Consolidation of Learning during Sleep in Children and Adults

Sophie Thomas

January 2008

Thesis submitted for the Doctoral degree in Clinical Psychology

Department of Psychology
University of Sheffield

Declaration

This thesis has not been submitted for any other degree

or to any other institution

Main Abstract

This thesis begins with a literature review investigating the relationship between childhood medical conditions related to sleep disturbance and cognitive impairment. Three categories of medical conditions associated with sleep disturbance and cognitive problems are identified: Sleep Disordered Breathing (SDB), Primary Sleep Disorders and Childhood Epilepsies. Findings suggest widespread evidence of a relationship between cognitive problems in SDB and childhood epilepsies. Potential mechanisms for these associations include the relatively recent theory that consolidation of learning (CoL) taking place during sleep may be disrupted.

Evidence that CoL occurs during sleep is mainly restricted to adult populations. This study aimed to replicate this research with both a sample of adults and a sample of children. Measures of CoL were adapted for children, and performance improvements overnight (CoL-N) were compared with those over an equivalent daytime period (CoL-D). Measures of IQ and self-reported sleep quality were included. Differences between CoL-N and CoL-D were not significant in either sample. However, post-hoc explorations revealed interesting observations regarding the modified measures and these will be informative to future research. The possibility of an association between sleep latency in adults and bedtime difficulties in children is also raised. Future research is recommended to increase understanding of CoL as this may have important implications for children at risk of learning disorders associated with sleep disruption.

The thesis concludes with a critical appraisal addressing professional learning, methodological limitations and implications for future research.

Acknowledgements

Firstly, I would like to thank Dr. Ingram Wright for his wisdom, support and patience in the face of my somewhat stubborn tendencies at times during this research. I have learned a great deal due to his experience and persistence. I would also particularly like to thank Dr. Claire Isaacs for providing extremely pragmatic and timely support to facilitate the completion of this thesis.

It is also important for me to thank all of the participants taking part in this research, and in particular the collaborating staff and children in the local schools and local church community.

I am also very grateful to Claire Huyton for her collaboration. It was a pleasure having her company, common sense, and knowledge along the way. Her practical support was also invaluable, particularly in volunteering to move various items of heavy research equipment for me whilst I was pregnant. Clare I am not sure how I would have managed without you.

On a more personal note, I would like to thank my parents for their support and valuable babysitting visits, and Tina White also for the latter. Lastly I would like to also thank my husband for his support and for helping me to take care of our beautiful baby daughter Emily to allow me to complete this research.

PAGE

MISSING

IN

ORIGINAL

Contents

List of Tables

Literature Review

Research Report

List of Figures

Literature Review

Research Report

Literature Review

Prepared in accordance with guidelines for submission to
Journal of Developmental Neuropsychology

The Impact upon Cognitive Functioning of Childhood Medical Conditions associated with Sleep Disturbance

Sophie Thomas

The impact upon cognitive functioning of childhood medical conditions associated with sleep disturbance

Abstract

This review explores the relationship between sleep disturbance and learning impairment in children. The focus is specifically on medical conditions associated with disturbed sleep. A thorough search of literature related to sleep and learning in children was conducted. The research meeting specified inclusion criteria was structured into three diagnostic categories: Sleep Disordered Breathing, Primary Sleep Disorders and Childhood Epilepsies.

The review begins with a brief introduction and a description of the search methodology before presenting the research identified. Findings suggest there is widespread evidence of a relationship between sleep disturbance and learning both in Sleep Disordered Breathing and in Childhood Epilepsies related to sleep disturbance, with or without the presence of seizures. The evidence regarding Primary Sleep disorders is limited, though supportive of some associations with learning problems.

Mechanisms accounting for the relationship between sleep and learning are discussed. In some cases there appear to be direct explanations for the cognitive impairments seen, however, in other cases cognitive difficulties appear to be at least partially attributable to sleep disruption. Ultimately, this review highlights the need for further research to better understand the relationship between sleep and cognitive impairment. Disrupted learning can have striking consequences for a child's learning and development. Therefore, this review supports a case for delivering assessments and interventions with respect to the cognitive as well as physical symptomatology, and for the provision of appropriate learning support where required.

Keywords: learning; cognitive; sleep; obstructive sleep apnea; epilepsy

1. Introduction

Childhood is a critical period for learning and development. Disruption of this dynamic process can not only lead to missed learning opportunities, but can in turn reduce the accessibility of further educational opportunities, and thus lead to a widening gap between such children and their peers. It is therefore important that we identify any factors likely to interrupt this learning process, and address them in a timely manner.

Recently a significant proportion of research has begun to highlight the role of sleep as a key factor for learning (Stickgold & Walker, 2005). Indeed evidence that sleep contributes to the consolidation of fresh memory traces comes from a wide range of experimental observations in adult populations (Stickgold, 2005). Research suggests that different stages of sleep may play different roles in such consolidation of learning (CoL) during sleep (Stickgold, 2005) and that qualitative changes in sleep architecture can be seen further to a period of learning (Gais, Molle, Helms & Born, 2002).

Whilst research to date has been mainly restricted to adult populations (Stickgold, 2005) sleep may also play a significant role in learning for children. During childhood sleep undergoes many changes, as sleep states become more defined, sleep time decreases and sleep cycle length increases (Stores, 2001). It is particularly interesting that during childhood, when learning is most active, sleep time is greatest. Despite this only recently has research on CoL during sleep in children commenced. Studies by Gomez, Bootzin and Nadell (2006) and Gais, Lucas and Born (2006) demonstrated improved performance further to a night asleep on artificial language familiarity in infants, and German vocabulary lists in older adolescents, respectively. However, evidence is not unanimous as a study by Fischer, Wilhelm and Born (2007) found children did not

display overnight improvements on implicit memory components of a serial reaction time task in the same way as adults, suggesting a potentially different role for implicit memory CoL in children to that in adults.

What is evident, however, is that sleep is important for daytime performance. A study investigating the effects of overnight sleep restriction in healthy children found higher cognitive functions, such as verbal creativity and abstract thinking, were impaired (Randazzo, Muehlbach, Schweitzer & Walsh, 1998). It is not surprising, therefore, that children suffering medical conditions impacting upon their sleep, may also demonstrate cognitive impairments which in some cases appear to be at least partially related to sleep disruption.

Consistent with preliminary findings that sleep is important for cognitive functioning in healthy, normally developing children, there is now a growing body of evidence suggesting a link between medical conditions related to disturbed sleep and learning disorders in childhood. Whilst reviews of the literature pertaining to the relationship between some specific conditions and learning can be found, these have not been integrated or considered together as a whole. In many cases this leads to attribution of the cognitive impairments to factors specific to the condition, when in fact similar learning problems are found in conditions of very different aetiology. Considering the impact of these conditions together allows us to consider any potentially similar mechanisms which could explain the learning impairments seen, including sleep disruption.

This review, therefore, aims to examine and present the pertinent literature on the relationship between sleep disturbance and cognitive impairment in childhood medical

conditions. It also aims to highlight the importance of managing not just the physical manifestations of such conditions but the impact upon childhood learning and development during this crucial period.

2. Methodology

The literature search comprised three distinct phases. An initial broad search was conducted in order to obtain an understanding of the literature. This was then utilised to form exclusion criteria for a more selective search strategy, thus narrowing down the large body of literature identified. Finally, once the medical conditions seen to be associated with sleep and learning disturbance had been identified, a search specific to these conditions was conducted to ensure comprehensive coverage. The process is described below:

2.1 Search Strategy: Phase 1 The following search terms (*Table.1*), selected to be as inclusive as possible, were utilised using three major search engines identified for their coverage of medical and psychological journals.

Table1: Initial Search Terms

	Database			
Search Terms	**ISI Web of Knowledge**	**Pubmed**	**PsychInfo 226/2007**	
Child AND sleep AND learning	128	450	214	
Child AND sleep AND memory	71	189	81	
Child AND sleep AND cognitive	211	376	261	
Child AND sleep AND development	405	1262	633	
PAPERS IDENTIFIED				4311

Results were merged to eliminate duplicate literature. Case reviews, letters and review articles not representing original research were excluded, although relevant references were extracted. For reasons of practicality, studies without abstracts and studies unavailable in English were excluded. Any inappropriately identified studies involving adult participants (over 18 years old) and animals were excluded using search engine filters and manual inspection. Studies of children less than two years old were also excluded due to the difficulty measuring cognitive functioning reliably within this age group. A body of literature on the relationship between performance and the technical neurophysiology of sleep architecture was not included as it was considered beyond the remit of this review.

2.2 Search Strategy: Phase 2 Remaining papers were reviewed by title, abstract, or in full where necessary. On first examination of the literature it could be seen that a large proportion comprised research focusing on the aetiology or management of a childhood condition, rather than the relationship between sleep and cognition. A further proportion involved studies of sleep architecture in medical conditions with reference to, but with no measure of learning. This initial review of the literature revealed the best indicator of the relevance of studies to be the inclusion of an objective measure of both sleep quality (such as a physiological measure or a medical diagnosis known to disrupt sleep) and an objective measure of cognitive performance (standardised cognitive testing or objective measures of school performance). Thus any remaining literature not including such measures was excluded at this stage. A list of the cognitive measures identified can be seen in *Table 2.* overleaf.

Table 2:. Cognitive Measures

Test	Description
Auditory Continuous Performance Task (ACPT)	Assesses auditory attention, by asking participants to indicate when a target word appears in a list of words verbally presented
Benders- Gestalt Test (BGT)	Evaluates visual-motor functioning, visual-perceptual skills, neurological impairment, by asking participants to copy nine figures presented on cards.
British Ability Scales for Children (BASC)	A wide range cognitive functioning measures allowing selection of scales tailored to specific circumstances
Benton Visual Retention Test (BVRT)	Measures visual perception and visual memory, as participants are asked to reproduce 10 designs, one at a time, from memory.
Block Span	A test of capacity to register visuo-spatial material. Children are asked to tap with their hand a sequence of blocks of increasing length as demonstrated by the examiner.
Childrens Category Test (CCT)	A measure of non-verbal concept formation, mental flexibility and problem-solving, independent of expressive language using a card sorting format.
Childrens Memory Scale (CMS)	A comprehensive assessment of attention, verbal and visual memory, short-delay and long-delay memory, recall, recognition, working memory and learning. Bottom of Form
Clinical Evaluation of Language Fundamentals (CELF)	Measures a broad range of expressive and receptive language skills in young children
Continuous Performance Test (CPT)	Three computerised, standardised, continuous performance tests including TOVA, IVT & Conners CPT..
Corsi Blocks Task (Corsi)	Measures spatial memory span, in a similar manner to Block Span above
Digit Span	A measure of digit span memory, by repeating a sequence of verbally presented numbers in the given order and in reverse.
Differential Ability Scales (DAS)	Comprehensive assessment measuring verbal and visual working memory, immediate and delayed recall, visual recognition and matching, processing and naming speed, phonological processing, and number concepts
Illinois Test of Abilities (ITA)	Measures 12 functions employed in the acquisition and use of language
Integrated Visual and Auditory Test (IVT)	A computerised, standardised, continuous performance test requiring sustained visual and auditory attention and mental flexibility.
Kaufman Assessment Battery for Children (KAB)	An in depth assessment of intelligence for children including verbal and non-verbal abilities
Leiter International Performance Scale (LIPS)	A totally nonverbal test of fluid intelligence, not significantly influenced by the level and quality of the child's educational, social, and family experience
Matching Familiar Figures Test (MFFT)	A match to sample perceptual recognition test where a child is asked to select a drawing matching the sample presented
Nepsy	Comprehensive test battery measuring attention, executive function, language, sensorimotor function, visuo-spatial ability, memory and learning. Identifies strengths as well as difficulties
Peabody Picture Vocabulary Test-Revised (PPVT-R)	A wide range measure of receptive vocabulary and a screening measure of verbal ability
Ravens Matrices (RM)	A non-verbal intelligence test. Children are asked to choose which of a series presented fits the missing box to complete the pattern
Rey Auditory-Verbal Learning test (RAVLT)	List of 15 nouns read aloud by the examiner for five consecutive trials. After each trial the child is asked to recall as many words as possible, and then to underline the words in a story.
Rey Complex Figure Test (RCFT)	This is a test of visuo-spatial constructional ability, planning, and memory. Children are instructed to copy a complex geometric design and then to reproduce it from memory after a short and long delay
Slosson Intelligence Test (SIT)	Assessment tool designed to be a brief estimate of general verbal cognitive ability
Story Recall	A test of short-term memory for verbal material. Two stories are read to the children who are then asked to retell immediately the stories in their own words with no prompting and again after a chosen delay.
Stroop Task	A test of directed attention, where the reader must read aloud the word not the conflicting colour ink, thus inhibiting any automatic response to do the latter
Test of Everyday Attention for Children (TEACh)	Assesses selective attention, sustained attention, attentional switching and divided attention using every day materials
Test of Variables of Attention (TOVA)	A computerised test of attention designed in a 'game like' format.
Token Test (TT)	Designed to assess verbal comprehension of commands of increasing complexity, using plastic tokens of varying colours, shape and size and corresponding instructions
Tower of London	Measures planning and problem-solving ability. Also measures visuo-motor integration, spatial processing, and short-term memory, using three balls on a wooden peg board to form patterns matching stimulus cards presented.
Trail Making Test (TMT)	This is a test of speed of visual search, attention, mental flexibility, and visuo-motor skill. Children are required to draw pencil lines to connect a number of circles containing: 1. consecutive numbers 2. alternating letters and numbers, whilst maintaining sequential order.
Verbal Fluency (VF)	Children are asked to generate words beginning with the letter F in a 1-minute period. Repeated with letters A and S.
Weschler Abbreviated Scale of Intelligence (WASI)	An abbreviated version of the Weschler assessments, assessing full scale IQ comprised of both verbal and non-verbal subcomponents.
Weschler Individual Achievement Test (WIAT)	A measure of reading comprehension comprised of a list of words to be read aloud
Woodcock-Johnson (W-J)	A comprehensive system for measuring general intellectual ability, specific cognitive abilities, scholastic aptitude, oral language, and academic achievement.
Weschler Intelligence Scale for Children R, III & IV (HAWIK in German)	A battery of tests assessing intelligence, including verbal and non verbal domains, perceptual organisation and processing speed
Wide Range Assessment of Memory and Learning (WRAML)	Battery of nine subtests yielding Verbal Memory Index, a Visual Memory Index, and a Learning Index.

Despite a comprehensive search, only three categories of medical conditions were identified as being linked with learning problems and sleep disturbance. These were: (1) Sleep Disturbed Breathing (SDB); (2) Primary Sleep Disorders and; (3) Childhood Epilepsies. In the case of childhood epilepsies, not all were relevant to this review. Whilst at least 25% of children with epilepsy are described as having learning disorders (Aldenkamp, Apherts, Dekker & Overweg, 1990) there are a great many interdependent factors potentially responsible for this. These include neurological damage, educational disadvantage due to time away from school, absences or seizures in the classroom, the impact of anti-epileptic medication and the psychosocial burden associated with the disorder (Anderson et al, *2001*). For this reason, only studies primarily concerned with the direct relationship between sleep, epilepsy and learning were included. These mainly concerned epileptic encephalopathies with characteristic electrical activity during sleep, such as Epilepsy with Continuous Spike Waves During Sleep (CSWS), Benign Epilepsy of Childhood with Centrotemporal Spikes (BECTS)/Benign Rolandic Epilepsy (BRE) and Landau Kleffner Syndrome (LKS).

2.3 Search Strategy: Phase 3 Once core literature had been established, each medical condition identified as pertinent to the relationship between learning and sleep was utilised as a keyword in the same search engines, alongside the terms *learning, cognitive, cognition, development* and *memory*. Using the 'related articles' function in the Pubmed search engine, and the bibliographies of literature identified, related literature was screened. Other studies by the authors of pertinent papers were also considered. The 50 remaining studies identified were then graded Level I to V according to their scientific validity (adapted from Mitchell & Kelly 2005) their relevance to this review and the quality of measures of both sleep and cognitive function (see grading criteria: *Table.3*). Studies with objective physiological measures of sleep

such as sleep studies (polysomnography: PSG) or electroencephalograms (EEG) and standardised cognitive assessments were graded more highly. Studies with questionnaire based measures of sleep were included in the final selection but were graded less favourably due to the subjectivity in self-report measures. Similarly whilst objective measures of academic performance, such as school grades, were seen as a measure of cognitive functioning, such studies were graded Level V due to the number of other psychosocial factors which admittedly impact upon performance in all arenas, but particularly upon school performance. Studies with self-report measures of cognitive functioning were not included due to their lower reliability and the availability of evidence gained using more objective measures. Those graded less favourably, without novel contributions, are discussed in less detail. All studies selected are summarised in *Table 4.*

Table 3: Grading Criteria

Study Grade	Grading Criteria
Level I	Randomised controlled trials with a standardised cognitive assessment and a physiological measure of sleep quality (EEG or PSG) or a medical diagnosis of a condition known to be related to sleep disturbance.
Level II	Non-randomised controlled studies with a standardised cognitive assessment and a physiological measure of sleep quality (EEG or PSG) or a medical diagnosis of a condition known to be related to sleep disturbance.
Level III	Studies without a control group but with a standardised cognitive assessment and a physiological measure of sleep quality (EEG or PSG) or a medical diagnosis of a condition known to be related to sleep disturbance.
Level IV	Studies with a standardised cognitive assessment and a self-report measure of sleep disorder (e.g. primary snoring).
Level V	Studies with any measure of sleep disorder listed above but with an objective measure of school performance in place of a standardised cognitive assessment or with only partial testing specific to one domain e.g visuo-spatial memory.

Table 4. List of studies identified

FIRST AUTHOR	N	POPULATION	COGNITIVE TESTS	CONCLUSIONS	Grade
1. SLEEP DISTURBED BREATHING					
Archbold 2004	12	SDB & controls	IVT	Children with mild SDB showed impaired executive functions (sustained attention, vigilance, mental flexibility) but were no different from controls in general IQ & reading ability	II
Avior 2004	19	OSA	TOVA	Data suggested that treatment of OSAS with T+A results in significant improvement in objective parameters of inattention and impulsivity.	III
Beebe 2004		OSA & Controls	Measure of IQ, verbal memory, processing speed	Marked relationship between OSA and attention/executive functioning. Minimal effects on IQ, verbal memory, processing speed. No relationship between cognitive functioning & indexes of hypoxia or sleep disruption.	II
Blunden 2000	32	PS & controls	CBCL, WPPSI, WRAML	PS group demonstrated reduced neurocognitive performance, specifically lower scores on memory, attention & IQ.	II
Carvhalho 2004	1180	SDB & other sleep disorders	Bender Visual Motor Gestalt Test - BT	As a whole, children did not present with cognitive dysfunction	III
Carvhalho 2005	1180	SDB & non-respiratory disorder	School performance	Sleep-disordered breathing, grades, and starting time to school interact to affect cognition in Brazilian children.	V
Emancipator 2006	835	SDB	PPVT-R, KAB, CPT	Children with SDB had poorer scores on almost all tests of cognition and achievement though not as great taking SES into account	II
Friedman 2003	41	OSA & controls	WPPSI	Children with OSA had lower scores compared to controls preoperatively which improved to level of control group postoperatively	II
Gotlieb 2004	205	SDB & controls	WPPSI, NEPSY	Children with SDB performed significantly less well on tests of executive function, memory & general intellectual ability.	II
Gozal 2001		SDB-snoring	School performance	Children with lower academic performance in middle school are more likely to have snored during early childhood and to require T&A for snoring compared with better performing schoolmates.	V
Gozal 2007	278	OSA	DAS NEPSY	HsCRP levels are higher in children with OSA, and particularly in those who develop neurocognitive deficits, suggesting that the magnitude of the inflammatory responses elicited by OSA is a major determinant of increased risk for neurocognitive dysfunction.	III
Halbower 2006	31	OSA & controls	WISC III & IV	Participants had lower IQ & executive function (verbal working memory & veral fluency) compared to controls	II
Kaemingk 2003	149	OSA & controls	WPPSI	Participants demonstrated poorer learning, memory, immediate recall, IQ & mathematics than controls, relative to severity of OSA	II
Kennedy 1998	26	PS & controls	WPPSI, WRAML	PS group displayed impaired memory & attention as well as lower IQ.	II
Kurnatowski 2006	221	OSA & controls	Token Test, DCS, RAVLT, RCFT	OSA was seen to be associated with memory problems, concentration & attention deficits, learning disability, language dysfunction, tower sensorimotor integration & perception	II
Lewin 2002	38	OSA & Controls	CBCL,DAS	Children in the OSA group demonstrated more problems with attention, reduced speed of information processing	II
Montgomery-Downs 2005	19	OSA & controls	DAS NEPSY	Prior to T&A, cognitive scores were significantly lower in OSA subjects versus controls; following T&A, OSA subjects' scores improved compared to pre-operative scores and did not differ from those of matched controls	II
O'Brien 2004	35	SDB & controls	NEPSY, DASCA	SDB group scored significantly lower for: mean scores of DASCA (and the Non-verbal Cluster), attention/executive function domain of NEPSY and 2 subtests in that domain (visual attention & executive function), and Phonological Processing.	II
O'Brien 2004	118	PS & controls	NEPSY, CBCL, DAS	PS group displayed impaired attention and decreased overall cognitive abilities	II
O'Brien 2004	199	PS & controls	NEPSY, DAS	Children in the Sleep Pressure High group significantly more likely to have deficits in memory, language abilities, verbal abilities, and some visuospatial functions than children in the SPSLow group	II
Owens 2000	18	OSA & controls	BASC,WPPSI,WRAML	Children with OSA demonstrated impairments in executive functioning/attention & learning, showing small improvements postoperatively.	II
Rhodes 1995	14	Morbidly Obese Children & OSA	WRAML	Children with obstructive sleep apnea had deficits in learning, memory, and vocabulary. Apneic/hypopneic events were inversely related to memory and learning performance among the entire sample.	III
Suratt 2006	114	SDB	WISC-IV	Snorers scored lower on vocabulary and similarities. Relationship between sleep latency & verbal memory & general memory. Frequency of apnea/hypopnea predicted vocabulary score.	III
Suratt 2007	56	SDB	WISC-IV	Shorter mean time in bed & history of nightly snoring predicted lower scores on vocabulary & similarities. Mean time in bed & apnea/hypopnea index predicted lower vocabulary & similarities scores. Variability in time in bed predicted lower vocabulary & similarities scores.	III

FIRST AUTHOR	N	POPULATION	COGNITIVE TESTS	CONCLUSIONS	Grade
2. CHILDHOOD EPILEPSIES					
Annett 1994	1041	Asthma	CPT, Memory	Mean IQ & cognitive & achievement tests were normally distributed	III
Baglietto 2001	9	BECTSS & BRE & Controls	Corsi, TMT, Stroop, Benton, WISC	Mean full-Scale IQ was in normal range, but significantly below controls. Participants had disorders in visuospatial short-term memory, attention, cognitive flexibility, picture naming and fluency, visuoperceptual skill & visuomotor coordination compared to controls. At IED remission scores not significantly different.	II
Croona et al 1999	10	BECTS & controls	DS, BS, RAVLT, TMT, SR, VF, ToL, RM.	Children demonstrated significantly lower scores than controls on cognitive tests. Intellectual abilities did not differ and neither did school functioning. Parents reported concentration difficulties and impulsiveness	II
Deonna et al 2000	22	BRE & occipital spikes (n=3)	WPPSI, WISC-R, RM	No single cognitive profile found. 4 showed delayed language development, 8 transient weak scores in one domain (verbal, visuospatial, memory) which improved/normalized during course of the study. Some with RS showed mild, transient cognitive difficulties throughout.	III
Giordani et al 2006	200	BECTS	PPVT-III WRAML	Participants displayed relative weaknesses in fine motor control, visual learning and attention in the presence of overall normal intellect, with simple partial seizures associated with more difficulty.	III
Gozal 1998	297	Children with SDB & controls	School performance	Grades increase significantly after adenotonsillectomy in children with SDB but not in those without SDB or those with SDB but untreated	II
Gudstadt 1989	99	Asthma	SIT, W-J	Participants demonstrated scores above 50th centile compared to age based norms	III
Gündüz, Demirbilek, Korkmaz 1999	20	BRE	WISC-R	In the patient group a presence of consanguinity, dyspraxia in the lower extremities, difficulties in go-no-go test, as well as some problems related to language such as disposed, minor motor deficits were significantly more frequent compared to controls.	II
Hattori 2002	17	BECTS & BRE	WISC-R, KAB, ITA, Benton, Token Test	Mental processing normal for BECTS & ABPE but generally lower for latter. BECTS significantly lower verbal expression & auditory sequential memory. Normal scores on other visual & verbal functions & LT memory. Similar profile for ABPE.	III
Heijbel & Bohman 1975	16	BRE & Controls	Benders Test	Epileptic seizures did not influence the children's intelligence. The visuomotor coordination was impaired in most children but this was not true for their verbal and nonverbal functions.	II
Lindgren et al, 2004	32	BRE	Digit Span, RAVLT, Story Recall, RCFT, Tower of London, VF, TMT, RM, WISC III	Children with BRE did not present any major cognitve difficulties when a mean of approximately 5 years had passed since onset of the typical syndrome, and at a time when most of them were seizure-free. Maturational factors apparently are of importance to the course of RE.	II
Northcott 2005	42	BRE	WISC III, WIAT, WRAML, VF, TMT, RCFT,	Children with BRE had normal intelligence & language ability. However, a specific pattern of difficulties in memory and phonologic awareness was found. EEG features were minimally associated with cognitive difficulties.	III
Northcott 2006	28	BRE	WISC III, WIAT, WRAML, VF, TMT, RCFT,	Improvement in cognitive functioning, particularly in the areas of verbal memory, receptive language ability, and phonemic manipulation, was demonstrated longitudinally	II
Pinton et al 2006	18	BECTSS	VF, IQ, phonological production, naming skills, syntactic comprehension	Mean IQ, verbal functions and memory were within the normal range. Drawing and visuo-spatial skills, attention and visuo-spatial memory were significantly weak. Reading, numeracy and/or spelling ability were significantly delayed by at least one academic in 10 children.	III
Robinson et al 2001		LKS & ESES	WISC III, KAB, LIPS, CELF	Length of ESES correlated strongly with eventual receptive & expressive language. All had impaired short-term memory at follow-up. Three children had language outcome within the normal range. No child with ESES lasting longer than 36 months had normal language outcome.	III
Roulet-Perez et al 1993	4	CSWS	WISC-R RCFT	Children followed between 1 1/2 & 4 yrs old, showed a pattern of behavioural & cognitive disturbances similar to that in some autistic-like disorders, but also in adult frontal syndrome, probably due to an unusual long-standing epileptic dysfunction involving frontal lobes.	III
Scholtes, Hendriks & Renier 2005	10	ESES (7 CSWS, 3 LKS)	Unspecified test of languge, attention, memory & visuospatial abilities	Cognitve dysfunction did not respond to valproate &/or benzodiazepines in 9 of 10 children. Good cognitive recovery after disappearance of ESES occurred in only 1, and partial recovery in 4. An unfavourable prognosis seems to be related to long-duration ESES and/or early onset.	III
Sinclair & Synder 2005	10	CSWS & LKS	WISC-III WPPSI-R	The patients received Prednisone 1 mg/kg/day for 6 months, 1 year, then yearly. Most patients had improvement in language, cognition, and behaviour .	III
Stephani & Carlsson 2006	36	BECTS & LKS	KAB, HAWIK III	No correlation was found between global IQ and the severity of the RDs. All the children had at least one specific learning disorder (sometimes long-lasting). When the children were treated, a correlation between cognitive and EEG improvement could not be demonstrated.	III
Völkl-Kernstock, Willinger & Feucht 2006	44	BECTS	HAWIK-III, KAB, DAT	Children with BECTS exhibited significant deficits in higher functions of spatial perception, including spatial orientation, basal and complex spatial memory. Deficits independent of anti-convulsive drug treatment	II
Weglage et al 1997	40	BRE & controls	Not specified	Patients were significantly impaired in their IQ, visual perception, short-term memory, psychiatric status & fine motor performance task. No significant differences could be computed for a simple finger-motor speed exercise or a linguistic performance test.	II
Yung et al 2000	78	BECTS	Diagnostic assessment only	Among BECTS 9% diagnosed with mild intellectual disability, 10% with borderline functioning and 17% with specific learning disabilities. Three children with BECTSS experienced language delay and regression.	III
3. PRIMARY SLEEP DISORDERS					
Blunden 2005	64	PS & behavioural sleep problems	WASI, TEACh, ACPT	Snoring and BSP were associated with impaired neuropsychological and psychosocial functioning. Snoring was associated with intelligence and attention deficits. BSP was associated with memory and behavioural deficits.	IV
Carvhalho 2004	1180	SDB & other sleep disorders	Bender Visual Motor Gestalt Test - BT	As a whole, children did not present with cognitive dysfunction	III
Hansen 2001	14	OSA /Narcolepsy	Information unavailable	Both groups scored lower than norms but improved with intervention	III

The literature identified is presented according to the diagnostic categories (*Fig.1)*, as whilst degrees of overlap are apparent they are separate diagnostic entities, each with unique features which allow us to consider the association between sleep disturbance and learning impairments differently. This in turn allows the consideration of potential mechanisms for the relationships between sleep disturbance and the types of learning problems identified. In the case of sleep disordered breathing (SDB) whilst much of the research pertains to homogeneous samples, a generic category of mixed aetiology research is also included (comprised of SDB, obstructive sleep apnea and primary snoring). In the cases of childhood epilepsies, there is a significant degree of overlap amongst some of the conditions presented, hence these categories have been collapsed, although for ease of comprehension some evidence is presented separately within these sections. Presentation of the evidence is followed by a discussion of literature demonstrating reversibility of cognitive impairment upon treatment of the medical condition. Remaining sleep disorders are considered under the heading Primary Sleep Disorders. As this research was limited it was not necessary to include subsections .

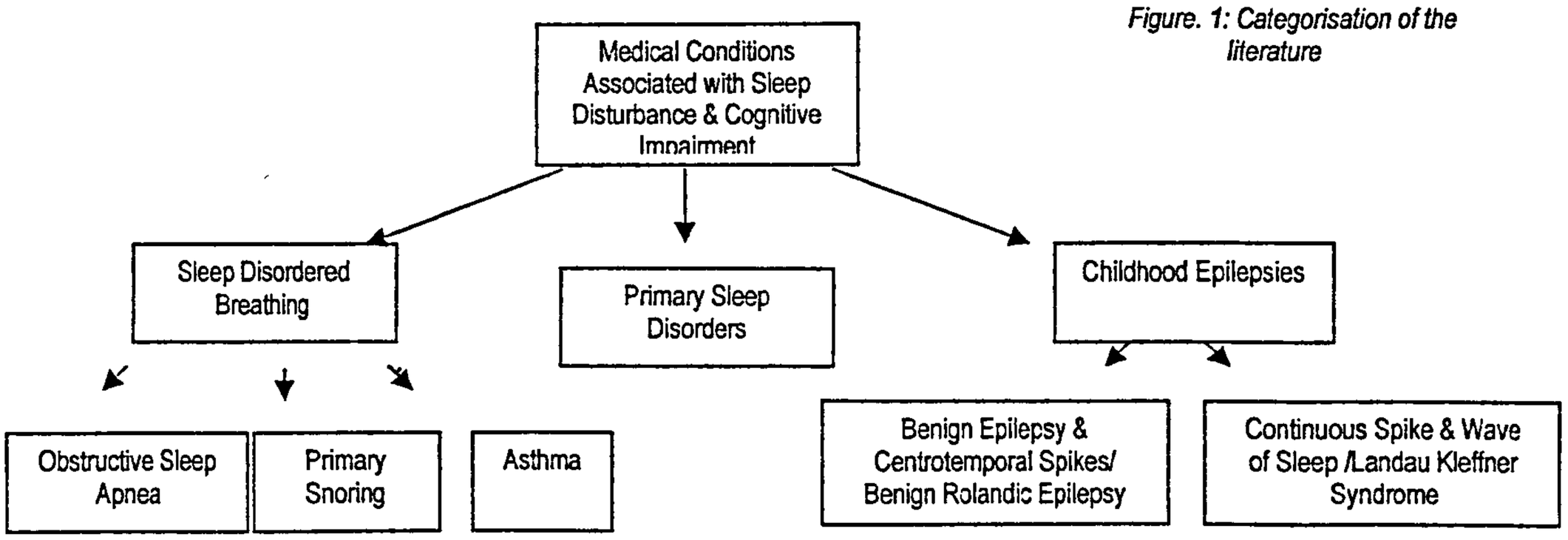


Figure. 1: Categorisation of the literature

3. Results

3.1 Sleep Disordered Breathing (SDB)

Sleep disordered breathing is an umbrella term for a range of conditions characterised by respiratory difficulties during sleep. These range from Obstructive Sleep Apnea (OSA) to partial obstructions, laboured breathing and simple snoring (Halbower, et al *2006*). OSA is a severe form of sleep disordered breathing, which involves repeated brief periods of respiratory cessation due to airway obstruction during sleep. This leads to sleep disruption through repeated arousal from sleep, which can prevent the sleeper reaching the deeper stages of sleep, and can in some cases lead to hypoxic periods where the sleeper is deprived of oxygen (Ali, Pitson & Stradling, 1993). Snoring is often a prominent symptom of OSA. However, many children who snore do not fulfil the criteria for OSA, are considered to have primary snoring (PS). Finally, included in this review are a small number of studies investigating the relationship between asthma, which is often associated with disruption to sleep and cognitive functioning.

3.1.1 Sleep disordered breathing of mixed aetiology

The literature with mixed SDB samples shall be described first as an introduction, before turning to homogeneous samples of OSA, PS and asthma. Four studies identified as investigating participants with generic SDB, each found an impact upon learning. In a study of 205 five-year-old children, 61 met the criteria for SDB, defined as 'frequent snoring, loud or noisy breathing during sleep, or witnessed sleep apnea' (Gottlieb et al, 2004). On comparing this group to asymptomatic children the SDB children had significantly lower performance on measures of memory, executive function and general intelligence. Whilst this was not a matched control study, the finding remained

when adjusting for demographic and respiratory health variables, and when children with OSA (thus more likely to be hypoxic) were removed from the analysis. Thus SDB symptoms with and without OSA were seen to impact cognitive function in five-year-old children.

This finding was supported by a study of 35 pairs of children matched for age, gender, socioeconomic status (SES), ethnicity and maternal smoking. Those with polysomnographically defined SDB were demonstrated to have significantly lower scores for General Conceptual Ability (similar to IQ), non-verbal performance, and attention/executive function. Poorer performance on phonological processing (important for learning to read) was also seen (O'Brien et al, 2004).

Impairments in executive functioning were found again in a study by Archbold, Giordani, Ruzicka & Chervin (2004) including 12 children recruited from an adenotonsillectomy waiting list (seven due to recurrent tonsillitis and five with obstructive SDB). Those in the SDB group demonstrated difficulties with sustained attention, vigilance and mental flexibility (Archbold et al, 2004). The severity of the SDB also appeared to be related to the extent of the impairment, but the children were no different from controls in IQ & reading ability. However, whilst this study controls well for the surgical and medical procedures, it was a small study and the lengthy test battery may have over inflated impairments due to test fatigue.

Recently a much larger study of 835 full and preterm children, of whom 164 children met the criteria for SDB, demonstrated poorer scores amongst the children with SDB on nearly all tests of cognition and achievement utilised. Interestingly the difference was not as great after adjusting for SES, although deficits in measures of academic abilities,

language comprehension, and planning and organizational skills remained (Emancipator et al, 2006). However, the SDB children were also more likely to be preterm, which may in itself increase the risk of learning impairment.

Thus, the above four studies, with varying strengths and weaknesses, have each suggested SDB to have an impact upon cognition including general intelligence (Gottleib et al, 2004), memory (Gottleib et al, 2004), non-verbal performance (O'Brien et al, 2004), attention (Archbold et al, 2004; O'Brien et al, 2004), mental flexibility (Archbold et al, 2004), planning and organisation/executive function (Archbold et al, 2004; Gottleib et al, 2004; O'Brien et al, 2004; Emancipator et al, 2006), phonological processing (O'Brien et al, 2004) and language comprehension (Emancipator et al, 2006). However, the mixed aetiology groups make it difficult to identify factors responsible. Thus studies focusing on a more homogenous category of SDB are important for refining understanding.

3.1.2 Obstructive Sleep Apnea

OSA represents the severe end of the SDB spectrum and is thought to occur in 1-3% of the population (Ali et al, 1993; Anuntaseree, Rookkapan, Kuasirikul & Thongsuksai, 2001; Brunetti et al, 2001; Gislason & Benediktsdottir, 1995). OSA in children is frequently associated with adenotonsillar hypertrophy or enlarged adenoids and tonsils (Kheirandish-Gozal, Sans Capdevila, Tauman & Gozal, 2006) which obstruct the airway.

There is growing evidence that OSA is associated with behavioural and attentional problems in children. An initial small study of morbidly obese children demonstrated

those with OSA to have deficits in learning, memory, and vocabulary (Rhodes et al, 1995). Whilst these results are likely to be confounded by other medical and psychosocial factors linked to obesity, they are supported by two small controlled studies of otherwise healthy children. A study of 28 children with OSA and 10 age-matched healthy controls detected significantly lower scores on a timed cancellation task measuring sustained attention, and a significant association between the severity of the OSA and measures of verbal ability (Lewin, Rosen, England & Dahl, 2002). Similarly Beebe et al (2004), found children with OSA to demonstrate lower behaviour regulation and reduced performance on measures of attention and executive functioning. The latter study observed minimal effects on measures of intelligence, verbal memory, or processing speed, though the researchers admit that their sample was small. Indeed this was the case for both studies, and controls were matched only by age, and not other factors such as SES. Despite this, these initial findings begin to shape the evidence suggestive of an impact of OSA on daytime cognitive functioning.

Further larger studies strengthen the evidence for an association between OSA and learning disorders. A prospective cohort study of 149 children with and without OSA related sleep disturbance (Kaemingk et al, 2003) found higher scores on a sleep apnea index to be associated with decreased learning (notable on immediate recall and arithmetic subtests) as well as reduced Performance IQ and Full scale IQ. More recently, Kurnatowski, Putynkski, Lapienis and Kowalska (2006) examined a population of 221 children, 117 with OSA related adenotonsillar hypertrophy and 104 healthy children. They found adenotonsillar hypertrophy in younger children (6-9 years) was associated with impairment of memory, concentration and attention, language dysfunction, lower sensorimotor integration and perception and learning disabilities. The older children (aged 10-13 years) were also seen to have memory problems and

learning disabilities, and more severe language dysfunction. The authors suggest the impairments to be caused by concentration and attention deficits. However, whilst the latter study stated controls were within a similar age range, neither matched controls, thus fundamental differences in the samples were possible. This issue was overcome by a further small but well designed study of children with severe OSA and healthy controls matched for age, gender, ethnicity and SES (thus providing a more thorough comparison) and yet still demonstrated the children with OSA to have significant deficits in IQ and executive functions (Halbower et al, 2006).

Thus, all of the studies relating to childhood OSA populations have identified relative impairments in some areas of cognitive functioning, including memory (Rhodes et al, 1995; Kurnatowski et al, 2006), learning (Rhodes, 1995; Kaemingk *at al* 2003), executive function (Beebe, 2004, Halbower et al, 2006), attention (Lewin et al, 2002; Beebe, 2004; Kurnatowski et al, 2006), vocabulary/verbal/language ability (Rhodes, 1995; Lewin et al, 2002; Kurnatowski et al, 2006), Performance IQ (Kaemingk et al 2003) and Full Scale IQ (Kaemingk *at al* 2003; Halbower *at al*, 2006). Only one small study found minimal or no effects on general intelligence or processing speed (Beebe et al, 2004).

3.1.3 Primary Snoring

It has also been recently found that children with suspected obstructive SDB were more likely to have impaired cognitive functioning if they had a history of nightly snoring (Surrat et al, 2006). Habitual snoring is estimated to occur in 10% to 12% of young children (Owen, Canter & Robinson, 1996) though it is not seen as a condition requiring intervention. However, in 1998 a study of 13 snoring children with an obstructive

respiratory disturbance index within the normal range, were seen to still have significantly reduced performance on mean scores for verbal IQ, global IQ, selective attention, sustained and memory index, compared to controls (Kennedy, Blunden & Hirte, 1998). A further study showed significantly impaired attention and lower memory and intelligence scores compared to controls, though within the normal range (Blunden et al, 2000). Whilst being controlled, both of the above are small studies, though similar findings were seen in a larger study of 114 children by O'Brien et al (2004). This study compared snoring children, without gas exchange abnormalities and thus unlikely to be hypoxic at night, to a control group. Whilst in the normal range, both overall cognitive abilities and certain language and visuospatial functions were significantly lower for the snoring group.

Thus, all three studies highlight the possibility of reduced cognitive performance, and the latter in the absence of gas exchange abnormalities, thus demonstrating an impact upon learning and development for children who snore but who are otherwise healthy and do not suffer severe OSA (Blunden et al, 2000).

3.1.4 Asthma

Stores, Ellis, Wiggs, Crawford and Thomson (2007) recently found children with nocturnal asthma had significantly disturbed sleep and performed less well on delayed recall, immediate recall and sustained attention though this was not statistically significant. There is also little other objective evidence of impairments in daytime functioning (Bender & Annett, 1999). In further generic asthma studies such as the Childhood Asthma Management Program (CAMP), a multicenter double-blind, randomized, placebo-controlled, clinical trial of two types of anti-inflammatory

medication, asthma symptoms were not found to be associated with reduced neurocognitive performance (Annett, Bender & Gordon, 1994). This corresponded with an earlier study in 1989 of 99 children hospitalised for severe asthma, where children were found to actually perform above the 50th percentile for age matched norms (Gudstadt et al, 1989). Thus whilst the most recent study indicates that reports of interruption in daytime functioning are not unfounded, further research is needed in this area to shed light upon the neuropsychological implications of nocturnal asthma.

3.1.5 Reversibility of Cognitive Impairment

An interesting feature of the relationship between sleep disturbance and cognitive function in SDB is the impact of treatment upon cognition, as there is growing evidence that neurocognitive performance can be seen to improve upon intervention. This is particularly interesting as on demonstrating an association between SDB and learning problems, it is not possible to conclude that the learning problems are directly related to the SDB. However, if such learning problems are seen to improve upon SDB symptom improvement, this increases evidence for the association between the two.

The first pertinent study (Ali, Pitson & Stradling, 1996) consisted of 12 children with SDB recruited from an adenotonsillectomy waiting list, matched by age and sex with 11 children with a history of snoring and sleep disturbance but no obvious sleep or respiratory problem (snorer group) and a control group of 10 children undergoing an unrelated surgical procedure. Post-operatively greater sleep disturbance seen in both SBD and snorer groups had been largely resolved as had dips in oxygen saturation in the SDB group. In line with this the SDB group showed significantly reduced inattention and an improvement in vigilance. The snorer group also demonstrated

improved vigilance, whereas the control group's performance did not change significantly. Whilst this study has only small numbers in each group, thus diminishing its statistical validity, the design attempts to separate the key factors likely to impact upon cognitive function, and demonstrates improved performance when the sleep disturbance is resolved. However, as this study was also concerned with behaviour and aggression the cognitive assessment was narrow and thus is limited in neuropsychological information.

In 2000 Owens, Spirito, Marcotte, McGuinn and Berkelhammer demonstrated children with SDB to have impairments in executive functioning/attention and learning compared to controls, and saw small improvements in executive functioning/attention postoperatively. Again this was a small study, similar that by Avior et al., (2004) which found an improvement in attention and impulsivity but neither study conducted fully comprehensive testing nor did they retest a control group, thus allowing the possibility of practice effects as SDB children completed the same tests a second time. However, the findings become much more convincing when considered alongside a larger study of 41 participants using a comprehensive intellectual assessment that demonstrated children with OSA to have lower scores compared to controls, which improved to the level of the control group post-operatively (Friedman et al, 2003). This extremely interesting finding was replicated in 2005 (Montgomery-Downs, Crabtree & Gozal) though unfortunately in both above studies researchers did not retest the control groups, thus improvement in treatment group scores may be biased by practise effects. The only study taking this into account demonstrated an improvement in school grades further to surgery (Gozal, 1998). Whilst school grades are often confounded by many other factors, follow-up data is easily available for controls, and thus the study was able to demonstrate that the improvement was unique to the treatment group. The control

group was interestingly composed of children with sleep associated gas exchange abnormalities who were also having difficulties at school, but whose parents did not seek intervention, thus providing a good comparison.

Thus, several studies comprise a convincing body of research indicating an improvement in cognitive function further to successful intervention. This increases confidence in the likelihood of a true association between SDB and learning problems. However, it is important to be aware that not all studies have demonstrated complete resolution of impairments. In a questionnaire study of 1588 participants, it was found that children with lower academic performance at 13-14 years old were more likely to have snored and undergone adenotonsillectomy earlier in their childhood, suggesting that the surgical intervention may not have completely reversed the effects (Gozal & Pope 2001). The researchers suggest that a "learning debt" may have developed prior to intervention which obstructed future development, and indeed it may be optimistic to assume that a period of cognitive dysfunction can simply be erased without some long term consequences.

3.2 Primary Sleep Disorders

Primary sleep disorders are sleep disorders not attributable to other medical conditions, medication or substance abuse (Buscemi, Vandemeer & Hooten, 2005). The review uncovered little literature pertaining to primary sleep disorders, though one small study cited by Hansen & Vandenberg (2001) cognitively assessed both children with OSA and children with narcolepsy and finding both to perform lower than the age based norms on measures of auditory attention, visual attention and memory, with both groups

improving after intervention. Hence, deficits and the reversibility upon intervention do not appear to be restricted to children with SDB.

A much larger study of 1180 Brazilian school children with SDB and non-respiratory sleep disorders, found that children with a range of sleep disorders did not display poorer performance than a control group on the Bender Visual Motor Gestalt Test (BT) (Carvalho et al, 2005). However, the authors admit that there may have been other psychosocial confounding factors within the groups and that the reliability of their questionnaire based assessment of sleep disorder may have been questionable. The BT is also restricted to one form of assessment (which involves copying figures) from which various interpretive scores are achieved. Whilst it is time efficient in both its administration and scoring, it is less comprehensive than many tests, and may be better utilised in conjunction with other assessment tools. Additionally, the plethora of research demonstrating cognitive impairment in children with SDB which was undetected in this study calls the general validity into question.

Behavioural sleep problems (BSP) whilst not primary sleep disorders, are also relevant and most appropriately included at this point. In a mixed study of both children who snore and children with behavioural sleep problems (BSP), both groups demonstrated reduced intelligence and attention scores compared to controls. Children in the BSP group and Snorers + BSP group showed reduced memory scores compared to snorers alone. In general BSP separately was associated with impaired neuropsychological functioning, specifically memory deficits compared to snoring which was associated with intelligence and attention deficits (Blunden, Lushington, Lorenzen, Martin & Kennedy, 2005).

3.3 Childhood Epilepsies

The epileptic encephalopathies are a group of disorders where neurological deterioration is attributable at least partly to the epileptic activity, independent of the aetiology. Thus improvement is also often seen upon intervention (Holmes & Lenck-Santani, 2005). Epilepsy is one of the most common neurological disorders in childhood (Shinnar & Pellock, 2002) with an estimated prevalence of approximately five to seven new cases in one thousand children per year from birth to age fifteen (Cowan, 2002) with many children potentially undiagnosed. It is also well known that epilepsy is associated with disturbed sleep as both nocturnal and daytime seizures can impact upon sleep quality (Bazil, Malow & Sammaritano, 2002).

Approximately 25% of patients with epilepsy are described as having learning disorders (defined as interfering with academic performance or reading, writing and mathematical abilities) compared to 2-10% in the general population. Overall, approximately 50% of children with epilepsy have school-related difficulties, with a third of these children requiring additional academic support (Aldenkamp et al, 1990). In reality the proportion of children requiring such support is likely to be higher as for many children the need for support is unidentified or support is not available. A seven year follow up study by Camfield et al in 1993 found 34% of 337 children with epilepsy yet normal IQ failed their school achievements.

Clearly daytime seizures including absences in the classroom are likely to interrupt attention and awareness. There are many other epilepsy related factors such as the impact of anti-epileptic medication on attention, school absence, psychosocial complications and neurological deterioration which are likely to have a large impact

upon learning (Anderson, Northam, Hendy & Wrennall, 2001) aside from sleep disturbance. However, it has also been seen that subclinical nocturnal seizures may affect learning performance (Beghi, De Maria, Gobbi & Veneselli, 2006) and such conditions are most interesting in investigating the relationship between sleep disturbance and learning as there are fewer confounding factors. Thus, as stated by the inclusion criteria this review only focuses on epilepsies in which sleep disturbance is a key feature.

3.3.1 Benign Epilepsy of Childhood with Centrotemporal Spikes (BECTS) and Benign Rolandic Epilepsy (BRE)

Benign Rolandic Epilepsy (BRE) also known as Benign Epilepsy of Childhood with Centrotemporal Spikes (BECTS) is characterised by brief partial seizures, with a high increase in EEG nightime paraxysmal activity as a key feature. Whilst seizures can occur during the daytime they usually occur during sleep (Holmes, 1997). It is still commonly believed that conditions such as BECTS do not cause any definite neuropsychological impairment (Hattori, 2002) perhaps as an early study demonstrated no impact of BRE on overall intelligence despite some impairments in visuomotor coordination (Heijbel & Bohman, 1975). However, this study comprised only 16 participants with controls matched only for age and sex, and utilised the Benders-Gestalt test which as discussed previously is not the most comprehensive test.

In fact more recent studies demonstrate contrasting findings. Stephani and Carlsson (2006) demonstrated that of 36 children with BECTS all had at least one specific learning disorder. More specifically this has been seen to include reading, spelling, auditory verbal learning, auditory discrimination with background noise and expressive

grammar (Staden, Isaacs, Boyd, Brand & Neville, 1998). Similarly Pinton, Ducot, Motte & Arbues, (2006) found reading, numeracy and/or spelling ability were significantly delayed by one academic year or more in ten of eighteen children with BECTS. Finally, a study of children with severe BECTS were seen to perform, as a group, significantly worse than controls in written language skills, specifically in spelling, reading aloud and reading comprehension (Papavasiliou, Mattheou, Bazigou, Kotsalis & Paraskevoulakos, 2005). Interestingly in the latter study the researchers suggest that some aspects such as the poor written language performance could be argued not to be specific to BECTS because it occurred in children with generally low cognitive capacity and/or pre-existing developmental dysfunctions. However, this is complicated as a family history of language delay or learning disability has been seen amongst children with BRE (Gündüz, Demirbilek & Korkmaz, 1999). Thus it is questionable whether it is possible to state that the low cognitive capacity or 'pre-existing' developmental dysfunctions are definitely not epilepsy related, given that epilepsy related cognitive dysfunction can be seen without the presence of seizures.

Whilst language difficulties are a key feature of the findings in many studies (Deonna et al, 2002; Gündüz, Demirbilek & Korkmaz 1999; Völkl-Kernstock, Willinger & Feucht, 2006) a study of 42 children with BRE demonstrated normal intelligence and language ability (Northcott et al, 2005). However, a specific pattern of difficulties in verbal and visual memory and phonologic awareness was found in this study which can potentially impact upon reading, memory and spelling.

Clearer findings come from larger, controlled studies, such as that by Weglage, Demsky, Pietsch & Kurlemann (1997) where 40 children with BRE, with and without seizures were compared with healthy controls matched for age, sex, and SES,

demonstrating the experimental group to be significantly impaired in their IQ, visual perception and short-term memory. However, unfortunately the study did not analyse seizure and non-seizure epilepsy groups separately. Similar findings have been seen in children with BECTS and controls well matched for age, sex and school. Children with BCETS had significantly lower scores on neuropsychological items assessing auditory-verbal memory and auditory verbal learning (Croona, Kihlgren, Lundberg, Eog-Olofsson, Eog-Olofsson, 1999). The BECTS group also displayed some difficulty with executive functions, specifically shifting strategies when problem-solving on the Trail Making Test. This coincides with executive functioning type disorders identified as difficulties in a go-no-go test (Gündüz, Demirbilek, Korkmaz 1999) and disrupted attention which has been shown in at least two studies of children with BECTS (Giordani et al, 2006; Pinton et al, 2006).

Visuo-spatial aspects have also been seen to be impacted with children with BECTS exhibiting significant deficits in higher functions of spatial perception, including spatial orientation, as well as in basal and complex spatial memory (Völkl-Kernstock, Willinger & Feucht, 2006). Pinton et al (2006) also found visuo-spatial skills, attention and visuo-spatial memory were found to be significantly weak compared to the normal range for age, but general IQ and memory to be normal. Similarly Giordani et al (2006) screened 200 BECTS children presenting for a clinical trial, finding relative weaknesses in visual learning in the presence of overall normal intellect.

Clearly it appears that studies have uncovered a range of deficits, and not all results are consistent. However, this may be due to the different functions assessed and different tests utilised. Deonna et al (2000) studied 22 children, 19 with BRE (and three with occipital spikes) and concluded that they could not identify a single cognitive profile,

though eight children required support at school, four had delayed language development and eight children had transient weak scores in one isolated domain (verbal, visuospatial, memory). However, this study also included different aetiological groups, and this may be an issue with many of the studies as epilepsy can manifest itself very differently in each child. There is also a degree of overlap between the epileptic encephalopathies and this is discussed below.

3.3.2 Continuous spike-wave of sleep (CSWS) and Landau Kleffner Syndrome (LKS)

Continuous spike-wave of sleep (CSWS) and Landau-Kleffner Syndrome (LKS) will be considered together as the boundaries are not as clear between these disorders as diagnosis often suggests, and often CSWS/ESES are displayed in LKS suggesting considerable overlap (Holmes & Lenck-Santini, 1997).

CSWS is a condition of childhood onset with characteristic epileptic activity occurring during at least 85% of slow wave sleep. Children with CSWS may or may not experience seizures but display what is known as electrical status epilepticus during sleep (ESES); a series of generalised spike-wave complexes occurring during sleep (Holmes & Lenck-Santini, 1997). What is most notable about this condition for the purpose of this review is that ESES does not occur during the awake state yet neuropsychological regression is often seen (Holmes & Lenck-Santani, 2005). Roulet-Perez, Davidoff, Despland & Deonna (1993) studied prospectively four children with 'epilepsy and continuous spike-wave sleep' syndrome, from 18 to 48 months of age. The children showed a pattern of behavioural and cognitive disturbances similar to that found in some developmental autistic-like disorders, but also in adult frontal syndrome.

Landau Kleffner Syndrome (LKS) is a condition characterised by sudden deterioration in language abilities. EEG abnormalities are usually activated by sleep, and at times only seen during sleep. As language dysfunction is such a prominent feature of LKS many studies are restricted to investigating language difficulties. However, cognitive deterioration can be seen, with or without the presence of seizures (Scholtes, Hendriks & Renier, 2005). For example, Rossi et al (1999) followed up patients affected by Landau-Kleffner syndrome (LKS) for over 9 years, all of whom displayed ESES. Of these, 75% also showed a global regression of cognitive and behavioural functions, with learning disabilities seen in 63.6%, and only 18.2% of cases presented a complete language recovery. Rossi et al suggest that LKS and ESES may represent two aspects of the same brain dysfunction that may exist separately or together. In a study of 18 children with LKS and ESES, as well all children having regression of receptive language, correlating with length of ESES all children had impaired short-term memory at follow-up (Robinson, Baird, Robinson & Siminoff, 2001).

It appears that CSWS in combination with BECTSS can have an additional impact. A mental processing composite (Kaufmen Assessment Battery and Wechsler Intelligence Scale for Children-Revised) within normal limits was found in all children with BECTS and Atypical Benign Partial Epilepsy (ABPE) which is characterised by CSWS, but generally lower in ABPE than in BECTS, with notably lower scores on verbal expression and auditory sequential memory. The researchers suggest that given the normal scores in the elementary cognitive functions, such as visual and verbal functions and long-term memory, disturbance in the process of executive functions such as flexibility, fluency, and working memory could cause this characteristic profile. Children with ABPE also showed the similar profile in the subtests of the Illinois Test

of Abilities to that of BECTS suggesting it is likely that both groups of children share a similar common cognitive dysfunction (Hatorri, 2002).

3.3.3 Reversibility of Cognitive Impairment

As with SDB the reversibility of the cognitive dysfunction upon treatment informs us about the nature of the relationships involved. Studies showing an improvement in cognitive function upon treatment of the epilepsy include that by Sinclair & Synder (2005) who demonstrated that upon treatment of LKS and CSWS with corticosteroids, all but one of ten patients manifested significant improvement in language, cognition, and behaviour, which continued after the corticosteroid trial.

As some of the epilepsies described remit spontaneously with age, it is also interesting to see if similar improvement in cognitive function is seen when seizures cease. A study of 26 children with BRE, with initial deficits in memory, learning of auditory-verbal, material and executive function demonstrated the same children did not present any major cognitive difficulties compared to controls when a mean of approximately five years had passed since onset of the typical syndrome, and at a time when most of them were seizure-free (Lindgren, Kihlgren, Lundberg, Melin & Eog-Olofsson, 2004). More recently longitudinal improvement in cognitive functioning, particularly verbal memory, receptive language ability, and phonemic manipulation has been seen in children with BRE (Northcott et al, 2006). Additionally notable improvements have been seen in IQ, visuomotor coordination, non-verbal short-term memory, sustained attention and mental flexibility, picture naming, and visual-perceptual performance at the time of IED remission, to the level of controls' performance on the same

assessments (Baglietto et al, 2002). Finally, Deonna et al (2000) also displayed that the impairments described earlier improved or normalized as EEG improved.

However, potentially due to the varying pathophysiology not all studies have shown such reversibility in cognitive impairments. Stephani & Carlsson (2006) found no correlation between IQ and the severity of the rolandic discharges, or between cognitive and EEG improvement upon treatment. Also in the study described earlier by Papavasiliou et al (2006) researchers described a dissociation between epilepsy outcome and learning problem outcome. Another disappointing outcome came from a long-term follow up study of ten children with ESES (including CSWS and LKS) treated with valproate and/or benzodiazepines. Cognitive dysfunction did not respond to treatment in nine of the ten children, and only one showed good recovery after the disappearance of ESES, with four demonstrating partial recovery. The researchers suggest that this prognosis was related to long-duration ESES and/or early onset of the epileptic activity. Therefore, it seems that the findings relating to improvement of cognitive function upon remission or intervention, are mixed and potentially related to the course of the epilepsy. An additional explanation may also be that in some cases whilst outward clinical symptoms of the epilepsy may no longer be present, interictal discharges or other subclinical activity during sleep may still be present.

4. Discussion

This review has compiled substantial evidence for associations between the clinical conditions related to sleep disturbance identified and cognitive impairment. However, what remains to be discussed are a number of potential confounding factors within this relationship, alongside the potential mechanisms for the associations observed.

Some of the confounding factors or alternative explanations to consider include; the effects of SES, testing bias, comorbid learning difficulties, and direct effects of the medical condition upon learning (including seizure activity in the case of epilepsy and hypoxia in the case of SDB). These will each be discussed in turn.

Whilst many of the studies attempted to control for variables such as age and gender, not all matched for SES. However, one of the studies noted the difference between the experimental and control group was not as great after adjusting for SES which begs the question of what impact this would have had on the results of the other studies, and whether or not those studies not controlling for SES overestimated the difficulties found. Conversely, this may be counteracted in some studies by the increased likelihood of families of higher SES to take part, when the difficulties may be more prevalent amongst low SES backgrounds. Thus, where SES is likely to have a high impact upon a variable such as learning it would be helpful if this were accounted for in the recruitment or the analysis. However, given that some of the studies have controlled for SES, and given the reversibility demonstrated, it is unlikely that this factor wholly explains the associations found.

Features of the assessment also need to be considered as sources of under-estimation or over-estimation of performance. Lengthy test batteries can easily lead to fatigue in children and thus lead to underperformance on all or some of the battery, particularly the latter components. Comprehensive assessment tools alternate subtests relating to difference indices to decrease the likelihood of test order impacting one index substantially. However, when utilising individually compiled batteries, this is more difficult, and the latter test may suffer. Alternatively, the one-to-one encouragement

and supervision available in the quiet testing environment can over inflate performance and produce results not representative of a child's capabilities in the classroom particularly those with difficulties in the areas of attention/executive function. This can lead to underestimation of difficulties.

A further factor worthy of consideration is that many of the epilepsy studies did not discuss the possibility of comorbid learning difficulties present prior to onset of the condition. In the case of epilepsy, it is not uncommon for developmental anomalies, or brain injury to precede onset of the condition. Whilst extreme cases are not likely to be eligible for the research described, more subtle cases may be missed, and could be argued to explain some of the learning problems identified. However, the studies demonstrating reversibility upon remission of the physical condition decrease the likelihood of comorbid learning deficits being fully responsible for the learning problems demonstrated.

In the case of many epilepsy conditions there are also direct effects of seizures and antiepileptic medication to consider. In order to counteract the latter, participants studied tended not to be taking medication, thus this alone could not explain the cognitive dysfunction. With regard to the impact of seizures this review attempted to include epilepsy conditions less likely to directly interfere with daytime performance. The links between sleep related epileptic activity and cognitive impairment identified were in some cases in the absence of daytime seizures (Blunden et al, 2000). One study found deficits in IQ significantly correlated with frequency of spikes in the EEG, but not with frequency of seizures suggesting seizures were not the prime factor in determining cognitive impairment (Weglage et al, 1997) and indeed some of the study participants were seizure free (Lindgren et al, 2004). It has also been found that where

cognitive function improved at remission, some interictal activity still existed during waking hours (and also during sleep but much reduced) thus implying that the daytime interictal activity was probably not responsible for the initial cognitive impairment (Bagglietto et al 2002). Naturally, in all of these cases the presence of subclinical seizure activity cannot be ruled out, however, it appears that the sleep disturbance itself is likely to be at least partially responsible for the impact upon cognition.

In the case of SDB whilst at least two studies have found apneic/hypopneic events to be inversely related to performance (Kaemingk et al, 2003; Rhodes et al, 1995) this was contradicted by Beebe et al (2004). The study by Kaemingk et al (2003) also found the degree of sleep disturbance to impact learning and memory. It is noteworthy that cognitive impairments are not restricted to OSA (Gottlieb et al, 2004) or SDB with definite gas exchange abnormalities, as in the study by O'Brien et al (2004) participants without gas exchange abnormalities were purposely selected. O'Brien et al (2004) also demonstrated performance to be related to a 'sleep pressure' score relating to sleep disturbance independent of respiratory disturbance or hypoxemia. Similarly snoring history has predicted more test scores than the number of episodes of apnea/hypopnea. Additionally, impairments in executive function have been seen to be more closely associated with sleep architecture patterns than levels of blood oxygen saturation (Surratt et al, 2006) with participants demonstrating less sleep time, less efficient sleep and particularly less Stage Two sleep (suggested to play a role in facilitating executive function; Smith and MacNeil, 1992). However, the authors admit it is possible that undetectable oxyhaemoglobin desaturations may impose adverse effects during critical ages for brain development.

It is also likely that a combination of factors are at play as MRI scans have revealed changes in brain metabolites potentially associated with actual physiological changes within the brain (Halbower et al 2006). Increased levels of high sensitivity C-reactive protein (indicating inflammatory response) have also been identified in children with OSA, particularly those with cognitive deficits, suggesting a relationship between the magnitude of the inflammatory response and increased risk for cognitive impairment (Gozal et al, 2007).

However, if it is hypothesised that at least some of the observed cognitive difficulties are attributable to the sleep disturbance itself, this raises questions as to the potential mechanisms for this. Some of the SDB and epilepsy studies cited above found impaired executive functioning and behaviour regulation (Beebe et al, 2004, Halbower et al, 2006) and demonstrated improved behaviour and/or inattention (Ali et al 1996; Croona et al, 1999; Lewin et al 2002) when the sleep disturbance is resolved. One possible explanation for this is the disruption of Stage Two sleep impacting upon executive function. Difficulties with attention and test application could have a knock on impact on other subcomponents of the tests.

Alternatively chronic sleep disruption over a long period of a child's life is a possible explanation for neurocognitive deficits in primary snorers (Kennedy et al, 1998) and it is possible that this disrupts consolidation of learning (CoL) during sleep. At the beginning of this review evidence for the existence of CoL during sleep was introduced (Stickgold & Walker, 2005) and there is also evidence that CoL is compromised by sleep deprivation in adults (Maquet, Schwartz, Passingham & Frith et al, 2003). Thus, this is a potential explanation for the associations found, which could be subject to explicit testing. The assessments utilised in the studies cited are static assessments of

functioning at a point in time, whereas measurement of CoL involves quantifying an active process during the night, thus representing a more rigorous experimental design.

It is extremely important that this area is subject to further research, as learning problems, even specific to one area, can have a widespread impact upon learning in development as very few in vivo tasks involve one pure cognitive domain. This means difficulties in one area such as attention or phonological processing may impact a child's ability to concentrate or comprehend instructions for any task, thus impacting performance as a whole. This in turn may decrease a child's confidence in their learning abilities, often manifesting as demotivation or behavioural problems.

Despite the potential impact of disrupted learning upon a child's life, at present decisions regarding treatment for the medical conditions discussed are usually made on the basis of the physical symptoms, and where these are not sufficiently serious, intervention is not considered. Whilst in some cases associated risks may not justify medical intervention there remains a role for timely neuropsychological assessment and educational intervention. The research by Gozal & Pope (2001) suggests that even temporary effects on learning may have longer term implications, as children fall behind their peers and miss out on key educational stages at school, which makes it difficult for them to 'catch up' from an educational and psychosocial perspective even when symptoms are improved. Thus, there is a strong case for further research to better understand the relationship between sleep disturbance and learning in children so that appropriate assessments and interventions can be identified and implemented.

5. Conclusions

This review has compiled a large body of research suggestive of a relationship between specific medical conditions associated with sleep disturbance and cognitive impairment. This could be explained by direct physiological factors or by sleep disruption which remains a common factor between these conditions. As such learning disruption can have a prominent impact upon development, timely medical, psychological and educational interventions are required to minimise potentially irreversible impact upon the learning and development of these children. To facilitate this process further research is required to increase understanding of the relationship between sleep and learning in children. Due to recent evidence suggesting the presence of consolidation of learning during sleep, further research capturing the impact of sleep disruption upon this process may provide a valuable addition to current understanding.

6. References

Aldenkamp, A., Alpherts, W.C., Dekker, M. J. A., Overweg, J. (1990). Neuropsychological aspects of learning disabilities in epilepsy. *Epilepsia 31* (4), 9-20.

Ali, N.J., Pitson, D.J., Stradling, J.R. (1993). Snoring, sleep disturbance, and behaviour in 4-5 year olds. *Archives of Disease in Childhood, 68*, 360-6.

Ali, N.J., Pitson, D., Stradling, J.R. (1994). Natural history of snoring and related behaviour problems between the ages of 4 and 7 years. *Archives of Disease in Childhood, 71*, 74-6.

Ali, N.J., Pitson, D., & Stradling, J.R. (1996). Sleep disordered breathing: effects of adenotonsillectomy on behaviour and psychological functioning. *European Journal of Pediatrics, 155*, 56-62.

Anderson, V., Northam, E., Hendy, J. & Wrennall, J. (2001). *Developmental Neuropsychology. A Clinical Approach.* Psychology Press. Hove: East Sussex.

Annett, R.D., Bender, B.G., Gordon, M. (2007). Childhood Asthma Management Program Research Group.Relating children's attentional capabilities to intelligence, memory, and academic achievement: a test of construct specificity in children with asthma. *Child Neuropsychology, 13*(1), 64-85.

Anuntaseree, W., Rookkapan, K., Kuasirikul, S., Thongsuksai, P. (2001). Snoring and obstructive sleep apnea in Thai school-age children: prevalence and predisposing factors. *Pediatric Pulmonology, 32*, 222-227.

Archbold, K.H., Giordani, B., Ruzicka, D.L., Chervin, R.D. (2004). Cognitive executive dysfunction in children with mild sleep-disordered breathing. *Biological Research for Nursing, 5*(3), 168-76.

Avior, G., Fishman, G., Leor, A., Sivan, Y., Kaysar, N., Derowe, A. (2004) The effect of tonsillectomy and adenoidectomy on inattention and impulsivity as measured by the Test of Variables of Attention (TOVA) in children with obstructive sleep apnea syndrome. *Otolaryngology Head and Neck Surgery, 131*(4), 367-71.

Baglietto, M.G., Battaglia, F.M., Nobili, L., Tortorelli, S., De Negri, E., Calevo, M.G., Veneselli, E., De Negri, M. (2001) Neuropsychological disorders related to interictal epileptic discharges during sleep in benign epilepsy of childhood with centrotemporal or Rolandic spikes. *Developmental Medicine and Child Neurology, 43*(6), 407-12.

Bazil, C.W., Malow, B.A., Sammaritano, M.R. (2002). *Sleep and Epilepsy: The Clinical Spectrum.* New York: Elsevier Science Publishing.

Beebe. D, B, Wells. C,T, Jeffries. J, Chini. B, Kalra. M, Amin. R, (2004). Neuropsychological effects of paediatric obstructive sleep apnea. *Journal of the International Neuropsychological Society, 10,* 962-975.

Beghi, E., De Maria, G., Gobbi, G., Veneselli, E. (2006). Diagnosis and treatment of the first epileptic seizure: guidelines of the Italian League against Epilepsy. *Epilepsia. 47*(5), 2-8.

Bender, B. G., Annett, R. D (1999) Neuropsychological outcomes of nocturnal asthma. *Chronobiology International, 16* (5), 695-710.

Blunden, S., Lushington, K., Kennedy, D., Martin, J., Dawson, D. (2000) Behavior and neurocognitive performance in children aged 5-10 years who snore compared to controls. *Journal Clinical Experimental Neuropsychology, 22*(5), 554-68.

Blunden, S., Lushington, K., Lorenzen, B., Ooi, T., Fung, F., Kennedy, D. (2004) Are sleep problems under-recognised in general practice? *Archives Disease Child, 89* (8), 708-712

Blunden, S., Lushington, K., Lorenzen, B., Martin, J., Kennedy, D. (2005). Neuropsychological and psychosocial function in children with a history of snoring or behavioural sleep problems. *The Journal of Paediatrics, 6*, 780-786

Brunetti, L., Rana, S., Lospalluti, M.L., Pietrafesa, A., Francavilla, R., Fanelli, M., Armenio, L. (2001). Prevalence of obstructive sleep apnea syndrome in a cohort of 1,207 children of southern Italy. *Chest, 120*, 1930-1935.

Buscemi, N., Vandermeer, B., Hooton, N. (2005). The efficacy and safety of exogenous melatonin for primary sleep disorders: A meta-analysis. *Journal of General Internal Medicine, 20,* 1151–1158

Camfield, C., Camfield, P., Gordon, K., Smith, B., Dooley, J. (1993). Outcome of childhood epilepsy: a population-based study with a simple predictive scoring system for those treated with medication. *Journal Pediatrics, 122*(6), 861-8.

Carvalho, L.B., Prado, L.F., Silva, L., de Almeida, M.M., Almeida e Silva, T., Lora, M.I., Prado, G.F. (2005) Cognitive dysfunction in children with sleep-disordered breathing. *Journal Child Neurology, 20*(5), 400-4.

Cortesi, F., Gianotti, F., & Ottaviano, S. (1999) Sleep problems and daytime behavior in childhood idiopathic epilepsy. *Epilepsia, 40*, 1557-1565

Cowan, L.D. (2002) The epidemiology of the epilepsies in children. *Mental Retardation and Developmental Disabilities Research Review. 8* (3), 171-81

Croona, C., Kihlgren, M., Lundberg, S., Eeg-Olofsson, O., Eeg-Olofsson, K.E. (1999) Neuropsychological findings in children with benign childhood epilepsy with centrotemporal spikes. *Developmental Medicine Child Neurology. 41* (12), 813-8.

Deonna, T., Zesiger, P., Davidoff, V., Maeder, M., Mayor C, Roulet E. (2000) Benign partial epilepsy of childhood: a longitudinal neuropsychological and EEG study of cognitive function. *Develomental Medicine Child Neurology, 42* (9), 595-603.

Emancipator, J.L., Storfer-Isser, A., Taylor, H.G., Rosen, C.L., Kirchner, H.L., Johnson, N.L., Zambito, A.M., Redline, S. (2006) Variation of cognition and achievement with sleep-disordered breathing in full-term and preterm children. *Archives of Pediatric and Adolescent Medicine 160* (2), 203-10.

Fischer, S., Wilhelm, I., & Born, J. (2007). Developmental Differences in Sleep's Role for Implicit Off-line Learning: Comparing Children with Adults. *Journal of Cognitive Neuroscience, 7*(19), 214-227.

Friedman, B.C., Hendeles-Amitai, A., Kozminsky, E., Leiberman, A., Friger, M., Tarasiuk, A., Tal, A. (2003) Adenotonsillectomy improves neurocognitive function in children with obstructive sleep apnea syndrome. *Sleep 26* (8), 999-1005.

Gais, S., Molle, M., Helms,. K., Born,. J. (2002) Learning-dependent increases in sleep spindle density *The Journal of Neuroscience, 22* (15), 6830-6834.

Gais, S. & Born, J. (2004) Low acetylcholine during slow-wave sleep is critical for declarative memory consolidation. *Proceedings of the National Academy of Science, 101*, 2140–2144.

Gais, S., Lucas, B., Born, J. (2006) Sleep after learning aids memory recall. Learning & Memory, *13*, 259-262.

Gislason, T., Benediktsdottir, B. (1995) Snoring, apneic episodes, and nocturnal hypoxemia among children 6 months to 6 years old. An epidemiologic study of lower limit of prevalence. *Chest, 107*, 963-6.

Giordani B, Caveney AF, Laughrin D, Huffman JL, Berent S, Sharma U, Giles JM, Garofalo EA. (2006) Cognition and behavior in children with benign epilepsy with centrotemporal spikes (BECTS). *Epilepsy Research, 70* (1), 89-94.

Gomez, R.L., Bootzin, R.R., Nadel, L. (2006) Naps Promote Abstraction in Language-Learning Infants. *Association for Psychological Science, 17* (8), 670-674.

Gottlieb, D.J., Chase, C., Vezina, R.M., Heeren, T.C., Corwin, M.J., Auerbach, S.H., Weese-Mayer, D.E., Lesko, S.M.(2004) Sleep-disordered breathing symptoms are associated with poorer cognitive function in 5-year-old children. *Journal of Pediatrics 145* (4), 458-64.

Gozal, D. (1998) Sleep-disordered breathing and school performance in children. *Pediatrics, 102,* 616-620.

Gozal, D. & Pope, D.W.J. (2001) Snoring during early childhood and academic performance at ages thirteen to fourteen years. *Pediatrics, 107*, 1394-9.

Gozal, D., Crabtree, V.M., Sans Capdevila, O., Witcher, L.A., Kheirandish-Gozal, L (2007) C-reactive protein, obstructive sleep apnea, and cognitive dysfunction in school-aged children. *American Journal of Respiratory and Critical Care, 176*(2), 188-93.

Gunduz, E., Demirbilek, V., Korkmaz, B. (1999) Benign rolandic epilepsy findings. *Seizure, 8,* 246-9.

Gutstadt, L.B., Gillette, J.W., Mrazek, D.A., Fukuhara, J.T., LaBrecque, J.F. & Strunk, R.C. (1989). Determinants of school performance in children with chronic asthma. *American Journal of Diseases of Children, 143,* 471-475.

Hansen, D., Vandenberg, B. (2001). Cognitive effects of sleep apnea and narcolepsy in school age children. *Sleep and Hypnosis, 3*(2), 73-80

Halbower, A.C., Degaonkar, M., Barker, P.B., Earley, C.J., Marcus, C.L, Smith, P.L., Prahme, M.C. (2006). Childhood obstructive sleep apnea associates with neuropsychological deficits and neuronal brain injury. *PLoS Med, 3*(8), 301.

Hattori, J. (2002). Higher brain dysfunction in benign childhood epilepsy with centrotemporal spike and atypical benign partial epilepsy of childhood. *No To Hattatsu, 34*(6), 484-90

Heijbel, J., Bohman, M. (1975). Benign epilepsy of children with centrotemporal EEG foci: intelligence, behavior, and school adjustment. *Epilepsia, 16*(5), 679-87

Holmes, G.L. (1997). Classification of seizures and the epilepsies. In: Schachter SC, Schomer DL, eds. *The comprehensive evaluation and treatment of epilepsy.* San Diego, CA: Academic Press 1-36.

Holmes, G.L., Lenck-Santini, P.P. (2006). Role of interictal epileptiform abnormalities in cognitive impairment *Epilepsy & Behavior. 8* (3), 504-15.

Kennedy, J.D.; Blunden, S.; Hirte, C. (2004). Reduced neurocogition in children who snore. *Pediatric Pulmonology, 37*, 330–337.

Kheirandish-Gozal, L., Sans Capdevila, O., Tauman, R., Gozal, D. (2006). Plasma C-reactive protein in non-obese children with obstructive sleep apnea before and after adenotonsillectomy. Journal Clinical Sleep Medicine. *In press*

Kaemingk, K., Pasvogel, A., Goodwin, J., Mulvaney, S., Martinez, F., Enright, P.L., Rosen, G., Morgan, W.J., Fregosi, R.F., Quan, S.F. (2003). Learning in children with sleep disordered breathing: findings of the Tucson Children's Assessment of Sleep Apnea (TuCASA) prospective cohort study. *Journal of International Neuropsychological Society, 9*, 1016-1026.

Kurnatowski, P., Putyński, L., Lapienis, M., Kowalska, B. (2006). Neurocognitive abilities in children with adenotonsillar hypertrophy. *International Journal Pediatric Otorhinolaryngology, 70* (3), 419-24.

Lewin, D.S., Rosen, R.C., England, S.J., Dahl, R.E. (2002). Preliminary evidence of behavioral and cognitive sequelae of obstructive sleep apnea in children. *Sleep Medicine, 3*(1), 5-13

Lindgren, Å., Kihlgren, M., Lundberg, S., Melin, L., Eeg-Olofsson, O. (2004) Development of cognitive functions in children with Rolandic epilepsy. A follow-up study. *Epilepsy Behaviour, 5,* 903-10.

Maquet, P., Schwartz, S., Passingham, R., & Frith, C. (2003). Sleep-related consolidation of a visuomotor skill: Brain mechanisms as assessed by functional magnetic resonance imaging. *Journal of Neuroscience, 23,* 1432–1440.

Montgomery-Downs, H.E., Crabtree, V.M., Gozal, D. (2005). Cognition, sleep and respiration in at-risk children treated for obstructive sleep apnoea. *European Respiratory Journal, 25*(2), 336-42.

Northcott, E., Connolly, A.M., Berroya, A., Sabaz, M., McIntyre, J., Christie, J., Taylor, A., Batchelor, J., Bleasel, A.F., Lawson, J.A., Bye, A.M. (2005). The neuropsychological and language profile of children with benign rolandic epilepsy. *Epilepsia, 46*(6), 924-30

Northcott, E., Connolly, A.M., McIntyre, A., Christie, J., Berroya, A., Taylor, A., Batcholer, J. Aaron, G., Soe, S., Bleasel, A.F., Lawson, J.A., Bye, A.M.E (2006). Longitudinal Assessment of Neuropsychologic and Language Function in Children With Benign Rolandic Epilepsy. *Child Neurology, 21*(6), 518-522

O'Brien, L.M., Mervis, C.B., Holbrook, C.R., Bruner, J.L, Klaus, C.J., Rutherford, J., Raffield, T.J., Gozal, D. (2004). Neurobehavioral implications of habitual snoring in children. *Pediatrics, 114* (1), 44-9.

O'Brien, L.M., Mervis, C.B., Holbrook, C.R., Bruner, J.L., Smith, N.H., McNally, N., McClimment, M.C., Gozal D. (2004). Neurobehavioral correlates of sleep-disordered breathing in children. *Journal of Sleep Research, 13*(2), 165-72.

O'Brien LM, Tauman R, Gozal D (2004). Sleep pressure correlates of cognitive and behavioral morbidity in snoring children. *Sleep, 27*(2), 279-82.

Owen, G.O., Canter, R.J., Robinson (1996). Snoring, apnea and ENT symptoms in the paediatric community. *Clinical Otolaryngology and Allied Sciences, 21*, 130 – 134.

Owens, J., Spirito, A., Marcotte, A., McGuinn, M., Berkelhammer, L. (2000). Neuropsychological and Behavioral Correlates of Obstructive Sleep Apnea Syndrome in Children: A Preliminary Study. *Sleep and Breathing 4* (2) 67-78.

Papavasiliou, A., Mattheou, D., Bazigou, H., Kotsalis, C., Paraskevoulakos, E. (2005). Written language skills in children with benign childhood epilepsy with centrotemporal spikes. *Epilepsy Behaviour, 6 (1)*, 50-8.

Pinton, B., Ducot, J., Motte, A..S., Arbuès., C. (2006). Cognitive functions in children with benign childhood epilepsy with centrotemporal spikes (BECTS) *Epileptic Disorders, 8 (1)*, 11-23.

Plihal, W. Born, J. (1997). Effects of early and late nocturnal sleep on declarative and procedural memory. *Journal of Cognitive Neuroscience 9*, 534–547.

Randazzo, A.C., Muehlbach, M.J., Schweitzer, P.K., & Walsh, J.K. (1998). Cognitive function following acute sleep restriction in children ages 10-14. *Sleep, 21*, 861-8.

Rhodes, S.K., Shimoda, K.C., Waid, L.R., O'Neil, P.M., Oexmann, M.J., Collop, N.A., Willi, S.M. (1995). Neurocognitive deficits in morbidly obese children with obstructive sleep apnea. *Journal of Pediatrics, 127* (5), 741-4.

Robinson, R.O., Baird, G., Robinson, G., Simonoff, E. (2001). Landau-Kleffner syndrome: course and correlates with outcome. *Developmental Medicine and Child Neurology, 43*, 243-247.

Roulet-Perez, E., Davidoff, V., Despland, P.A., Deonna, T. (1993). Mental and behavioural deterioration of children with epilepsy and CSWS: acquired epileptic frontal syndrome. *Developmental Medicine and Child Neurology, 35*, 661-74.

Rossi, P.G., Parmeggiani, A., Posar, A., Santi, A., Santucci, M. (1997). Benign myoclonic epilepsy: long-term follow-up of 11 new cases. *Brain Development, 19* (7), 473-9.

Reuveni, H., Simon, T., Tal, A., Elhayany, A., & Tarasiuk, A. (2002) Child behavior and quality of life before and after tonsillectomy and adenoidectomy. *Archives of Otolaryngology Head & Neck Surgery, 128*, 770-775.

Scholtes, F.B.J., Hendriks, M.P.H., & Renier, W.O. (2006). Cognitive deterioration as a result of Electrical Status Epilepticus during Slow Sleep. *Epilepsy and Behavior, 6*, 167-173.

Schmidt, H., Cohrs, S., Heinemann, T, Geerdt, C., Djukic, M., Hemann, B., Wallesch, C.W., & Nau, R. (2006). Sleep disorders are long-term sequelae of both bacterial and viral meningitis. *Journal of Neurology, Neurosurgery and Neuropsychiatry, 77* (4), 554-558.

Shinnar, S., Pellock, J.M. (2002). Update on the epidemiology and prognosis of pediatric epilepsy. *Journal of Child Neurology, 17,* Suppl 1: S4-17.

Sinclair, D.B, Snyder, T.J. (2005). Corticosteroids for the treatment of Landau-kleffner syndrome and continuous spike-wave discharge during sleep. *Pediatric Neurology, 32* (5), 300-6.

Smith, C., MacNeill, C. (1992). Memory for motor task is impaired by stage 2 sleep loss. *Sleep Research, 21*, 139.

Staden, U., Isaacs, E., Boyd, S.G., Brandl, U., Neville, B.G (1998). Language dysfunction in children with Rolandic epilepsy. *Neuropediatrics, 29*, 242–248.

Stephani, U., Carlsson, G. (2006). The Spectrum from BECTS to LKS: The Rolandic EEG Trait—Impact on Cognition. *Epilepsia, 47*(2), 67-70.

Stickgold, R., Whidbee, D., Schirmer, B., Patel, V., & Hobson, J. (2000). Visual discrimination task improvement: A multi-step process occurring during sleep. *Journal of Cognitive Neuroscience, 12*, 246-54.

Stickgold, R (2005). Sleep-dependent memory consolidation. *Nature, 437*, 1272-1278

Stickgold, R., Walker, M.P. (2005) Memory consolidation and reconsolidation: What is the role of sleep? *Trends in Neuroscience, 28*(8), 408-415.

Stores, G. (2001). A Clinical Guide to Sleep Disorders in Children and adolescents. Syndicate of the University of Cambridge: The Press.

Stores, G., Ellis, A.J., Wiggs, Crawford, C., Thomson, A. (2007). Sleep and psychological disturbance in nocturnal asthma. *Archives of Disease in Childhood, 78*, 413-419.

Suratt, P.M., Peruggia, M. D., Andrea, L., Diamond, R., Barth, J.T., Nikova, M., Perriello, V.A. Johnson, M.L. (2006). Cognitive function and behavior of children with adenotonsillar hypertrophy suspected of having obstructive sleep-disordered breathing. *Pediatrics, 118* (3), 771-81.

Urschitz, M.S., Guenther, A., Eggebrecht, E., Wolff, J., Urschitz-Duprat, P.M., Schlaud, M., & Poets, C.F. (2003). Snoring, Intermittent Hypoxia and Academic Performance in Primary School Children. *American Journal of Respiratory and Critical Care Medicine, 168*, 464-468.

Völkl-Kernstock, S., Willinger, U., Feucht, M. (2006). Spacial perception and spatial memory in children with benign childhood epilepsy with centro-temporal spikes (BECTS). *Epilepsy Research, 72*(1), 39-48.

Walker, M., Brakefield, T., Morgan, A., Hobson, J., & Stickgold, R. (2002). Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron, 35*, 205-11.

Walker, M.P., Brakefield, T., Hobson, J.A., & Stickgold, R. (2003). Dissociable stages of human memory consolidation and reconsolidation. *Nature, 42,* 616-20.

Weglage, J., Demsky, A., Pietsch, M., Kurlemann, G. (1997). Neuropsychological, intellectual, and behavioral findings in patients with centrotemporal spikes with and without seizures. *Developmental Medicine Child Neurology, 39*(10), 646-51.

Research Report

Prepared in accordance with guidelines for submission to Journal of Developmental Neuropsychology

Sleep dependent learning consolidation in children and adults

Sophie Thomas

Abstract

There is good evidence that consolidation of learning (CoL) takes place during sleep. However, to date CoL research has been mainly restricted to adult populations, despite childhood being a crucial time for learning. This study, therefore, aimed to replicate research conducted with adults with a sample of children. Two learning tasks successful in measuring CoL over night (CoL-N) in adults were adapted for administration with children. Performance improvements overnight (CoL-N) were compared with those over an equivalent daytime period (CoL-D). Given the adaptations to the measures an adult sample was also included to indicate whether results were a feature of CoL in childhood or attributable to the modifications to the measures. A measure of non-verbal IQ and self-reported sleep quality were also included, in order to investigate their relationship with CoL-N.

Analyses revealed the differences between mean CoL-N and CoL-D were not significant in the adult or child sample for either learning task. However, post-hoc analyses revealed some interesting findings regarding properties of the modified measures. Whilst modifications may have reduced sensitivity to CoL, expected performance trajectories could be demonstrated in some individual cases, and some indications as to the sensitive aspects of the tests were evident. An interesting association between sleep latency in adults and bedtime difficulties in children also suggested that this early part of the night may somehow be important for CoL. Correlations between the remaining aspects of the sleep questionnaire and non-verbal IQ were not found. Overall, the research uncovered many challenges to assessing CoL in children, and revealed interesting learning which will provide direction for future research in measuring CoL in both adult and child populations.

Key words: Learning, consolidation, sleep, adults, children, measures.

Introduction

The relationship between sleep and learning has direct implications for understanding the importance of quality sleep. There is good evidence that sleep disruption is associated with cognitive difficulties particularly in medical conditions such as sleep disturbed breathing (Gottlieb, et al 2004) and certain epileptic encephalopathies of childhood which lead to disruption of normal learning and development (Aldenkamp, Apherts, Dekker & Overweg, 1990). The need to further understand this relationship is crucial. If sleep associated cognitive problems can be better understood, intervention strategies can be considered and implemented. This is particularly important in childhood which is a critical period for learning and development both in terms of brain development and opportunities to access education. It is also a period of vulnerability to clinical conditions associated with sleep and learning disturbance such as sleep disordered breathing and epilepsy.

1.1. Consolidation of Learning During Sleep in Adult Populations

There has been a surge of interest in the relationship between sleep and learning in recent years. One popular theory is that memories are somehow consolidated during sleep. The term consolidation refers to both the reduction in fragility of a memory (stabilisation), and the improvement that occurs offline (enhancement) which describes learning between training sessions without further training (Robertson, Pascual-Leone & Miall, 2004). Increasing evidence that sleep contributes to the consolidation of fresh memory traces comes from a wide range of experimental observations in adult populations (Stickgold, 2005) which shall be discussed below. Due to differing findings, evidence has been categorised into that relating to declarative or procedural memories. The term 'declarative memory' refers to knowing 'what' happened,

consciously available fact based memories including memory for past events, general knowledge and meaning. Procedural memory is a form of non-declarative memory, which normally refers to knowing 'how' to do something. It is often difficult to verbalise and acquired with practice requiring repetitions over a longer period of acquisition or exposure (Cohen & Squire, 1980). Procedural memories also include implicit learning which is a more passive process of acquiring knowledge through repeated exposure without conscious awareness, as opposed to explicit learning which is more conscious (Schachter, 1987).

1.2. Declarative Memory based Consolidation of Learning during Sleep

As early as 1924, research implying a relationship between declarative memory retention and sleep can be found (Jenkins & Dallenbach, 1924) though this was thought to be due to the lack of sensory interference during sleep rather than an active CoL-N process. Historically, evidence has been inconclusive with regard to CoL and declarative memories, and this is complicated by the fact that declarative memories do not always improve over time, thus it is less easy to demonstrate off-line learning. However, recently research has demonstrated a significant improvement on a semantically related word-pair associates task associated with the quality of slow wave sleep (SWS) (Gais & Born, 2004). In contrast such improvements were not seen in the cases of unrelated word-pairs or a face-name association task (Backhaus & Junghanns, 2006) demonstrating that not all declarative tasks are sensitive to CoL-N. Emotional salience has also been seen to play a key role in sensitivity of declarative memories to sleep, as learning of emotionally arousing pictures has been seen to be susceptible to CoL-N compared to neutral pictures (Hu, Stylos-Allan & Walker, 2006). Recently, other types of visual memory have been found to be consolidated during sleep. Ferrara

et al (2006) tested participants on memories of views seen on a defined neighbourhood route, finding most improvement after an undisturbed nights' sleep. Overall, it seems that research supporting CoL-N and declarative memory is accumulating, however, this may depend on subtleties of the tasks chosen. Certainly not all tasks are sensitive to CoL-N and further research is needed to establish the conditions under which COL-N is seen.

1.3. Procedural Memory based Consolidation of Learning during Sleep

The research is more unequivocal regarding CoL-N and procedural memory. One of the most prominent studies, by Walker, Brakefield, Hobson and Stickgold (2002) compared consolidation of learning during the day (CoL-D) to that over an equivalent night time period (CoL-N) by means of performance improvements on a sequential finger-tapping task. They demonstrated a 20% increase in motor speed without loss of accuracy after a night asleep, while an equivalent period of time awake provided no significant benefit (Walker et al, 2002). When participants were trained on a sequential finger-tapping task over a series of days small practice dependent improvements occurred before but not after the large gains post sleep (Walker et al, 2003). Also whilst the largest gain was seen after the first night of sleep, further gains were also demonstrated after additional nights of sleep. Similarly, on a sequential finger to thumb tapping task using a specially adapted glove, participants demonstrated sleep dependent delayed performance improvements during the first day or night post-training (Fisher et al, 2002). More recently improvement on a finger-tapping task has also been demonstrated following daytime naps (Walker & Stickgold, 2005).

An alternative procedural memory exercise seen to be sensitive to CoL-N is a pursuit tracking task (Maquet, Schwartz, Passingham & Frith, 2003). Participants were required to track a target moving along a trajectory predictable on the horizontal but not the vertical axis, using a joystick. Retesting after three days showed improvement in a sleep group on the learned trajectory, relative to a sleep-deprived group, as well as increased brain responses to the learned trajectory measured by magnetic resonance imaging (MRI). Daytime naps have also been seen to be sufficient to improve performance on a tracking task but not on declarative memory tests such as memory for semantically related word pair associates or a face-name association task (Backhaus & Junghanns, 2006). Finally, sleep dependent learning has also been demonstrated on a motor reaching task (Huber, Ghilardi, Massimini & Tononi, 2004).

One of the seminal areas of procedural memory studies focused on visual perceptual learning, by means of a computerised visual texture discrimination task (VDT). The primary task for participants is to distinguish between a horizontal or vertical array of three diagonal lines, displayed briefly in a specific quadrant of the visual field, amongst a background array. To ensure focus on the centre of the screen, and thus specificity in the visual field, participants were also required to distinguish between a letter T or L presented in the centre of the screen. The target screen was followed by a distractor mask screen with a varying interval between the two. The primary task of array discrimination becomes more difficult as the inter stimulus interval (ISI) became shorter. Again researchers compared CoL-D with CoL-N finding performance did not improve during the period of wakefulness (Stickgold, Whidbee, Schirmer, Patel & Hobson, 2000) but improved significantly overnight (Karni, Tanne, Rubenstein, Askenasy & Sagi, 1994). However, improvement was lost upon disruption of rapid eye

movement (REM) sleep (Karni et al, 1994) and impaired if early or late night sleep (usually dominated by SWS) was disrupted (Gais, Plihal, Wagner & Born, 2000).

1.4. Consolidation of Learning during Sleep in Children

Thus it can be seen that evidence for CoL-N on certain learning tasks in adult populations is rapidly accumulating with particularly robust findings regarding procedural learning. However, childhood is a period dominated by intense learning and long periods of sleep which undergo many changes in early childhood, as sleep states become more clearly defined, sleep time decreases and sleep cycle length increases (Stores, 2001). Even in middle childhood and adolescence, longer sleep time can be seen. A study by Randazzo, Muehlbach, Schweitzer & Walsh (1998) found that overnight sleep restriction led to impairments in higher cognitive functions, such as verbal creativity and abstract thinking, demonstrating an important role for sleep in cognitive function. Despite this, further research with children is limited, particularly that relating to CoL. However, that which has been identified is discussed below. Whilst distinctions between declarative and procedural memory studies are fairly clear in the adult studies, some of the tasks utilised with children include components of both types of learning, thus the research shall be presented as a whole.

Acknowledging that little is known about the role of sleep in CoL in young children Gomez, Bootzin and Nadel (2006) assessed familiarity (measured by differential gaze) with an artificial language in a group of 40 15-month-old infants. Infants who had taken a nap, appeared to recognise a pattern in the artificial language better than those in a 'no nap' condition, suggesting flexible learning which is essential for language development. However, the research was based on a small sample, as a substantial

proportion of infants were excluded as it proved difficult to control infant naps or distress during the experimental phases. A study of 12 high school students learning English-German vocabulary lists, found an increased rate of immediate forgetting when vocabulary was learned in the morning, compared to the evening, the key variable assumed to be the intervening sleep between encoding and retrieval. A second experiment found that of participants learning the list in the evening, those who were later sleep deprived performed more poorly at 48 hours after learning (Gais, Lucas & Born, 2006). However, the majority of the sample was 17 and 18 years old, thus bordering adulthood.

One of the few studies to examine CoL-N in school age children is that by Fischer, Wilhelm & Born (2007) which compared the performance of adults and children on implicit memory formation on a serial reaction time task. Interestingly, children demonstrated a sleep dependent deterioration in measures of implicit sequence knowledge compared to gains seen in adults. This study warns of the danger of simply generalising the research in adult populations to children, and assuming that findings are likely to be replicable. The authors suggest there may be a preferential effect of sleep towards the enhancement of explicit aspects of the task performance which interferes with implicit performance gains, thus implying a different role in consolidation of learning for children. It is also possible that systematic confounding factors relating to the complexities of testing children are partially responsible and these are discussed below.

1.5 Challenges of investigating consolidation of learning with children

Whilst there are some indications that some CoL-N may take place in children, clearly more research is needed to investigate this relationship in childhood populations. However, as demonstrated in the studies above, there are many challenges replicating this research with childhood populations. Children make very different participants to adults, and the cognitive assessment of children requires a unique approach. Children are more easily distracted (Diamond, 1995), less able to regulate their behaviour and attention on a task that is not appealing (Anderson, Northam, Hendy & Wrennall, 2001), and less able to divide their attention on tasks with a heavy working memory load particularly with the added complication of complex instructions (Manly, Robertson, Anderson & Nimmo-Smith, 1999). However, many of the CoL-N measures utilised in adult studies are repetitive, require complex instructions and rely heavily on divided attention.

Additionally, it has been demonstrated in the adult research, that not all tasks are sensitive to CoL-N perhaps because not all types of learning involve CoL-N. Indeed initially CoL-N research focused on animal studies, and progress into research involving any human participants was slow, for several reasons including the difficulty identifying suitable measures of learning likely to show a benefit from sleep, this leading to conflicting results (Cartwright, 2007). Now that this has been partly addressed in adult populations, the migration of this research to childhood populations presents a further challenge in identification of suitable measures of CoL-N for children.

Therefore, conducting research on CoL-N in children requires the identification and modification of measures of CoL-N which are appealing to children and within a child's

capability. Only then is there a chance of a child being able to fully apply themselves to a task, to give valid results. However, in adapting measures one needs be wary of changing the essential elements of the task and disrupting their sensitivity to CoL-N. Thus measures need to be both ecologically and experimentally valid. If the expected result is not found, one is left with the question as to whether this is a feature of the population or the modified measures. Therefore it seems important that measures chosen are also tested on an adult population, and the results compared.

1.6. Research Aims

This research ultimately aims to form part of the process of investigating the presence of CoL-N in children, with a view to us being able to investigate how this is disrupted in clinical populations, and how suitable interventions can be adopted. However, before understanding pathology we need to fully understand childhood CoL-N process in a 'normal' population and first we need to learn how we can reliably measure this.

Thus the main aim of this study is to adapt measures of CoL-N seen to be successful in adult populations and apply them with children. The study utilises two measures shown to be sensitive to CoL-N in adult populations:

1. Visual Discrimination Task (VDT: Karni & Sagi, 1991)
2. Pursuit Tracking task (PTT: Maquet et al, 2003).

These tasks have also been chosen for their potential to be modified for children. Research has indicated that there is little age-related change in visual selective attention (Manly et al, 1999) suggesting that younger children have a better chance of being able

to complete non-language mediated visual tasks which are also not as likely to be mediated by education as a word-pair task, for example. These tasks are also computerised which has the added advantage of appeal to children and this also allows standardised administration. However, given the repetitive nature and experimental appearance of the tasks (and indeed all CoL tasks) they require substantial modification to be both ethically and practically appropriate for children as well as being suitably appealing to maximise motivation and thus valid performance.

In order to assess the impact on the modifications on sensitivity to CoL-N this study also includes an adult population. If appropriate adaptations of tasks can be conducted, it is hypothesised that a CoL-N effect will be seen in both the adult and childhood participant groups.

To assess CoL-N this study will compare daytime learning consolidation CoL-D with CoL-N on the same two tasks in a non clinical sample of children and adults. It explores how the performance improvements seen after a period asleep compare to those of a comparable period awake. It also takes the opportunity to explore the relationship between CoL-N and both a measure of intellectual ability and a questionnaire based measure of sleep quality.

1.7. Experimental Hypotheses

Experimental hypothesis 1: It is predicted that CoL-N on the modified tasks will be greater than that over an equivalent wakeful daytime period (CoL-D) in the *adult* group.

Experimental hypothesis 2: It is predicted that CoL-N on the modified tasks will be greater than that over an equivalent wakeful daytime period (CoL-D) in the *child* group.

Secondary Aims

In addition to the above specific hypotheses the study also aims to explore any emerging relationships between sleep quality CoL-N and intellectual ability (as measured by the Matrix Reasoning test from the Wechsler Abbreviated Scale of Intelligence (WASI)) and sleep quality (as measured by the Pittsburgh and Paediatric Sleep Questionnaires). Based on previous research presented it might be predicted that better sleep quality may be associated with more efficient CoL-N. Similarly, given evidence that IQ is associated with more efficient memory (Lezak, Howieson & Loring, 2004) it may be predicted that higher IQ will be associated with greater CoL-N.

2. Method

2.1 Participants A power analysis assuming a medium to large effect size (d=0.65, alpha=0.05) given large effect sizes seen in previous studies (d=1.35; Karni & Sagi, 1994) yet allowing for higher variability in children's performance, revealed a sample of 21 participants per group would yield 80% power. In total, twenty-eight children and twenty-eight adults were recruited per group yielding a total sample of fifty-six participants. Potential participants with any known learning difficulties, psychiatric or medical conditions known to impact upon sleep or cognitive functioning were excluded from the study. All children taking part were attending mainstream school.

Child Participants Twenty-eight children were recruited from local schools, aged between 4 and 11 years old (mean age=8.04, SD=2.06: 16 female and 12 male). Of this total sample twenty-four children completed all three sessions of at least one of the two cognitive tasks and twenty-one children completed both cognitive tasks. Due to practical constraints twenty-one children completed the VDT and twenty-three children

completed the PTT. The mean Matrix Reasoning scaled score for the sample using the Wechsler Abbreviated Scale of Intelligence™ (WASI™) 10.5 (SD=2.9).

Adult participants. Twenty-eight adult participants, between the ages of 18 and 73 years (mean age = 27.28, SD = 13.45, 19 female and 9 male) were recruited from the University of Sheffield and through acquaintances of the researchers. Twenty-one participants completed all three sessions of at least one of the cognitive tasks and twelve participants completed both cognitive tasks. Nineteen adults completed the PTT and due to some logistical difficulties a more modest number of twelve adults completed the VDT. The mean Matrix Reasoning scaled score for the sample was 11.4 (SD=2.5)

2.2 Recruitment

Recruitment and data collection were carried out in collaboration with a second researcher also interested in administering two newly developed learning tasks. Thus participants were recruited to complete all four tasks at each of the three sessions. Data collection was also carried out in collaboration in order to maximise efficiency for both parties, and for the participants. The collaborating researcher recruited a majority of the student adult participants by advertising in the University of Sheffield Psychology department. Twenty-three adults were undergraduate and postgraduate students recruited from the University of Sheffield Psychology Department. The remaining five participants were recruited through informal networks via friends and colleagues.

Children were recruited via local schools. Twenty-one of the children were recruited from two local mainstream primary schools. It was necessary to recruit children from schools with breakfast and after-school clubs as the standard school day was too short to allow a CoL-D phase of sufficient length. Children and their parents were approached

by school staff to ask if they wished to participate in the study, and further information was provided upon request. Seven further children were recruited through existing contacts such as colleagues and friends.

Adult participants, parents and children were each provided with an age appropriate information sheet (Appendix 3a, 3b, 3c) which broadly informed participants of the purpose of the study. Participants were reassured that participation was voluntary and that they were free to withdraw at any time if they so wished. Adult participants wishing to take part gave signed informed consent (Appendix 3f). Children gave informed assent (Appendix 3e) and signed consent was obtained from a parent or legal guardian (Appendix 3d). The timing of the sessions was negotiated with parents and the school where appropriate.

Adult participants were offered a £10 cash reward for taking part. Schools were offered a small donation towards school funds, which was agreed would be spent in a manner to directly benefit the children.

All recruitment procedures for the study were approved by the Department of Psychology Ethics Sub-Committee, University of Sheffield.

2.3. Materials

Participants completed four cognitive tasks at each of the testing sessions lasting up to a total of 30 minutes. This included two cognitive tasks as part of this study (VDT and PTT) and a further two tasks as part of the study by Huyton (2008). The additional two tasks included a story recall based on the subtest of the Children's Memory Scale

(Cohen, 1997) and a procedural motor task incorporating a specially designed glove based on that by Fischer, Hallschmid, Elsner, and Born (2002). Tasks were delivered in a random counterbalanced order with pragmatic allocation of participants to conditions in order to maximise efficiency of the testing resources within the available time of the participants.

Due to the substantial modifications required two pilot phases were conducted in order to assess the impact of these modifications, and to ensure that the children were able to complete the tasks. Six children aged 5-8 years (4 male and 2 female) and two young adults were recruited via a local Church Sunday School, and six children aged 5 to 11 years (4 female and 2 male) were recruited in collaboration with a local primary school. The main aims of the adaptations were as follows:

1. To create instructions that children would be able to relate to and comprehend.

2. To decrease the divided attention and working memory load of the tasks so that children could focus on the essential elements of the tasks.

3. To shorten the tasks so that they were within the capabilities of children to complete.

4. To increase the visual and semantic appeal of the tasks to maximise motivation in participants.

5. To ensure the tasks remained at an appropriate level of difficulty for the adult participants.

6. To attempt to maintain the essential elements of the task, and thus their sensitivity to CoL.

The two tasks are described overleaf, along with the piloting procedure in order to explain the decisions taken during the modification process.

2.3.1. Pursuit Tracking Task (PTT) This task is a procedural learning task based on that utilised by Maquet et al (2003). Participants were presented with a moving target (red circle) on a computer display and were asked to follow this with a yellow cross which was manipulated using the joystick. Participants were instructed to maintain the yellow cross as close to the moving target as possible at all times. The non-dominant hand was used to ensure performance did not rely on pre-existing motor skills and to minimise interference of normal daytime activity (Maquet et al., 2003).

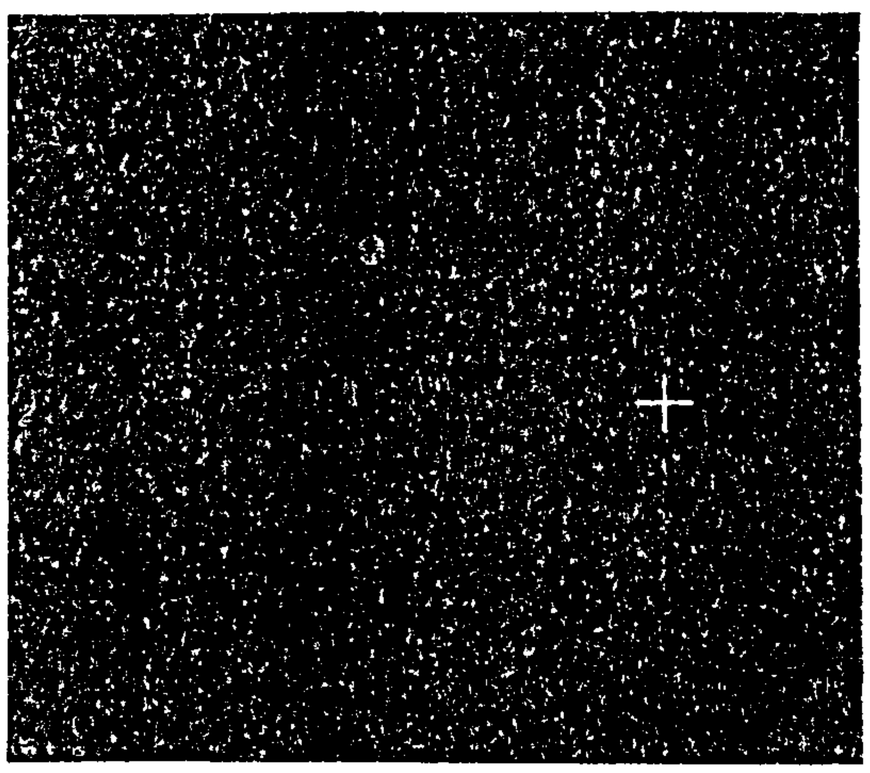


Figure 1 PTT Stimulus Screen.

Participants were not informed that the trajectory of the target was manipulated in a predictable manner. The coordinates of the target were programmed to be described by a single sine wave (frequency: 0.423 Hz) along the horizontal axis, and by the sum of four non-harmonic sine waves (frequency: 0.267, 0.341, 0.413, and 0.673 Hz) on the vertical axis. As a result, the trajectory followed by the target was easily predictable along the horizontal axis but less predictable along the vertical axis. The overall impression was of chaotic movement and explicit recognition of the systematic function is rarely reported (Maquet et al, 2003). The initial task consisted of 30 trials of 18 seconds.

PTT: Initial Modifications The task was recreated as a game called Chase. Participants were informed that they were required to chase the red spot with the yellow cross using their mouse, to see if they could 'catch it', and remain as close as possible. The task was presented on a standard 15" TFT screen and the custom joystick replaced by a more accessible PC mouse. The number of trials was reduced to 8 to be more realistic for children to complete, but the length of each trial expanded to 30 seconds to allow a familiarisation period.

Piloting the Pursuit Tracking Task

PTT Pilot Phase 1

During the initial pilot phase children demonstrated that they were able to track the target on the PTT task. Initial issues are described in Table 1:

Table 1: Pilot Session 1 Feedback on PTT

Main Issues Arising with PTT	Adaptive Action
Standard mouse was not reliable for tracking the target	Introduced high accuracy optical mouse
Instructions open to misinterpretation	Instructions lengthened and clarified
Children complained about using non-dominant hand as they found this difficult	Further explanation and reassurance added to instructions

***PTT Pilot Session 2*:** Further to the above adaptive actions being taken, the modified measure was re-piloted, displaying only two further remaining issues described in Table 2:

Table 2. Pilot Session 2 Feedback on PTT

Main Issues Arising with PTT	Adaptive Action
Adults found the task too easy. Target stimulus moving slowly and easy to track. Ceiling performance quickly reached, and no improvement seen between trials.	Speed of target and frequency of Sine wave harmonic increased.
Children complained that their arm ached by the end of the trials	Trials reduced from 30 to 25 seconds

The graph below left (*Fig.2*) demonstrates the asymptotic performance reached on the PTT by an adult pilot participant. Similar to the VDT participants were finding the task relatively easy and reaching their best performance quickly, thus not improving between sessions. To counteract this, the speed of the target and frequency of the sine wave were increased, in order to make the task more difficult. Re-piloting then demonstrated more learning across all three trials (*Fig. 3*).

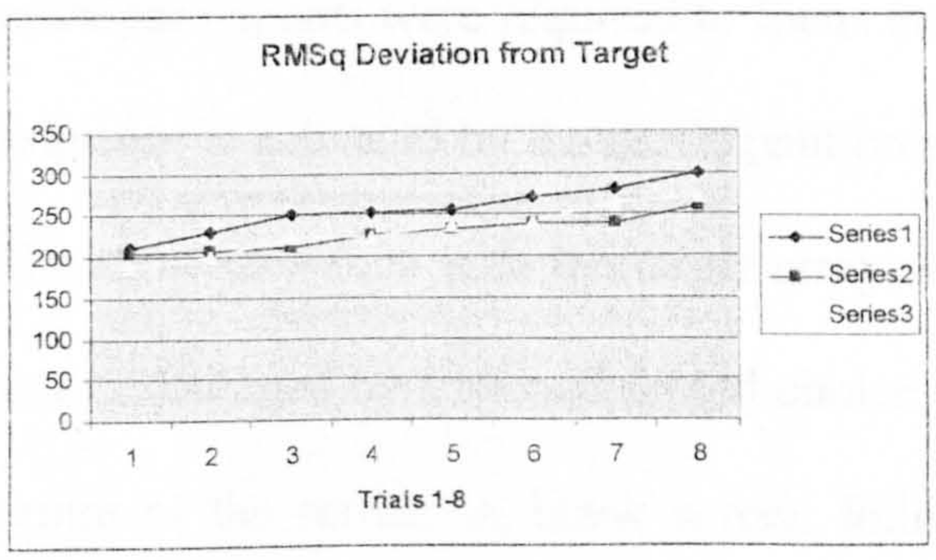


Figure 2. Pilot adult performance on PTT, demonstrating little improvement across sessions 2-3.

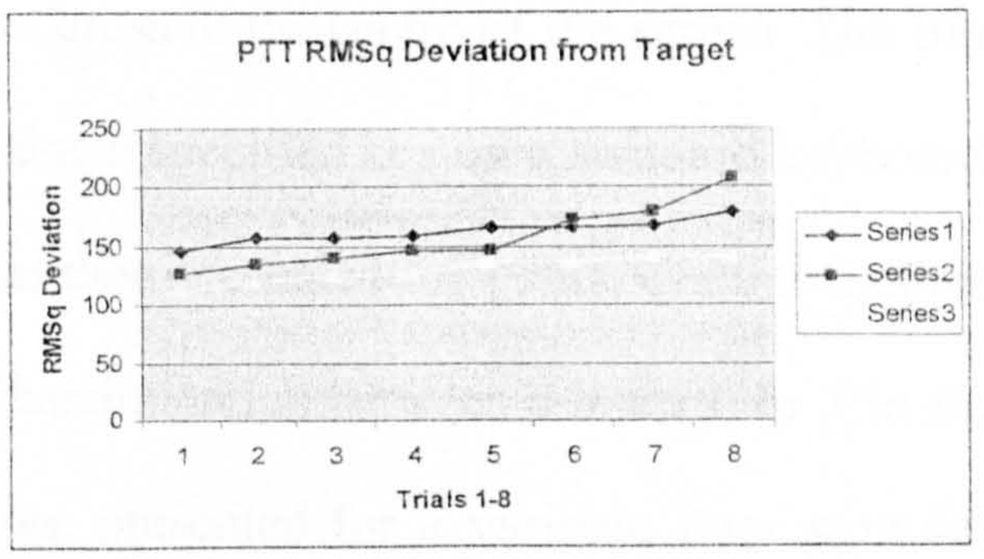


Figure 3. Graph demonstrating learning across trials 1-3

Final PTT task. The final task consisted of 8 trials of 25 seconds each, using a high accuracy optical mouse. The three trials were repeated on each of the three testing sessions. All children and adults confirmed that they were familiar with using a mouse, and this was supported by researcher observation.

2.3.2. Visual Discrimination Task (VDT)

This task was based on the task used by Stickgold et al (2000). It is a basic texture discrimination task, with performance improvements taking place in assemblies of neurons active at a very early pre-attentive stage of visual processing (Stickgold et al., 2000). The original black and white task comprised computer generated textures, with a target array of three diagonal lines arranged on either a vertical or horizontal plane,

amongst a 19 x 19 lattice background of horizontal lines presented for 17ms on a 15 inch monitor.

The exact position of the target array varied but remained in the lower left quadrant, as learning has been demonstrated to be specific to the location within the visual field (Karni & Sagi, 1991). To maintain the position in the visual field, at the start of the tasks participants were required to focus on a cross in the centre of the screen. The trial sequence is activated by the participant pressing a specified key on a standard keyboard. The stimulus screen with the target array was then presented for 17ms. Central fixation was encouraged by a second forced choice discrimination between a letter L or T in the centre of the screen. A blank screen follows, presented for a variable inter stimulus interval (ISI) of 1000-0ms. This was followed by a textural masking screen for a further 17ms. Finally, a screen asking respondents to identify the direction of the array and then the colour of the mouse was presented. The difficulty of this task is primarily dictated by the variable ISI as this sets the temporal limit of stimulus perception (Karni & Sagi, 1991). In the original study each experimental session comprised 16-20 blocks of 50 trials per block.

Initial Modifications to the VDT In order to increase appeal to children and to simplify instructions the task was redesigned as a colourful game called 'Mousehunt', programmed using E-Prime software. The task was shortened considerably and designed around a story about a 'mouse thief'. Participants were required to identify the direction of the mouse footprints (thus discriminating between the vertical and horizontal arrays) and to maintain central fixation were asked to also identify the colour of the mouse in the centre of the screen (pink or blue). In order to minimise the working memory load required in recalling the keys for corresponding responses, a specifically

designed keyboard was created with large buttons displaying pictures of the different coloured mice, and the array orientations. Therefore participants had to simply depress the button with the matching picture. This also aimed to add to the visual appeal of the task. In keeping with the original task, the exact position of the target array varied but remained in the lower left quadrant.

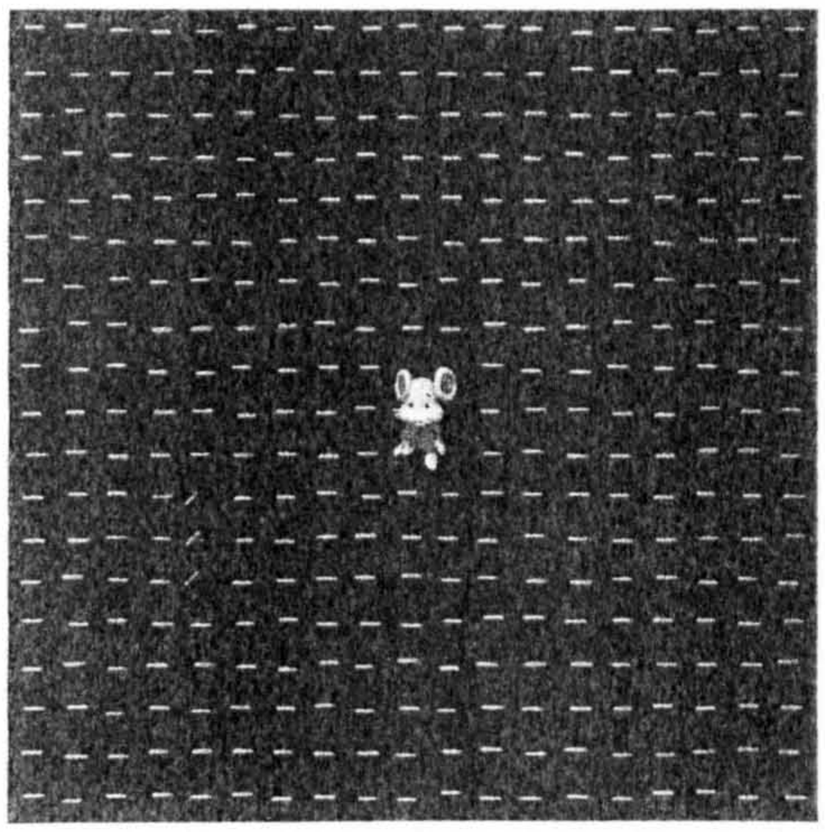


Fig. 4 Target Stimulus Screen (17ms)

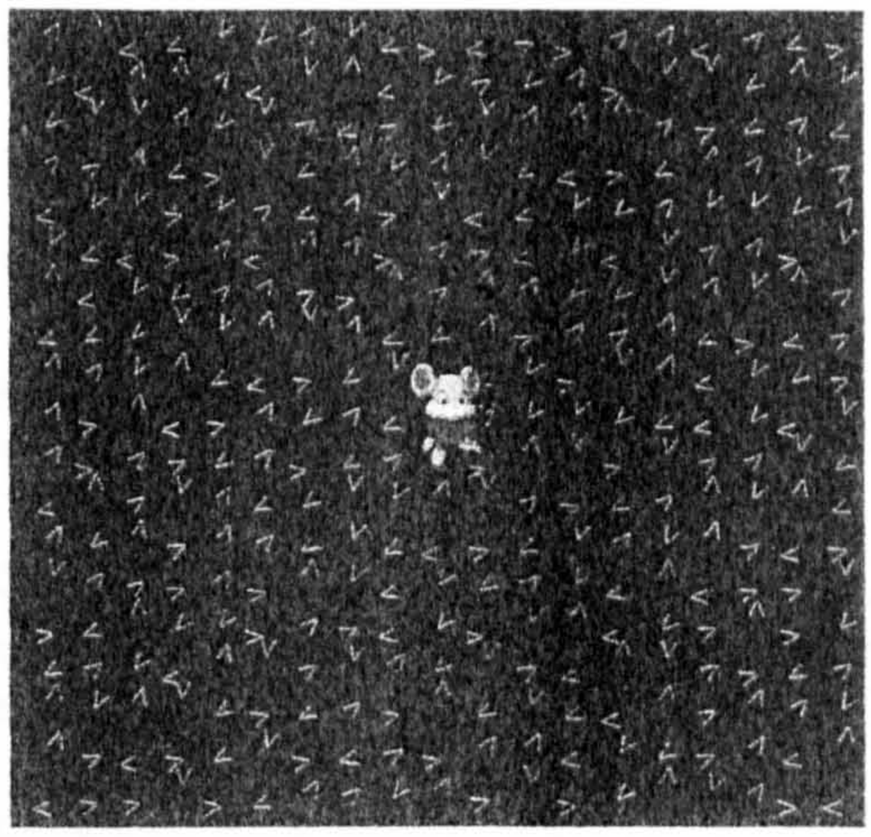


Fig.5 Mask Screen (17ms)

At the start of the task participants were requested to focus on a small grey mouse in the centre of a blank screen. The trial sequence is activated by the participant pressing a green 'Go' key on an adapted keyboard. The stimulus screen (*Fig 4.*) is then presented for 17ms followed by a blank screen presented for a variable inter stimulus interval (ISI) of 1000-0ms. This is followed by a masking screen (as per the original study but using green rather than black and white) for a further 17ms (*Fig. 5*). Finally, a screen asking respondents to identify the direction of the array and then the colour of the mouse is presented. At this stage the task was shortened to 200 stimuli presentations (10 blocks of 20).

Piloting the Visual Discrimination Task The above qualitative modifications were piloted in three phases in order to ensure children were able to complete the essential elements of the task, and to investigate appropriate task parameters.

VDT Pilot Phase 1 Children were given some simple presentations of the task, which confirmed that even young children were able to utilise the specially adapted keyboard, and that they were able to succeed with practice. During the first piloting phase the following issues were identified leading to the adaptive action described (*Table. 3: below*).

Table 3: Pilot phase 1 Feedback for VDT

Main Issues Arising with VDT	**Adaptive Action**
Length of task was prohibitive. Children became tired and bored and could not finish the task	Test shortened from 200 to 100 presentations
Children could not recall the direction of the target array once they had responded to the colour of the mouse. Too difficult to divide their attention between the two tasks.	Fixation question (colour of the mouse) removed. Children only required to identify the direction of target array
Initial ISI trials too fast. Children disheartened and confused by initial difficulty of task.	One block of a longer ISI of 1000ms added. Training sessions added to instructions with positive feedback and repetition until correct response.
Some children described the task as boring	Attractive sounds and more colourful images added to the opening screen and instructions
Elements of the instructions open to misinterpretation	More instructions added with greater clarity

VDT Pilot Phase 2 Further to the above modifications a second pilot phase was conducted, identifying and resolving some further issues described in table 4 (below)

Table 4: Pilot phase 1 Feedback for VDT

Main Issues Arising with VDT	**Adaptive Action**
Children looking directly at the target array once the fixation question (colour of the mouse) had been removed. Thus target array not in specified position on visual field.	Fixation question replaced, but order of question exchanged. Children asked the direction of the target array before mouse colour. Fixation mouse also added to masking screen to make his non-essential question less difficult.
Children still found the task boring and were not motivated until the end.	Task structured into four levels and a Total Points facility added with encouraging instructions e.g. "You have reached Level 2! You have scored 180 points. Keep going!"
Older children and adults finding task too easy and reaching a ceiling performance in the first session	Blocks with shorter ISI expanded. Number of presentations increased from 100 to 135
Younger children uncomfortable during task	Higher chair and cushions obtained for younger children

It was also particularly noticeable that adult participants were getting around 80% correct on the first session of the VDT and improving very little, if at all between sessions, suggesting they were reaching ceiling performance *(Fig.6)* thus the addition of less difficult presentations at the beginning and more difficult presentations towards the end aimed to allow increased confidence at the start and a challenging end for those requiring this.

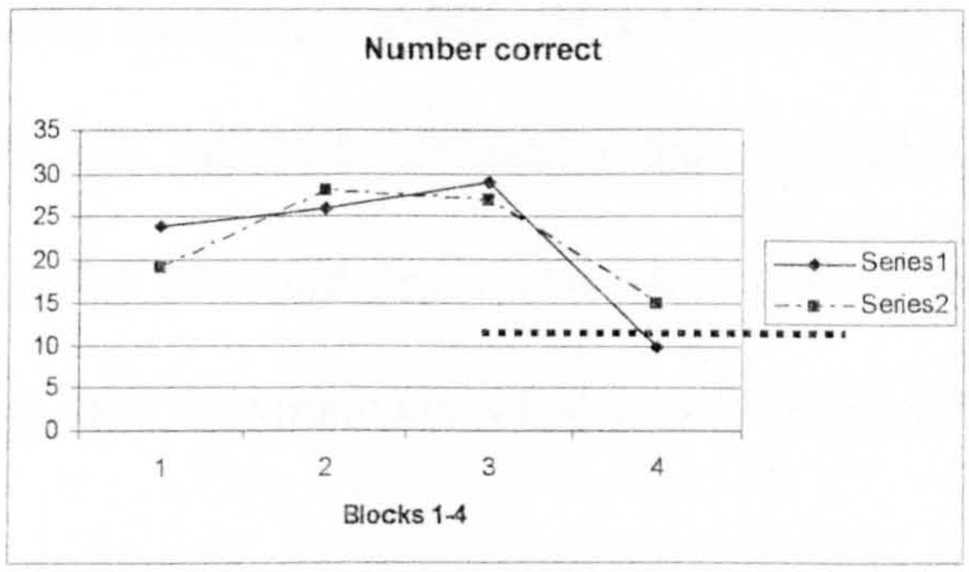


Figure 6. Graph representing 2 sessions on VDT with limited learning occurring. Dotted line represents threshold for chance performance

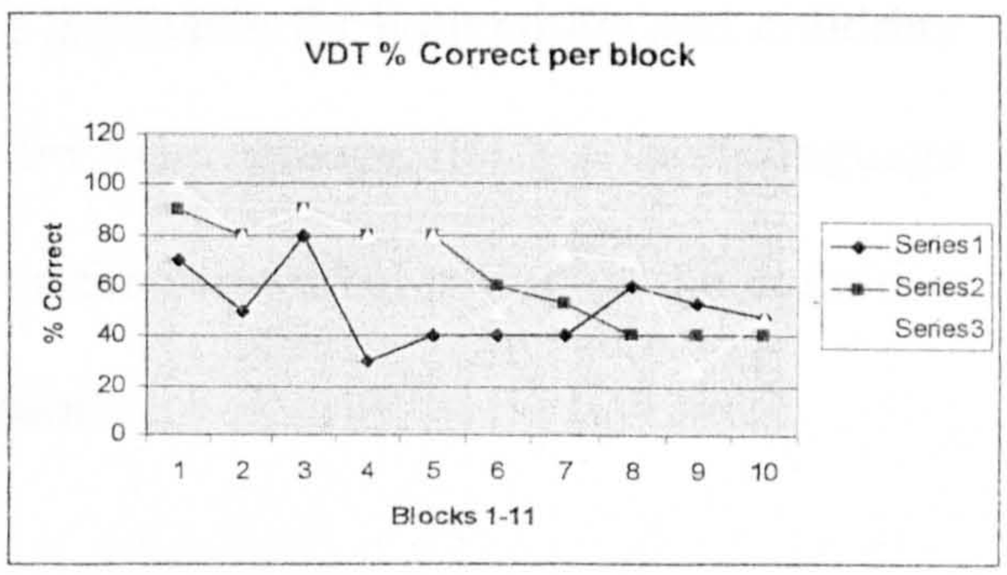


Figure 7. Graph demonstrating the expected decrease in accuracy with increasing difficulty of task

VDT Pilot Phase 3 Final versions of the tasks were administered in order to assess performance across the complete testing session. The graph above (*Fig. 7*) demonstrates example performance of a pilot participant on the VDT which demonstrates the decreased accuracy as the task becomes progressively more difficult, and the learning between each testing session (represented by series 1-3).

Final VDT task: The final task comprised 11 blocks of decreasing ISI, of which 8 blocks contained 10 trials, and 3 blocks contained 15 trials, yielding a total of 135 presentations, and thus a total potential score of 135. The ISI presentations in decreasing order were 1000ms, 400ms, 300ms, 200ms, 150ms, 100ms, 80ms, 60ms, 40ms, 20ms, 0ms. The fixation question, regarding the colour of the mouse remained but children were asked to identify the array orientation first. Participants were encouraged to remain engaged in the task by positive feedback regarding their successful score as they reached each 'level' of the game.

2.3.3 Matrix Reasoning Test In addition to completing the CoL tasks all participants were asked to complete the Matrix Reasoning sub-test of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Performance on this subtest reflects individuals' ability to mentally manipulate abstract symbols and to perceive the relationships among them. It provides a measure of non-verbal fluid reasoning and general intellectual ability (Wechsler, 1999). It is suitable for both adults and children, with age matched normative data available for both groups. It is a non-language mediated task, and thus a suitable measure given the non-verbal nature of the cognitive tasks, and the young age of some of the participants.

2.3.4. Sleep Questionnaires As a measure of sleep quality, adult participants were asked to complete the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, and Kupfer, 1989; Appendix 3g). This is a self-rated questionnaire, which has been shown to be a reliable and valid measure of sleep quality and disturbance over a one-month time interval. Output data includes an estimate of mean sleep time per night, as well as scores for the following sleep factors: sleep latency, sleep disturbances, habitual sleep efficiency, subjective sleep quality, sleep medication, and daytime dysfunction.

Parents of child participants were asked to complete the Paediatric Sleep Questionnaire (PSQ; Chervin, Hedger, Dillon, and Pituch. 2000; Appendix 3h) on behalf of their child. This has been shown to be a valid and reliable tool for assessing childhood sleep disturbances (Chervin et al., 2000). It provides an estimate of mean sleep time per night, alongside scores for the following sleep factors: parent/child interactions during the

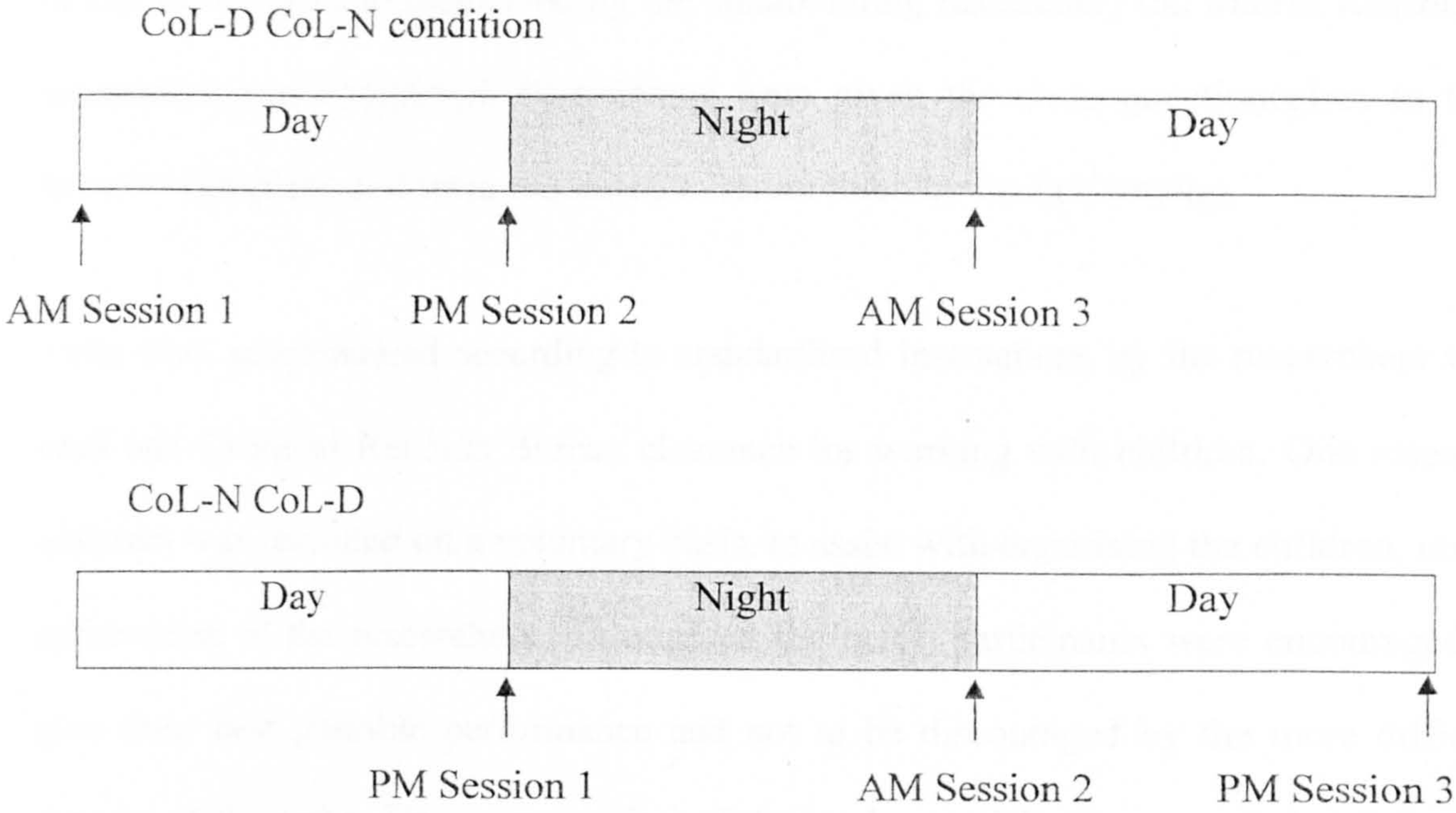
night, parasomnias, sleep fragmentation, daytime drowsiness and bedtime difficulties. On both questionnaires, higher scores represent greater sleep disturbance.

2.4 Design

A quasi-experimental within-subjects design was employed involving an uncontrolled convenience sample. The same neuropsychological measures were used, within the same group of children and adults, pre and post periods of sleep and wakefulness.

Participants completed two cognitive tasks (VDT and PTT) on three occasions. Testing sessions were either consecutive morning-evening-morning, or a consecutive evening-morning-evening, thus providing both a daytime (CoL-D) and night time (CoL-N) learning condition whilst counterbalancing order effects (see *Fig. 8*). Given the time commitment required, participants were assigned to the conditions upon a practical basis, as negotiated with participants, parents or the school. For example, some participants found it difficult to attend in the evening due to other activities or transport, thus they were assigned to completing the CoL-D phase first thus requiring attendance on two mornings and just one evening. For the PTT 11 adults and 13 children undertook the CoL-D condition first and 8 adults and 11 children the CoL-N condition first. For the VDT 6 adults and 13 children undertook the CoL-D condition first and 6 adults and 8 children the CoL-N condition first.

Fig 8: Testing phases demonstrating counterbalancing across night time vs daytime conditions.



2.5. Procedure

Further to obtaining signed consent, children and adults were allocated time slots for their three testing sessions. All participants were reminded they were free to withdraw at any time and asked if they had any further questions about the study. Participants completed the four CoL tests once each, on each of the three testing sessions. In the case of adult participants completion of the cognitive tasks took place in a quiet private room, and the four tests were completed in random order. Assessment of children took place in a large quiet room in school which included two testing stations with separate laptop computers at opposite ends of the room. Children rotated between the stations in random order, with no more than two children completing tests at any one time. Any children waiting to complete tasks waited outside or quietly in the room under supervision.

During the last testing session (which was the shortest due to decreasing time demands of one of the tasks implemented by the collaborating researcher) the Matrix Reasoning assessment was completed. Participants were given the sleep questionnaires to take home to complete, and were requested to return them by the last session.

Tests were administered according to standardised instructions by the researchers who each had Criminal Records Bureau clearance for working with children. One research assistant was recruited on a voluntary basis, to assist with organising the children, under supervision of the researchers. Throughout the tasks, participants were encouraged to give their best possible performance and not to be discouraged by the more difficult aspects of the tasks. Upon completion of the study, participants were de-briefed as to the nature of the study and were invited to ask any questions they wished.

3. Results

Descriptive statistics for performance differences during CoL-N and CoL-D for both the PTT and VDT in both groups are summarised in *Table. 5*, and changes in performance across the three testing sessions can be seen in *Figure. 9 and 10* where performance improvements are denoted by decreased scores on PTT and increased scores on VDT.

Table 5- Summary descriptive statistics

	Adult		**Child**	
	CoL-D	**CoL-N**	**CoL-D**	**CoL-N**
PTT	x=0.54, SD=34.2	x=20.9, SD=32.1	x=8.1, SD=40.0	x=11.1, SD=34.3
VDT	x=2.75, SD=1.71	x=1.92, SD=1.79	x=.57, SD=2.2	x=1.0, SD=2.0

Fig. 9 PTT performance over time

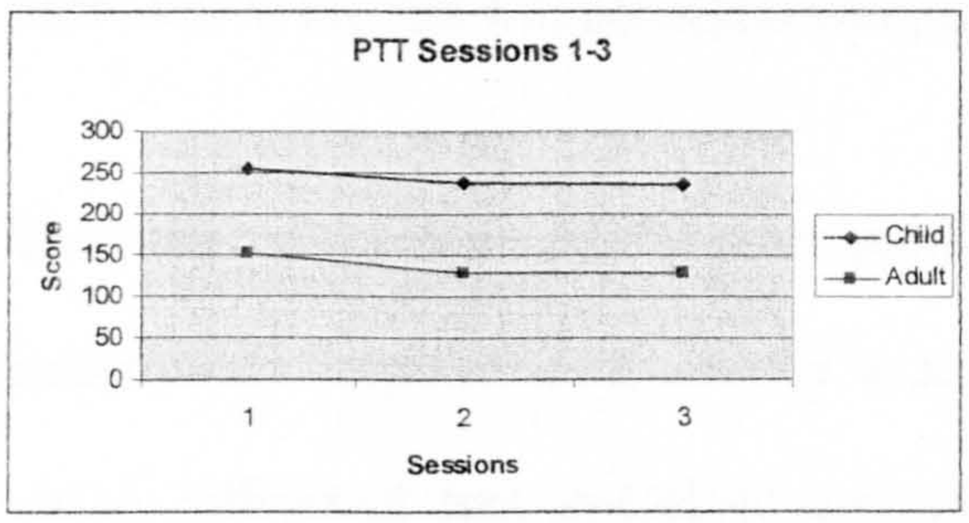
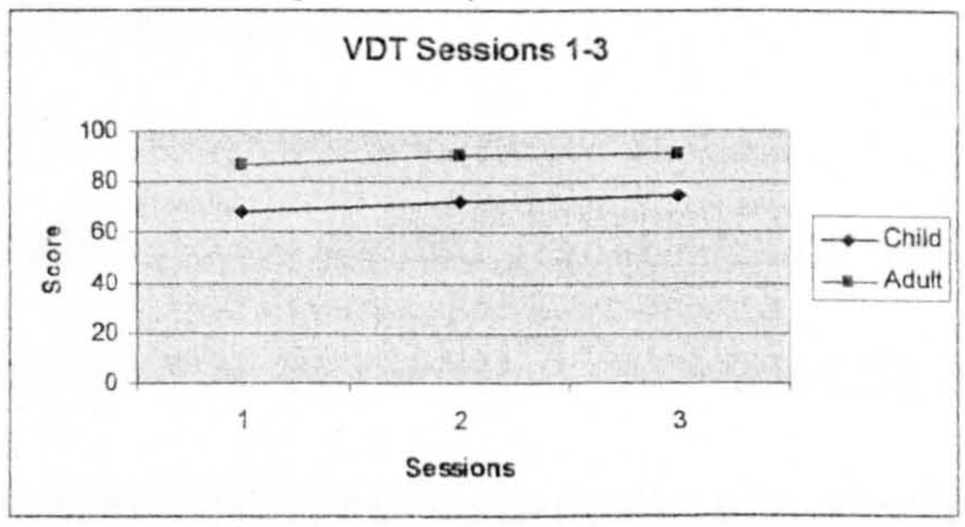


Fig. 10 VDT performance over time



Two tailed paired-sample *t* tests were carried out to compare the means for the two conditions: CoL-N and CoL-D across the two different tasks. For all analyses alpha was set at 0.05.

3.1. Pursuit Tracking Task (PTT)

For the PTT the output represented the average root mean square (RMS) deviation per trial of the yellow mouse controlled cross from the red moving target, this being a measure of tracking distance, and therefore accuracy.

3.1.1. Child Participant Group

PTT Cumulative RMS *y* and *x* axis When the data was considered as a whole there was a small visible difference between performance improvements between CoL-N (x=11.1, SD=34.3) and CoL-D (x=8.1, SD=40.0) but this was not significant (t(23)=.266, p=.29).

PTT RMS *y* axis and *x* axis independent analysis Due to the difference in predictability of the x and y axis, and thus potentially different levels of implicit learning, the output was also analysed and segregated according to total RMS deviation for each axis. When the improvement in the RMS deviation on the less predictable y axis was considered alone there was a visible difference between performance

improvements between CoL-N (x=1154.2, SD=730.3) and CoL-D (x=447.3, SD=1439.5) but this was not significant (t(23)=.982, p=.34).

The same calculations on the more predictable x axis yielded similar results with the performance improvements on the x axis for CoL-N (x=836.2, SD=2544.2) being visibly different to that on CoL-D (x=1509, SD=4350.1) but statistically non-significant (t(23=.64 p= .53).

3.1.2. Adult Participant Group

PTT Cumulative RMS *y* and *x* axis. When the adult data was considered as a whole there was a considerable visible difference between mean performance improvements between CoL-N (x=20.9, SD=32.1) and CoL-D (x=0.54, SD=34.2) but this was not significant (t(18)=-1.44, p=.17).

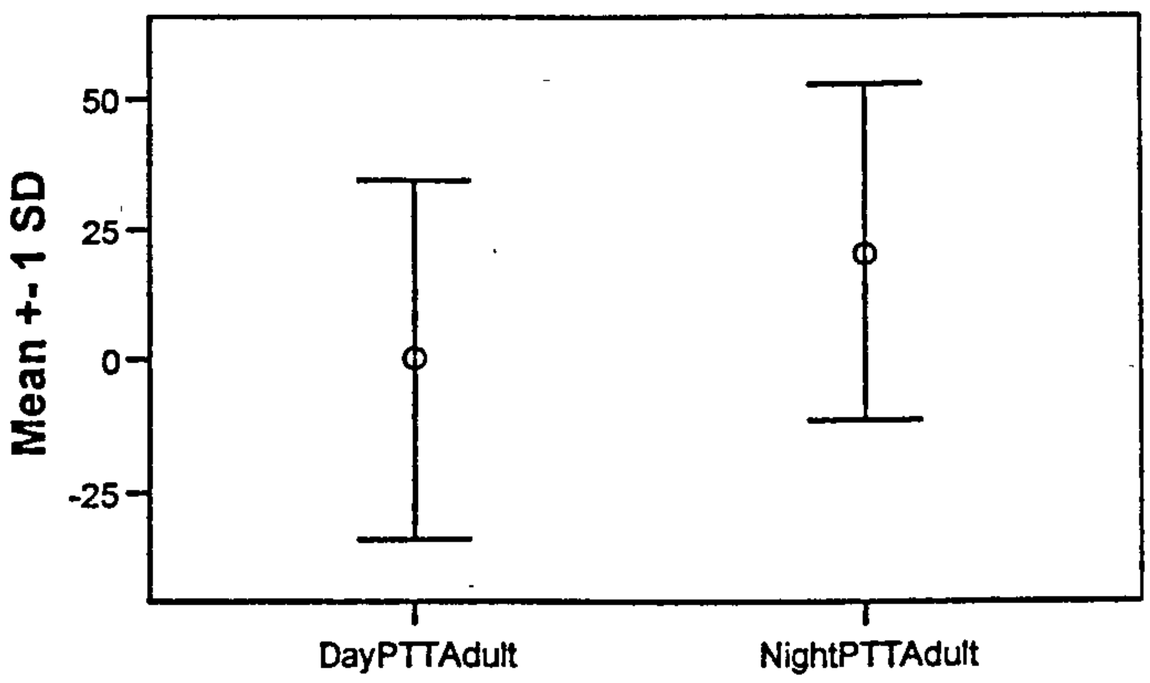


Figure 11. Error Bars CoL-D PTT Adult vs CoL-N PTT Adult

PTT RMS *y* axis and *x* axis independent analysis When the data was segregated as with the data in the child group a significant difference between CoL-N and CoL-D was not found for RMS deviation performance improvement on the x axis (CoL-D x=261.0, SD=1706.1; CoL-N; x =949.5, SD=1735.2; t(18)=.10, p=.33) or y axis (CoL-D x=483.2, SD=1507.3; CoL-N x=794.0, SD=1198.3; t(18)=.62, p=.54)

4.2. Visual Discrimination Task (VDT)

4.2.1. Child Participant Group

In the original study the output score utilised was the ISI at which accuracy fell below 80%. However, due to the shortened task and degree of data noise visual inspection revealed that the data was not amenable to this kind of analysis, so a simplified total accuracy score was chosen as the dependent variable. When performance was compared between the CoL-N (x=1.0, SD=2.0) and CoL-D (x=.57, SD=2.2) conditions there was no significant difference between the two (t(20)=-.13, p=.90).

4.2.2. Adult Participant Group

For logistical reasons and due to technical difficulties for the adult participant group VDT data collection was ceased at n=12. On analysing the output data from these participants, a significant difference between the CoL-N (x=1.92, SD=1.79) and CoL-D (x=2.75, SD=1.71) conditions was not found (t(11)=.33, p=.75).

4.3. Correlational Analyses

4.3.1 Sleep Questionnaires

Analyses of the association between sleep questionnaire variables and CoL-N on the PTT or VDT can be seen in Table. 6 for adult participants and Table. 7 for child participants. Interestingly significant correlations were found for adult participants and sleep latency on the VDT, and for child participants and bedtime difficulties on the PTT. However, given the number of correlations conducted when Bonferroni correction was applied these correlations were not significant (Abdi, 2007).

Table 6: Correlations for Adult Participants

Adult Participants	PTT Correlation (Pearson)	VDT Correlation (Pearson)
Average sleep time	r=.25, N=13, p=.41	r=-.26, N=10, p=.48
Sleep quality	r=-.51, N=13, p=.08	r=-.51, N=10, p=.13
Sleep latency	r=-.28, N=13, p=.36	**r=.68 N=11, p=.02**
Sleep dysfunction	r=.28, N=13, p=.36	r=.46, N=10, p=.18
Sleep disturbance	r=.04, N=10, p=.91	r=.01, N=6, p=.98
Sleep efficiency	r=.39, N=13, p=.19	r=-.35, N=10, p=.33

Table 7: Correlations for Child Participants

Child Participants	PTT Correlation (Pearson)	VDT Correlation (Pearson)
Night time parent-child interactions	r=-.4, N=18, p=.09	r=.16, N=16, p=.56
Sleep fragmentation	r=-.30, N=18, p=0.23	r=-.38, N=15, p=.16
Parasomnias	r=-.43, N=18, p=.07	r=-.17, N=16, p=.56
Daytime drowsiness	r=-.29, N=19, p=.23	r=.13, N=16, p=.63
Bedtime difficulties	**r=-.53, N=19, p=.02**	r=.12, N=15, p=.66

4.3.2 Matrix Reasoning

In the child group a correlation between performance on the Matrix Reasoning task and CoL-N test performance was not seen on the PTT (r=-.30, N=16, p=.27) or the VDT (r=.17, N=14, p=.59). Similarly in the adult group there was no significant correlation with the VDT (r=.04, N=10, p=.92) or PTT (r=-.38, N=14, p=.41) demonstrating that there was no association between performance on visual reasoning task and CoL-N.

4.4. Additional Post-hoc Analyses

Whilst it is acknowledged that post-hoc analyses are prone to Type I error, some exploratory analyses were conducted to investigate further why tests had not yielded significant effects, with the aim of providing learning for future research.

4.4.1 Practice Effects: Whilst the testing order was counterbalanced so that some participants completed the CoL-N phase first and vice versa, paired sample *t* tests were conducted to assess for order effects in the event that participants improve more over the first learning phase than the second, or vice versa.

PTT Practice Effects: There was an interesting significant difference between learning interval one (x=23.7, SD=23.1) and learning interval two (x=-1.5, SD=15.7) for the adults' performance improvement on the PTT ($t(18)$=3.6, p=.02). Thus adults improved more on their first learning interval than their second on the PTT suggesting they may be reaching ceiling performance after their first CoL phase.

VDT Practice Effects: For child participants there initially appeared to be an order effect in that participants appeared to improve more on the first learning interval (x=2.6, SD=2.0) than the second though this was not significant (x=-1.0, SD=2.1). As a whole participants' performance appeared to deteriorate a little though this was also not statistically significant ($t(20)$=1.1, p=.28). In the case of the adult participants testing for order effects also did not reveal a significant difference ($t(11)$=.33, p=.75) for improvements between the first and second testing sessions

4.4.2 Corrections for equipment: As for the child participants the tests were delivered using two laptop computers, results gained using the same laptop only were analysed (to

account for potential different processing speed). The difference between the performance improvements on CoL-N (x=14.7, SD=27.2) and CoL-D (x=1.7, SD=32.9) conditions was greater again, but not significant (t(13)=1.05, p=.314).

4.4.3. Performance Curve Analyses: In order to learn more about the sensitivity of the measures close visual inspection was conducted for a randomly sampled subset of 10 of the original participants.

In the case of the PTT, two subsets of participants were found. Five of the adults displayed performance without an expected pattern of improvement with practice and the remaining five demonstrated a learning curve with improvement over time. A good example of this has been chosen for the purpose of demonstration (*Fig. 12*). However, of those who were seen to improve with performance, the performance curve revealed a ceiling effect. The participant displayed below in *Fig.13* is a particularly good example of improvement between the first and second testing session, but performance then levelled out between the second and third session. It can also be seen that there was a greater performance change in the first 4 trials, presumably whilst the participant had not yet mastered the task. However the sample of participants displaying this pattern was too small for formal analysis.

Figure. 12 PTT Participant 156y

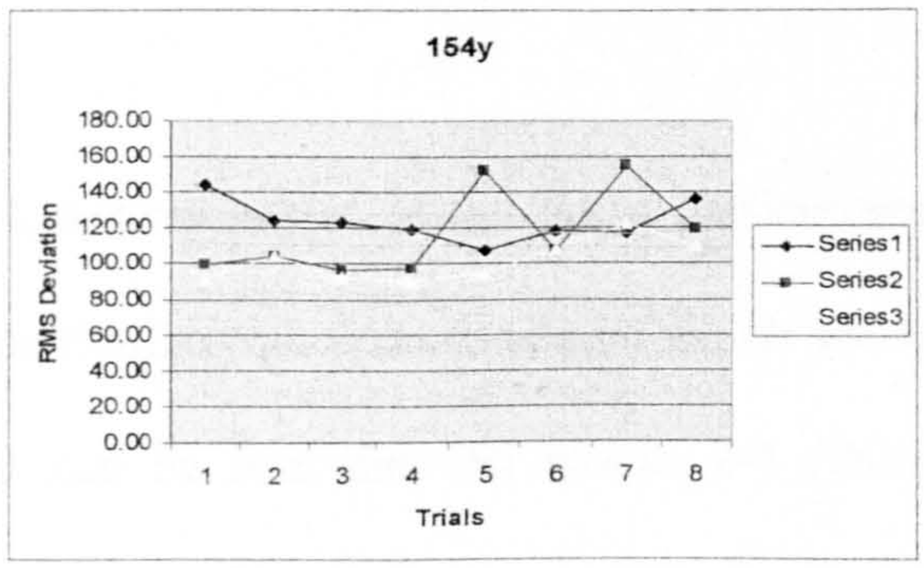
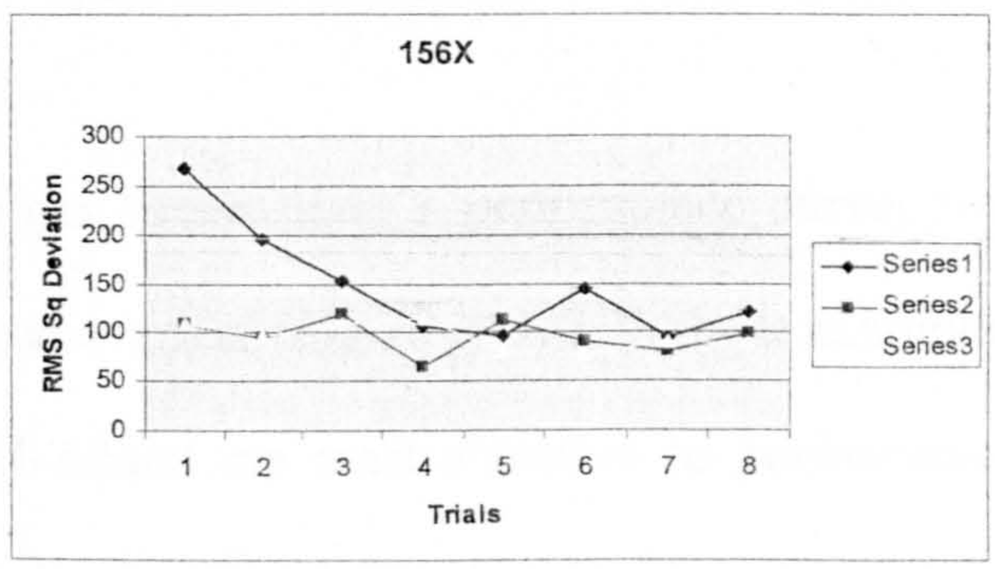


Figure.13PTT Participant 156x



With regard to the child data eight out of the ten demonstrated data which was more chaotic *(fig. 14)*. The remaining two showed steady performance without improvement

across the task or between trials (*fig. 15*) and none of the children demonstrated consistent improvement between trials as seen for the adult data.

Figure. 14 PTT Participant 104x

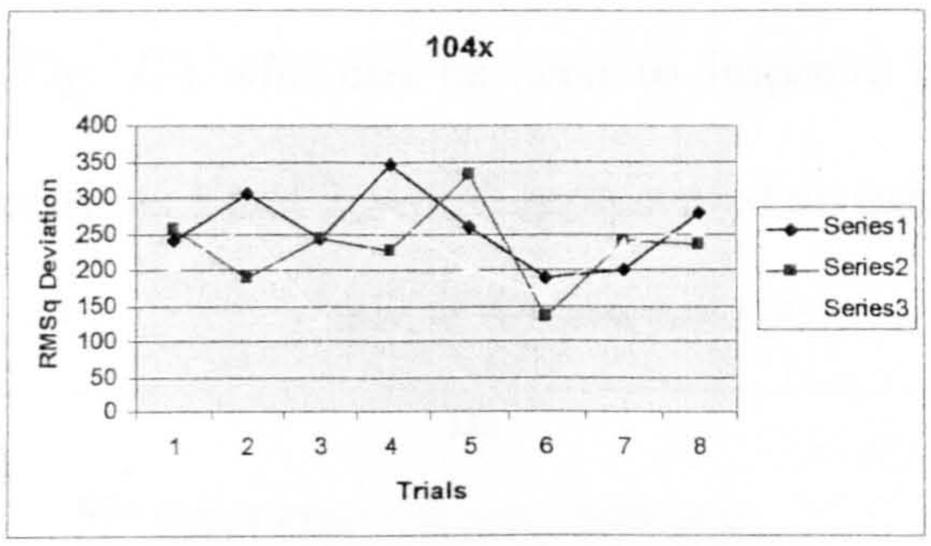
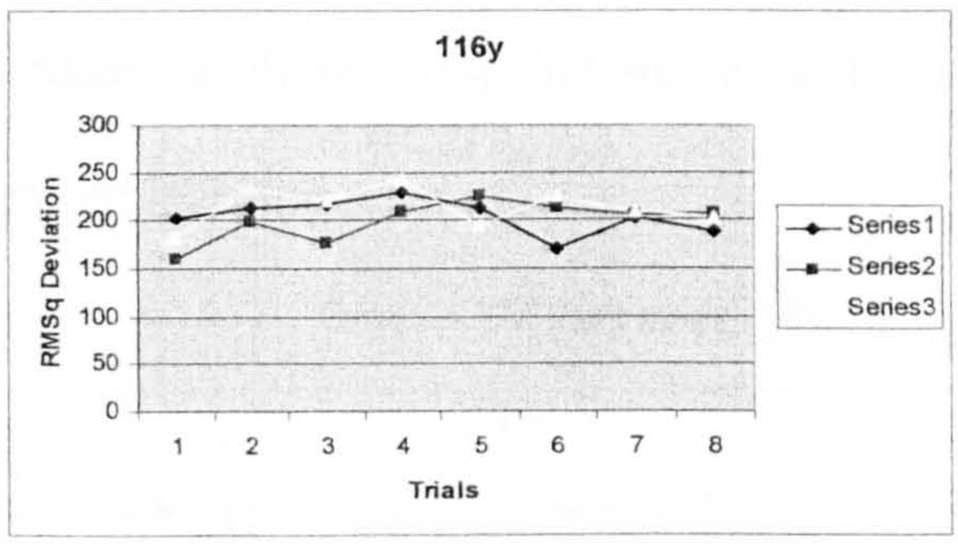


Figure.15 PTT Participant 116y



In the case of the adult VDT four participants did not follow any consistent pattern of decreased accuracy with increasing difficulty of the task within each session or any differences in performance between sessions as demonstrated by Fig. 16 where much of the accuracy is below 60% and thus representative of chance performance, with the exception of a short period in session 1. For comparison, the curves seen in Fig. 17 are performance curves for repeated trials on the original unmodified VDT which show significant CoL (Karni & Sagi, 1991).

Figure. 16 VDT Data Participant 154

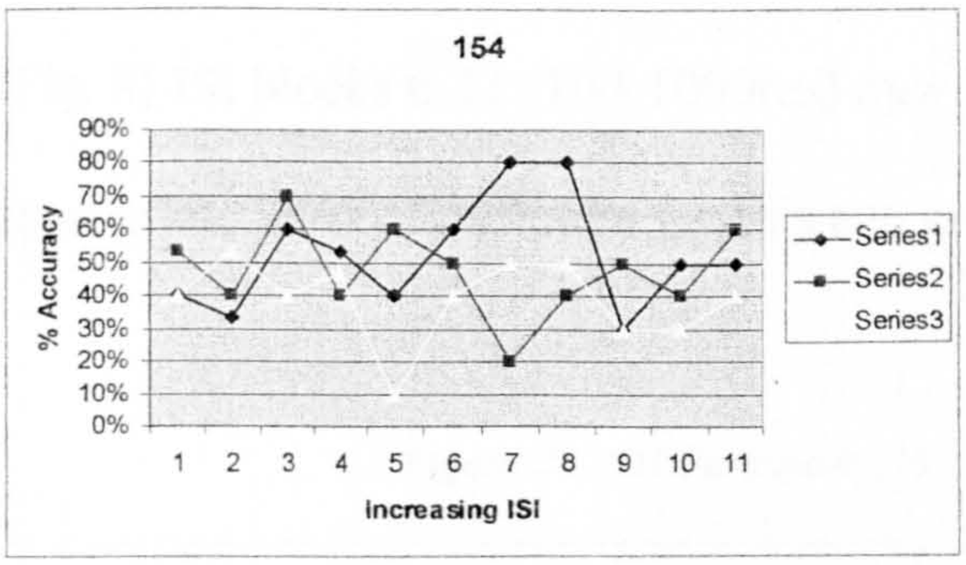
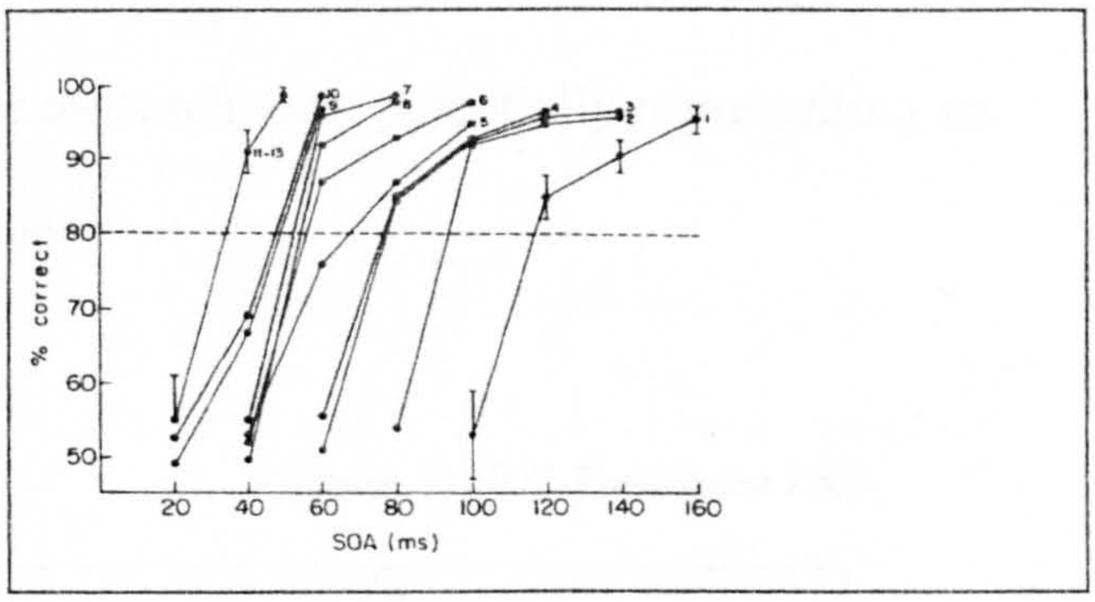


Figure. 17-Performance curves (Karni & Sagi, 1991)



A second subset of six adult participants did demonstrate a performance curve, two particularly good examples of which are seen overleaf *(Fig.18 & 19)*. In these examples it can be seen that ISI blocks 2-4 (ISI-20-60ms) are most sensitive to performance change before performance falls to chance levels. Also in the latter two sessions these participants both scored 100% for this proportion of the task. On considering CoL-D vs

CoL-N whilst demonstrating learning between session 1 and 3 participant 155 (fig.12) performed less well in session 2 than session 1, thus this participant did not display the expected CoL across sessions. CoL can be better demonstrated with participant 156 (*Fig. 17*) who can be seen to improve between each session, and more so between sessions 1 and 2, which represented an overnight learning session.

Figure. 18 VDT Participant 155

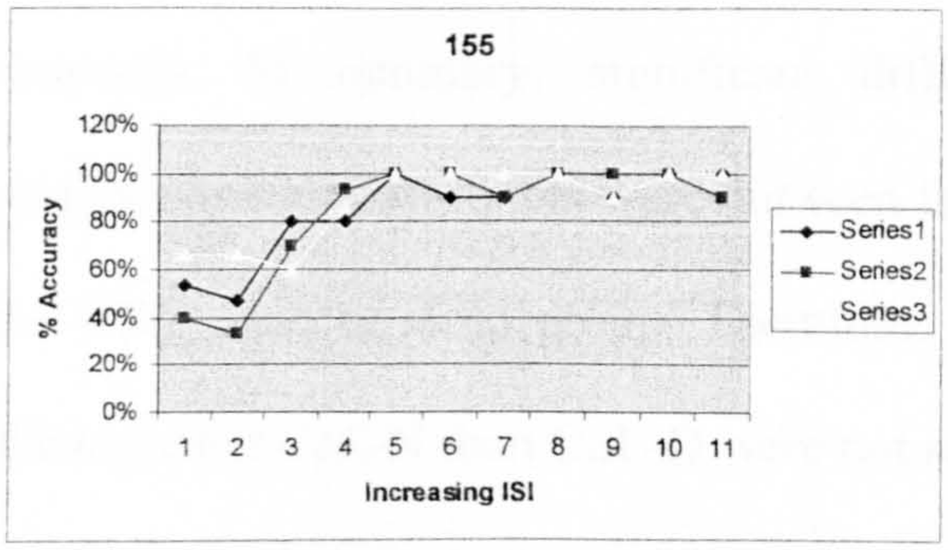
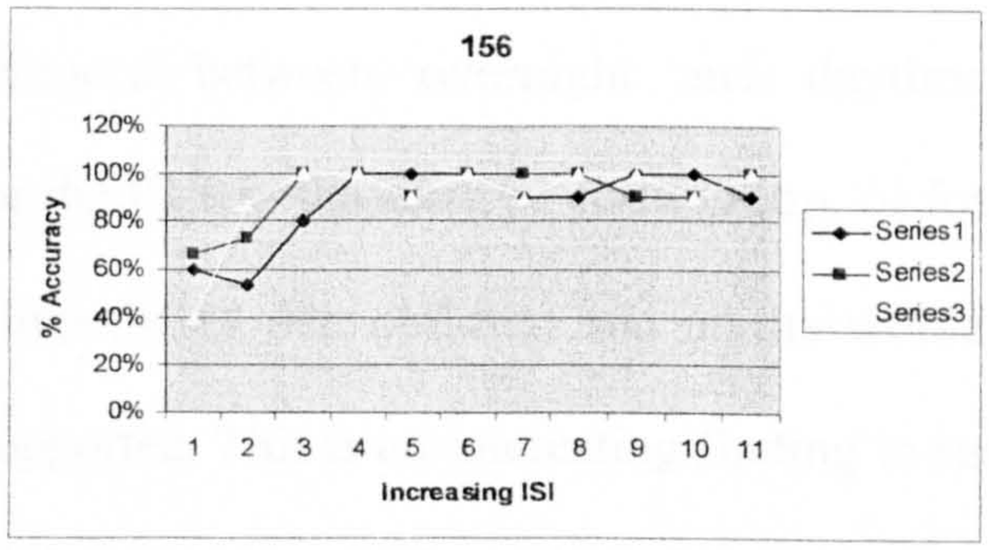


Figure.19 VDT Participant 156



For the child participants again four participants demonstrated an expected performance curve (eg. *Fig 20*) and the remaining six did not (eg *Fig.21*). Performance curves, where seen were less distinct that that seen in the adult sample. In the child sample accuracy was decreasing from the beginning of the task, and the period of success as per the adult participants (between 80-100% accuracy) was not evident. In the case of participant 108 (Fig. 8) ISI blocks 6-11 (100-1000ms) may be most relevant, potentially representing an appropriate level of difficulty for this age group.

Figure. 20 VDT Partcipant 116

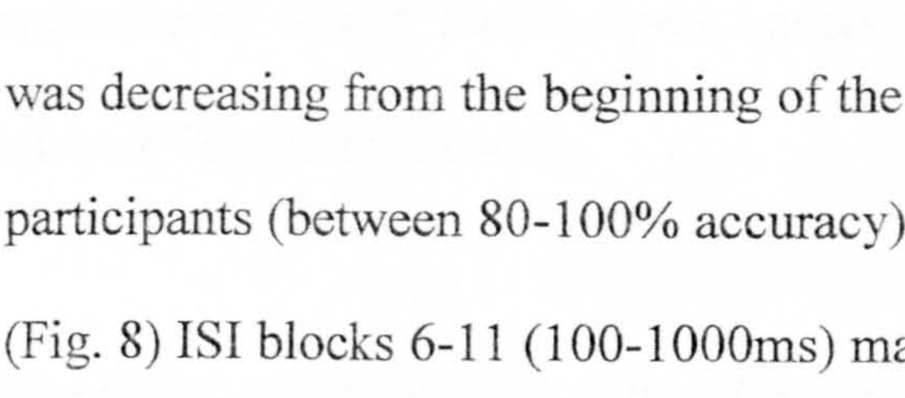
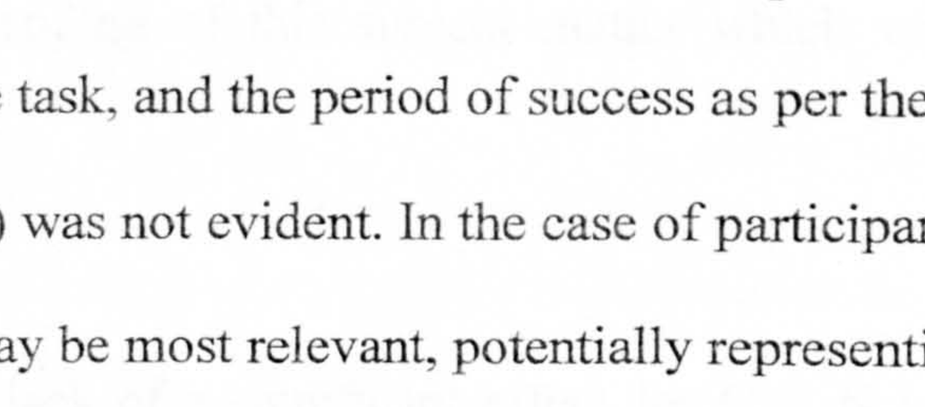


Figure. 21 VDT Participant 108



5. Discussion

The aim of this study was to attempt to develop appropriate tools to assess the differences between CoL-N and CoL-D in a childhood population, and to utilise an adult group as a comparison to validate the specificity and sensitivity of the adapted measures. In summary, significant differences between overnight and daytime performance improvements were not seen for the PTT in the adult or child group, or for the VDT adult or child group. Therefore, hypotheses that children and adults would show greater CoL-N than CoL-D were not supported. This is an interesting finding in its deviation from that which was predicted, and thus warrants further discussion. There are several alternative explanations for the findings and each of these is discussed below. The discussion also highlights elements of the study that are informative in the learning encountered which builds upon understanding of this subject matter which will be relevant for future research.

One initial potential explanation for the lack of a significant effect for CoL-N is that CoL-N does not occur for the chosen tasks in these groups of participants. Indeed despite the infant study by Gomez et al (2006) and the study of German vocabulary learning (Gais et al, 2006) indicating there to be evidence that CoL-N may exist in children these were both verbal tasks, compared to the non-verbal tasks used in this study. In the more implicit memory procedural task studied by Fischer et al (2007) CoL-N in children was not found. Fischer et al (2007) suggest that there may be a developmental difference between children and adults with regard to CoL-N. Indeed it remains possible that children do not consolidate information in the same way or at the same rate as adults. There are certainly anatomical differences during development as

the maturation of neural structures required including myelination of nerve fibres means that information is transmitted more slowly (Case, 1992) and storage capacity is underdeveloped in children (Pascual-Leone, 1970). Thus it is possible that there are differences in the nature or magnitude of CoL-N, which were accurately reflected by this study.

At first sight it seems that this may not explain the lack of an effect for the adult data, however, with hindsight there are some questions regarding the adult sample, which may still support a theory of developmental differences in CoL-N. In the study by Fischer et al (2007) the adult sample were aged 20-30 years and in the study by Karni & Sagi (1991) the mean age of participants was 24.8 years. Whilst in this study mean age was just over 27 years old this was skewed by two older adult participants (aged 66 and 73), and eight of the participants were undergraduates under the age of 21 (mean age 19.3). Whilst technically adults, there is evidence to suggest that the brain is still maturing at this age and does not resemble the brain in the mid twenties (Bennett & Baird, 2006). Similarly it is very reasonable to assume that older adults may not consolidate at the same rate given what we know about deterioration of the brain in later life. Thus it is possible that this study is demonstrating that children, young adults and older adults do not consolidate learning during sleep to the same extent, or do so differently.

However, despite the above explanation being worthy of consideration it needs to be considered that this is not consistent with the findings of the study by Huyton (2008) which did demonstrate an effect for CoL-N for the same populations. One of these tasks was again a verbal task which may explain the difference, though the second was not. Thus, given that the results are at odds with this outcome and with the majority of other

recent CoL studies, this explanation may be less likely. Also given that a proportion of the participants did display the expected performance curves, it appears more likely that the results were a feature of the study including the adaptations to the measures and the low power and high variance exacerbated by some of the complexities associated with the populations studied, and these issues shall be discussed in turn.

Therefore, one contributing explanation for the findings is that adaptation of the measures may have reduced their specificity or sensitivity to CoL-N. As the original measures were visually unappealing and repetitive, with complex instructions and multiple demands, it was necessary to conduct substantial modifications. It was, therefore, an unavoidable risk that this would alter the sensitivity of the measures.

Certainly observations from the post-hoc analyses indicated a possibility that in the case of the VDT adults who did engage seemed to only be challenged by the very last stages of the tasks and achieved a high rate of success on the first two thirds of the task. As the task had been shortened the latter part which appeared to be most challenging for adults consisted of fewer presentations than the original task, and thus sensitivity was reduced. Conversely, performance curves revealed indications that the VDT was too difficult for many of the children taking part, as not only did many not demonstrate performance dependent on the difficulty of the task, those who did, rarely achieved an initial level of success and showed deteriorating performance from the outset. This is likely to have had implications for children's confidence and subsequently their motivation or ability to engage with the task. Thus, whilst some participants showing the expected pattern of learning, it appears that modification of the tasks to be suitable for both adults and children, may have led to a middle ground which was not compatible with either sample. On the PTT analyses revealed that adult participants improved significantly

more on the first learning phase, seemingly due to reaching a test ceiling, and also appeared to improve most in the first 4 trials, whereas post-hoc observations suggested children did not consistently improve. Thus, the justification for including an adult sample in order to control for modification to the task, may have been at the expense of compromising the suitability of the tasks for either participant group.

A third, and related contributing factor to the results may be a lack of engagement on behalf of the participants. The post-hoc visual inspection suggested a subset of both adult and child participants with not demonstrable performance pattern. This data 'noise' was likely to have impacted significantly upon the outcome and an explanation for this needs to be considered. A significant amount of data 'noise' is common in assessments with children, as their ability to concentrate and apply themselves fully to tasks is understandably variable. Incomplete development of frontal lobes in childhood makes strategic application and behaviour regulation difficult (Anderson et al, 2001) and a greater resistance to interference (alternate factors competing for attention) develops with age (Diamond, 1995). Whilst selective visual attention has been reported to be well developed in younger children sustained attention has not (McKay, Helperin, Schwartz & Sharma, 1994). However, whilst cognitive assessments with children are complicated by these issues they are not usually prohibitive, thus other factors were likely to have been at play.

It is possible that the tests contributed to the difficulties the participants may have had applying themselves to the tasks. The divided attention aspect of the VDT task remained quite demanding post-modification as giving two simultaneous discrimination tasks appeared to be the only way to maintain fixation on the centre of the screen. Additionally, research has demonstrated that children over nine years are less

disadvantaged by task complexity, suggesting a developmental spurt in aspects of divided attention around this time (Manly et al, 1999). However, most of the children who consented to take part were under nine years old. Also younger children tend to benefit less from task familiarity, compared to older children who appear more able to utilise prior knowledge to improve performance (Anderson & Lajoie, 1996). Thus perhaps aspects of the tasks were too challenging for the younger children who were also not able to take full advantage of task familiarity.

Whilst every attempt was made to increase the appeal of the tasks to children, they doubtlessly do not compare to the levels of stimulation provided by modern computer games. Indeed clinical observation suggested that children were losing interest in the tasks, and needed to be reminded and encouraged to maintain their attention and motivation, thus creating variable performance throughout. It is possible that the tasks were not sufficiently appealing to overcome the challenging task of maintaining the children's attention. There is also a possibility that despite attempts to simply the tasks, children still perceived them as too difficult, which again carries the risk of children becoming quickly demotivated and thus disengaging from the task.

It may appear less clear how this could contribute to the lack of a significant effect in the adult group, however, post-hoc analyses revealed a similar subset of data in the adult group which did not display any consistent performance improvements, and it is quite likely that similar concentration issues were replicated in the adult group. This group was largely composed of students with lifestyles which may have threatened the CoL-D and CoL-N conditions, in that many of the students may have not have slept appropriately during the CoL-N condition and may also have slept during the CoL-D condition. One participant was excluded for daytime rather than night-time sleeping,

alongside excessive alcohol consumption. However, it is suspected that other participants may have failed to mention this due to the monetary incentive paid on completion regardless of performance, thus the validity of their performance may have been questionable. Additionally, some of the adults were also observed to find the tests monotonous and appeared to be losing interest. It is possible that some of the adults perceived the tasks as geared towards children and thus not sufficiently challenging to warrant full attention.

Thus, the above issues doubtlessly contributed to the high variance and thus low power which are ultimately likely to be largely responsible for the lack of significant findings. Finally, other methodological weaknesses due to practical constraints may have contributed to the findings. The CoL-D and CoL-N phases were not always of identical length as would have been ideal, and participants were not randomised to these conditions, neither were the numbers in each group equal. This was difficult to avoid without compromising recruitment, but it may have impacted the outcome.

Many of these factors may also contribute to the findings relating to the subsidiary aims. An association between Matrix Reasoning scores and CoL-N performance was not found on either the adult or child group, suggesting that a relationship between non-verbal IQ and CoL-N was not found in adults or children. Correlations between the sleep questionnaire variables and CoL-N were also not found in either group with two exceptions. A positive correlation between bedtime difficulties and CoL-N was found, suggesting that there was a relationship between difficulties at bedtime, such as unwillingness to go to bed, and CoL-N in children. In adults a positive correlation was found between CoL-N and sleep latency (the time it takes to fall asleep). Whilst Bonferroni corrections suggested this may not be significant given the number of

correlations conducted, it is interesting that in both cases these are related to the 'going to sleep' period, rather than the issues during sleep. Indeed children who find it difficult to settle themselves to sleep are perhaps more likely to exhibit behavioural problems at this point, such as unwillingness to go to bed, or repeatedly getting up out of bed, so these may be aspects of the same process exhibited differently between children and adults. It is interesting to consider why this aspect of sleep hygiene was correlated with CoL-N. Possible explanations are that there is a crucial feature of sleep architecture in the early phase of sleep or that it is this simply related to lost total sleep. According to the results it is less likely to be the latter as a correlation between hours slept and performance was not found. It is interesting that it has been found that learning is impaired if early or late night sleep (usually dominated by SWS) was disrupted (Gais et al, 2000) thus this may be relevant to this finding. There may also be a relationship with other personality or mental health characteristics, such as anxiety or behavioural problems or endocrine responses which are likely to impact both learning and sleep latency. In future this particular aspect of the sleep process may be worth investigating. Indeed some children with epilepsy often have seizures as they fall asleep which is likely to impact sleep latency/early SWS sleep.

Thus, whilst the main hypotheses were not supported, the process of this study has raised many further questions and issues for consideration in designing future research. Certainly, more research is required in both comparing CoL-N to CoL-D in children and in the comparison of this with adult populations where CoL-N findings are more robust. However, before this takes place further work is required on developing appropriate measures which are sufficiently appealing and of the appropriate level of difficulty so that they are appropriately challenging for children, yet also suitable for adults. During the process of this study it has been identified that this is quite a challenge, and one may

now question whether it is realistic to modify a test to be suitable for both adults and children.

However, the process of modifying and testing the tasks has led to some constructive learning for future measurement of CoL. Whilst creating different versions of the same test would also make it difficult to compare the two groups, at this point, there may be justification for focusing on comparing CoL-N and CoL-D in children only even if this does raise questions about the measures if an effect is not found. However, the two groups may be reconciled with one test if the dimensions of the tasks were extended at either extreme to create a more challenging aspect for adults during the latter part of the task, and a simplified start. Interestingly, this research has been able to suggest levels of difficulty appropriate for both children and adults and future research may be able to isolate and extrapolate the tasks around the points of sensitivity on the curves displayed. For example, post-hoc analysis performance curves for the VDT suggested adult performance to be most sensitive to CoL around ISI 20-60ms whereas children may be more sensitive to CoL around ISI 100-1000ms. These may be the perceptual availability of the stimuli where discrimination is challenging but not so difficult that it becomes demotivating. Further post-hoc reanalysis of the data isolating these segments of the tasks may give further indications regarding their sensitivity to CoL, and guide future research. Ideally, a task which is capable of catering for both ends of the spectrum by adjusting difficulty according to performance by missing or adding trials may be a potential solution. Whilst this was considered during the design it was beyond the remit of the programming expertise available.

If one were to replicate this research using children and adults, in addition to the above development of the tasks, the adult sample could be improved by a wider demographic

spread of participants both in terms of age, lifestyle and intellectual ability. In this case the students, and also those recruited from other networks were homogenous in terms of many of these factors.

Ideally a study focused purely on validating measures as suitable to demonstrate learning over time may initially be required, before a CoL-N and CoL-D are compared. It would also be beneficial if resources were such that a dedicated quiet testing environment was available at times which would facilitate CoL-N and CoL-D phases of equal length, and if participants were able to be randomized to the counterbalanced groups. It would also be interesting to conduct further research into sleep latency and CoL-N.

With further improvements and confidence in the measures, it would be extremely interesting how children with clinical conditions known to be related to sleep disturbance and learning difficulties perform. Whilst a significant difference between CoL-N and CoL-D within the non-clinical participants was not found, despite the apparent difference in means in three of the cases, had a clinical population been included a difference between the two groups may have been apparent. Thus there is certainly scope for this type of study design in the future.

Ultimately, whilst this study has not found effects to support the initial hypothesis that CoL-N will be greater than CoL-D in both adults and children, notable steps forward have been taken in understanding the complexity of this task, particularly with regard to developing suitable measures. This study, therefore, becomes one of the building blocks for the foundation of research into CoL-N in childhood. It has helped to increase understanding about further research required, so that we may gradually increase our

comprehension of this relationship. CoL-N is not only an extremely interesting phenomenon but it is hoped that further understanding of the relationship between learning and sleep will in turn have vital clinical implications for supporting children with learning difficulties associated with sleep disturbance and maximising their learning potential.

6. Conclusions

The aim of this research was to investigate the presence of CoL-N in children by attempting to identify and test potential measures for CoL-N in children. The hypothesis, that the measures, if successful would demonstrate an advantage of CoL-N as compared to CoL-D in both adults and children were not supported. However, post-hoc analyses revealed interesting observations regarding the sensitivity of the measures for children and adults, and this gives important information and direction for future further development and validation of such measures.

This research has also revealed challenges manifested in the amount of variability in the data and likelihood that many of the participants, both adults and children, were not able to fully engage with the tasks. This needs to be considered strongly in modifications to both the measures and recruitment need to be taken in order to maximise the concentration and motivation of participants in CoL tasks.

As part of the study a measure of non-verbal IQ and a measure of sleep quality was also undertaken. No correlations were found between CoL-N and non-verbal IQ. However, a potential association between CoL-N and bedtime difficulties in children, and sleep latency in adults was implied. Thus there may be an aspect of the early part of sleep that is crucial to CoL-N, which would form an interesting subject of future research.

Overall, the research has made some interesting progress in addressing the question of the existence in CoL-N in children and how this may be measured, and has uncovered many of the difficulties with this task. It has aided the development of suggestions for

further research and methodological improvements which may reduce the impact of some of these, and may clarify the nature of the relationship between learning and sleep in children. It is hoped that further understanding of this relationship can lead to research in clinical populations, and that this will in turn inform strategies for interventions to maximise learning opportunities for children at risk of disrupted learning and development due to sleep disturbance.

References

Abdi, H. (2007). Bonferroni and Sidak corrections for multiple comparisons in Salkind, N.J. (ed.): *Encyclopedia of Measurement and Statistics*. Thousand Oaks, CA: Sage

Aldenkamp, A., Alpherts, W.C., Dekker, M. J. A., Overweg, J. (1990). Neuropsychological aspects of learning disabilities in epilepsy. Epilepsia, *31* (4), 9-20.

Anderson, V. A., Lajoie, G. (1996). Development of memory and learning skills in school-aged children: a neuropsychological perspective. *Applied Neuropsychology, 3* (4), 128-39

Anderson, V., Northam, E., Hendy, J. & Wrennall, J. (2001). *Developmental Neuropsychology. A Clinical Approach.* Hove: Psychology Press.

Backhaus, J., Junghanns, K. (2006). Daytime naps improve procedural motor memory. *Sleep Medicine, 7*(6), 508-12

Bennett, C.M., Baird, A.A.(2006) Anatomical changes in the emerging adult brain: a voxel-based morphometry study. *Human Brain Mapping, 27*(9), 766-77.

Buysse, D.J., Reynolds, C.F., Monk, T.H., Berman, S.R., & Kupfer, D.J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatric Research, 28* (2), 193-213.

Cartwright, R. (2007). Response to Rosalind Cartwright's Letter to the Editor. *Sleep Medicine Reviews, 11* (4), 329-333.

Case, R. (Ed) (1992). *The Mind's Staircase: Exploring the conceptual underpinnings of children's thought and knowledge*. New Jersey: Laurence Erlbaum Associates.

Chervin, R.D., Hedger, K., Dillon, J.E., Pituch, K.J. (2000). Pediatric Sleep Questionnaire (PSQ): validity and reliability of scales for sleep disordered breathing, snoring, sleepiness and behavioural problems. *Sleep Medicine, 1,* 21-32.

Cohen, M. J. (1997). *Children's Memory Scale*. San Antonio, TX: The Psychological Corporation; Harcourt Brace & Company.

Cohen, N.J. & Squire, L.R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science, 210,* 207-210.

Diamond, A. (1995). Evidence of robust recognition memory early in life even when assesed by reaching behaviur. *Journal of Experimental Child Psychology, 49,* 419-474.

Ferrara, M., Iaria, G., De Gennaro, L., Guariglia, C., Curcio, G., Tempesta, D., Bertini, M. (2006). The role of sleep in the consolidation of route learning in humans: a behavioural study. *Brain Research Bulletin, 71* (1-3), 4-9.

Fischer, S., Hallschmid, M., Elsner, A.L., & Born, J. (2002). Sleep forms memory for finger skills. *Proceedings of the National Academy of Sciences, 99,* 11987–11991.

Fischer, S., Wilhelm, I., & Born, J. (2007). Developmental Differences in Sleep's Role for Implicit Off-line Learning: Comparing Children with Adults. *Journal of Cognitive Neuroscience, 7*(19), 214-227.

Gais, S., Plihal, W., Wagner, U., Born, J (2000). Early sleep triggers memory for early visual discrimination skills. *Nature Neuroscience, 3* (12), 1335-9.

Gais, S. & Born, J. (2004). Low acetylcholine during slow-wave sleep is critical for declarative memory consolidation. *Proceedings of the National Academy of Science, 101,* 2140–2144.

Gais, S., Lucas, B., Born, J. (2006). Sleep after learning aids memory recall. *Learning & Memory, 13* (3), 259-62.

Gomez, R.L., Bootzin, R.R., Nadel, L. (2006). Naps Promote Abstraction in Language-Learning Infants. *Association for Psychological Science, 17* (8), 670-674.

Gottlieb, D.J., Chase, C., Vezina, R.M., Heeren, T.C., Corwin, M.J., Auerbach, S.H., Weese-Mayer, D.E., Lesko, S.M. (2004). Sleep-disordered breathing symptoms are associated with poorer cognitive function in 5-year-old children. *Journal of Pediatrics, 145* (4), 458-64.

Hu, P., Stylos-Allan, M., Walker, M.P. (2006). Sleep facilitates consolidation of emotional declarative memory. *Psychological Science, 17* (10), 891-8.

Huber, R., Ghilardi, M.F., Massimini, M., Tononi, G. (2004). Local sleep and learning. Nature, 430 (6995), 78-81

Huyton, C. (*unpublished*) 'Sleep Dependent Learning'

Jenkins, J.G., & Dallenbach, K.M. (1924). Oblivescence during sleep and waking period. *American Journal of Psychology, 35*, 605-612.

Karni, A., Sagi, D. (1991). Where practice makes perfect in texture discrimination: Evidence for primary visual cortex plasticity. *Proceedings of the National Academy of Sciences, 88*, 4966-4970.

Karni, A., Tanne, D., Rubenstein, B.S., Askenasy. J.J., Sagi, D. (1994). Dependence on REM sleep of overnight improvement of a perceptual skill. *Science, 29,* (5172) 679-82.

Lezak, M.D., Howieson, D.B. & Loring, D.W. (2004). *Neuropsychological Assessment: Fourth Edition.* New York: Oxford University Press.

McKay, K.E., Halperin, J.M., Schwartz, S.T., Sharma, V. (1994). Developmental analysis of three aspects of information processing: sustained attention, selective

attention, and response organisation. *Developmental Neuropsychology, 10*, 121-132.

Manly, T., Robertson, I., Anderson, V., Nimmo-Smith, I. (1999). *Test of Every Day Attention for Children.* Cambridge, UK.

Maquet, P., Schwartz, S., Passingham, R., & Frith, C. (2003). Sleep-related consolidation of a visuomotor skill: Brain mechanisms as assessed by functional magnetic resonance imaging. *Journal of Neuroscience, 23*, 1432–1440.

Mitchell, R.B., Kelly, J. (2005). Behaviour, neurocognition and quality of life in children with sleep disordered breathing. *International Paediatric Otorhinolaryngology, 70*, 395-406.

Randazzo, A.C., Muehlbach, M.J., Schweitzer, P.K., & Walsh, J.K. (1998). Cognitive function following acute sleep restriction in children ages 10-14. *Sleep, 21*, 861-8.

Robertson. E, M, Pascual-Leone. A, Miall. R, C, (2004). Current concepts in procedural consolidation. *Nature Reviews Neuroscience, 5*, 1-7.

Roth, D.A., Kishon-Rabin, L., Hildesheimer, M., Karni, A. (2005). A latent consolidation phase in auditory identification learning: time in the awake state is sufficient. Learning & Memory, *12* (2), 159-64.

Schacter, D. L. (1987). Implicit memory: history and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501-518

Stickgold, R., Whidbee, D., Schirmer, B., Patel, V., & Hobson, J. (2000) Visual discrimination task improvement: A multi-step process occurring during sleep. *Journal of Cognitive Neuroscience, 12*, 246-54.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature, 437*, 1272-1278

Stores, G. (2001). A Clinical Guide to Sleep Disorders in Children and adolescents. Syndicate of the University of Cambridge: The Press.

Walker, M., Brakefield, T., Morgan, A., Hobson, J., & Stickgold, R. (2002) Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron, 35*, 205-11.

Walker, M.P., Brakefield, T., Hobson, J.A., & Stickgold, R. (2003) Dissociable stages of human memory consolidation and reconsolidation. *Nature, 42,* 616-20.

Wechsler, D. (1999) *Wechsler Abbreviated Scale of Intelligence (WASI)*. San Antonio, TX: Harcourt Brace & Company.

Critical Appraisal

Sophie Thomas

1. Introduction

The following critical appraisal aims to examine the research process in terms of challenges, learning experiences and outcomes. A discussion of the planning, implementation and research process is followed by consideration of methodological weaknesses and implications for future research.

2. Origins of the Study

My interest in sleep and learning in children was sparked by Dr. Ingram Wright, who with an interest already in this field had developed a relationship with Dr. Primhak, Consultant Paediatrician in Respiratory Medicine at Sheffield Children's Hospital. Already aware of the relationship between OSA and learning problems in children, and the preliminary evidence supporting reversibility of this further to surgical intervention, both Dr. Primhak and Dr. Wright were keen to explore this further with a pre-post surgery study. It seemed it would be interesting to measure the physiological and cognitive changes further to adenotonsillectomy surgery in a group of children diagnosed with OSA. It was hypothesised that further to surgery children would improve on both physiological sleep attributes as measured in the sleep laboratory, and on measures of learning, specifically measures of CoL-N. With an interest already in children's learning I was fascinated by this phenomenon, the limited research in this field, and the potential impact such reversibility of learning problems could have on a child's development and consequent life experience. Thus I chose to conduct a study to further investigate this area.

The design phase of the project occurred without any major obstacles and eventually Local Research Ethics Committee approval was gained as was funding support from

Sheffield Children's Hospital. The identification and development of measures required substantial investment of my time, as well as the time of another researcher developing different potential measures of CoL-N in children. Similarly the complexities and intricacies of the sleep laboratory and polysomnography equipment represented a steep and interesting learning curve for me to feel confident in managing this equipment. However, whilst having consulted ENT surgeons, as the referrers of participants to this study, about the likely participant flow, the actuality bore little resemblance to their predictions. Having predicted 1-2 potential referrals per week, in the first six months of recruitment only 4 participants were referred, the majority of whom did not meet the inclusion criteria for the study. At this point surgery waiting times had increased from 3 to 6 months, increasing the timeline from study entry point to completion for each participant. All attempts were made to establish the obstacles to recruitment and to assess the future feasibility of the study, but it transpired that the participants were simply not going to be available within the timeframe of this study. Thus, sadly it transpired that the timescale of the study was likely to be far longer than had been predicted, and would be outside of the scope of my Doctorate in Clinical Psychology research (though I was to continue with this study).

However, I had already learned a great deal during the first phase of this study. I learned about the research design and governance process, and the frustrations and complexities of obtaining Local Research Ethics Approval, whilst also digesting a whole new area of academic interest expertise, and juggling other ethical, clinical and life demands. Mostly I had learned a valuable lesson about the unpredictability of research. I learned how important it is to be realistic about recruitment and about timescales. I also learned that despite careful planning, many factors can be out of your control. This can include the unpredictability of timescales such as the length of time it may take to obtain

governance, ethical approval or any other processes relying on third parties with multiple demands upon their time. During this time one can also feel incapacitated in being unable to progress with the research. In this case, the unpredictability had been with regard to recruitment. The flow of participants was far less than had been predicted by the expert parties, and it is my understanding that this is not unusual, and ultimately one year later this dictated that suitability of this project for my Doctorate in Clinical Psychology. However, fortunately having commenced this study in good time (this being a positive lesson learned) sufficient time remained for me to be sure that I had given this study every opportunity to succeed in the timeframe, whilst also having time to complete an alternative study.

Already familiar with, and interested in the subject of this first study, I was still keen to undertake research which would shed light on the phenomenon of CoL-N in children, and ideally complement the original study. My experience had led me to become clear that whilst the implications of better understanding CoL-N in children are greatest for clinical populations such as those in the above study, firstly more research was required in order to identify suitable measures of CoL-N for children, and to further understand CoL-N in a non-clinical population. Through the experience gained during my involvement with this first study, I began to take a step back and consider the simpler matter of measuring CoL-N in non-clinical samples, as really before we study pathology we need to have a good understanding of what is 'normal'. Otherwise it is difficult for us to identify deviation from this.

Now having a clear idea that, in order to inform the impact of clinical conditions affecting sleep on children's learning and development, we needed to begin with attempting to identify and measure CoL-N in a non-clinical population, I began to form the ideas which would form the basis for the design of this research project.

3. Study Design

Keen to develop measures which would allow me to attempt to identify the phenomenon of CoL-N in a non-clinical sample of children, I began to consider the measures to be utilised and the design of the study. To measure CoL-N in children it would be necessary to have a comparison of learning which was not consolidated during the night. As with most of the adult studies introduced in the literature review it would be necessary to compare the CoL-N phase with a daytime phase. There would be two obvious ways to do this; a within or between subjects design. The former, most popular in the adult research, would involve comparing children's consolidation overnight with that during the day, utilising the same group of children. The latter would involve two groups of children, a night time consolidation group, and day time consolidation group. Careful thought was given as to the most appropriate design. A between subjects design would not require such a time commitment on the part of the participants, as they would need to complete the cognitive tasks only twice, either side of a 12 hour period, rather than three times over a 36 hour period. Given busy family lives, and multiple demands placed upon parents, this was an important practical factor which would be likely to influence the ease of recruitment of participants, and thus the likely success of the project. However, this reduced commitment for each participant was counterbalanced with the numbers of participants to be required. Given the expected individual differences between the children, the numbers required for a between subjects study were to be far greater, placing a far greater demand upon recruitment. Even if recruitment of such numbers had been realistic there would be a risk that the individual differences between the children would be too great, and it would be difficult to match children accordingly given the resources of the study. I therefore decided, having

consulted Dr. Adrian Simpson, Lecturer in Statistics, and my supervisor Dr. Ingram Wright, that the most suitable design would be a within-subjects design, comparing children's own performance over the day and night.

Initially this study aimed to measure CoL-N in children only, given that CoL-N had been measured repeatedly in adult populations. However, the development or adaptation of measures also needed to be considered (discussed below) and this would create a version of the measures not previously utilised with adults. I was always aware that in modifying or developing a measure there was a risk of altering the specificity of the measure to CoL-N, particularly given the literature which had demonstrated the subtleties of this relationship. Hence, I felt there was a great risk of not being clear about whether a finding should be attributed to the sample of children, or to the specificity of the measure. It therefore seemed that the only way to account for this would be to also involve an adult sample in the study. This way if an effect for CoL-N was not found in the childhood sample, by comparing this result to that of the adult sample, it would be possible to gain an idea of whether the result was specific to the childhood sample, and therefore likely to be a developmental feature, or whether it was a feature of both samples, and thus likely to be attributable to the measures.

4. Developing the Measures

The lack of established measures of CoL-N in children was a challenging aspect of this study. However, I had already given much thought to measures of CoL-N in the design of the first study, and in order to complement the OSA study it seemed appropriate to employ the same measures where possible. The time invested in the development of the measures was much greater than I had ever anticipated. It involved a great deal of

liaison with technicians and IT experts in order to overcome the solution of a simple response mode (the specially adapted keyboard), and was in fact one of the most challenging aspects of the research project. It stretched my abilities beyond my comfort zone and into some areas where my strengths do not naturally reside, such as computer programming. The use of E-Prime to create Mousehunt was a challenge in itself, as it involved learning a new skill and completely new software. In order to try to replicate the VDT as closely as possible I contacted Dr. Stickgold in the USA via email and asked for his advice on the replication of his measure and gained further information on the specifics of test administration not available in the publication. Dr. Stickgold was helpful and enthusiastic about my aspirations, and introduced me to his Computer Programmer who was able to send files and further descriptions of their software. However, deciphering the information sent to me, was a challenge, and highlighted the advantage of conducting research with allocated expert resources. The programming was also made more difficult by a number of licensing and software failure issues that took many weeks to solve, and with hindsight there are improvements I would have made to the measures, which at the time were limited by my limited software knowledge. However, the outcome when the first pilot child said he enjoyed the 'game' and wanted to tell his parents all about it, was immensely satisfying. Now I am comfortable with the knowledge that I would be able to create a bespoke test again in the future should it be required.

5. Recruitment and Relationship Management

Once the tasks were complete the next stage was recruitment, which involved making new contacts. Introducing myself to schools, via telephone and in writing, was a challenging task. There was an important role in gaining the trust and commitment of

schools if that study was to be a success. I learned, that as I suspected, writing to schools was not effective, as letters became lost in the vast amount of administration they are faced with and thus telephoning was a more fruitful strategy. Inevitably this involved multiple phone calls, as even the most co-operative school, had other pressures such as OFSTED assessments, and were unable to give a definite answer for some time. Whilst needing to understand that the school needed to be given space to make a decision in their own timeframe, this involved several nerve wracking periods awaiting their decision as to whether or not they would be able to collaborate, particularly given the short time frame available for this study. However, it did not seem ethical to approach too many schools at the same time, as whilst it would have been a pleasure to have a choice of schools to collaborate with, it was important not to damage the reputation of the University or myself, by having to turn down and opportunity when a school had taken the time to consider my proposal.

Throughout my time collaborating with the two schools, I learned a great deal about research relationship management, and gained insight into the pressures placed upon schools and teachers which limited their capacity to collaborate. However, I also learned a great deal about the positive experience both the school and the children were able to gain from collaborating in the research, in terms of the special occasion this created, their learning about the study and research itself, but also their learning about taking part in something to benefit the wider community. Most children were very excited about the important role they had played in taking part in the research, and thrived on the praise they received for taking part, and the certificate they received. I personally enjoyed being in the school and the relationships that were created, and it was probably one of the most fun aspects of the study. However, there were also a great number of challenges with the participant groups, which are addressed below.

6. Conducting Research with Children

The biggest learning experience of this research, involved the experience of conducting research with children. In general I find working with children a lot of fun. They are dynamic and unpredictable. However, assessing children also brings with it several challenges. I was aware of this having worked with children in a clinical setting, however this does not always have such an emphasis on absolute standardisation of tests or their delivery, and can be tailored towards a child's needs. There is also less time pressure in a clinical setting, and one can spend more time getting to know a child and gaining their trust, or assessing at their own pace. However, the pressure in schools was such that children needed to be tested back to back and as quietly as possible so as not to disturb the other children. This was difficult as many of the children were excited at the deviation from their standard school routine, and thus very distractible. Many children, excited at their latest score, would turn to talk, and miss the next stimuli, or forget they what they were doing altogether! This was not helped by their friend peering at the window, and hoards of children passing at the sound of the school bell. Even curious teachers entered the testing environment to watch and ask questions, not always aware of the importance of the children's concentration. Some of the younger children also became tired towards the end of the school day, which again made it difficult for them to remain motivated, particularly as the tests were quite monotonous at times. Ultimately, encouraging the children to concentrate on the task whilst bearing in mind that they were volunteers and did not have to take part involved a tricky balance. It was important to be aware the power dynamic we had entered, in that the children were at school and thus expected to do as adults asked them, even if this was not quite their preference. However, all the children were volunteers and it was important to me that this remained a positive experience for the children.

There was also a balancing act in the demands we placed upon the schools, such as asking for the appropriate tables and chairs, and for it to be as quiet as possible, whilst again being aware that they were already helping us a great deal by allowing us access to the school and the children. Again it was also important to be aware of building relationships for the University and future research, particularly as one of the schools had a grievance with previous researchers. It was also important to ensure we took utmost care of the health and safety of the children when walking them between classrooms, up and down stairs, and that we managed situations like trips to the toilets sensitively and appropriately.

7. Conducting Research with Students

This adult participant group also presented its own challenges. Whilst students form an extremely accessible participant group, who are familiar with research processes, and motivated by financial incentives, many also lead varied and fun social lives. This particularly impacts upon a study which requires participants to arrive at 9am in the morning! Several students did not arrive for the morning sessions, and one student arrived still inebriated from the previous night, having had very little sleep. In order to encourage attendance to all three sessions, participants were not given their incentive until the last session. Regardless, some students attended the first two, but not the last session, which meant that two sessions had been invested in the data collection but the data could not be used. Unfortunately a lot of time was wasted this way. However, understandable there was only a small incentive for them to be reliable, and I understand this is often the case with participants in any study.

8. Advantages of Research Collaboration

Both this project, and the initial project, involved collaborating with a many different parties. The OSA project involved a team of five collaborators, each with different expertise and vested interests, and all with multiple demands upon their time, thus creating a logistical challenge to simply arrange a meeting. However, I learned a great deal from the perspectives of Dr. Rob Primhak, Consultant Respiratory Pediatrician, due to his many years of experience and accumulated wisdom. Similarly, my collaboration with Dr. Ruth Kingshott, Polysomnographic Technologist, involved the marrying of hugely different perspectives and experience, towards a joint goal, giving me the opportunity to learn huge amounts not only about physiological measures of sleep, but from her incredible skills working with fragile children and generally putting both children and adults at ease. During this time we forged a relationship which has continued.

Additionally, spending the early hours of the morning with staff in the Sheffield Children's Hospital, and managing the needs of a family admitted to the sleep laboratory overnight, was a huge learning experience, giving me an insight both into the experiences of children in hospital and that of the staff caring for these children.

The largest part of my collaboration, however, was with Clare Huyton, PhD student in our joint pursuit of data collection. I have learned that there are many advantages to collecting data collaboratively, particularly when managing groups of young children who cannot be left unaccompanied. Working as a pair we were able to monitor children taking part in each other's cognitive tests, and at times administer each other's tests, whilst the other party managed other issues such as liaising with parents or teachers, or

PAGE

MISSING

IN

ORIGINAL

With respect to the adult sample it would have been better if the sample had been much more varied with respect to IQ, age and social demographics. This would have avoided the issues created by the young sample, and would have avoided some of the issues of motivation of this population. However, to attract a wider adult population further resources would have been required to attract and manage such participants. One of the main issues was premised to conduct the research. Whilst I was able to gain collaboration from a church for testing children and adults in the local community, this added a significant financial cost to the project which would have meant sacrificing participants numbers, and also there were concerns regarding insurance and ethics, particularly with the children.

For both samples randomisation of participants to the two counterbalanced CoL-N and CoL-D conditions would have been far more scientific and would have reduced the impact of order effects. It would also have been a more equal comparison of the CoL-N and CoL-D phase had been of exactly the same length for all participants. Given the brevity of children's days at school, even with an after school club it was also impossible to create CoL-N and CoL-D phases of absolutely equal length. If each child could have been assessed in the home environment at 7am and 7pm this would have provided a better comparison, however, assessing children in their own homes was too ethically complex and resource intensive within the constraints of this research. For similar practical reasons children were also not randomly allocated to the two testing order groups. Recruitment was already difficult and thus it was necessary to fit around the plans of parents and the school and their attendance was dictated by their availability rather than the research timetable.

attend at 9.30am, but it was not possible to gain access to premises or felt to be appropriate or safe for researchers to be conducting assessments late in the evening. Thus again it was very difficult to obtain CoL-N and CoL-D phases of equal length. A further challenge of working with young students described above, was that it was again difficult to be sure that they had gained a full nights sleep and had not napped during the day. One participant was excluded due to excessive alcohol consumption but not all participants were likely to be completely honest about their social activities. A final disadvantage of students as participants is the homogenous intellectual and age demographic they represent, which has already discussed.

There were also many issues with the tests which have been described in the study. Once adapted for children the VDT was not suitably challenging for adults, and there are concerns that modification may have reduced the sensitivity to CoL-N. However, this was a dilemma as modifications did need to be made and all efforts were made to maintain the essential elements of the task, but we do not have sufficient knowledge about testing CoL-N to know exactly what these are. The tests still remained a little monotonous and not as appealing for children as I would have liked and further investment into this, with further time and resources would be worthwhile. Ultimately, despite every attempt being made to make the learning tasks fun and appealing, they were unlikely ever to compare with the wealth of stimulation and intricate graphics provided by modern games consoles. In an ideal world the assessment tasks would be designed to a higher standard with more advance technology. Children are also easily... ... demotivated and this was a difficult issue as it was necessary to maintain the essential elements of tasks such as the VDT which was essentially a difficult task to begin with, despite efforts to increase a training period to inspire early confidence. These factors

PAGE

MISSING

IN

ORIGINAL

on learning. If this is successful it will identify where intervention is most needed and the measures can again be utilized to monitor the effectiveness of interventions upon CoL-N. This in turn has the potential to have an important impact on the lives of children potential at risk of disturbed CoL.

Appendices

Appendix 1

Letter of approval of proposed journals for submission

Guidelines for authors: Journal of Developmental Neuropsychology

JOURNAL GUIDELINES FOR SUBMISSION: Journal of Developmental Neuropsychology. Laurence Erlbaum Journals

Instructions for Authors

Aims and Scope:
Developmental Neuropsychology is devoted to exploring the relationships which exist between brain and behavior across the life span. The journal will publish scholarly papers on the appearance and development of behavioral functions such as language, perception, and cognitive processes as they relate to brain functions and structures. Some examples of subjects that would be appropriate for publication are studies of early cognitive behaviors in normal and brain-damaged children, plasticity and recovery of function after early brain damage, the development of complex cognitive and motor skills, and specific and nonspecific disturbances such as learning disabilities, mental retardation, schizophrenia, stuttering, developmental aphasia, and so forth. Appropriate gerontologic topics include neuropsychological analyses of normal age-related changes in brain and behavioral functions (e.g., in sensory, motor, cognitive, and adaptive abilities), studies of age-related diseases of the nervous system, and recovery of function in later life.

Empirical studies, research reviews, case reports, critical commentary, and book reviews will be published. By publishing both basic and clinical studies of the developing and aging brain, the editors hope to encourage scholarly work that advances the understanding of the field of developmental neuropsychology.

Address manuscripts to the Editor:
Contributors should submit four copies of manuscripts for review to Dennis L. Molfese, Editor, Developmental Neuropsychology, Birth Defects Center, Department of Molecular, Cellular, & Craniofacial Biology, University of Louisville, 501 S. Preston St., Room 301, Louisville, KY 40202. Manuscripts should be highly legible copies and will not be routinely returned to authors.

To facilitate anonymous review, only the article title should appear on the first page of the manuscript. An attached cover page must contain the title, authorship, and an introductory footnote with professional titles, mailing addresses, and telephone numbers of the authors and any statements of credit or research support. Every effort should be made by the authors to see that the manuscript itself contains no clues to their identities.

In order to accommodate the various forms of developmental neuropsychology that mark pertinent research in the areas described, articles of varied length will be published. Manuscripts should be prepared according to the guidelines established in the *Publication Manual of the American Psychological Association* (5th ed.). (Copies may be obtained from APA, 750 First Street, NE, Washington, DC 20002-4242.)

For final accepted manuscripts, authors are strongly encouraged to submit manuscripts on disk. The disk should be prepared using MS Word or WordPerfect and should be clearly labeled with the authors' names, file name, and software program. A hardcopy printout that exactly matches the disk must be supplied. Each manuscript must be accompanied by a statement that it has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere. Authors are responsible for obtaining permission to reproduce copyrighted material from other sources and are required to sign an agreement for the transfer of copyright to the publisher. All accepted manuscripts, artwork, and photographs become the property of the publisher. All parts of the manuscript should be typewritten, double-spaced, with margins of at least one inch on all sides. Number manuscript pages consecutively throughout the paper. Authors should also supply a shortened version of the title suitable for the running head, not exceeding 50 character spaces. Each article should be summarized in an abstract of not more than 100 words. Avoid abbreviations, diagrams, and reference to the text in the abstract.

References:
Cite in the text by author and date (Smith, 1983). Prepare reference list in accordance with the APA Publication Manual, 5th ed. Examples:

Journal: Tsai, M., & Wagner, N. N. (1978). Therapy groups for women sexually molested as children. *Archives of Sexual Behaviour*, 7, 417-427.
Book: Millman, M. (1980). *Such a pretty face*. New York: W. W. Norton.
Contribution to a Book: Hartley, J. T., & Walsh, D. A. (1980). Contemporary issues in adult

development of learning. In L. W. Poon (ed.), *Ageing in the 1980s* (pp. 239-252). Washington, DC: American Psychological Association.

Illustrations:
Illustrations submitted (line drawings, halftones, photos, photomicrographs, etc.) should be clean originals or digital files. Digital files are recommended for highest quality reproduction and should follow these guidelines:

- 300 dpi or higher
- Sized to fit on journal page
- EPS, TIFF, or PSD format only
- Submitted as separate files, not embedded in text files

Color illustrations will be considered for publication; however, the author will be required to bear the full cost involved in their printing and publication. The charge for the first page with color is $900.00. The next three pages with color are $450.00 each. A custom quote will be provided for color art totaling more than 4 journal pages. Good-quality color prints should be provided in their final size. The publisher has the right to refuse publication of color prints deemed unacceptable.

Tables and Figures: Tables and figures (illustrations) should not be embedded in the text, but should be included as separate sheets or files. A short descriptive title should appear above each table with a clear legend and any footnotes suitably identified below. All units must be included. Figures should be completely labeled, taking into account necessary size reduction. Captions should be typed, double-spaced, on a separate sheet. All original figures should be clearly marked in pencil on the reverse side with the number, author's name, and top edge indicated.

Proofs and Reprints: Page proofs are sent to the designated author using Taylor & Francis' Central Article Tracking System (CATS). They must be carefully checked and returned within 48 hours of receipt. Reprints of individual articles are available for order at the time authors review page proofs. A discount on reprints is available to authors who order before print publication.

The University Of Sheffield.

Department Of Psychology.
Clinical Psychology Unit.

Doctor of Clinical Psychology (DClin Psy) Programme
Clinical supervision training and NHS research training & consultancy.

Clinical Psychology Unit
Department of Psychology
University of Sheffield
Western Bank
Sheffield S10 2TP UK

Telephone: 0114 2226570
Fax: 0114 2226610
Email: dclinpsy@sheffield.ac.uk

11 June 2007

Sophie Thomas
Third year trainee
Clinical Psychology Unit
University of Sheffield

Dear Sophie

I am writing to indicate our approval of the journal(s) you have nominated for publishing work contained in your research thesis.

Literature Review: Developmental Neuropsychology

Research Report: Developmental Neuropsychology

Please ensure that you bind this letter and copies of the relevant Instructions to Authors into an appendix in your thesis.

Yours sincerely

Andrew Thompson
Director of Research Training

Appendix 2

Ethical Approval Letter: University of Sheffield, Department of Psychology

Ethics Subcommitte

Sophie Thomas

From: Paschal Sheeran [p.sheeran@sheffield.ac.uk]

Sent: 29 January 2008 07:48

To: pcp04sm@sheffield.ac.uk

Subject: Fwd: Re: Ethics of "Sleep-dependent learning consolidation in children"

Date: Fri, 9 Feb 2007 11:22:04 +0000
To: pcp04sm@shef.ac.uk, c.huyton@shef.ac.uk
From: Paschal Sheeran <p.sheeran@shef.ac.uk>
Subject: Re: Ethics of "Sleep-dependent learning consolidation in children"
Cc: Nicolson.Rod
Bcc:
X-Attachments:

Dear Ms Thomas and Ms Huyton,

Thank you for the amendments to your submission to the Department of Psychology Ethics Sub-Committee ("Sleep-dependent learning consolidation in children").

DESC has now had the opportunity to consider your proposal. I am pleased to inform you that the ethics of your research are approved.

Sincerely,

Professor Paschal Sheeran

Chair, Department of Psychology Ethics Sub-Committee

--

Paschal Sheeran, PhD
Professor of Psychology
Department of Psychology, University of Sheffield
Sheffield S10 2TN, UK
Phone: +44 (0) 114 222 6578
Fax: +44 (0) 114 276 6515
http://www.shef.ac.uk/psychology/staff/academic/paschal-sheeran.html

Appendix 3

Information Sheets
Consent Forms
Measures

Appendix 3A	Parents Information Sheet
Appendix 3B	Information Sheet – Children 6-12yrs
Appendix 3C	Information Sheet- 13yrs +
Appendix 3D	Parents Consent Form
Appendix 3E	Children's Assent Form
Appendix 3F	Adult Consent Form
Appendix 3G	Pittsburgh Sleep Index
Appendix 3H	Paediatric Sleep Questionnaire

THE UNIVERSITY OF SHEFFIELD
Clinical Psychology Unit
Department of Psychology

Appendix 3A

Contacts: Sophie Thomas (07976 097596) Clare Huyton (0114 222 6644)) Dr. Ingram Wright (0114 222632)

INFORMATION SHEET

Study title: Sleep dependent learning consolidation in children and adults

Can you and your child help us with our research study?!

What is study about?

We are interesting in understanding more about how children learn and how this is connected to sleep. This is important as many children suffer from difficulties sleeping, and this may be related to poor concentration and school performance. However, at the moment, we don't know how this works. Research has shown that when we learn a new skill, we get better at it after a night asleep. We think this is because the brain 'practises' the skill during sleep, and helps fix it in our memory. This process is called 'consolidation of learning'. The purpose of our study is to learn more about how children consolidate information while they are sleeping.

We are conducting research at Sheffield Children's Hospital with children who have difficulties sleeping due to medical conditions such as epilepsy and sleep apnea. However, to understand the link between sleep and learning we need some children from the local community who don't have these problems to help us.

What will be involved?

Your child will play some learning games which are tests of memory and concentration including remembering a short story, tapping fingers in certain sequences and some computer games. These will take about 35 minutes. We would like your child to do these three times. They can start in the evening, then repeat the games the following morning and then the following evening OR they can start in the morning and repeat the games the same evening and the following morning. It is important that they take part in the games either side of a night asleep and a day awake so we can compare their improvement overnight versus during the day. We may also ask you some questions about how well your child sleeps.

Do we have to take part?

No of course not. We would be grateful for your help but it is up to you and your child to decide if you want to take part. If you do decide to take part, you will be asked to sign a consent form, but you can still change your mind at any time.

What are the advantages and disadvantages to taking part?

Most children find our learning games fun and enjoy taking part in something that will benefit other children. There are no risks to taking part in the learning games. You are very welcome to come with your child. There will be cake and refreshments available!

Your child will be given a participant number so the results of their games will be anonymous and they will not be compared with other children. Nobody other than the researchers will have access to the results. All of our researchers have the necessary security clearance to work with children.

We hope the results of the study will enhance our understanding of learning problems in children with sleep disorders, and may help us understand better the best course of treatment for such children. As we are relying on the help of families to advance our research we are happy to offer an incentive of £10 per child taking part, if you are happy for them to receive this. Please inform us if you are not.

What if I wish to complain about the way in which this study has been conducted?

If you have *any* cause to complain about *any* aspect of the way in which you have been approached or treated during the course of this study, please contact Dr. Ingram Wright, Clinical Psychology Unit, University of Sheffield, Western Bank, Sheffield, S10 2TP

(Note: If your child has photosensitive epilepsy or there is any reason you feel they should not play computer games please inform us. If your child has any other medical conditions or food allergies you feel we need to be aware of again please discuss this with us),

THE UNIVERSITY OF SHEFFIELD

Clinical Psychology Unit

Department of Psychology

Contacts: Sophie Thomas (07976 097596) Clare Huyton (0114 222 6644)) Dr. Ingram Wright (0114 222632)

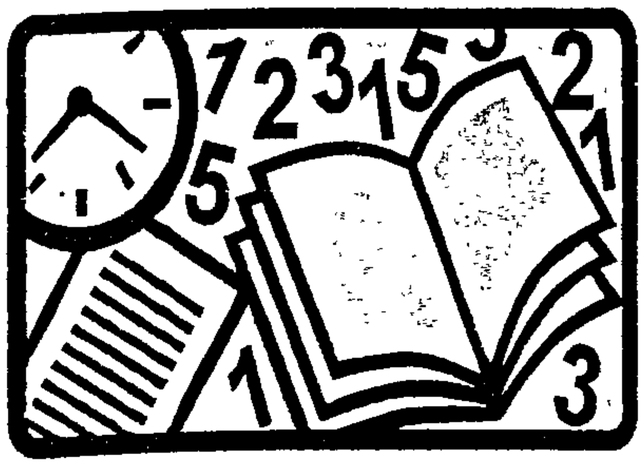
INFORMATION SHEET

(FOR YOUNG PEOPLE AGED 6-12YRS)

Project title: **Sleep dependent learning consolidation in children and adults**

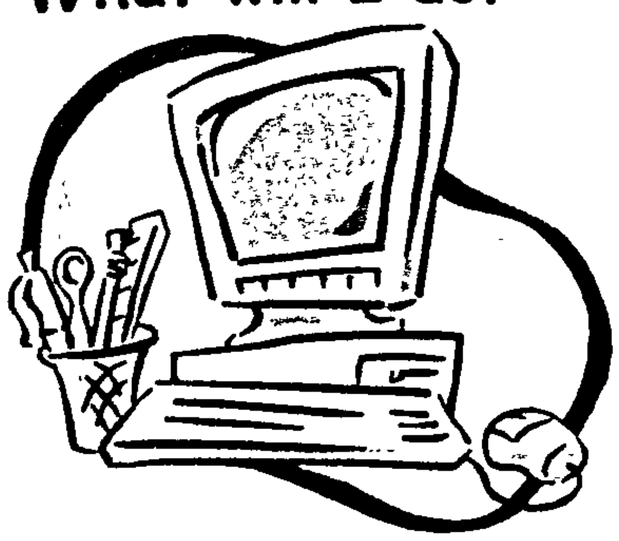
Do you want to help us with our project?!

What is the study for?



We are finding out more about how children learn, and how sleep is important for learning. Some children have problems sleeping and this might be why they find school work difficult. We want to find out more about this, but need you to help us!

What will I do?



If you want to join our project we will ask you to do some puzzles and computer games, which we hope you will find fun! They take about 35 minutes. We will want you to do them three times including before you go to bed, and in the morning when you wake up.

Do I have to take part?

No of course not. We only want you to help us if you want to, and you can change your mind if you want to. The people you will meet are very friendly! You can bring your Mum or Dad with you if you want. There will be drinks and cakes for them while they wait!

How will joining in the study help?

Your help will help us understand more about sleep and how we learn. This will help us find the best medicines for children who have illnesses which mean they can't sleep very well.

Does it matter how well I do?

No. This does not matter at all. We won't tell anyone else about this either. Your scores get written down next to your own special number so nobody knows which score is yours.

Can I ask more questions?

You can ask us any questions you like about the project. Your mummy and daddy can also ask us if they want to know more.

Thank you for taking the time to read our information . 

THE UNIVERSITY OF SHEFFIELD

Clinical Psychology Unit

Department of Psychology

Contacts: Sophie Thomas (07976 097596) Clare Huyton (0114 222 6644)) Dr. Ingram Wright (0114 222632)

INFORMATION SHEET

Study title: **Sleep dependent learning consolidation in children and adults**

Can you help us with our research study?!

What is study about?

We are interesting in understanding more about how we learn and how this is connected to sleep. This is important as some people suffer from difficulties sleeping, and this may be related to poor concentration and daytime performance. However, at the moment, we don't know how this works. Research has shown that when we learn a new skill, we get better at it after a night asleep. We think this is because the brain 'practises' the skill during sleep, and helps fix it in our memory. The purpose of our study is to learn more about this.

We are conducting research with adults and children who have difficulties sleeping due to medical conditions such as epilepsy and sleep apnea. However, to understand the link between sleep and learning we need some adults and children from the local community who don't have these problems to help us by taking part.

What will be involved?

You will take part in some learning games which are tests of memory and concentration including remembering a short story, tapping fingers in certain sequences and some computer games. These will take about 35 minutes. We would like you to do them three times. You can start in the evening, then repeat the games the following morning and then the following evening OR you can start in the morning and repeat the games the same evening and the following morning. It is important that you take part in the games either side of a night asleep and a day awake so we can compare people's improvement overnight versus during the day. We may also ask you some questions about how well you sleep.

Do I have to take part?

No of course not. We would really appreciate your help but it is up to you to decide if you want to take part. If you do decide to take part, you will be asked to sign a consent form, but you can still change your mind at any time.

What are the advantages and disadvantages to taking part?

Most people find the learning games fun. There are no risks to taking part in the learning games. As we are relying on your help we are offering a £10 incentive for taking part.

You will be given a participant number so your results will be anonymous and will not be compared to those of other participants. Nobody other than the researchers will have access to the results.

We hope the results of the study will enhance our understanding of learning problems in children and adults with disturbed sleep, and may help us understand better the best course of treatment for them.

What if I wish to complain about the way in which this study has been conducted?

If you have *any* cause to complain about *any* aspect of the way in which you have been approached or treated during the course of this study, please contact Dr. Ingram Wright, Clinical Psychology Unit, University of Sheffield, Western Bank, Sheffield, S10 2TP

(Note: If you have photosensitive epilepsy or there is any reason you feel you should not play computer games please inform us).

THE UNIVERSITY OF SHEFFIELD

Clinical Psychology Unit
Department of Psychology

Contacts: Sophie Thomas (07976 097596) Clare Huyton (0114 222 6644)) Dr. Ingram Wright (0114 2226632)

Consent/Assent Form

Study title: Sleep dependent learning consolidation in children and adults

Participant Identification Number: _____

Name of researchers: Sophie Thomas & Clare Huyton

Parent/guardian to initial box

1. I confirm that I have read and understood the information sheet for the above study and have had the opportunity to ask any questions. ☐

2. I understand that my child's participation is voluntary and that I am free to withdraw him/her at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I agree for my child to take part in the above study ☐

Name of child		
Name of parent/guardian giving consent	Date	Signature
Researcher	Date	Signature

THE UNIVERSITY OF SHEFFIELD
Clinical Psychology Unit
Department of Psychology

Contacts: Sophie Thomas (07976 097596) Clare Huyton (0114 222 6644)) Dr. Ingram Wright (0114 2226632)

Consent/Assent Form

Study title: Sleep dependent learning consolidation in learning and adults

Participant Identification Number: _____

Name of researchers: Sophie Thomas & Clare Huyton

Parent/guardian to initial box

1. I confirm that I have read and understood the information sheet for the above study and have had the opportunity to ask any questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I agree to take part in the above study ☐

Name	Date	Signature

Researcher	Date	Signature

THE UNIVERSITY OF SHEFFIELD

Clinical Psychology Unit
Department of Psychology

Contacts: Sophie Thomas (07976 097596) Dr. Ingram Wright (0114 222632)

Assent Form for children and young people

(Assent means saying you agree to do something)

Study title: **Sleep dependent learning consolidation in children and adults**

Participant Identification Number: _____

	Please tick the box
1. Have you read the information sheet about the project?	
2. Has somebody else told you about the project?	
3. Do you understand what the project is about?	
4. Have you asked any questions you want to?	
5. Have you had your questions answered?	
6. Are you happy to take part?	

If you **don't** want to take part, **don't** sign your name! If you do want to take part, please write your name here and today's date. If you don't like writing, you could draw a smiley face instead. Someone else can fill in your name for you.

Your name _____

Date _____

The person who explained this project to you needs to sign too.

Print Name _____

Signature _____

Date _____

Note: To be accompanied by parental consent form

PITTSBURGH SLEEP QUALITY INDEX (PSQI)
(Buyusse et al., 1989)

Instructions:
The following questions relate to your usual sleep habits during the past month ONLY. Your answers should indicate the most accurate reply for the majority of days and nights in the past month.
Please answer all questions.

1. During the past month, when have you usually gone to bed at night?
USUAL BED TIME_____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?
NUMBER OF MINUTES_____

3. During the past month, when have you usually gotten up in the morning?
USUAL GETTING UP TIME_____

4. During the past month, how many hours of *actual sleep* did you get at night? (This may be different than the number of hours you spend in bed.)
HOURS OF SLEEP PER NIGHT_____

For each of the remaining questions, check the one best response. Please answer ***all*** questions.

5. During the past month, how often have you had trouble sleeping because you.....

(a) cannot get to sleep within 30 minutes
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(b) Wake up in the middle of the night or early morning
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(c) Have to get up to use the bathroom.
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(d) Cannot breathe comfortably.
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(e) Cough or snore loudly.
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(f) Feel too cold.
Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(g) Feel too hot.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(h) Had bad dreams.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(i) Have pain.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

(j) Other reason(s), please describe_____

How often during the past month have you had trouble sleeping because of this?
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?
Very good _____
Fairly good _____
Fairly bad _____
Very bad _____

7. During the past month, how often have you taken medicine (Prescribed or "over the counter") to help you sleep?
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?
No problem at all _____
Only a very slight problem _____
Somewhat of a problem _____
A very big problem _____

10. Do you have a bed partner or share a room?
No bed partner or do not share a room _____
Partner/ flatmate in other room _____
Partner in same room, but not same bed _____
Partner in same bed _____

11. If you have a bed partner or share a room, ask him/her how often in the past month you have had.....
(a) Loud snoring.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____
(b) Long pauses between breaths while asleep.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____
(c) Legs twitching or jerking while you sleep.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____
(d) Episodes of disorientation or confusion during sleep.
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____
(e) Other restlessness while you sleep: please describe_____
Not during the Past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

PAEDIATRIC SLEEP QUESTIONNAIRE (PSQ)
(Gianotti et al., 1995)

1. Relationship to child of person completing questionnaire (mother, father etc.)

_____

2. Age of child (years) _____

3. Date of birth of child____/____/____

4. Sex of child male ☐ female ☐

5. Please give the names of any chronic medical problems (except epilepsy) that the child currently has

_____

_____

6. Please give the name of any learning or behavioural disabilities which the child currently has (e.g. ADHD, dyslexia, autism, special educational needs etc.)

_____

_____

My child...

	Always	Quite often	Sometimes	Just a few times	Never
7. Goes to bed willingly	☐	☐	☐	☐	☐
8. Falls asleep alone	☐	☐	☐	☐	☐
9. Falls asleep in his/her own bed	☐	☐	☐	☐	☐
10. Falls asleep in parental bed	☐	☐	☐	☐	☐
11. Wakes up 1-2 times per night	☐	☐	☐	☐	☐
12. Wakes up 3-4 times per night	☐	☐	☐	☐	☐
13. If wakes, remains awake for under 30 mins	☐	☐	☐	☐	☐
14. If wakes, remains awake for over 30 mins	☐	☐	☐	☐	☐
15. If wakes, will only fall asleep again with parental presence	☐	☐	☐	☐	☐

16. After waking in the night goes to parents bed	☐	☐	☐	☐	☐
17. Wakes up to eat	☐	☐	☐	☐	☐
18. Moves a lot while sleeping	☐	☐	☐	☐	☐
19. Sweats a lot while sleeping	☐	☐	☐	☐	☐
20. Shares the bedroom with parents (even if there is another sleeping place)	☐	☐	☐	☐	☐
21. Sleeps in the parental bed	☐	☐	☐	☐	☐
22. Twitches while sleeping or trying to sleep	☐	☐	☐	☐	☐
23. Wakes up from sleep confused and disoriented	☐	☐	☐	☐	☐
24. Talks in sleep	☐	☐	☐	☐	☐
25. Walks in sleep	☐	☐	☐	☐	☐
26. Grinds the teeth during sleep	☐	☐	☐	☐	☐
27. Has problems with bedwetting	☐	☐	☐	☐	☐
28. Wakes up from sleep screaming and confused	☐	☐	☐	☐	☐
29. Has bad dreams	☐	☐	☐	☐	☐
30. Snores while sleeping	☐	☐	☐	☐	☐
31. Is refreshed and in a good mood upon waking in the morning	☐	☐	☐	☐	☐
32. Is sleepy while sitting and/or studying	☐	☐	☐	☐	☐
33. Is sleepy while watching TV	☐	☐	☐	☐	☐
34. Is sleepy whilst sitting and talking to other people	☐	☐	☐	☐	☐

35. Falls asleep at school ☐ ☐ ☐ ☐ ☐

36. What time does your child usually go to bed on week nights?

37. What time does your child usually wake up on week days?

38. What time does your child usually go to bed on weekend nights?

39. What time does your child usually wake up at the weekend?

40. How long does it normally take your child to get to sleep?

41. Does your child take naps during the day?

yes ☐ no ☐

42. If yes, for how long?

Appendix 4

Additional Data: Further descriptive statistics

Results- Further Descriptive Statistics

Visual Discrimination Task

	Session1 Score	Session2 Score	Session3 score	Phase 1 Change	Phase 2 Change	CoL-D Change	CoL-N Change
Child Mean	68.3	72.5	74.3	4.2	1.9	2.3	3.7
Child Standard deviation	9.9	11.2	11.4	8.6	7.0	7.5	8.3
Adult Mean	86.3	90.3	91.0	4.0	0.7	2.8	1.9
Adult Standard deviation	23.2	24.3	26.5	6.8	4.7	5.9	6.2

Pursuit Tracking Task

	Session1 Score	Session2 Score	Session3 score	Phase 1 Change	Phase 2 Change	CoL-D Change	CoL-N Change
Child Mean	255.1	238.0	236.0	17.2	2.0	8.1	11.0
Child Standard deviation	66.9	73.6	74.0	31.6	41.7	40.0	35.3
Adult Mean	151.8	128.1	129.6	23.7	-1.5	0.5	20.9
Adult Standard deviation	52.5	42.9	42.6	23.1	15.7	34.2	32.1

Matrix Reasoning

	Adult Participants		Child Participants	
	t score	Scaled score	*t* score	Scaled score
Mean	54.5	11.4	51.0	10.5
Standard deviation	8.0	2.5	9.5	2.9

Sleep Questionnaire

Child Sample	Mean	Standard deviation
Age	8.4 s	2.1
Sleep time	10.9	0.7
Parent child interactions	5.8	2.7
Sleep fragmentation	8.6	2.4
Parasomnias	11.6	3.1
Drowsiness	8.6	2.5
Bedtime difficulties	8.8	3.6

Adult Sample	Mean	Standard deviation
Age	21.9	4.1
Sleep time	7.7	1.2
Sleep quality	1.1	0.8
Sleep medicine	0.2	0.6
Sleep latency	2.5	2.1
Sleep dysfunction	1.7	1.2
Sleep disturbances	6	4.5
Sleep efficiency	89.2	9.2