects and have a meaningful impact on patients' quality of life, as improvements on test scores mean little to a patient if such improvements do not transfer to their everyday difficulties. It is therefore reasonable to recommend that future studies of CCR explore wider training effects to ascertain the broader benefits of CCR both cognitively, but also in terms of patient functioning and quality of life.

Limitations

The main limitation of this review was the small number of poor quality studies identified to examine the research question, a reflection of state of the current CCR evidence base. The 11 studies identified were heterogeneous in terms of CCR programme, timing of CCR, amount of CCR and outcome measures utilised to measure effectiveness of CCR, which made a systematic review of the evidence limited. Due to the heterogeneity of the CCR literature a narrative review may have been more appropriate to depict the emergence of this diverse evidence-base.

Conclusion

The present review demonstrated that there is insufficient evidence to evaluate whether CCR is an effective way of rehabilitating executive functioning in patients with ABI, due to the small number and poor quality of the studies. Consequently, no conclusions can be drawn about the effectiveness of retraining attention and only tentative conclusions can be made which suggest that WM can be retrained following ABI. The secondary aims of the review were also poorly realised as it was not possible to reliably ascertain from the 11 studies whether time post-ABI, and/or the amount and intensity of CCR influences outcome. It was however possible to conclude that researchers are heavily relying on near-transfer tasks to evidence the effectiveness of CCR and are not readily exploring far-transfer tasks.

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Research Report

Is digit span a predictor of attention and executive functioning in adults with acquired brain injury? Implications for working memory training

Abstract

Working memory (WM) training involves patients repeatedly completing simple WM tasks similar to digit span (DS), a task which entails recalling a string of digits, forwards and backwards. Following intensive WM training some improvements in patients' WM and high-order cognitive abilities (i.e. attention and executive functioning) have been demonstrated, proposed to be due to training stimulating the high-order components of WM also involved in attentional and executive processes. However, numerous researchers contend that DS does not adequately stimulate the high-order components of the WM system and therefore training exercises analogous to DS are unlikely to result in the reported improvements. This study aimed to provide neuropsychological evidence regarding the relationship between participants' DS, attention and executive functioning. Neuropsychological assessment scores of 94 patients who had suffered an acquired brain injury were statistically analysed. Specifically examination of whether DS performance predicted performance on a range of attention and executive functioning measures was undertaken. Analyses demonstrated that participants' scores on the backwards DS task significantly predicted a range of their attentional scores and their performance on a test of inhibition, whilst their performance on the forward DS task did not. Consequently, WM training that entails tasks similar to backward DS could potentially result in improvements of both attentional and inhibitory abilities.

Practitioner points:

- Training patients' DS could lead to improvements in their attentional abilities and inhibitory control.
- WM training exercises similar to backwards DS are potentially the most effective at facilitating improvements in attentional and inhibitory abilities.
- Clinicians should report patients' DSF and DSB scores separately as evidence suggests they measure different cognitive constructs.

Baddeley and Hitch's (1974) well-known conceptualisation of WM specifies that it is a temporary mental workspace, limited in its capacity, used to hold and manipulate information in short-term memory (STM); verbal information in the 'phonological loop' and visual in the 'visuospatial sketchpad'. See appendix D for a diagrammatic representative of this model. These two storage systems are thought to be supervised and coordinated by the 'central executive', an attentional control system which directs attention towards specific information, controls the flow of information, filters out irrelevant information, ignores interference and manages conflicting information (Engle, 2002; Morrison & Chein, 2011); high-order processes sometimes referred to as 'executive attention' (Engle & Kane, 2004). WM tasks can be categorised as either being simple, when they only activate one of the storage systems or complex, when they stimulate the central executive and one or more of the storage systems. Consequently, an individual's WM not only represents the amount of information they can temporarily store (their WM capacity), but also aspects of their high-order cognitive processing. The executive, attentional processes of the central executive are believed to be closely related to and integral to other executive functions (Baddeley, 1996), which are further described. Both executive functions and attention are accepted to be multifactorial constructs, for convenience and brevity only a few conceptualisations are described.

Executive functions are a group of high-order regulatory cognitive processes that supervise, coordinate and control the deployment of a wide range of lower level cognitive functions (Coolidge & Wynn, 2005; Cicerone, Levin, Malec, Stuss & Whyte, 2006). They include decision making, inhibition, planning, problem solving and reasoning (Chan, Shum, Toulopoulou & Chen, 2008). Sohlberg and Mateer (2001) conceptualise six components of executive functioning: (a) initiation and drive, (b) inhibition (the ability to ignore and override automatic or habitual responses; Aron, 2007), (c) maintenance of behaviour, (d) organising and sequencing, (e) thinking flexibly and creatively, and (f) monitoring and modifying behaviour. These high-order cognitive processes are required for effective everyday functioning, for example to engage in social conversations, manage household tasks and finances and attain career goals (Gross & Grossman, 2013).

Attention enables the processing of information from the environment, Posner and Boies (1971) propose there are three neural attentional networks; the alerting system (becoming and staying aware of the environment), orienting system (directing attention to specific stimuli in the environment) and the executive system (managing conflict between stimuli, switching between stimuli or ignoring stimuli). Posner and Boies' executive network has been closely related to Baddeley and Hitch's central executive. Clinical models of attention, for example Solhberg and Mateer's (2001) also refer to executive attentional processes i.e. selective (selecting information to attend to), switching (shifting focus between information sources) and divided (simultaneously processing information) attention, which collectively can be termed as 'executive attention'.

Consequently, WM (particularly the central executive) has been demonstrated to be closely related to both attention and executive functioning; for example attentional control (Kane, Bleckley, Conway & Engle, 2001), executive control (Kane et al., 2007), fluid intelligence; the ability to reason and think logically (Engle, Tuholski, Laughlin & Conway, 1999; Colom, Abad, Rebollo & Shih, 2005; Kane et al., 2004) and problem solving skills (Hambrick and Engle, 2003).

WM

Impairment of WM is one of the most common types of cognitive dysfunction following acquired brain injury (ABI; Lundqvist, Grundstrom, Samuelsson & Ronnberg, 2010); an impairment demonstrated to have a detrimental impact on return to functioning (Spitz, Ponsford, Rudzki & Maller, 2012). This is predominantly due to the architecture of the skull, the frontal lobes of the brain are especially vulnerable to damage in traumatic brain injury (TBI; Cicerone et al., 2006). These areas of the brain are heavily involved in executive functions (Stuss & Levine, 2002), including attentional control and WM.

Encouragingly, research has revealed that rehabilitation of WM may be possible, a recent review demonstrated tentative evidence that WM responds well to restitutory techniques (Davison, 2014), where patients repeatedly complete exercises that stimulate their WM system; forcing damaged WM functions to work again (das Nair & Lincoln, 2012). Morrison and Chein (2011) note that effective WM training should include tasks that target and stimulate the central executive; tapping multiple modalities, adapting difficulty, requiring a high cognitive workload, involving maintenance of information with interference and including rapid information processing, thus requiring high-order processing. Consequently, effective WM training could potentially not only improve an individual's capacity to temporarily hold and manipulate information in their STM, but also enhance their central executive, thus their high-order, executive processing.

Cogmed. As WM training has shown promise, commercial training packages have been developed. A group of Swedish researchers developed a commercially available computerised WM training software programme called 'Cogmed'. Cogmed training involves the completion of a variety of on-screen visuospatial WM tasks i.e.

remembering the positioning of sequential stimuli and then reproducing the stimuli in the same order, reverse order or after the stimuli had been rotated, as well as verbal WM tasks i.e. remembering the sequences of letters or digits forwards and/or backwards (Lundqvist et al, 2010). Consequently, Cogmed training predominantly trains individuals on simple span tasks which put increasing demands on WM capacity, with only a few complex WM tasks that may stimulate the central executive.

Over the past ten years there has been exploration of the effectiveness of Cogmed training in a wide range of populations across the lifespan; healthy children and adolescents (Thorell, Lindqvist, Bergman, Bohlin & Klingberg, 2009); children with WM problems (Dunning, Holmes & Gathercole, 2013); children and adolescents with ADHD (Holmes et al., 2010; Klingberg et al, 2005); healthy adults (Brehmer, Westerberg & Bäckman, 2012); older adults (Brehmer et al., 2011); and adults with ABI (Johansson & Tornmalm, 2012; Lundqvist et al., 2010; Westerberg et al., 2007). Following Cogmed training researchers have demonstrated improvements in individuals' WM capacity, as measured predominantly by performance on simple WM span tasks (Brehmer et al, 2011; Brehmer et al., 2012; Klingberg et al, 2005; Thorell et al, 2009; Westerberg et al, 2007) and less frequently on complex WM tasks (Dunning et al, 2013; Holmes et al, 2009; 2010; Lundqvist et al, 2010). Furthermore, improvements have been demonstrated in individuals' high-order cognitive functioning following Cogmed training, for example their attention (Brehmer et al, 2012; Lundqvist et al, 2010; Thorell et al, 2009; Westerberg et al, 2007), inhibition (Klingberg et al, 2005) and reasoning (Klingberg et al, 2005), such transfer effects to high-order cognitions have been hypothesised to be due to the training stimulating the central executive (Brehmer et al, 2012).

However, numerous researchers are sceptical about the proposed benefits of WM training (Hulme & Melby-Lervag, 2012; Shipstead, Hicks & Engle, 2012). First, there is increasing unease about the methodological limitations of the Cogmed evidence-base: poor research designs (Hulme and Melby-Lervag, 2012); inadequate description of training (Jaeggi Buschkuehl, Jonides & Shah, 2012); and use of non-adaptive control groups (Jaeggi et al, 2012; Shipstead et al., 2012). Second, Jaeggi and colleagues (2012) raised specific concerns about the lack of understanding as to why improvements in other cognitive functions occur following Cogmed training and are dissatisfied with the unfounded speculations currently being made. These researchers emphasise the need to identify and understand the underlying mechanisms of Cogmed training. Third, Shipstead, Hicks and Engle (2012) question the overreliance on simple WM tasks similar to those included within Cogmed training to evaluate the training as this poses significant problems in terms of confounding practice effects. Consequently, Shipstead and colleagues (2012) advise against just using simple WM tasks and emphasise the need for a wider variety tasks, and of more complex WM tasks to be utilised in the evaluation of Cogmed training.

Digit Span (DS)

The majority of exercises in Cogmed are similar to DS (a simple WM task), one of the most commonly utilised WM assessment tools (Lezak, Howieson & Loring, 2004). The DS subtest from the Wechsler Adult Intelligence Scale (Third Edition; WAIS-III; Wechsler, 1997) is frequently applied in clinical and research practice (Hester, Kinsella & Ong, 2004). It involves individuals first repeating a string of digits that gets progressively longer, representing their digit span forward (DSF). Second, repeating a string of digits in reverse order, representing their digit span backward (DSB) (Baddeley, 1992; Wechsler, 1997). Miller’s law (1956) argues that on average individuals can only hold seven digits in their WM (plus or minus two), thus the average DSF should be around seven. Black (1986) demonstrated in an ABI population an average DSF of 5.9 and DSB of 4.0. Research has demonstrated that WM tasks are associated with individuals' general intellectual functioning (Conway, Kane & Engle, 2003), age (Hester et al., 2004) and mood (Chepenik, Cornew & Farah, 2007).

However, there has been some debate as to whether DS measures a unitary construct or two different constructs, as it has been demonstrated that DSF is representative of STM i.e. measuring the capacity of their phonological loop, whilst the DSB is more representative of WM i.e. high-order executive control, measuring the function of the central executive (Glisky, Polster & Routhieaux, 1995; Hale, Hoeppner & Fiorello, 2002). Furthermore, some researchers are of the opinion that simple WM tasks such as DS do not adequately stimulate the central executive, as they place fewer demands on attentional control (Engle, 2002) and allow individuals to chunk information as they are not processing other information (Cowan, 2005), therefore Daneman and Carpenter (1980) suggest that DS does not effectively measure WM. Coincidentally, or as a result of this debate, Wechsler has recently introduced an additional component to the WM subtest of the WAIS-IV (Wechsler, 2008), 'Digit Sequencing' which entails repeating in ascending order a sequence of digits that gets progressively longer. Wechsler argue the inclusion of Digit Sequencing will enhance the assessment of WM, presumably by stimulating the central executive more effectively.

Due to doubts about the validity of simple WM tasks for assessing WM many researchers instead employ more complex WM tasks, such as the reading span (Daneman & Carpenter, 1980), operation span (Daneman & Carpenter, 1980), counting span (Case, Kurland & Goldberg, 1982) and rotation span tasks (Shah & Miyake, 1996); dual tasks where individuals receive stimuli to be recalled alongside another unrelated attention demanding task (Schmiedek, Hildebrandt, Lövden, Lindenberger & Wilhelm, 2009). Complex WM tasks have been demonstrated to be closely associated with fluid intelligence, managing interference and inhibition, sustainment of goals and distractibility (Engle, 2002), thus are believed to more effective at measuring the functioning of the central executive (Lehto, 1996). Furthermore, McCabe, Roediger, McDaniel, Balota and Hambrick (2010) demonstrated that complex WM task scores were correlated with executive functioning scores in adults, suggesting that complex WM and executive functioning tasks assess a common underlying construct i.e. executive attention.

The abovementioned findings pose a significant problem for Cogmed training, specifically whether the simple WM tasks privileged within the training adequately stimulate the central executive of WM and are therefore likely to result in the proposed improvements of high-order cognition. Few researchers have explored whether individual's DS performance is related to their performance on measures of executive functioning, thus indicating whether it adequately taps into the 'executive' aspects of WM. Two studies to date have explored the relationship between children's DS scores with measures of their attention and executive functioning; Rosenthal, Riccio, Gsanger and Jarratt (2006) did not demonstrate correlational or predictive relationships between DS scores and parental ratings of attention and executive functioning. Conversely, Hale, Hoeppner and Fiorello (2002) demonstrated that children's DSB scores were predictive of their attention and executive functioning scores, but not their DSF scores. Consequently, there is ambiguity as to whether DS performance predicts attention and executive functioning.

Present Study

The present study aimed to investigate whether the reported improvements of high-order cognition following Cogmed WM training e.g. attention (Brehmer et al, 2012; Lundqvist et al, 2010; Thorell et al, 2009; Westerberg et al, 2007) and executive functioning (Klingberg et al, 2005) are supported by neuropsychological evidence. Specifically, an investigation was conducted to assess whether DS, the focus of many Cogmed training exercises, is associated with measures of attention and executive functioning, enabling an evaluation of whether training analogous to DS could facilitate improvements in these high-order cognitions.

An investigation was conducted to assess whether participants' DS performance correlates with and/or predicts their performance on a range of attention and executive functioning measures. However, as evidence suggests that DSF is representative of STM functioning, whilst DSB is representative of WM capacity, an examination was also conducted to assess whether participants' DSF and DSB performances correlates with and/or predicts their attention and executive functioning performances to a similar degree.

Based on the evidence from the aforementioned WM literature, two main research hypotheses were advanced:

- Hypothesis 1: Participants' DSF performance will not correlate with or predict their performance on attention and executive functioning measures.
- Hypothesis 2: Participants' DSB performance will correlate with and predict their performance on attention and executive functioning measures

Method

Design

A database of routinely collected neuropsychological assessment scores was accessed. Data were extracted and entered into correlation and multiple linear regression analyses.

Participants

All participants were patients discharged from the Neuropsychology service at Sheffield's Royal Hallamshire Hospital following routine neuropsychological assessment. Neuropsychological assessments were utilised for diagnostic purposes and to identify cognitive strengths and weakness to focus rehabilitation techniques.

Inclusion and Exclusion Criteria

All participants were over 18 years of age and had either sustained a brain injury, received a diagnosis of neurological pathology or were undergoing investigations for a neurological disorder that was affecting their cognitive functioning. Included patients were allocated to one of nine assessment clinics depending on their diagnosis and/or treatment: deep brain stimulation (DBS; which is carried out for a range of movement disorders including Parkinson's disease, dystonia and tremor); epilepsy surgery; epilepsy non-surgery; general neurology (GN; miscellaneous neurological conditions); memory impairment and/or dementia (M&D); multiple sclerosis (MS); neuro-oncology (N-Onc); neuro-surgery; and sub-arachnoid haemorrhage (SAH). Patients allocated to a 'query organic' clinic, whose cognitive complaints were hypothesised to be due to functional aetiology were excluded. All participants included in correlation and regression analyses had completed all of the neuropsychological assessments of interest, with complete and available test scores.

Procedure

An electronic database containing anonymous pre-collected data from the Neuropsychology service was accessed, containing demographic details of all patients discharged from the service over the past four years i.e. age, gender and clinic allocated to, indicating the probable aetiology of their cognitive difficulties. If a neuropsychological assessment was performed, the database contained patient's raw test scores on a range of neuropsychological assessments and mood questionnaires; selected, completed and scored by the assessing Clinical Psychologist. A comprehensive neuropsychological assessment would ordinarily involve the assessment of intellectual functioning, attention, memory, language, executive functioning and visuospatial skills.

Starting at the most recent data recorded in June 2014 and working backwards, data was extracted until a sample size of at least 77 was achieved. This sample size was estimated through a priori power analysis calculated using linear regression settings in GPower, using a moderate effect size (0.50) and up to 10 predictor variables. Participant datasets that did not include the neuropsychological assessment scores of interest were excluded from the correlation and regression analyses, but were collated to enable comparison of the included sample with the excluded sample, in terms of participant characteristics.

Measures

Neuropsychological assessments of WM, attention and executive functioning were selected to enable the study's hypotheses to be investigated, as well as those assessing IQ and mood. Test selection was restricted by those readily available and regularly used in the Neuropsychology service as part of routine clinical practice. A number of measures initially chosen were not included due to it becoming evident during data extraction that clinicians did not regularly utilise them. Selected measures were known to be reliable and valid measures of the constructs of interest. The following measures were included:

WM. The DS subtest from the WAIS-III (Wechsler, 1997) was selected as a measure of participants' WM, enabling the assessment of participants' longest DSF and DSB, as well as total DS score; DST. The WAIS-III has been thoroughly scrutinised and demonstrated to have high reliability and validity, and robust normative data (Garland, 2005; Silva, 2008). The newer fourth edition of the WAIS (WAIS-IV; Wechsler, 2008) had only recently been introduced to the Neuropsychology service thus few patients were likely to have been assessed on it. Consequently, the WAIS-IV DS subtest was not selected as a measure of participants' WM.

Attention. Four subtests from Test of Everyday Attention (TEA, Robertson, Ward & Ridgeway, 1994); elevator counting (EC), elevator counting with distraction (ECD), telephone search (TS) and telephone search dual task (TSC) were selected as measures of participants' attention. Descriptions of the components of attention each subtest assessed are based on a factor analysis described in the TEA manual. EC involves counting auditory tones, thus raw scores represent participants' auditory sustained attention (maintaining attentional focus); ECD involves counting low pitched auditory tones whilst ignoring high pitched tones, representing participants' auditory selective attention; TS involves identifying symbols in a telephone directory, representing participants' visual selective attention; TSC involves identifying symbols in a telephone directory whilst counting auditory tones, representing participants' divided attention. Therefore, three of the selected TEA subtests assessed executive aspects of attention as per Sohlberg and & Mateer's model (2001). The TEA "is the only test of attention that gives a broad overview by breaking attention down into theoretically distinct factors" and has been demonstrated to be reliable and valid (McAnespie, 2001, p. 55).

Executive functioning.

Delis Kaplan Executive Function System (DKEFS). Two subtests from the DKEFS (Delis, Kaplan & Kramer, 2001); Letter Fluency, and Category Fluency, were selected as measures of participants' executive functioning. Both Letter and Category Fluency assess participants' abilities to retrieve specific words from phonetic and sematic memory respectively, requiring planning, monitoring, judgment, decision-making, inhibition of irrelevant information and selection of the correct responses (Oria, Costa, Lima, Patrick & Guerrant, 2009). Letter Fluency raw scores demonstrate how many words beginning with F, A and S participants were able to generate in three one-minute segments respectively, whilst Category Fluency raw scores demonstrate the number of animals and boys names they could generate in two one-minute segments. However, clinicians frequently utilised a stand-alone Animal Fluency and omitted the boy names section, consequently participants' raw scores on the animal component of the DKEFS Category Fluency subtest was utilised alongside the stand-alone Animal Fluency measure, creating a new Animal Fluency variable. The reliability and validity of the DKEFS test battery has been thoroughly explored and demonstrated (Delis, Kramer, Kaplan & Holdnack, 2004).

Hayling Sentence Completion Test (Hayling). The Hayling Test (Burgess & Shallice, 1997) was also selected as a measure of participants' executive functioning; a measure of participants' response speed and inhibition, comprised of two sections; Hayling 1 and Hayling 2. However, only participants' scores on Hayling 2 are representative of the abovementioned executive functions; where participants complete sentences with words that make no sense in the context of the sentence. Hayling 2 produces two raw scores of interest; time taken and number of errors made e.g. how many times they failed to suppress the sensible response, creating two variables; Hayling Time and Hayling Errors. The Hayling has been demonstrated to be a reliable and valid assessment of dysexecutive syndrome, synonymous with executive dysfunction (Burgess & Shallice, 1997).

Intelligence. The WAIS-III (Wechsler, 1997) or the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999) were selected as measures of participants' IQ. The WAIS-III and WASI provide an estimate of an individual's IQ between 40 and 130, an average IQ is between 90-110, a superior IQ above 120 and an impaired IQ below 70. Due to the WAIS-III being a long assessment many clinicians use shorter versions like the WASI, but there are also pro-rated short-forms, most notably compiled by Crawford, Allum and Kinion (2008). The Crawford short-form involves the completion of seven of the ten WAIS-III subtests, demonstrated to reliably estimate IQ (Crawford et al., 2008; Girard, Axelrod & Wilkins, 2010). The Crawford short-form was readily utilised in the Neuropsychology service and was therefore also accepted as a measure of participants' IQ.

Mood. The Generalised Anxiety Disorder 7-item Scale (GAD-7; Spitzer, Kroenke, Williams & Löwe, 2006) and Physical Health Questionnaire (PHQ-9; Kroenke, Spitzer & Williams, 2001) were selected as measures of participants' mood. The GAD-7 and PHQ-9 are widely used measures of anxiety and depression, both found to have good reliability and validity (Kroenke et al., 2001; Spitzer et al, 2006). The GAD-7 is scored between 0-21, with scores over 8 indicative of clinically significant anxiety, whilst the PHQ-9 is scored between 0-27, with scores over 10 suggestive of clinically significant depression.

However, the Neuropsychology service used to administer the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) to assess patients' mood, so it was also accepted as a measure of participants' mood. The HADS consists of seven items relating to the HADS anxiety sub-scale and seven to the HADS depression sub-scale. Each sub-scale is scored between 0-21, with scores over 10 suggestive of clinical caseness. The HADS is a widely used measure of anxiety and depression, found to have good reliability and validity (Bjelland, Dahl, Haug & Neckelmann, 2002). Participants therefore had completed either the HADS, or the GAD-7 and PHQ-9, not both. In order to include both the GAD-7 and PHQ-9, and the HADS as assessments of mood, clinical cut offs were utilised and participants described as either having clinically significant anxiety and depression or not; creating two dichotomous mood variables.

For the majority of the selected measures a high score represented greater ability, for example higher IQ represented greater intelligence. However, for a few measures; the TS, TSC, Hayling Time, Hayling Errors and mood questionnaires the converse was true; a low score indicated greater ability or wellbeing, for example faster reaction time, fewer errors and fewer mood symptoms. This influenced the nature of the relationship these measures had with other variables i.e. a negative relationship.

Ethics

Patient consent was not required in the present study as only anonymised pre-collected data was used; no patient identifiable data was accessed. Furthermore, NHS ethical approval was received from NRES Committee North East - Newcastle

& North Tyneside 2 (see appendix E) and research governance approval from Sheffield Teaching Hospitals NHS Foundation Trust.

Statistical Analysis

First, significant differences between the included and excluded samples were assessed for, in terms of age, gender, clinic, anxiety, depression, IQ and DS scores. Assumption of normality was judged using histograms, skewness and kurtosis statistics (over 1.96), Shapiro-Wilk statistics (at $p < .05$), and equality of variance was evaluated using Levene's test (at $p < .05$). When one or more of these indicators revealed a non-normal distribution Mann-Whitney tests were utilised, otherwise independent sample t-tests were used. Chi-squared tests were performed on categorical variables i.e. gender, clinic, anxiety and depression. To ease analysis the clinic categories were collapsed from nine to six clustering smaller clinics based on similarity of neurological pathology. The six clinics were: Epilepsy (including epilepsy surgery and non-surgery clinics), GN, M&D, MS, N-Onc and Vascular (including DBS, neuro-surgery and SAH clinics).

Second, Pearson's correlations were utilised to explore the relationships between the variables; chiefly the correlations between the eight attention and executive functioning criterion variables, and DSF and DSB (two predictor variables) as well as the five confounding variables; age, gender, anxiety, depression and IQ. When assumptions of normality were not met (as described above), Spearman's rank order correlations were used. Inter-correlations were also calculated to explore the relationships between the eight criterion variables, two predictors and five confounders, this enabled identification of potential multicollinearity (significantly correlated predictors). As multiple tests were conducted on the same dataset, to control for increased risk of type 1 errors, correlations were conservatively interpreted using a Bonferroni correction; p values were divided by the number of comparisons made on each variable.

Third, each criterion variable (EC, ECD, TS, TSC, Letter Fluency, Animal Fluency, Hayling Time and Hayling Errors) was entered into a multiple linear regression model, with the two predictors (DSF and DSB), five confounders (age, gender, IQ, anxiety and depression) and other potential predictors (either attention or executive functioning variables).

Entering of variables. Due to the exploratory nature of the present study all possible combinations of predictors were explored to reveal the unknown effect of DSF and DSB on attention and executive functioning scores. Thus a backward, stepwise selection method was chosen, enabling the data to direct the findings. Variables that improved the model most when removed were omitted and repeated until no further improvement of the model was possible (critical value of $p = .05$ was used for inclusion in the model). This method enabled examination of the study's two research hypotheses, whether DSF and DSB significantly contributed to the prediction of the criterion variables.

Model parameters. The "goodness of fit" of each model was reported first, with a significant F-ratio indicating significantly improved prediction of the criterion variable by fitting the model. Reported R^2 values revealed the variance of each criterion variable accounted for by the predictors, whilst Adjusted R^2 indicated the shrinkage of this value if the model was applied to a different population. Unstandardised regression coefficients revealed the change in the criterion variable associated with a one unit increase in each predictor, when all other predictor variables were held constant. The contribution of individual predictors was demonstrated by t statistics revealing whether they contribute to a significant change in R^2 and how much variance in the criterion variable each predictor accounted for (change in R^2). Additionally, results of mediation and moderation analyses between the final predictors was reported, these were performed using Hayes' PROCESS custom tool (Hayes, 2012).

Assumptions. Normality was visually judged by the appearance of histograms and scatterplots of standardised residuals, and independence of errors evaluated using the Durbin-Watson statistic (values significantly different from 2 indicative of correlated residuals). Inter-correlations were examined to highlight significantly correlating predictors labelled as measuring the same cognitive construct, indicating they were most likely measuring the same thing; these variables were removed leaving only the predictor that most highly correlated with the criterion variable. Additionally variance inflation factors (VIF) and their associated tolerance statistics were utilised to assess multicollinearity; with any VIF greater than 10, an average VIF significantly greater than 1, or a tolerance below 0.2 indicating highly correlating predictors.

Outliers. Casewise diagnostics were utilised to assess for outliers. More than 5% of the standardised residuals above or below 2 indicated potential bias, whilst greater than expected values on a number of statistics indicated influential cases; Cook's distance (values greater than 1), centred leverage (value three times the average leverage) and Mahalanobis distance (critical values obtained from chi-squared tables dependent on number of predictors in the final model).

Results

Ninety-four patients were included in the study from a total of 1299 patients discharged from the Neuropsychology service between January 2010 and June 2014. Although 1044 (903 + 141) representative adult ABI patients were excluded for a variety of reasons (see Figure 1) their demographics, mood and cognitive assessment scores were collated to enable comparison of the included and excluded samples.

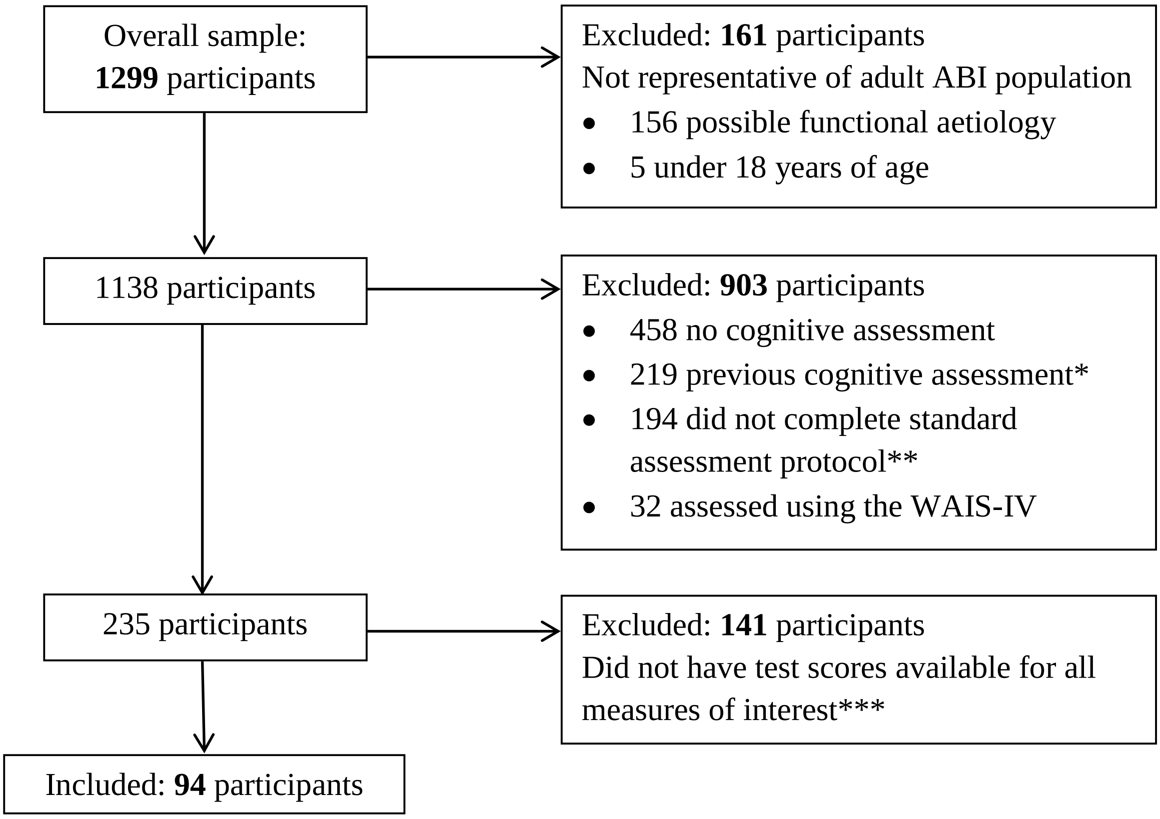

Figure 1: Process of participant selection

*Participants were excluded from the study if they had been previously assessed (prior to 2010), as they may have displayed practice effects in their more recent assessment. **Some participants were assessed by clinicians using non-standardised assessment protocols. ***These participants had undergone a comprehensive cognitive assessment, thus had at least IQ, DS and mood scores.

Descriptive Statistics

The included and excluded samples were compared to identify any significant differences in terms of demographics (see Table 1), mood and cognition (see Table 2).

Table 1

Descriptive statistics of age, gender and clinic

Sample	*N*	Age (years)	Gender		Clinic					
			M	**F**	**Epilepsy**	**GN**	**M&D**	**MS**	**N-Onc**	**Vascular**
Included	94	18-78 Mean 46.62 SD 13.46	45 47.9%	49 52.1%	16 17%	35 37.2%	15 16%	17 18.1%	4 4.3%	7 7.4%
Excluded	1044	18-86 Mean 53.32 SD 14.94	541 48.2%	503 51.8%	178 17.0%	145 13.9%	363 34.8%	112 10.7%	27 2.59%	219 21.0%

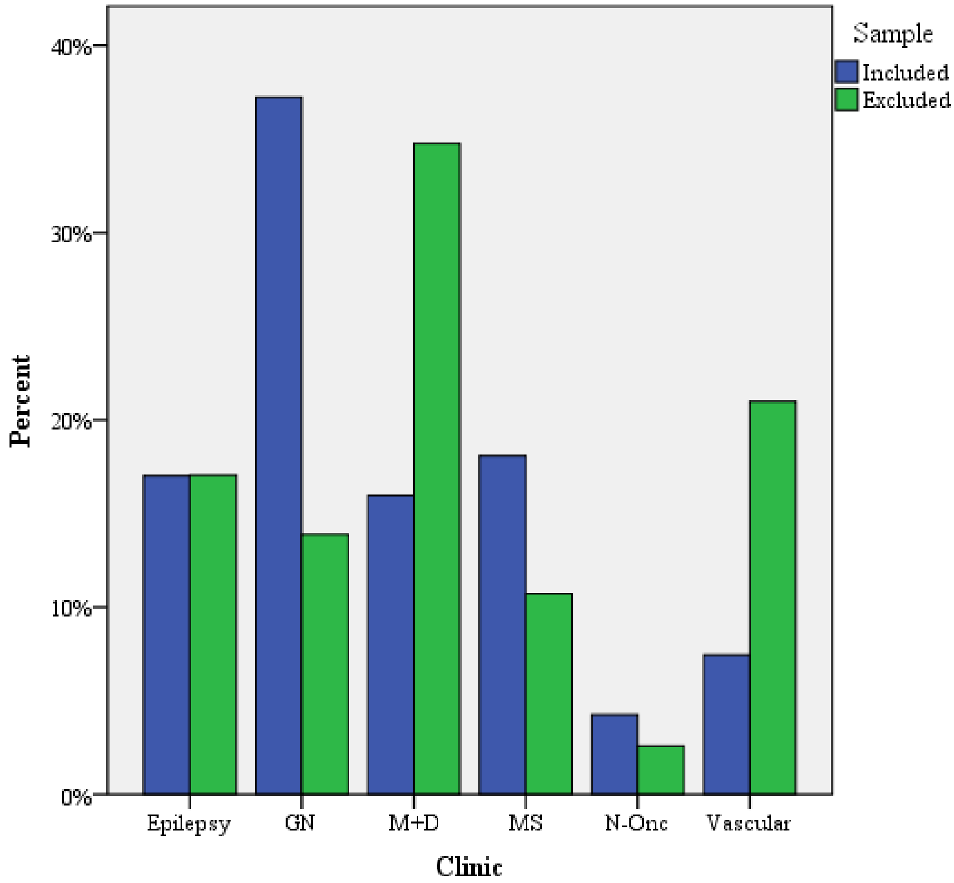

Figure 2. Percentage of participants per clinic, comparison of included and excluded samples

Age, gender and clinic. Neither samples' age distribution was normally distributed (included: skewness (1.98, *SE* = .25); excluded: skewness (-4.21, *SE* = .08), kurtosis (-2.97, *SE* = .15) and Shapiro-Wilk statistic (*S-W* = 0.98, $p < .001$)). Mann-Whitney demonstrated a significant difference between the age of the two samples ($U = 35211$, $p < .001$, $r = -.013$); excluded participants were significantly older than the included participants. No significant difference was demonstrated in the gender of the two samples ($X^2 = 0.58$, $p = .27$), both samples had almost equal numbers of males and females participants. Significant differences in the clinics to which participants were allocated was demonstrated between the two groups (X^2 =

51.85, $p < .001$), with higher numbers of GN participants in the included sample, and M&D and Vascular participants in the excluded sample (see Figure 2).

IQ, DS and mood. The variances of the two samples' IQ distributions were not equal ($F = 5.94$, $p = .02$); Mann-Whitney demonstrated no significant difference in IQ between the two samples ($U = 6365$, $p = .61$, $r = -.033$). Chi-squared test demonstrated no significant differences in the clinical levels of anxiety ($X^2(1,235) = 1.53$, $p = .22$) or depression ($X^2(1,235) = 0.73$, $p = .39$) between the two samples. No significant differences were demonstrated in DST scores between the two samples ($t(233) = 0.52$, $p = .60$). Both samples DSF scores were not normally distributed (included: $S\text{-}W = 0.90$, $df = 94$, $p < .001$; excluded: $S\text{-}W = 0.95$, $df = 141$, $p < .001$); Mann-Whitney demonstrated no significant difference of DSF scores between the two samples ($U = 6287$, $p = .50$, $r = -.045$). Lastly, both samples' DSB scores were not normally distributed (included: $S\text{-}W = .93$, $df = 94$, $p < .001$; excluded: skewness 3.24, $SE = .25$, $S\text{-}W = 0.92$, $df = 141$ $p < .001$); Mann-Whitney demonstrated no significant difference of DSB scores between the two samples ($U = 6125.50$, $p = .31$, $r = -.066$).

Attention and executive functioning measures. Table 3 summarises the included participants' scores on the four attention and four executive functioning variables of interest; criterion variables.

Table 2

Descriptive statistics of IQ, DS and mood

Sample	*N*	IQ	DS			Mood*	
			DST	DSF	DSB	Anxiety	Depression
Included	94	62-133 Mean 97.66 SD 14.61	7-24 Mean 14.97 SD 3.71	3-8 Mean 5.95 SD 1.16	2-7 Mean 4.44 SD 1.20	49 52.1%	46 48.9%
Excluded**	141	54-137 Mean 96.09 SD 18.32	3-27 Mean 14.69 SD 4.22	2-9 Mean 6.07 SD 1.43	2-8 Mean 4.31 SD 1.31	85 60.3%	61 43.3%

**number of participants with clinically significant levels of anxiety and depression as measured by either the HADS or GAD-7 and PHQ-9. **excluded participants who had complete IQ, DS and mood scores.*

Table 3

Descriptive statistics of attention and executive functioning scores

Criterion Variables	Mean Raw Score (Range)	Standard Deviation (SD)
Attention		
EC	6.39 (3 – 7)	1.10
ECD	6.88 (1 – 10)	2.88
TS*	3.66 (1.9 – 11.7)	1.42
TSC*	3.97 (-1.6 – 26)	5.56
Executive Functioning		
Letter Fluency	34.64 (8 – 73)	12.65
Animal Fluency	18.15 (3 – 36)	6.05
Hayling Time*	49.12 (0 – 211)	40.72
Hayling Errors*	7.72 (0 – 39)	10.29

N = 94

**low scores represent greater ability*

Correlation Analysis

Criterion and predictor variables. To test the study's hypotheses, the eight criterion variables; EC, ECD, TS, TSC, Letter Fluency, Animal Fluency, Hayling Time and Hayling Errors were entered into correlations with the two predictor variables; DSF and DSB, as well as five confounding variables; age, gender IQ, anxiety and depression (see Table 4 for correlation coefficients). Findings are conservatively interpreted using a Bonferroni correction; critical value p = .05 was divided by seven respectively, revealing a corrected critical value of p = .007, only correlations demonstrated to be significant at this level are reported as significant.

Hypothesis 1. DSF significantly correlated only with ECD (p = .001), but there was a trend towards a significant correlation with EC (p = .015) and Letter Fluency (p = .013).

Hypothesis 2. DSB significantly correlated with all four attention variables (EC p < .001; ECD p < .001; TS p < .001; TSC p = .003) and Hayling Errors (p = .003), and there was a trend towards a significant correlation with Animal Fluency (p = .019) and Letter Fluency (p = .037).

Confounders. Gender did not significantly correlate with any of the criterion variables, whilst age only significantly correlated with TS (p = .001). Similarly, anxiety did not significantly correlated with any of the criterion variables (only a trend towards a significant correlation with EC, p = .008), whereas depression significantly correlated with EC (p = .001), TS (p = .006) and there was a trend towards a significant correlation with ECD (p = .026) and TSC (p = .012). Lastly, IQ significantly correlated with EC (p = .002), TS (p < .001) and there was a trend towards a significant correlation with TSC (p = .013), IQ also significantly correlated with Letter Fluency (p < .001) and Animal Fluency (p < .001).

Table 4

Correlation coefficients demonstrating the relationships between the criterion variables, and predictor and confounding variables

Criterion Variables	Predictor Variables		Confounding Variables				
	DS		IQ	Demographics		Mood✧	
	DSF	DSB		Age	Gender	Anxiety	Depression
Attention							
EC	.25*	.51**	.31**	ns	ns	-.27*	-.34**
ECD	.34**	.41**	ns	ns	ns	ns	-.23*
TS✧	ns	-.35**	-.41**	.33**	ns	ns	.28**
TSC✧	ns	-.30**	-.26*	ns	ns	ns	.26*
Executive Functioning							
Letter Fluency	.26*	.22*	.56**	ns	ns	ns	ns
Animal Fluency	ns	.24*	.46**	ns	ns	ns	ns
Hayling Time✧	ns	ns	ns	ns	ns	ns	ns
Hayling Errors✧	ns	-.30**	ns	ns	ns	ns	ns

***p* < .007; Bonferroni critical value, **p* < .05, ns; not significant ✧ low scores representing greater ability/wellbeing

Inter-correlations.

Criterion variables. All eight criterion variables (EC, ECD, TS, TSC, Letter Fluency, Animal Fluency, Hayling Time and Hayling Errors) were entered in a correlation matrix to explore the inter-relationships and identify potential multicollinearity (see Table 5). Findings are conservatively interpreted using a Bonferroni correction; the critical value p = .05 was divided by seven, revealing a critical value of p = .007.

Attention variables. Only ECD significantly correlated with all of the other attention variables (EC p < .001; TS p = .001; TSC p < .001), EC and TSC additionally significantly correlated with each other (p < .001) and there was a trend towards a significant correlation with TS (p = .011; p =.027 respectively), thus TS did not significantly correlate with any other attention variables. Due to many of the attention variables highly correlating with each other, all four variables could not be entered into the regression models together due to possible multicollinearity. As ECD significantly correlated with all of the other attention measures; EC, TS and TSC, demonstrating that it was capturing a range of attentional constructs, just ECD was entered into regression models as a predictor.

Executive functioning variables. Letter Fluency and Animal Fluency significantly correlated with each other (p < .001), Letter Fluency correlated with no other executive functioning variables, whereas Animal Fluency significantly correlated with Hayling Time (p < .001) and there was a trend towards a significant correlation with Hayling Errors (p = .015). Hayling Time and Hayling Errors also significantly correlated with each other (p < .001). Due to Hayling Time and Hayling Errors, and Letter Fluency and Animal Fluency highly correlating, all four variables could not be entered into the regression models together, due to possible multicollinearity. As Hayling Errors and Letter Fluency were…they were entered as predictors into regression models.

Attention and executive functioning variables. TS and TSC both significantly correlated with Animal Fluency (p < .001; p = .003 respectively). TS significantly correlated with Letter Fluency (p = .003), whilst there was a trend towards a significant correlation between TSC and Letter Fluency (p = .037). ECD only significantly correlated with Animal Fluency (p = .001), but there was a trend towards a significant correlation between ECD and Hayling Time (p = .009) and Hayling Errors (p = .041). EC did not significantly correlated with any executive functioning variables, there was only a trend towards a significant correlation between EC and Letter Fluency (p = .019) and Animal Fluency (p = .016).

Table 5

Correlation coefficients demonstrating the relationships between the eight criterion variables

	Attention				Executive Functioning			
	EC	**ECD**	**TS✧**	**TSC✧**	**Letter Fluency**	**Animal Fluency**	**Hayling Time✧**	**Hayling Errors✧**
Attention								
EC								
ECD	.46**							
TS✧	-.26*	-.33**						
TSC✧	-.37**	-.45**	.23*					
Executive Functioning								
Letter Fluency	.24*	ns	-.31**	-.22*				
Animal Fluency	.25*	.35**	-.41**	-.31**	.54**			
Hayling Time✧	ns	-.27*	.27*	.21*	ns	-.36**		
Hayling Errors✧	ns	-.21*	.28**	.28**	ns	-.25*	.50**	

**$p < .007$; Bonferroni critical value, *$p < .05$, ns; not significant ✧ low scores representing greater ability/wellbeing

Predictor and confounding variables. The two predictors (DSF and DSB) and five confounders (age, gender, IQ, anxiety and depression) were entered into a correlation matrix to explore the inter-relationships and identify potential multicollinearity (see Table 6). Findings are conservatively interpreted using a Bonferroni correction, the critical value p = .05 was divided by six respectively, revealing a critical value of p = .008.

Both DSF and DSB were significantly correlated (p < .001), DSB also significantly correlated with IQ (p < .001), depression (p = .007) and there was trend towards a significant correlation between DSB and anxiety (p = .034), and DSF and anxiety (p = .044). IQ did not significantly correlate with any other variables other than DSB, there was only a trend towards a significant correlation with age (p = .033). Gender did not significantly correlate with any variable. Anxiety and depression were significantly correlated (p < .001), this indicated the two mood measures may have been measuring the same construct, thus only depression was entered as a confounder into the regression models.

Table 6

Correlation coefficients demonstrating the relationships between the two predictor and five confounding variables

	Predictors			Confounders			
	DS		IQ	Demographics		Mood✧	
	DSF	DSB		Age	Gender	Anxiety	Depression
Predictors							
DSF							
DSB	.49**						
Confounders							
IQ	ns	.48**					
Age	ns	ns	.22*				
Gender	ns	ns	ns	ns			
Anxiety✧	-.21*	-.22*	ns	ns	ns		
Depression✧	ns	-.28**	ns	ns	ns	.60**	

**p < .008; Bonferroni critical value, *p < .05, ns; not significant ✧ low scores representing greater ability/wellbeing

Multiple Linear Regression

To test the study's two research hypotheses, multiple linear regression analyses were conducted to investigate whether participants' attention and executive functioning scores can be predicted by their DSF and DSB scores. Models exploring the prediction of participants' attention scores are reported first, followed by executive functioning scores; the results will focus on the contribution of DSF and DSB.

Attention. Four backwards, stepwise regression analyses were performed, criterion variables EC, ECD, TS and TSC were each entered into a model with predictors (DSF and DSB), confounders (age, gender, depression and IQ) and potential executive functioning predictors (Letter Fluency and Hayling Errors).

EC. It was demonstrated that depression and DSB explained a significant amount of variance in EC ($F(2, 91) = 13.06$, $p < .001$, $R^2 = .22$, Adjusted $R^2 = .21$), none of the other variables significantly predicted EC. See Table 7 for regression coefficients, which demonstrates that if DSB increases by one, EC is predicted to increase by .34, when depression is held constant. Model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Table 7

Regression coefficients of EC model, with significance tests

Predictor	***b***	**95% CI**	***SE***	***t***	***p***
Depression	-0.44	-0.86 - -0.02	.21	-2.06	.042
DSB	0.34	0.16 – 0.52	.09	3.82	< .001

b – unstandardized beta, 95% confidence intervals of b, SE – standard error of beta

On its own DSB was demonstrated to significantly account for 19% of the variance in EC (R^2 change = .19, $F(1, 92) = 21.119$, $p < .001$), whilst depression accounted for a significant 10% (R^2 change = .10, $F(1\ 92) = 10.02$, $p = .002$), overall accounting for 29% of variance in EC. However, when entered into the model together DSB and depression only significantly accounted for 22% of variance in EC. Exploratory mediation analyses revealed this to be due to DSB having a partial significant mediation effect on depression; when depression and DSB were entered into the model together the predictive relationship with EC was reduced because DSB explains part of the relationship between depression and EC. Figure 3 illustrates the significant direct and indirect effect of depression on EC, a large indirect effect was demonstrated (K^2 = .11) and the significance of this effect was indicated by a Sobel test (Z = -2.35, p = .02). No other significant mediation or moderation effects were demonstrated.

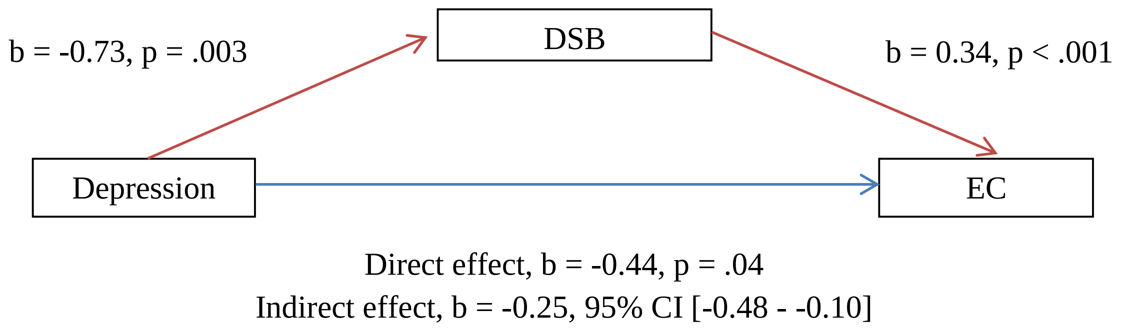

Figure 3. Direct and indirect effects of depression on EC.

ECD. It was demonstrated that only DSB explained a significant amount (15%) of variance in ECD (F(1, 92) = 16.75, p < .001, R^2 = .15, Adjusted R^2 = .15), none of the other variables significantly predicted ECD. See Table 8 for regression coefficients, which demonstrate that if DSB increases by one, ECD is predicted to increase by .95. All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Table 8

Regression coefficients of ECD model, with significance test

Predictor	***b***	**95% CI**	***SE***	***t***	***p***
DSB	0.95	0.49 – 1.40	.23	4.093	< .001

b – unstandardized beta, 95% confidence intervals of b, SE – standard error of beta

TS. It was demonstrated that age, DSB and IQ explained a significant amount of variance in TS (F(3, 90) = 22.11, p < .001, R^2 = .42, Adjusted R^2 = .41), none of the other variables significantly predicted TS. See Table 9 for regression coefficients, which demonstrate that if DSB increases by one, TS is predicted to decrease by .26, when age and IQ are held constant. All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Table 9

Regression coefficients of TS model, with significance tests

Predictor	***b***	**95% CI**	***SE***	***t***	***p***
Age	0.05	0.03 - 0.07	.01	5.734	< .001
DSB	-0.26	-.480 - -0.04	.11	-2.372	.020
IQ	-0.04	-.059 - -0.02	.01	4.524	< .001

b – unstandardized beta, 95% confidence intervals of b, SE – standard error of beta

On its own DSB was demonstrated to significantly account for 13% of the variance in TS (R^2 change = .13, $F(1, 92) = 13.67$, $p < .001$), age a significant 12% (R^2 change = .12, $F(1, 92) = 12.18$, $p = .001$ and IQ a significant 19% (R^2 change = .19, $F(1, 92) = 21.20$, $p < .001$), overall accounting for 44% of variance in TS. However, when entered into the model together age, DSB and IQ only significantly accounted for 42% of variance in TS. Exploratory mediation analyses revealed this to be due to IQ having a partial significant mediation effect on DSB; when IQ and DSB were entered into the model together the predictive relationship with TS was reduced because IQ explains part of the relationship between DSB and TS. Figure 4 illustrates the significant direct and indirect effect of DSB on TS, a large indirect effect was demonstrated ($K^2 = .16$), the significance of this effect was indicated by a Sobel test ($Z = -2.70$, $p = .007$). No other significant mediation or moderation effects were demonstrated.

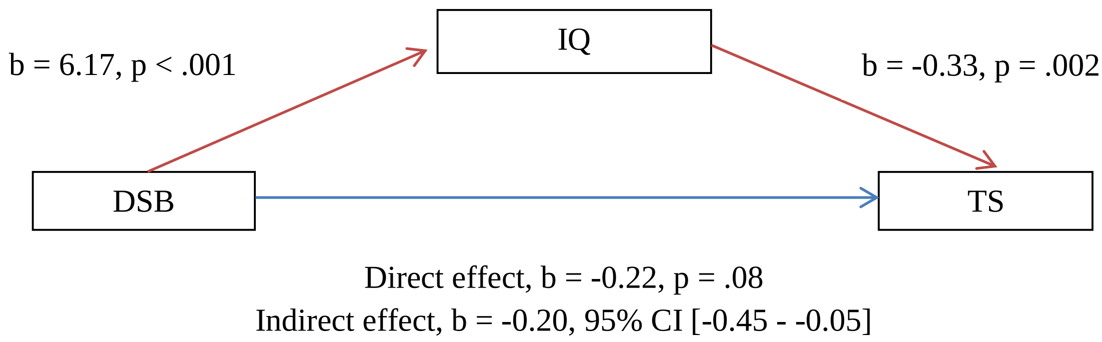

Figure 4. Direct and indirect effects of DSB on TS.

TSC. It was demonstrated that only Letter Fluency explained a significant amount of variance in TSC (F(1, 92) = 10.20, p = .002, R^2 = .10, Adjusted R^2 = .09). All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Executive functioning. Four backwards, stepwise regression analysis were performed, criterion variables Letter Fluency, Animal Fluency, Hayling Time and Hayling Errors were each entered into a model with predictors (DSB and DSF), confounders (age, gender, depression and IQ) and a potential attention predictor (ECD).

Letter Fluency. It was demonstrated that only IQ explained a significant amount of variance in Letter Fluency (F(1, 92) = 41.79, p < .001, R^2 = .31, Adjusted R^2 = .31). All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Animal Fluency. It was demonstrated that age, ECD, gender and IQ explained a significant amount of variance in Animal Fluency (F(1, 89) = 11.29, p < .001, R^2 = .34, Adjusted R^2 = .31). All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Hayling Time. It was demonstrated that only ECD explained a significant amount of variance in Hayling Time ($F(1, 92) = 8.19$, $p = .005$, $R^2 = .08$, Adjusted $R^2 = .07$). All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Hayling Errors. It was demonstrated that only DSB explained a significant amount (5%) of variance in Hayling Errors ($F(1, 92) = 4.67$, $p = .033$, $R^2 = .05$, Adjusted $R^2 = .04$), none of the other variables significantly predicted Hayling Errors. See Table 10 for regression coefficients, which demonstrate that if DSB increases by one, Hayling Errors is predicted to decrease by .88. All model assumptions were met, and no outliers or influential cases were detected (see appendix F).

Table 10

Regression coefficients of Hayling Errors model, with significance test

Predictor	***b***	**95% CI**	***SE***	***t***	***p***
DSB	-1.89	-3.63 - -0.15	0.88	2.16	.033

b – unstandardized beta, 95% confidence intervals of b, SE – standard error of beta

Discussion

The present study aimed to investigate whether participants' DS performance correlated with and/or predicted their attention and executive functioning performance, enabling examination of whether WM training exercises, analogous to DS, could lead to improvements in participants' attention and executive functioning. However, DS comprises of two components, DSF and DSB (evidenced to tap into different cognitive constructs; DSF associated with STM storage and DSB with

WM), it was hypothesised that only participants' DSB scores would be significantly associated with their attention and executive functioning scores.

Correlational and Predictive Relationships

It was demonstrated that participants' DSF significantly correlated with only performance on one measure of selective attention. Participants' DSF did not correlate with their executive functioning performance nor was DSF performance predictive of participants' attention or executive functioning performances. Consequently, the hypothesis was partially confirmed, suggesting little evidence to indicate that WM training exercises similar to DSF would result in improvements of attention or executive functioning.

It was revealed that participants' DSB significantly correlated with their performance on all attention measures (measures of both basic and executive attentional processes) and with participants' performance on a measure of inhibition, but not on the other measures of executive functioning included. Similarly, participants' DSB performance predicted their attention (sustained, selective and divided) and inhibition scores, thus aspects of both their attentional and executive functioning performances. Participants' DSB was demonstrated to be more predictive of their attentional performance than other high-order cognitive variables i.e. IQ and measures of executive functioning (Letter Fluency and Hayling Errors; measures of planning, monitoring, judgment, decision-making and inhibition) and more predictive of participants' inhibitory control than IQ and a measure of executive attention (ECD; a selective attention measure). Consequently, the hypothesis was confirmed, there is evidence to suggest that WM training exercises comparable to DSB could result in improvements of basic and executive attention, and aspects of executive functioning, specifically inhibitory control.

Mediations. Further mediation analyses revealed how and why few of the predictor variables influenced the criterion variables. First, DSB was revealed to mediate the effect of depression on EC; participants' level of depression (clinical or non-clinical) was demonstrated to significantly influence their DSB, which then significantly influenced their EC (a measure of sustained attention). Findings indicate that an improvement in participants' mood would directly improve their ability to sustain attention on stimuli in the environment, but would also improve their DSB, which in turn would also lead to an improvement in their sustained attention (and conversely any decline).

Second, IQ was demonstrated to mediate the effect of DSB on TS; participants' DSB scores were demonstrated to significantly influence their IQ, which then significantly influenced their TS (a measure of visual selective attention). Findings indicate that an improvement in participants' DSB would directly improve their ability to visually select information from the environment, but also improve their IQ, which in turn would also lead to an improvement in their selective attention (and vice versa any decline). In summary participants' DSB was demonstrated to be significantly influenced by their level of depression and to also have a significant influence on their IQ, therefore highlighting the important role of confounding variables in explaining the relationships between DSB and visual selective and sustained attention.

Different Cognitive Constructs

The findings demonstrated that DSF and DSB are differentially associated with attentional and executive functioning measures. DSF was associated with few attentional and executive functioning measures, suggesting DSF does not adequately represent the central executive of WM (heavily involved in attentional and executive processes) and instead may be more representative of STM and the two storage systems of WM. DSB was revealed to be associated with a range of attentional and executive functioning measures indicating it may be representative of the central executive of WM. Furthermore, it was revealed that DSB and not DSF was significantly correlated with IQ, further evidencing DSBs association with high-order cognitive processing. Consequently, the findings tentatively support the research of Glisky, Polster and Routhieaux (1995) and Hale, Hoeppner and Fiorello (2002) who propose that DSF and DSB do not measure a unitary construct, with DSF representative of STM and DSB of WM.

Implications for WM Retraining

The findings suggest that the training methods currently employed in Cogmed, predominantly training on simple WM exercises similar to DS, could lead to improvements in patients' attentional abilities and inhibitory control. The most effective exercises in the Cogmed training programmes at facilitating such improvements in attention and inhibition have been revealed to be exercises similar to the DSB subtest of the WAIS-III. It would therefore be most effective for WM training programmes such as Cogmed to include activities that involve the storage and manipulation of stimuli (as is required in DSB) and to remove exercises that just involve storage and recall of stimuli (as is required in DSF), as such exercises have not been demonstrated to be associated with the attentional or executive functioning abilities of participants.

Furthermore, complex WM tasks as utilised by Daneman and Carpenter (1980), which involve storage and manipulation of stimuli whilst also performing another unrelated attention demanding task, may be even more closely associated with attentional and executive functioning processes due to their dual task nature.

WM training employing complex WM may therefore lead to more significant improvements in participants' high-order cognitive processing. However, there is yet to be a WM training programme that utilises complex WM exercises, thus further investigation is warranted.

Clinical Implications

First, the present study revealed that it may be possible to improve patients' attentional and inhibitory abilities by training and improving their WM abilities, providing neuropsychological evidence to support the far-transfer claims currently being made by Cogmed researchers. These encouraging findings indicate that the CCR of WM could potentially trigger a wide range of cognitive improvements. Consequently, CCR has the potential to make a significant contribution to the effective cognitive rehabilitation of patients with ABI.

Second, the present study demonstrated that DSF and DSB are unlikely to be measuring a unitary construct and are most likely measuring different components of the WM system; DSF the STM storage systems and DSB the central executive. The findings, if further corroborated, have significant implications for the use of the DS subtest in clinical practice. Commonly clinicians report patients' DST scores, as a measure of their WM functioning, however the results indicate that clinicians should report both patients' DSF and DSB separately as measures of their STM and WM functioning. Combining these two scores together could lead to loss of important information about patients cognitive functioning i.e. superior STM abilities could mask significant WM difficulties.

Confounders

The influence of the five confounding variables (age, gender, IQ, anxiety and depression) entered into the analyses was examined further. It was demonstrated that gender and anxiety had no significant associations with any of the attention, executive functioning or DS measures. Age significantly correlated only with TS (a measure of visual selective attention), which is likely to be because the TS subtest involves visual scanning and motor speed, both of which ordinarily deteriorate in old age. Otherwise age was demonstrated to not be associated with any of the other attention, executive functioning or DS measures. IQ was demonstrated to be associated with some attention and executive functioning abilities, demonstrating the close association between intelligence and high-order cognitive processes. Lastly, participants' level of depression was demonstrated to be significantly associated with attention and DS measures. These findings suggest that clinical levels of depression can have a negative impact on cognitive functioning, however due to limitations of one of the depression measures (PHQ-9), this finding may not be reliable.

The PHQ-9 includes a question about whether participants have had "trouble concentrating on things, such as reading the newspaper or watching television". The response to this question may be attributed to cognitive changes or mood related deterioration, therefore confounding what construct participants' depression scores represent. Furthermore, the PHQ-9 has been demonstrated to be less sensitive in older adults with cognitive impairment (Boyle et al., 2010), due to reporting of cognitive difficulties as symptoms of low mood.

Generalisability of Findings

The included participants were demonstrated to be reasonably representative of an adult ABI population referred to Neuropsychological services for routine cognitive assessment, as they did not significantly differ from the excluded participants in terms of DS ability, gender, IQ and levels of clinical anxiety and depression. Furthermore, both the included and excluded samples achieved an average DSF of 6 and DSB of 4, thus similar scores to Black's (1986) sample of ABI patients, indicating the included sample's DS scores were as expected for an adult ABI population. It was not possible to compare the included and excluded participants in terms of attentional and executive functioning abilities, thus cannot conclude whether the included sample is representative of the wider ABI population in terms of these abilities.

Unfortunately, the included participants were demonstrated to be significantly younger than the excluded participants, and significantly more of the included participants were assessed in GN clinics, whereas significantly more excluded participants were assessed in M&D or Vascular clinics. Consequently, participant age and aetiology significantly differed between the two sets of participants and may therefore limit the generalisibility of the findings to a wider adult ABI population, as older patients with memory and vascular difficulties were not adequately represented.

Some potential reasons for fewer older patients being included within the study are; first as older adults are increasingly seen for assessment of suspected memory decline their cognitive assessments are likely to focus on comprehensive memory assessment and may therefore involve briefer assessment of attention and executive functions. Second, clinicians may utilise assessments normed specifically for an older population. Third, clinicians may perform briefer or modified cognitive assessment of older adults due to concerns about the demands of testing and increasing motor and sensory difficulties (APA, 2013). Consequently, fewer older patients will have had complete test scores on the measures of interest for inclusion in the study.

Limitations

Apart from the limitations in terms of generalisability described above, the present study had a number of methodological limitations. First, the measures utilised were heavily restricted by the assessments currently being employed by the Neuropsychology service. Due to the service having only recently introduced the WAIS-IV it was not possible to include this measure. The inclusion of Digit Sequencing may have enabled exploration whether more complex WM exercises are more closely associated with attentional and executive functioning performance of participants. Additionally, other assessments of executive functioning may have been selected if a wider choice had been available, for example the Behavioural Assessment of Dysexecutive Syndrome (Wilson, Alderman, Burgess, Emslie & Evans, 1996) and a wider range of the subtests from the DKEFS (Delis, Kaplan & Kramer, 2001). This may have enabled further exploration of whether participants' DS scores predicted a wider range of their executive functioning scores, thus further exploring the utility of CCR.

Second, when extracting participant information from the pre-collected database, extraction of test scores was limited to those of IQ, DS, attention and executive functioning, as these were most pertinent to answering the study hypotheses. With hindsight test scores could have been extracted for a number of other assessments, for example immediate and delayed memory, information processing speed and visuospatial skills to explore whether these cognitive abilities were predictive of attention and executive functioning; enabling better control for external variables. However, due to the wide variety of memory assessments and only occasional need for assessment of visuospatial skills, it is likely that few patients would have complete test scores on these measures, thus inclusion of such measures may have severely limited the present study's sample size.

Third, despite Klingberg et al., (2005) demonstrating improved patient reasoning following Cogmed training, the present study failed to explore whether participants DS performance was correlated or predictive of their reasoning performance. The WAIS-III includes a subtest defined as a measure of abstract reasoning, the Matrix Reasoning subtest. However, due to the way in which test scores were recorded in the database only patients' overall IQ scores were recorded and therefore scores on individual subtests were not available for extraction. Consequently, it is recommended that more detailed test scores are recorded in future to enable access to the complete range of subtest scores.

Four, as previously mentioned one of the depression measures, PHQ-9 was confounded due to inclusion of a question closely related to cognitive functioning. It would therefore be advisable that in future mood questionnaires tailored to an ABI population are utilised to limit the impact their cognitive difficulties have on measuring their psychological wellbeing.

Conclusion

Correlation and regression analyses demonstrated that ABI participants' DS scores significantly correlated with and predicted a range of attention scores and one executive functioning score (a measure of participants' inhibition). Consequently, this study provides neuropsychological evidence which indicates that WM training which entails exercises similar to DSB could result in improvements of both participants' attentional abilities and inhibitory control, supporting the findings of Brehmer et al., (2012), Klingberg et al., (2005), Lundqvist et al., (2010), Thorell et al., (2009) and Westerberg et al., (2007). Additionally DSF and DSB were demonstrated to measure different cognitive constructs (DSF representative of STM, and DSB representative of WM) and thus should be reported separately by clinicians.

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Appendices

Appendix A - Downs and Black Checklist

***COPY OF DOWNS AND BLACK CHECKLIST REMOVED TO CONFORM WITH COPYRIGHT LEGISLATION**

***COPY OF DOWNS AND BLACK CHECKLIST REMOVED TO CONFORM WITH COPYRIGHT LEGISLATION**

***COPY OF DOWNS AND BLACK CHECKLIST REMOVED TO CONFORM WITH COPYRIGHT LEGISLATION**

Appendix B - Downs and Black Sub-scale Scores

Study	Downs and Black sub-scales					
	Reporting (10)	External Validity (3)	Bias (7)	Confounding (6)	Power (1)	Total (27)
Attention						
Sturm et al., (2004)	7	1	5	2	0	15
Zickefoose et al., (2013)	9	0	5	1	0	15
Hauke et al., (2011)	6	1	4	1	0	12
Sturm et al., (2003)	8	0	2	1	0	11
Attention plus						
Prokopenko et al., (2013)	10	1	6	5	0	22
Li et al., (2013)	9	1	4	2	0	16
Lojek & Bolweska (2013)	9	0	5	2	0	16
Fernandez et al., (2012)	8	0	5	1	0	14
WM						
Akerlund et al., (2013)	10	1	5	4	0	20
Lundqvist et al., (2010)	9	2	5	3	1	20
Westerberg et al., (2007)	10	1	5	3	1	20
Mean (%)	8.64 (86.36)	0.73 (24.24)	4.64 (66.23)	2.27 (37.88)	0.18 (18.18)	16.45 (60.94)

Appendix C - Amount and Intensity of CCR

Study	Length of Session (minutes)	Weeks of Training	Number of Sessions	Total Time (minutes)	Intensity (minutes per week)
Attention					
Hauke et al., (2011)	45	3	15	675	225
Sturm et al., (2004)	45	4	14	630	157.5
Sturm et al., (2003)	60	3	14	840	280
Zickefoose et al., (2013)	30	8	40	1200	150
Attention plus					
Fernandez et al., (2012)	50	12	60	3000	250
Li et al., (2013)	60	5	8	480	96
Lojek & Bolewska (2013)	60	15	30	1800	120
Prokopenko et al., (2013)	30	2	14	420	210

Study	Length of Session (minutes)	Weeks of Training	Number of Sessions	Total Time (minutes)	Intensity (minutes per week)
WM					
Akerlund et al., (2013)	37.5	5	25	937.5	187.5
Lundqvist et al., (2010)	52.5	5	25	1312.5	262.5
Westerberg et al., (2007)	40	5	25	1000	200
Mean (N = 11)	46.4	6.1	24.6	1117.7	194.4

Appendix D – Working Memory Model

The working memory model proposed by Baddeley and Hitch (1974).

***COPY OF WORKING MEMORY MODEL REMOVED TO CONFORM WITH COPYRIGHT LEGISLATION**

Appendix E - NHS Ethical Approval Letter

NHS
Health Research Authority

NRES Committee North East - Newcastle & North Tyneside 2

Room 002
JARROW Business Centre
Rolling Mill Road
Jarrow
NE32 3DT

Telephone: 0191 428 3561

01 August 2014

Miss Sarah Davison
Trainee Clinical Psychologist
Sheffield Health and Social Care NHS Foundation Trust
Clinical Psychology Unit
Department of Psychology
University of Sheffield
Western Bank
Sheffield
S10 2TN

Dear Miss Davison

Study title:	**Is digit span a predictor of attention and executive function in patients with brain injury? Implications for working memory training**
REC reference:	**14/NE/1094**
Protocol number:	**STH 18550**
IRAS project ID:	**160322**

The Proportionate Review Sub-committee of the NRES Committee North East - Newcastle & North Tyneside 2 reviewed the above application via email correspondence.

We plan to publish your research summary wording for the above study on the NRES website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to make a request to postpone publication, please contact the REC Manager – Mrs Helen Wilson, nrescommittee.northeast-newcastleandnorthtyneside2@nhs.net

Ethical opinion

On behalf of the Committee, the sub-committee gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

A Research Ethics Committee established by the Health Research Authority

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations.

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion").

Summary of discussion at the meeting

The PRS Sub-Committee confirmed the study raised no material ethical issues *under the following headings:*

Social or scientific value; scientific design and conduct of the study; Recruitment arrangements and access to health information, and fair participant selection; Favourable risk benefit ratio; anticipated benefit/risks for research participants (present and future); Care and protection of research participants; respect for potential and enrolled participants' welfare and dignity; Informed consent process and the adequacy and completeness of participant information; Suitability of the applicant and supporting staff; Independent review; Suitability of supporting information; Other general comments and Suitability of research summary.

Approved documents

The documents reviewed and approved were:

Document	*Version*	*Date*
IRAS Checklist XML [Checklist_21072014]		21 July 2014
REC Application Form [REC_Form_21072014]		21 July 2014
Referee's report or other scientific critique report [Scientific Approval Letter]		15 July 2014
Research protocol or project proposal [Research Protocol]	2	27 June 2014
Summary CV for Chief Investigator (CI) [Sarah Davison CV]		16 July 2014
Summary CV for supervisor (student research) [Dr Claire Isaac CV]		16 July 2014

Membership of the Proportionate Review Sub-Committee

The members of the Sub-Committee who took part in the review are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators

- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

14/NE/1094	Please quote this number on all correspondence

Yours sincerely

pp

Dr Ray Wainwright
Chair

Email: nrescommittee.northeast-newcastleandnorthtyneside2@nhs.net

Enclosures:	*List of names and professions of members who took part in the review*
	"After ethical review – guidance for researchers"
Copy to:	*Samantha Heaton, Sheffield Teaching Hospitals NHS Foundation Trust*

A Research Ethics Committee established by the Health Research Authority

Appendix F - Analysis of Assumptions and Outliers

Model	Independence of Errors	Multicollinearity Statistics		Outliers	Influential Cases		
	Durbin Watson Statistic	Average VIF (range)	Average Tolerance (range)	Casewise Diagnostics over 2 (%)	Average Cook's Distance (range)	Average Centered Leverage (range)	Average Mahalanobis Distance (range)
Attention							
EC	1.86	1.10 (n/a)	0.91 (n/a)	8.51	0.01 (0 - 0.18)	0.02 (0.01 – 0.05)	1.98 (0.98-4.71)
ECD	1.97	1.00 (n/a)	1.00 (n/a)	4.25	0.01 (0 - 0.14)	0.01 (0.001 - 0.05)	0.99 (0.13 - 4.60)
TS	1.11	1.26 (1.05 – 1.38)	0.80 (0.72 – 0.95)	3.19	0.02 (0 - 0.75)	0.03 (0.002 - 0.11)	2.97 (0.17 - 10.62)
TSC	2.26	1.00 (n/a)	1.00 (n/a)	6.38	0.01 (0 - 0.22)	0.01 (0 - 0.09)	0.99 (0.001 - 9.19)

Model	Independence of Errors	Multicollinearity Statistics		Outliers	Influential Cases		
	Durbin Watson Statistic	Average VIF (range)	Average Tolerance (range)	Casewise Diagnostics over 2 (%)	Average Cook's Distance (range)	Average Centered Leverage (range)	Average Mahalanobis Distance (range)
Executive Functioning							
Letter Fluency	2.22	1.00 (n/a)	1.00 (n/a)	4.25	0.01 (0 – 0.11)	0.01 (0 – 0.06)	0.99 (0.001 – 5.96)
Animal Fluency	1.78	1.05 (1.00 – 1.09)	0.96 (0.92 – 1.00)	3.19	0.01 (0 – 0.12)	0.004 (0.01 – 0.12)	3.96 (1.04 – 10.85)
Hayling Time	2.24	1.00 (n/a)	1.00 (n/a)	3.19	0.01 (0 – 0.22)	0.01 (0 – 0.05)	0.99 (0.002 – 4.17)
Hayling Errors	1.86	1.00 (n/a)	1.00 (n/a)	7.44	0.01 (0 – 0.12)	0.01 (0.001 – 0.05)	0.99 (0.13 – 4.60)