The relationship between sleep duration and working memory in children

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Abstract

Background

While sleep appears to have a robust relationship with working memory (WM) performance in adults, the picture in children is less clear.

Aims

The current study investigated the relationship between sleep duration and WM in children, with both correlational and experimental aspects to the design. The research also aims to clarify valid and effective ways to measure sleep duration with children in their home setting.

Sample

The participants were eight classes of children aged 9-10 years. A total of 220 children were involved, of which 107 experienced a sleep education intervention and 113 formed a control group.

Methods

Data were collected via sleep diaries, sleep knowledge questionnaires and tests of WM and attention. In each class, 10 children also wore an actigraph to record

objective sleep data. The intervention was adapted from the ACES programme (Blunden, 2007b).

Results

Most sleep variables showed no significant correlation with WM scores at baseline. There was a negative association between diary sleep duration and verbal WM, which was not significant after controlling for socioeconomic status. Actigraphy showed no relationship between sleep duration and WM, but there was a positive correlation between sleep efficiency and visual WM when socioeconomic status was partialled out. The intervention had a sustained effect on sleep knowledge but not on sleep duration or efficiency. With regard to methodology, sleep diary data were not systematically affected by introducing actigraphy as an objective sleep measure. Repeated measurements proved difficult with this age group and there were higher dropout rates from sleep diary completion than from repeatedly wearing an actigraph.

Conclusions

The relationship between sleep and WM in 9-10 year old children is weak at best, but suggests that shorter sleep with higher efficiency is related to better WM scores. Sleep duration could be effectively measured by actigraphy alone, without sleep diaries. Sleep interventions may be more effective if targeted rather than universal, and future research could use a neurodevelopmental perspective to help explain why the relationship between sleep and WM appears to change with maturity.

Literature review

Introduction

Sleep and working memory are two areas which have significant impact on outcomes for children. Sleep quality and duration can affect a range of other variables including emotional regulation (Gruber, Cassoff, Frenette, Wiebe, & Carrier, 2012), executive functioning (Sadeh, Gruber, & Raviv, 2002), academic attainment (Wolfson & Carskadon, 1998) and physical health such as obesity (Chen, Beydoun, & Wang, 2008). Working memory has been shown to predict academic attainment (Alloway & Alloway, 2010), especially in Maths (Gathercole, Pickering, Knight, & Stegmann, 2004). Working memory is even thought to be a core cognitive problem in psychiatric conditions including schizophrenia (Lee & Park, 2005) and attention deficit hyperactivity disorder (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005).

There may also be a relationship between sleep and working memory. In a review, Kopasz et al. (2010) concluded that, "most studies support the hypothesis that sleep facilitates working memory as well as memory consolidation in children and adolescents" (p.167). However, they reviewed only three studies including measures of working memory (as opposed to measures of short term memory, learning or implicit memory), with only one of those showing a relationship between working memory and sleep variables (Steenari et al., 2003).

It is possible to intervene directly to improve working memory, at least in the short term, with adaptive programmes which train capacity over hundreds of trials (Melby-Lervag & Hulme, 2013; Shipstead, Redick, & Engle, 2012). There is a large and increasing body of evidence in this field, with controversy over how effective such training can be in the long term and how generalizable the effects might be (Gathercole, Dunning, & Holmes, 2012; Redick et al., 2013; Hulme & Melby-Lervag, 2012). There are also direct interventions under development to improve sleep knowledge and sleep behaviours, although these are at a much earlier stage of validation (Blunden, Chapman, & Rigney, 2012).

This paper aims to synthesise knowledge from the two applied fields of working memory and sleep behaviours. The purpose is to evaluate current understandings of how the two might be linked and possible next steps for research.

What is sleep?

Sleeping is a curious phenomenon, in which animals enter a, "reversible behavioural state of perceptual disengagement from and unresponsiveness to the environment" (Carskadon & Dement, 2011, p. 16). Sleep is a universal behaviour found in all animals, follows a regulated pattern in each species and there are deleterious effects if this pattern is seriously disrupted (Cirelli & Tononi, 2008).

Although we tend to refer to being either, "asleep," or, "awake", humans experience a range of states of consciousness at different times (Tassi & Muzet, 2001). The sleep state can be broadly divided into two main types: rapid eye-movement (REM) and non rapid eye-movement (NREM), and in humans NREM can be further divided into four stages. Across a period of sleep, brain activity cycles through the stages of REM and NREM sleep which are distinguishable by the frequency of neuronal electrical activity (Walker & Stickgold, 2006). The pattern of sleep stages is known as sleep architecture. Healthy adults usually progress through the NREM stages and back, followed by a period of REM sleep. This cycle takes around 90 minutes and is then repeated, with increasing REM durations towards the end of the sleep period (Carskadon & Dement, 2011).

Measurements of sleep include sleep duration (total amount of time spent asleep in a 24-hour period) and sleep quality (subjectively feeling refreshed from sleep and objectively showing sleep efficiency, i.e. spending high proportions of the time in bed actually asleep). There are a number of ways to measure these aspects of sleep. Subjective measures include sleep diaries, usually recording bed times, sleep times, wake times and sleepiness over the course of one week, and questionnaires about usual sleep habits which do not capture daily variations. Objective measures include polysomnography, in which the participant wears recording electrodes overnight, and actigraphy which involves a watch-like device with an accelerometer to measure movement, usually worn on the non-dominant wrist. Polysomnography is done in a sleep laboratory, usually for one or two nights, and can be combined with video recordings to match up observable behaviours with electrical discharge patterns from the brain. Actigraphy can be carried out at home, and is usually done over the course of a week, followed by data analysis using software which infers periods of sleep or wakefulness from the intensity and duration of movements recorded.

Development of sleep

Sleep duration and architecture changes over the course of maturation. Total sleep duration within a 24-hour period decreases, from around 15 hours for babies to nine hours in middle childhood and less than eight hours by the age of 16 years (Galland, Taylor, Elder, & Herbison, 2012; Gradisar, Gardner, & Dohnt, 2011; Iglowstein, Jenni, Molinari, & Largo, 2003).

According to Crabtree and Williams (2009), newborn babies sleep little and often, starting with active sleep (a precursor to REM sleep in which the baby moves often because the neural mechanisms that govern muscle paralysis during sleep are not yet developed) and moving into quiet sleep. By three months of age, most babies are starting to sleep more at night than in the day, and show definable stages of NREM during quiet sleep. At six months, sleep episodes usually start with NREM sleep and move into REM sleep later in the cycle (similar to the normal adult pattern). The ratio of REM to NREM sleep changes, from more REM sleep in babies to more NREM sleep by the end of the first year of life.

After the first year, napping in the daytime tends to decrease (although this pattern is highly dependent on the context) so that almost all sleep occurs at night-time by the age of four years. Night-time wakings are common in the pre-school years (Schwichtenberg & Goodlin-Jones, 2010). In the primary school years, sleep habits become less variable with most children getting 8-10 hours per night (Galland et al., 2012). Girls tend to sleep longer than boys, and both genders report feeling more sleepy in the daytime as they progress through primary school (Sadeh, Ravi, & Gruber, 2000).

Adolescence marks a period of rapid change in many aspects of sleep. Some of these changes are maturational and relate to the hormonal changes of puberty, such as the circadian shift towards later bed times and later wake times, while others are age-related, such as the overall reduction in total sleep time accounted for by reductions in NREM sleep time (Colrain & Baker, 2011). Over the course of the school years, the discrepancy between school nights and weekends increases (Gradisar et al., 2011), suggesting that young people may be getting insufficient sleep when a wake-time is externally set and then recovering when the schedule allows.

The focus of this research was children towards the end of primary school (age 9-10 years), at which point most children have established a sleeping pattern without daytime naps (Thorleifsdottir, Bjarnsson, Benediktsdottir, Gislason, & Kristbjarnarson, 2002) and are starting to take more responsibility for their own behaviours (e.g. Such & Walker, 2004), while not yet undergoing the rapid changes of puberty (e.g. Laberge et al., 2001).

Cultural influences on sleep

Sleep patterns, in adults and during development, are influenced not only by biology but also by culture (Jenni & O'Connor, 2005). Community norms and expectations may have an important role to play in when, where and for how long people sleep. For example, in China children tend to have a shorter night-time sleep duration than those living in the USA (Liu, Liu, & Wang, 2003; Liu, Liu, Owens, & Kaplan, 2005). The authors suggest that some reasons for this difference include earlier school start times in China, greater homework demands, napping during the daytime and increased prevalence of bed-sharing. The frequency of sleep problems as reported by parents is also higher in China than the USA in these studies, which may be partly due to greater parental awareness of what happens during the night if the parent is sharing the room or even the bed with their child.

Recommendations for sleep practices are therefore likely to reflect what we know about biological needs but also culturally normative behaviours. Sleep hygiene is often used to describe a person’s bedtime environment and routine, with good sleep hygiene including behaviours which promote sleep and excluding behaviours which might make it harder to get to sleep or stay asleep (e.g. Mastin, Bryson, & Corwyn, 2006). The fit between an individual’s sleep need and what is considered appropriate sleep hygiene in their context may be a key factor in whether a sleep problem is perceived. For example, in Italy children may often be invited to stay up late with the family. Falling asleep during a family gathering is considered perfectly acceptable, rather than being expected to go to sleep in their bedroom and to go to bed earlier than older members of the family (Ottaviano, Giannotti, Cortesi, Bruni, & Ottaviano, 1996). Interestingly, Italian adolescents report themselves to have more regular bedtime routines than American teenagers, so the difference in sleep hygiene practices earlier in childhood appears to develop in opposite directions in these two countries (LeBourgeois, Giannotti, Cortesi, Wolfson, & Harsh, 2005). Again, this difference may reflect cultural factors: perhaps Italian adolescents are expected to develop their own sleep habits and to be responsible for the consequences of those habits, while American children are expected to follow adult-set rules which they rebel against during their teenage years.

As well as broad cultural norms such as these national approaches, individual families may have their own cultural practices around sleep which affect a child's sleep behaviours. One obvious difference between families might be whether the child usually sleeps in their own room, or shares the bedroom with another family member. One might hypothesise that room sharing would increase the probability of sleep problems, due to the other person creating stimuli which disturb sleep, however the evidence suggests that sharing a room with a sibling makes no significant difference to children's sleep behaviours (Kahn et al., 1989; Stein, Mendelsohn, Obermeyer, Amromin, & Benca, 2001; Worthman & Brown, 2007).

Another family-level difference might be whether the child stays in the same home throughout the week, or lives across more than one home (for example if the parents are separated and have shared parenting arrangements). Likewise, family stress would be likely to impact upon sleep behaviours (for example, witnessing parents arguing or domestic abuse). Family members on different diurnal schedules may also impact the sleep patterns of a child (for example, a parent who works shifts or an older sibling who goes out until late at night). Surprisingly little research has been published investigating the relationship of such living environments with children's sleep behaviours; in fact no evidence about the impact on sleep of living in more than one home could be found. For shift-working parents, much has been written about the adults feeling sleep deprived (e.g. Geiger-Brown, Trinkoff, & Rogers, 2011) but nothing about the impact of their comings and goings on children's sleep. In terms of family stress, Meltzer and Mindell (2007) found significant correlations between mothers' reports of their own distress and of their children's sleep problems, although this finding could be an artefact of participants' response bias.

The direction of cause and effect in sleep behaviours and sleeping context is not always clear. For example, bed sharing and room sharing with parents was correlated with sleep problems in Chinese children of school age (Li et al., 2008), but this does not necessarily mean that sharing the sleeping environment caused the sleep problems. It may be that having another person in the room generated stimuli which disturbed the child's sleep pattern, thus causing problems such as night-time wakings and parasomnias (nightmares, sleep walking and other disturbances during sleep). Alternatively, the child may have been experiencing sleep problems so the adult decided to sleep with them in the hope of alleviating the difficulties. A third possibility is that co-sleeping enabled the adult to be more aware of the child's sleep problems, although this explanation would not account for the increased prevalence of problems outside of the bedroom such as daytime sleepiness and bedtime resistance.

Finally, an increasingly prevalent cultural factor influencing sleep behaviours must be the use of media. A full discussion of how television, computer, games console, tablet and mobile phone usage might relate to sleep is beyond the remit of this paper. However, a recent systematic review of this topic by Hale and Guan (2015) suggests that there is a positive correlation between screen time and shorter sleep duration in children of school age. The mechanisms by which media use might affect sleep include elevated light levels, elevated arousal levels, motivation to sleep or to stay awake, feelings of worry and feelings of anticipation. While it seems obvious that increased media use may delay or disrupt sleep, this assumption is being challenged by studies such as that of Tavernier and Willoughby (2014), indicating that in adults at least, increased media use may be a way of coping with sleep problems rather than causing them.

Functions of sleep

Given the risks involved in sleep, during which the individual is not able to respond to threats, presumably it must fulfil important functions. It has been remarkably difficult, however, to specify exactly why we sleep and whether the functions of sleep are the same in all animals.

A common approach to researching sleep functions has been to monitor the results of sleep deprivation. Paradigms include acute sleep deprivation (asking participants to stay awake for a set period of time), longer-term sleep restriction (asking participants to reduce their usual sleep duration for several nights) and recruiting participants who are chronically sleep deprived (e.g. people with insomnia). A wide range of functions have been shown to be impaired by sleep deprivation, including:

- Metabolic and endocrine regulation, which can lead to weight gain (Gozal & Kheirandish-Gozal, 2012)

- Emotional regulation, towards both positive and negative stimuli (Simola, Liukkonen, Pitkaranta, Pirinen, & Aronen, 2014)
- Memory consolidation (Henderson, Weighall, Brown, & Gareth Gaskell, 2012)
- Maintaining attention or vigilance (Lim & Dinges, 2008)
- Other executive functions – although it is unclear how far decrements in these tasks are related to impaired attention (Killgore, 2010)

Different aspects of sleep may be involved with different functions. For example, NREM sleep and REM sleep may have complementary effects on long-term memory formation, being involved in reorganisation and consolidation respectively (Diekelmann & Born, 2010). In terms of emotional regulation, REM sleep appears to be more important than NREM sleep (Walker & van der Helm, 2009).

Working memory

One function frequently found to be affected by sleep deprivation in adults is working memory (Fortier-Brochu, Beaulieu-Bonneau, Ivers, & Morin, 2012; Lim & Dinges, 2010). Working memory is described by Alan Baddeley (2012) as, "a hypothetical limited capacity system that provides the temporary storage and manipulation of information that is necessary for performing a wide range of cognitive activities" (p. 7). Baddeley goes on to present the development of the model of working memory which he set out and built upon with Graham Hitch, which includes the original components of central executive, auditory and visuo-spatial elements along with an episodic buffer for information integrated from different senses.

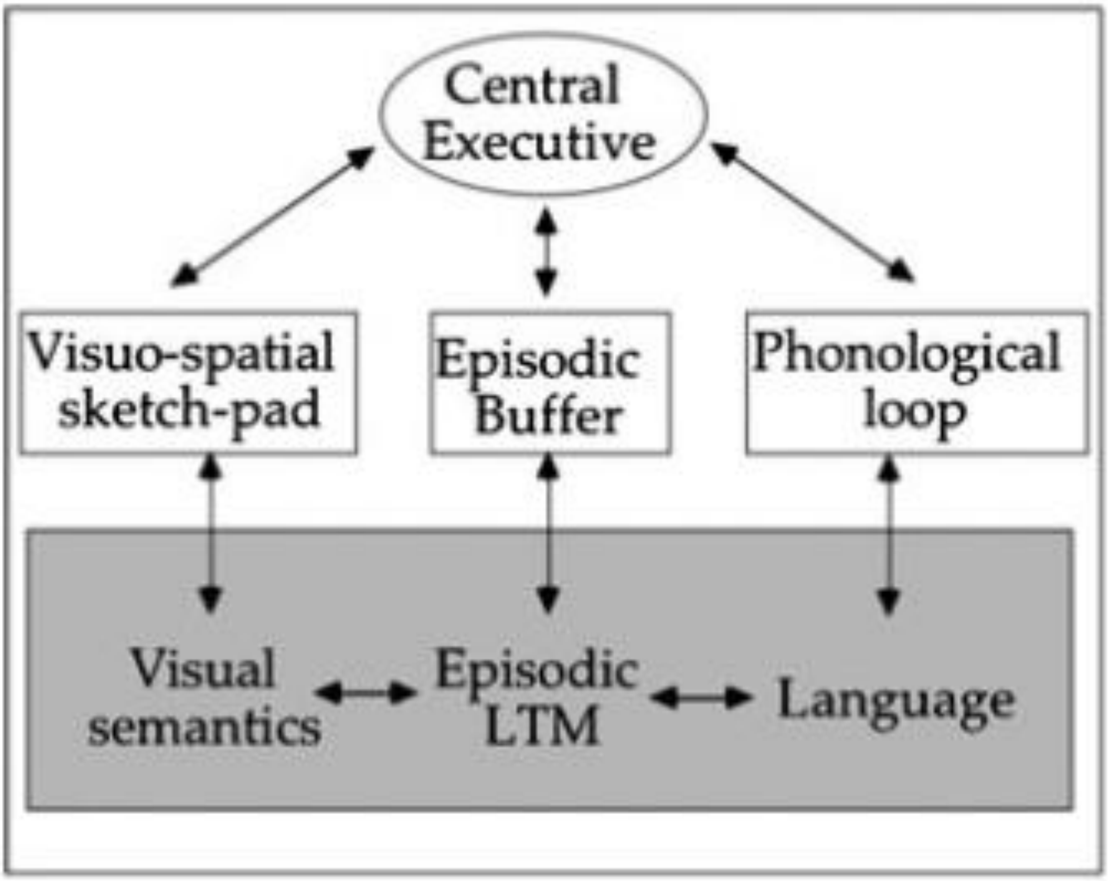

Figure 1: Model of working memory components (Baddeley, 2000, p.421)

Consistent with Baddeley and Hitch's model, Alloway, Gathercole and Pickering (2006) showed that short term memory (STM) is separate from working memory (WM). Their analysis suggests that the phonological loop and visuo-spatial sketch pad can act as simple storage mechanisms (hence separable verbal and spatial STM), and when the task requires manipulation of the stored information, the central executive becomes more involved (hence verbal and spatial WM are more highly correlated than verbal and spatial STM because the same central executive resource is used for WM but not STM tasks).

Long-term memory (LTM) is also distinguishable from WM, although WM may draw upon LTM especially in chunking or categorising information based on existing knowledge (Baddeley, 2012). The distinction between WM and LTM goes back to

William James' 19th century description of primary and secondary memory, as Jeneson & Squire (2012) remind us. Qualitatively, Alloway and Gathercole (2006) describe the difference between WM and LTM being the, "catastrophic loss," (p. 134) of information from WM when attention is taken away from it, or when capacity is exceeded. Information in LTM, on the other hand, may be retrieved again in the future. Some authors have suggested that all memory is LTM, with attentional mechanisms bringing memories into short-term activation (Cowan & Chen, 2009). Most researchers do posit that LTM is separate from WM, although there is conflicting evidence about the neural substrates for each system (e.g. Jeneson & Squire, 2012; Nee & Jonides, 2011).

There is ongoing controversy about the relationship between working memory and attentional control. Baddeley (2000; 2012) conceptualises the central executive as an attentional system, which interacts with the three "storage" elements to form working memory (see Figure 1). Others see working memory as nothing more than attentional control (Chun, 2011), although this view is not consistent with evidence that WM measures can predict variance in IQ over and above attention measures (Unsworth & Spillers, 2010). Overall it would appear WM is not a unitary construct, and it may be an artefact of the combination of attention, STM and LTM or may be a function in itself.

Whatever the nature of working memory, measures designed to tap this construct have been shown to predict outcome variables including general intelligence (Suss, Oberauer, Wittmann, Wilhelm, & Schulze, 2002; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Kane, & Engle, 2003; Ackerman, Beier, & Boyle, 2005) and academic attainments (Bull & Scerif, 2001; Bull, Espy, & Wiebe, 2008; Cain, Oakhill, & Bryant, 2004; Gathercole et al., 2004).

Development of working memory and its neural substrates

Like many other cognitive skills, performance on tasks designed to measure working memory improves as a child matures, continuing to improve into young adulthood (McAuley & White, 2011). In the normal course of development, simpler tasks can be performed at adult levels by an earlier age (e.g. delayed face recognition is at ceiling by nine years old), while more complex tasks such as organising strategies to aid WM continue to show improvement across childhood (Luciana, Conklin, Hooper, & Yarger, 2005).

In terms of the neural basis of working memory, a meta-analysis of imaging studies involving adults identifies a fronto-parietal network which seems to be consistently involved in any task making WM demands (Rottschy et al., 2012), and longitudinal data link the development of both the frontal and parietal lobes (see Figure 2) to improvements in working memory performance (Darki & Klingberg, 2015; Tamnes et al., 2013).

Figure 2: Key neuroanatomical areas (retrieved from brightfocus.org on 12 August 2015)

There is also some evidence that the neural substrates recruited for working memory tasks shift as children mature. Finn, Sheridan, Kam, Hinshaw and D'Esposito (2010) found that young women aged 15 used the hippocampus (see Figure 2) as well as the fronto-parietal network for WM tasks, but by the age of 18 this hippocampal activation was no longer significant. In 9-10 year old children, Chaddock et al. (2010) found a correlation between hippocampal volume and a task designed to measure relational memory, which was very similar to other reported measures of visual working memory. Thomason et al. (2009) also found that children aged 7-12 used parahippocampal areas for WM tasks more than adults, and for spatial WM tasks the occipital cortex was also more active in children than in adults.

This change in how the brain handles working memory tasks corresponds with maturation processes, with prefrontal cortex being the last area to undergo synaptic pruning and myelination of white matter (Lenroot & Giedd, 2010) and therefore not ready to play a greater part in WM processing until later in development.

Ways to improve working memory

Because working memory seems to be an important contributor to achievement in a range of areas, much effort has been put into finding ways to improve WM capacity. Computerised programmes such as Cogmed (e.g. Klingberg, Forssberg, & Westerberg, 2002), Memory Booster (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010) and Jungle Memory (e.g. Alloway, 2012) have been commercially available for some years now. Morrison & Chein's (2011) review also included strategy training approaches, although the results have been less encouraging in this area. In some cases, commercial packages have been launched with no published evidence of their effectiveness (e.g. Memory Magic, reviewed by Tayler, 2015). Looking at working memory as part of a broader group of executive functions, Diamond & Lee's (2011) wide ranging review included potential interventions such as martial arts, high-intensity exercise, yoga and mindfulness. Food intake can also affect working memory performance in children (Wesnes, Pincock, Richardson, Helm, & Hails, 2003). However, to date no research is available which looks at sleep as a target for intervention which may improve working memory.

Neural mechanisms by which sleep may affect working memory

In adults, imaging studies have confirmed that sleep deprivation affects working memory performance by changing activation in prefrontal and parietal areas (see Figure 3), with the nature of the changes being dependent on task difficulty (Chee &

Choo, 2004; Choo, Lee, Venkatraman, Sheu, & Chee, 2005; Lythe, Williams, Anderson, Libri, & Mehta, 2012; Wu et al., 2006). Recent data suggest that sleep deprivation may specifically decrease connectivity in the prefrontal cortex (Verweij et al., 2014), although the molecular mechanisms by which sleep affects frontoparietal functioning remain unclear.

Figure 3: Brain areas involved in children's working memory (retrieved from gettyimages.co.uk on 12 August 2015)

Experimental studies in rodents have focused on the hippocampus (see Figure 3), which is thought to be particularly sensitive to sleep deprivation in both rodents (Ruskin, Liu, Dunn, Bazan, & LaHoste, 2004) and humans (Van Der Werf et al., 2009). Such research provides initial indications that sleep plays a role in protein synthesis, and sleep deprivation can lead to changes in the expression of genes that govern this process (Hagewoud et al., 2010; Vecsey et al., 2012). In addition, rodent studies have shown that sleep deprivation can inhibit the genesis of new neurons in the hippocampus (Hairston et al., 2005; Ruben et al., 2003), and that this process can be reversed by growth hormone (Kim, Grover, Bertolotti, & Green, 2010). In humans, it would seem that the growth hormone usually available to normally developing children is not sufficient to prevent sleep deprivation from inhibiting neuronal growth, as Taki et al. (2012) report that sleep duration is correlated with hippocampal volume in children.

Putting the evidence regarding the hippocampus together, it is theoretically plausible that sleep deprivation could cause slower neurogenesis in this brain region, and because children use the hippocampus more than adults for working memory tasks, this could be a mechanism by which reduced sleep impairs WM performance in children. Alternatively, or perhaps in addition, sleep deprivation may impede the development of the fronto-parietal network which subserves mature working memory processes. Consistent with this second hypothesis, adolescents reporting chronically poor sleep showed less activation in the frontal cortex during a cognitive control task (Telzer, Fuligni, Lieberman, & Galvín, 2013).

Sleep and working memory in children: a systematic literature review

The key question for this review was, "what are the effects of sleep duration on working memory in children?" The age range 9-10 years was of particular interest (see section on development of sleep) but all ages were considered and then studies with children under 16 years old were selected. A literature search was conducted on 1st November 2014 using PsychInfo and PubMed. The terms "sleep" and "working memory" were combined, resulting in 282 hits from PsychInfo and 360 from Pubmed. After excluding 181 duplicates, the total number of unique hits was 461.

These results were then filtered as follows:

- Peer reviewed journal articles only
- English language only
- Excluding populations with conditions that may affect neuropsychological functioning (e.g. studies of people with epilepsy, sleep apnoea, drug users and elderly people)
- Excluding empirical studies where sleep duration or working memory was not a variable

This process resulted in 107 different articles. Two of these articles were meta-analyses and formed the starting point for this review, since systematic reviews of this nature are considered to be at the top of the hierarchy of evidence (Scott, Shaw, & Joughin, 2001). Both meta-analyses are of studies involving adults aged at least 18 years, with one focusing on the cognitive effects of short-term sleep deprivation (Lim & Dinges, 2010) and the other on long-term insomnia (Fortier-Brochu et al., 2012). Both reviews found that working memory was one of the two most affected cognitive functions (moderate combined effect sizes of $r = -0.555$ and $r = -0.42$

respectively). A further meta-analysis was identified outside the original search, which concerned children aged 5-12 years (Astill, Van der Heijden, Van IJzendoorn, & Van Someren, 2012). Working memory was not analysed as an individual variable, but WM measures were categorised as executive functioning along with response inhibition, planning, set-shifting and creative thinking. All the effect sizes in this study were much smaller than in the adult meta-analyses, however due to the large numbers of participants the association between sleep duration and executive functioning (including WM) was statistically significant (14 studies with a total of 2390 participants; $r = 0.07$, $p > 0.05$). Taken together, these meta-analytic findings suggested that there may be a link between sleep and working memory which warranted further investigation.

Of the 107 articles returned, 17 included children in their remit. Three of these were review papers and the remainder reported original research findings, of which 10 studies included measures of both sleep parameters (including duration, not just EEG or ratings of sleep problems) and working memory (not just short term memory such as forward digit span tasks). A further five studies researching the links between working memory and sleep in children were found through wider searches (replacing “working memory” with “cognition”, “IQ” and “functioning”, also searching for these terms in Google Scholar and following up references listed in the selected articles). Figure 4 represents the literature search strategy; Table 1 summarises the 15 selected studies resulting from this search.

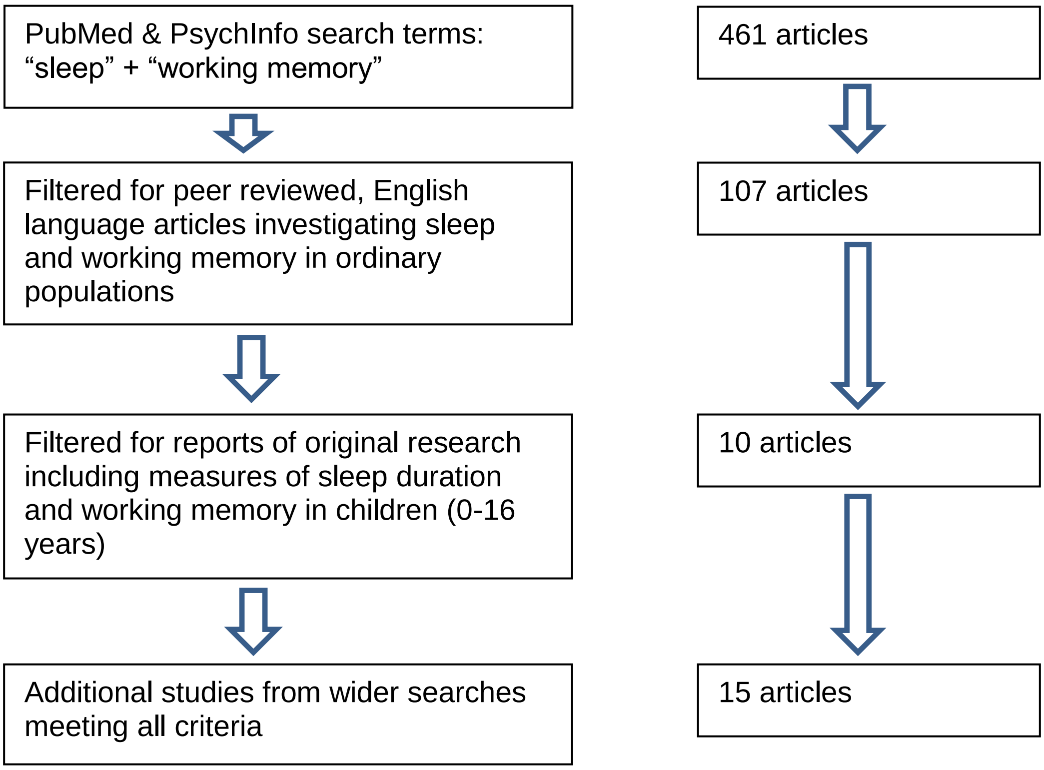

Figure 4: Literature search strategy flow diagram

Table 1: Research relating measures of sleep duration and working memory in children

Authors & year	Participants	Design	Sleep measures	WM measures	Main results
Beebe, Difrancesco, Tlustos, McNally, & Holland (2009)	N = 6 Ages 13-16 years Community sample USA	Experimental sleep restriction	Actigraphy Sleep diary (self)	Computerised n-back task (0 and 2-back used)	No statistically significant association between WM performance after usual sleep and after sleep restriction. fMRI data showed that brain activity was magnified after the sleep restriction, suggesting that more mental effort was required to achieve similar performance.
Buckhalt, El-Sheikh, & Keller (2007) *	N = 166 Ages 8-9 years Community sample USA	Correlational study	Actigraphy Sleep diary (parent) Parent report of sleep problems	Woodcock-Johnson III (Numbers Reversed and Auditory WM tasks)	No association between any sleep parameter (sleep duration, efficiency, reported sleep problems) and WM. However, in low SES children, sleep efficiency predicted WM.
Calhoun et al. (2012)	N = 508 Ages 6-12 years Community sample USA	Correlational study	PSG Parent report of excessive daytime sleepiness	WISC-III Digit span	PSG and parent report were unrelated. Parent report of sleepiness was significantly correlated with WM but measures of sleep duration and efficiency were not.
Cho et al. (2015) *	N = 1740 Ages 6-7 years Community sample Australia	Correlational study	Parent report of sleep duration, regularity and problems	AWMA Backwards digits and Mister X	Significant associations between sleep variables and verbal WM but not visual WM.
Geiger, Achermann, & Jenni (2010) *	N = 60 Ages 7-11 years Community sample Switzerland	Correlational study	CCQT (parent report) Actigraphy	WISC-IV Working memory index	Questionnaire and actigraphy sleep duration was negatively correlated with WM; significant for weekend data and approaching significance for weekdays.

Authors & year	**Participants**	**Design**	**Sleep measures**	**WM measures**	**Main results**
Gradisar, Terrill, Johnston, & Douglas (2008)	N = 143 Ages 13-18 Community sample Australia	Correlational study	Online sleep questionnaire (self)	Letter-number sequencing adapted from WISC-IV; operation span task	Inverted-U relationship: WM best for participants with medium sleep duration, compared to those with shorter and longer sleep durations.
Gruber et al. (2010) *	N = 39 Ages 7-11 years Community sample Canada	Correlational study	Actigraphy MSLT Sleep diary (parent) Subjective report of sleepiness	WISC-IV Digit span & Letter-Number Sequencing	No significant associations between sleep duration and WM. Associations between sleep efficiency and WM not reported.
Jiang et al. (2011)	N = 40 Ages 13-20 years 20 aged 13-16 and 20 aged 18-20 Community sample China	Experimental sleep restriction	Actigraphy Sleep diary (self)	Computerised task of letter manipulation and matching, also arithmetic task	Association found between sleep restriction and poorer arithmetic scores in the 13-16 age group.
Konen, Dirk, & Schmiedek (2015)	N = 110 Ages 8-11 years Community sample Germany	Repeated measures (3 times per day for 31 days), no experimental manipulations	Smartphone sleep diary (self)	Smartphone verbal and visual updating tasks	Inverted-U relationship: WM morning performance best after average sleep duration but worse after extended or restricted nights' sleep.
Sadeh, Gruber, & Raviv (2003) *	N = 77 Ages 9-12 years Community sample Israel	Experimental sleep restriction or extension	Actigraphy	Computerised visual forward and backward digit span	Sleep extension significantly enhanced forward (but not backward) span.

Authors & year	Participants	Design	Sleep measures	WM measures	Main results
Steenari et al. (2003)	N = 60 Ages 6-13 years Community sample Finland	Correlational study	Actigraphy Sleep diary (parent)	Computerised verbal and visual n-back tasks (0, 1 and 2-back used)	Sleep duration and efficiency were significantly correlated with error rate in the more demanding WM tasks
Van der Heijden, de Sonneville, & Swaab (2013)	N = 303 Ages 7-12 years Community sample Netherlands	Correlational study	Sleep diary (parent)	Amsterdam Neuropsychological Tasks: 4 Letters task	Sleep duration was negatively correlated with WM.
Vriend et al. (2012)	N = 32 Ages 8-12 years Community sample Canada	Correlational study	Actigraphy Sleep diary (parent) Parent report of sleep problems	Digit span modified from WISC-IV Spatial span modified from WRAML	No significant association between sleep duration or efficiency and WM (composite of auditory and spatial measures).
Vriend et al. (2013)	N = 32 Ages 8-12 Community sample Canada	Experimental sleep restriction and extension	Actigraphy Sleep diary (parent)	Digit span modified from WISC-IV & WRAML Finger Windows	Significant difference between WM performance after restricted compared to extended sleep. Differences with normal sleep not reported.
Wolfe et al. (2014)	N = 21 Ages 15-20 Videogame players Australia	Correlational study	Actigraphy	Difference in operation span task performance between evening and morning	No relationship between sleep duration and WM performance next morning.

Abbreviations: AWMA = Automated Working Memory Assessment; BRIEF = Behaviour Rating Inventory of Executive Function; CCQT = Children's ChronoType Questionnaire; fMRI = functional magnetic resonance imaging; MSLT = Multiple Sleep Latency Test; PSG = polysomnography; SES = socio-economic status; WISC-III/IV = Wechsler Intelligence Scale for Children, 3rd/4th edition; WM = working memory; WRAML = Wide Range Assessment of Memory and Learning

Asterisks indicate studies which were identified in addition to the original PubMed/PsychInfo search.

Overview of associations

The 15 selected studies were examined for their findings regarding relationships between sleep and working memory variables. Only reported analyses are represented in Table 2; it is likely that many more null results were found but not reported (Ioannidis, Munafo, Fusar-Poli, Nosek, & David, 2014). In addition, all of the studies using actigraphy to measure sleep duration also collected sleep diaries, but only used the actigraphy data in their analyses as it was seen to be a more objective measure.

Overall, eight of the 15 studies found no direct relationship between any measures of sleep duration and working memory, while the other seven studies found a range of relationships: positive and negative linear correlations, and inverted-U relationships where working memory performance was reduced at both long and short sleep durations.

Table 2: Results of selected studies

	Objectively measured sleep duration	Reported sleep duration	Experimental manipulation of sleep duration	Other sleep variable
Verbal WM	**4 no association** (Buckhalt, El-Sheikh, & Keller, 2007; Calhoun et al., 2012; Gruber et al., 2010; Wolfe et al., 2014) **1 negative correlation** (Geiger, Achermann, & Jenni, 2010)	**1 positive correlation** (Cho et al., 2015) **2 negative correlations** (Geiger et al., 2010; Van der Heijden, de Sonneville, & Swaab, 2013) **1 inverted U relationship** (Gradisar, Terrill, Johnston, & Douglas, 2008)	**3 no association** (Beebe, Difrancesco, Tlustos, McNally, & Holland, 2009; Jiang et al., 2011; Sadeh, Gruber, & Raviv, 2003)	**2 positive correlations with sleep efficiency** (Buckhalt et al., 2007 - only at low SES; Steenari et al., 2003) **1 positive correlation with daytime sleepiness** (Calhoun et al., 2012)
Visual WM	**1 positive correlation** (Steenari et al., 2003)	**1 no association** (Cho et al., 2015)		**1 positive correlation with sleep efficiency** (Steenari et al., 2003)
Combined verbal & visual WM	**1 no association** (Vriend et al., 2012)	**1 no association** (Konen, Dirk, & Schmiedek, 2015)	**1 positive association** (Vriend et al., 2013)	**1 inverted U relationship with relative sleep duration** (Konen et al., 2015)
Other	**1 positive correlation with audiospatial WM** (Steenari et al., 2003)		**1 positive association with Digits Forward task** (Sadeh et al., 2003) **1 association with brain activity** (Beebe et al., 2009)	

No relationship between sleep and working memory?

Over half of the selected studies (n = 8) reported no statistically significant relationship between sleep and working memory (Beebe et al., 2009; Buckhalt et al., 2007; Calhoun et al., 2012; Gruber et al., 2010; Jiang et al., 2011; Sadeh et al., 2003; Vriend et al., 2012; Wolfe et al., 2014). While these findings would appear to cast serious doubt on the hypothesis that sleep affects working memory in children, there are some methodological issues which need to be considered.

Sample size has a direct effect on the probability of finding a statistically significant result among the data (Field, 2013, p. 73). It would therefore be unlikely that Beebe et al. (2009) would be able to detect any statistical relationship between sleep and working memory, as their study included only six participants. The small sample size was used because the main aim of the study was to examine brain activity during working memory tasks, so the main outcome measures were functional magnetic resonance imaging results. While no differences in WM performance were found, consistent differences were noted in brain activation: the regions used to complete WM tasks showed even greater activation after sleep deprivation, as if the brain was working harder to achieve the same results. Likewise, Vriend et al. (2012) reported a partial correlation (controlling for age) between sleep duration and working memory scores of r = -0.28, which could be considered a medium effect size (Cohen, 1992, p. 157) but which does not reach statistical significance because there were only 32 participants.

In addition, reducing the variability within the sample will reduce the probability of finding a significant correlation between measures (Goodwin & Leech, 2006). Five of the selected studies excluded children with sleep, learning, behaviour and mental health problems (Buckhalt et al., 2007; Gruber et al., 2010; Jiang et al., 2011; Sadeh et al., 2003; Vriend et al., 2012) with only Vriend et al. (2012) acknowledging the possibility that reduced variance may have affected their results.

There is a difference between long-term sleep habits and daily variation in the duration of sleep each night. Wolfe et al. (2014) looked at a single night's sleep after being allowed to stay up late playing computer games, and their outcome measure was the difference in working memory performance between the evening and the morning tests. They found that sleep duration did not significantly mediate this measure of working memory. They did, however, find that sleep duration mediated the difference in sustained attention measures from evening to morning. In these older participants (aged 15-20 years), it seems that short term variation in sleep duration may influence attention, but no effect was found on working memory. This study also suffers from a small sample size with low variance among participants, so there may be smaller effects on WM that did not reach statistical significance.

An additional problem with all of the studies finding no association between sleep and working memory is that only linear relationships were tested. Two of the studies which did find an association noted a skewed quadratic relationship: an inverted-U shaped relationship in which both short and long sleep durations were linked to poorer WM performance (Gradisar et al., 2008; Konen et al., 2015). It is possible that some of these eight studies may have found an association between working memory and sleep if non-linear relationships had been tested.

Finally, there may be important mediating factors which could mask any overall relationship between sleep and working memory. For example, Buckhalt et al. (2007) noted that socioeconomic status acted as a mediator: sleep efficiency was correlated with WM performance but only in children from families of low socioeconomic status. They hypothesised that high socioeconomic status brings resilience against the effects of poor sleep. Weeknight or weekend measures may also make a difference, particularly in older children when their weekend sleep duration tends to be greater compared to weeknights (Gradisar et al., 2011). Related to this finding, sleep duration is also greater during school holidays compared to term times (Szymczak, Jasinska, Pawlak, & Zwierzykowska, 1993), raising the possibility that the relationship between sleep and WM may vary depending on school schedules. Interestingly, for the 10-year-olds in the Szymczak et al. (1993) study, no significant seasonal variations in sleep duration were found, suggesting that time of year should not affect studies of sleep in this age group.

A positive linear relationship between sleep and working memory?

Three studies showed a positive correlation: longer sleep durations were associated with better working memory performance (Cho et al., 2015; Steenari et al., 2003; Vriend et al., 2013). The samples in the first two of these studies showed the opposite characteristics than those of the studies finding no relationship between sleep and WM: these were relatively large sample sizes with variance maintained by excluding very few children. Vriend et al. (2013) reported on the same sample as their study from the previous year, but this time focused on the effects of manipulating sleep duration rather than correlations between baseline data.

In fact, the sample size in Cho et al. (2015) was so large that they risked finding statistically significant results for very small effects. To counteract this problem, Cho et al. (2015) cited effect sizes, which adjust for these sample size biases (Field, 2013, p. 79). The authors confirmed that the effect sizes reported were Cohen's *d*

(G. Roberts, personal communication, 28th April 2015). In this study, a positive association between reported sleep duration on school nights and verbal working memory was found (although with a wide confidence interval: *d* = 0.3; 95% CI 0.0 to 0.5, p = 0.02), but no such relationship with visual working memory (*d* = 0.0, 95% CI -0.3 to 0.3, p = 1). One reason for this difference may be ceiling effects: the mean performance on this standardised visual WM task was at the 75th centile, while the mean performance of verbal WM was at the 63rd centile. This study is suggestive of a relationship between sleep duration and working memory, but confidence in the findings could be increased if the parental reports of sleep duration were corroborated by objective measurement such as actigraphy.

Steenari et al. (2003) found that sleep duration, efficiency and latency were all significantly correlated with visual and auditory working memory performance at the higher levels of task difficulty. The tasks were rather unusual, using an auditory-spatial n-back task rather than any measure of verbal WM. On closer inspection, it is notable that the table of results presented gives correlation coefficients controlling for age only. The authors found that visual and auditory WM performance at all levels of difficulty was correlated with socioeconomic status. When they reanalysed their data controlling for socioeconomic status, the effects of sleep mostly disappeared and sleep duration was no longer associated with WM performance. Unfortunately these general linear models are not reported in enough detail to know exactly what analysis was done, why a repeated measures model was chosen when all measures were only taken once, and how much variance in working memory performance was explained by each factor (age, socioeconomic status, gender and sleep variables).

Vriend et al. (2013) used an experimental design, taking a baseline and then asking participants to restrict and extend their sleep by one hour for four weeknights in each condition. The reporting of how successful participants were at changing their sleep duration is inconsistent, stating that all participants achieved a minimum of 30 minutes' sleep extension but not stating the range of sleep restriction achieved. A key problem with the analysis in this study is that all comparisons are between the long sleep and short sleep conditions. It would have been much more informative to include the baseline condition as well, in order to identify any non-linear effects and to analyse whether any changes are caused by sleep extension, sleep restriction, or both. In addition, the authors give only combined data for both visual and verbal WM tasks, making it impossible to tell whether the association with sleep duration is significant for both modalities. The analysis provided is an ANOVA, in which WM performance in the short-sleep condition is found to be significantly poorer than in the long-sleep condition. No effect size is given, but from the means and standard deviations provided, Cohen's *d* can be calculated as 0.46 which would be considered a medium effect size (Cohen, 1992, p. 157).

A negative linear relationship between sleep and working memory?

Both Geiger et al. (2010) and Van der Heijden et al. (2013) found that sleep duration was negatively correlated with verbal working memory, i.e. children sleeping for longer scored worse on verbal working memory tasks. Neither study included a measure of visual working memory. Sample sizes were relatively large (60 and 333 participants respectively).

Geiger et al. (2010) report both actigraphic and parent-reported habitual sleep timings, finding that both were associated with working memory scores. Interestingly the correlations between sleep duration and WM reached significance at the 0.05 level for weekends but not for weekdays, which perhaps reflects a more natural sleep duration than weekdays which usually have more rigid bedtimes and wake times. Geiger et al. (2010) report correlations adjusting for age and socioeconomic status, with Pearson *r* values between 0.21 and 0.29 for the correlations between WM and different measures of sleep duration, which is a medium effect size (Cohen, 1992, p. 157). This effect size is particularly impressive given the restricted sample variance in terms of socioeconomic status, and its skew towards participants of higher socioeconomic status which might reduce the effects of sleep on WM performance (Buckhalt et al., 2007).

Van der Heijden et al. (2013) were primarily interested in parental report of whether their child tended to be more of an evening or a morning person, however they also gathered a parentally-completed sleep diary for one week. While the response rate was relatively high for the sleep diaries (80%), no analysis of non-responders is provided so there may be bias within the sample. Working memory was assessed using the Four Letters task from the Amsterdam Neuropsychological Tasks (De Sonneville, 1999). Unfortunately this task confounds verbal and spatial WM, as the participant has to judge whether the letter they just saw is both present and in the right location within an array of four letters. Given the small number of possible locations, the task has been classified as a verbal WM task for the purposes of this review because the main load on recall is the letter itself. In this study, correlations (adjusted for age, gender and socioeconomic status) between sleep duration and WM were statistically significant at the 0.05 level but represented a relatively small effect size (weekdays r = 0.18; weekends r = 0.16); this finding is explained by their large sample size, which increases the significance of effect sizes.

In both these studies, a negative association between sleep and cognitive function was found for a range of skills, not just working memory, suggesting that these findings are not simply chance but represent either a real effect or systematic biases within the studies.

An inverted U relationship between sleep and working memory?

Two studies (Gradisar et al., 2008; Konen et al., 2015) found an inverted U-shaped relationship, in which children with medium sleep durations achieved higher working memory scores than either long or short sleepers. Both found that the curve was skewed towards shorter sleep, i.e. short sleep is associated with lower WM scores than long sleep durations.

Gradisar et al. (2008) took a cross-sectional approach and divided their participants into three groups for analysis: those getting less than eight hours' sleep per weeknight, those getting eight to nine hours and those getting over nine hours' sleep per weeknight. This method split the participants into roughly equal groups. Analysis was carried out using ANCOVA, controlling for age, gender and vocabulary score as a proxy for IQ. Socioeconomic status was not measured in this study. For both measures of WM, there was a significant main effect of sleep duration group. Pairwise comparisons showed that the differences between the medium and short sleep groups were statistically significant ($p < 0.05$) and medium to large Cohen's *d* effect sizes were reported ($d = 0.56$ for Letter Number Sequencing and $d = 0.92$ for Operational Span). Inspection of the means and standard deviations shows that the long sleep group also had lower WM scores on both measures, but because the pairwise comparisons did not reach statistical significance, the effect sizes were not reported. They can be calculated, however ($d = 0.37$ for Letter Number Sequencing and $d = 0.17$ for Operational Span), showing small to medium size effects according to Cohen (1992). Correlation analyses looking for quadratic relationships were not conducted, but from the data reported these might have fit the data better than a linear model.

The other study finding a similar pattern was that of Konen et al. (2015), who took the innovative approach of issuing their participants with smartphones, on which participants were invited to answer questions on three occasions per day. The times at which data were collected had been pre-agreed with the school, so that teachers were aware when the children would be prompted to complete their data collection and could plan these breaks into the day. Collecting data daily for a month meant that the authors could identify each child's usual sleep habits and any nights when they departed from this pattern. While the sleep duration measures in this study are self-report and not objective data, they may be more accurate than most diary studies because the children were prompted every morning to report their bedtime and waketime, rather than having a weekly diary which might be completed retrospectively. The authors gave 2 WM tasks: one verbal and one spatial, but all of the results report combined data rather than verbal and visual WM separately.

While Konen et al. (2015) found no overall between-subjects correlation between working memory scores and reported sleep duration, they noted a relationship between morning WM scores and the previous night's sleep duration in comparison to that child's mean sleep duration. The findings showed that WM scores were optimal on mornings when the child had an average duration of sleep the previous night, and lower with longer or shorter sleep durations. No quantitative analysis of the strength of this quadratic relationship was reported, but the change in r^2 from sleep duration was 3.1% including linear and quadratic relationships (T. Konen, personal communication, 5 March 2015). This is a small effect size (Pearson's r = 0.17). It is unlikely to be a clinically significant association, since even children reporting that they slept six hours less than usual on the previous night showed a working memory performance decrement of less than half a standard deviation (WM accuracy at average sleep duration = 0.67, standard deviation = 0.28, WM accuracy at six hours below average sleep duration estimated from graph = 0.56).

Weight of evidence assessment

When considering these studies together, it is important to take into account their quality and relevance, so that some will be given greater weight than others. Gough (2007) gives a framework for assigning weight of evidence (WoE) in systematic literature reviews, which is used here. The criteria are set out in relation to this specific review question, and then each study is judged against them (Table 3).

Weight of evidence A (Generic quality) – Does the study have a clear purpose and a relevant method to achieve it? Is the study clearly described and are the analyses appropriate?

Weight of evidence B (Relevance of method) – This review is centred on the effects of sleep duration on working memory. Since this question involves a causal link, experimental studies will be given greater weight than cross-sectional studies. In addition, studies using actigraphy will be given greater weight as this captures objective data in an ecologically valid way. Studies using polysomnography will have lower weighting as they measure sleep in an artificial environment, and studies using only sleep diaries or reported habits will have lower weighting as they underestimate total sleep duration (particularly night-time wakings) (e.g. Holley, Hill, & Stevenson, 2009). Studies using measures of verbal and visual working memory and analysing these separately will be given greater weight than those using only verbal WM measures, or reporting only combined visual and verbal WM scores.

Weight of evidence C (Relevance of focus) – Studies aimed specifically at researching the relationship between sleep and working memory will be given greater weight; those focused on other questions with this as a subsidiary focus will be given lower weight. This review focuses particularly on children aged 9-10 years, so studies including this age range will be given greater weight.

Weight of evidence D (Overall) – A judgement combining the previous three WoE assessments to give an overall rating of the extent to which that study helps to describe the effects of sleep duration on working memory in 9-10 year-old children.

Table 3: Weight of evidence analysis

Authors & year	WoE A Generic quality	WoE B Relevance of methodology	WoE C Relevance of focus	WoE D Overall
Beebe, Difrancesco, Tlustos, McNally, & Holland (2009)	High	Low	Low	Low
Buckhalt, El-Sheikh, & Keller (2007)	High	Medium-high	Medium	Medium
Calhoun et al. (2012)	Medium	Low	Low	Low
Cho et al. (2015)	Medium	Low-medium	Medium-high	Medium
Geiger, Achermann, & Jenni (2010)	Medium-high	Medium	Medium	Medium
Gradisar, Terrill, Johnston, & Douglas (2008)	High	Medium	Medium	Medium
Gruber et al. (2010)	High	Medium-high	Medium-high	High
Jiang et al. (2011)	Low	Medium	Medium	Low
Konen, Dirk, & Schmiedek (2015)	High	Low	Medium	Medium
Sadeh, Gruber, & Raviv (2003)	High	Medium-high	High	High
Steenari et al. (2003)	Medium	Medium-high	High	Medium
Van der Heijden, de Sonneville, & Swaab (2013)	Medium-high	Low	Medium	Medium
Vriend et al. (2012)	Medium	Medium	Medium-high	Medium
Vriend et al. (2013)	Medium	Medium-high	Medium-high	High
Wolfe et al. (2014)	Medium	Low-medium	Low	Low

All four of the studies with low WoE D ratings found no association between sleep duration and memory. Of the three studies with high WoE D ratings, one (Vriend et al., 2013) found a positive linear relationship between sleep duration and working memory. The other two studies with high WoE D ratings found no significant association between sleep duration and WM, but did report associations between sleep and other related cognitive functions: short term memory (Sadeh et al., 2003) and perceptual reasoning (Gruber et al., 2010). The remaining eight studies received a medium WoE D rating, representing a mix of study designs and findings.

The WoE analysis does not systematically indicate a set of findings which are more likely to answer the review question; studies of medium and high weightings provide conflicting evidence about the existence and nature of any relationship between sleep and working memory. This result may reflect the state of the evidence base in this field, which draws from a wide range of methodological approaches and participant groups. The inconclusive WoE analysis also suggests that relationships between working memory and sleep duration in children may be less robust than in adults, with more complexity in terms of mediating factors and mechanisms which may change throughout child development. While this WoE analysis has not helped to draw conclusions about how sleep affects WM in children, reviewing the evidence in this way has highlighted some methodological aspects of research design which could help guide future work towards answering the question.

Conclusions

The existing research looking specifically at the relationship between sleep and working memory in children is small, although there are many related studies which look at the relationships between sleep and other variables including other aspects of cognition. The methodologies used are highly variable, including cross-sectional studies, longitudinal studies and experimental studies manipulating sleep duration. Subjective measures of sleep range from parent questionnaires to sleep diaries (self- or parent-completed), and objective measures include actigraphy and polysomnography. Measures of working memory also vary from study to study, with many omitting measures of visual WM or combining visual and verbal results into a single WM score. These variations in research design may contribute to the lack of a clear relationship between sleep and working memory being found, although if there was a robust association we might expect these different methodologies to confirm it through triangulation of data.

Developmental issues complicate the issue further. Recent research has indicated that the neural basis of working memory functions changes over the course of childhood, with hippocampal areas subserving WM until the fronto-parietal network matures. It is therefore entirely possible that the relationship between sleep and WM may vary during development, if sleep affects brain areas differentially.

In conclusion, while many authors write as if there is a well established link between sleep behaviour and working memory in children (e.g. Kopasz et al., 2010), this literature review shows that the relationship is not clear at all. Results of published studies range from finding no relationship between sleep and WM, to linear relationships in both directions, to U-shaped relationships. Within the studies involving an experimental manipulation, all showed effects of changing sleep duration on at least one variable, but with no consistency about which aspects of memory were impacted. There is therefore a clear role for future research in clarifying whether sleep is reliably related to WM in children at different stages of development, whether changes in sleep can produce changes in WM performance, and the identification of factors which may mediate any effects of sleep on WM at different ages.

Future research

This literature review leads to a number of recommendations for the design of future research to help us understand the effects of sleep on working memory in children.

First, the sample to be studied needs to represent the range in the population. Restricting variance in the sample by exclusion criteria such as learning difficulties, behavioural difficulties or even sleep duration (Vriend et al., 2012 ; Vriend et al., 2013 report two phases of the same study in which children who habitually slept less than 8 hours or more than 12 hours per night were excluded) is likely to reduce the effect size in a phenomenon which is already far from robust. In particular, limiting the sample to children from families of higher socioeconomic status (SES) may reduce the effect size if the findings of Buckhalt et al. (2007) can be generalised. Proactive voluntary participation in research tends to skew the sample towards higher SES participants (e.g. Damery et al., 2011), so one possible solution would be to use a study design which could ethically use opt-out consent in order to include the whole SES range.

Second, developmental factors need to be taken into account. Children of different ages may well show different relationships between sleep and WM performance, with one hypothesis being that the relationship might grow stronger as the child matures and relies more upon fronto-parietal networks to undertake WM tasks. Studies should therefore correct for age statistically or ensure that their sample(s) are from narrow age ranges likely to be at a similar stage of brain development.

The measures used should include actigraphy for the most ecologically valid objective way to measure sleep duration. In all the selected studies using both objective and self- or parent-reports, the methods appear to measure different things and the report measures overestimate sleep duration. Objective sleep duration has repeatedly been found to bear no relation to subjective tiredness or daytime sleepiness (Calhoun et al., 2012; Gruber et al., 2010), however individual differences may explain this null finding as children experiencing sleep restriction relative to their normal duration do report feeling more tired (Sadeh et al., 2003). Future research should consider gathering and analysing both sleep diary and actigraphy measures, in order to capture these different aspects of sleep.

Measures of working memory should include both visual and verbal WM, analysed separately. Most studies have used measures of verbal WM only, or combined the two into a single measure of WM, but when the two are analysed separately (as in Cho et al., 2015) there may be differences between verbal and visual WM in their relationship with sleep variables.

Finally, more longitudinal experimental studies would be helpful. As in the work of Vriend et al. (2012; 2013), studies including an intervention to manipulate sleep allow for a cross-sectional analysis of baseline data and also an analysis of intervention effects. Studies of this nature can provide a better understanding of causation than correlations alone.

Empirical study

Introduction

It is often stated that sleep has a well-established relationship with cognition, such that shorter sleep duration is associated with poorer cognitive function (e.g. Beebe, 2012; Durmer & Dinges, 2005; Ferrie et al., 2011; Killgore, 2010; Luber et al., 2008). This paper aims to test this supposition, specifically examining sleep and working memory (WM) in junior aged children.

A recent meta-analysis of studies involving total sleep deprivation in adults found a robust effect for attention, processing speed, short term memory, working memory and reasoning abilities (Lim & Dinges, 2010). Another meta-analysis, this time of studies comparing adults with and without insomnia, showed significant effect sizes for some cognitive skills (working memory, episodic memory, problem solving) but not others (alertness, language and procedural memory) (Fortier-Brochu et al., 2012). An earlier meta-analysis showed significant effects of sleep deprivation on cognitive functioning, with even greater effects on mood (Pilcher & Huffcutt, 1996). These adult studies suggest that there is a consistent correlation between reduced sleep duration and reduced WM functioning.

In children, Astill, Van der Heijden, Van Ijzendoorn and Van Someren (2012) conducted a meta-analysis of studies relating sleep duration and efficiency to cognitive and behavioural variables. Unfortunately, the relatively small number of studies available meant that this analysis collapsed data from a wide age range (5-12 years, and including studies with participants whose age range overlapped with this range). In addition, cognitive measures were collapsed into categories, e.g. "executive functions," within which Astill et al. (2012) included measures of skills that they describe as inhibitory control, working memory and cognitive flexibility. The study designs included both sleep deprivation and naturally occurring variations in sleep duration, unlike the adult meta-analyses. Their findings were mixed but all effect sizes were small ($r = 0.02$ to $r = 0.1$; $r = 0.07$ for executive functions). While the findings for executive functions were statistically significant, the effect size is so small as to call into question the authors' conclusion that, "Executive functioning and the prefrontal cortical circuits involved thus appear sensitive to sleep curtailment even early in development and quite robustly so" (p. 1124). Focusing exclusively on school performance, another meta-analysis also found a small effect size ($r = 0.069$) for sleep duration (Dewald, Meijer, Oort, Kerkhof, & Bogels, 2010). The relationship between sleep and cognition therefore seems to be less robust in children than in adults, and these meta-analyses do not provide specific information about sleep and working memory.

Working memory is a cognitive function of particular interest to educators. There is no commonly accepted definition of WM, but Baddeley (2012) describes it as, "a hypothetical limited capacity system that provides the temporary storage and manipulation of information that is necessary for performing a wide range of cognitive activities" (p. 7). Working memory is, therefore, distinct from short-term memory which only requires information to be reproduced without manipulation, and from long-term memory which holds information after it has been used for its original purpose. Working memory has been found to predict future academic achievement (Alloway & Alloway, 2010; Bull et al., 2008), especially in maths (Gathercole et al., 2004), and has been implicated in the development of reading difficulties (Alloway, 2009; Gathercole, Alloway, Willis, & Adams, 2006).

Theoretically a link between sleep and working memory would be plausible, given the shared neural substrates. During sleep in adults, prefrontal cortex is differentially deactivated (Braun et al., 1997; Maquet, 2000; Muzur, Pace-Schott, & Hobson, 2002) compared to other areas of the brain. More recently, research methods enabling an analysis of functional connectivity have found that not only is the prefrontal cortex less active during sleep, it is also decoupled from other areas of the brain (Horovitz et al., 2009; Yoo, Gujar, Hu, Jolesz, & Walker, 2007).

This same brain area is particularly important in WM tasks, as part of a fronto-parietal network (Rottschy et al., 2012). Animal and human studies show that lesions to the dorsolateral prefrontal cortex result in working memory problems (Barbey, Koenigs, & Grafman, 2013; Levy & Goldman-Rakic, 1999; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Petrides, 2000). Non-invasive stimulation to the prefrontal cortex can alter WM performance (Brunoni & Vanderhasselt, 2014). In addition we are starting to gain some understanding of the neurochemical basis underlying WM functions, and the genes contributing to individual differences in those systems (Blasi et al., 2015; Gelao et al., 2014), lending further credence to the importance of networks involving the prefrontal cortex in adult WM performance.

Studies using imaging methods to look at brain activity during WM tasks after sleep deprivation in adults confirm that the fronto-parietal network reduces its activity in line with reductions in WM performance (Chee et al., 2006; Mu et al., 2005). However, with more demanding tasks, participants were able to use compensatory mechanisms and showed higher activation in prefrontal cortex along with performance more similar to before the sleep deprivation. (Chee & Choo, 2004; Drummond & Brown, 2001).

While the majority of the evidence would suggest that sleep duration is linked to working memory performance in adults, through mechanisms involving the functioning of the fronto-parietal network, the evidence for this link in children is much less clear.

Studies investigating relationships between sleep behaviour and working memory performance in children have reported mixed results. Many have found no significant association between the two, either through correlational analyses (Buckhalt et al., 2007; Calhoun et al., 2012; Gruber et al., 2010; Konen et al., 2015; Vriend et al., 2012; Wolfe et al., 2014) or by experimental manipulation of sleep duration (Beebe et al., 2009; Jiang et al., 2011; Sadeh et al., 2003). Other studies have found an association between sleep duration and WM performance, but without consistency in the nature of the relationship. Some find a positive correlation (more sleep is related to better WM scores; (Cho et al., 2015; Steenari et al., 2003; Vriend et al., 2013), others a negative correlation (shorter sleep is related to better WM scores; (Geiger et al., 2010; Van der Heijden et al., 2013) and still others an inverted-U relationship (optimal sleep is related to better WM scores with worse performance at both longer and shorter sleep durations; (Gradisar et al., 2008; Konen et al., 2015).

The neural development underlying the maturation of working memory skills may go some way to explaining why the relationship between sleep and WM is less robust in children. There is some evidence that the fronto-parietal network which subserves WM performance in adults (Rottschy et al., 2012) takes a long time to reach maturity, and that improvements in WM across childhood are related to the maturation of this network (Darki & Klingberg, 2015; Tamnes et al., 2013). In the meantime, children appear to make more use of hippocampal areas to perform WM tasks (Chaddock et al., 2010; Finn, Sheridan, Kam, Hinshaw, & D'Esposito, 2010; Thomason et al., 2009). It may therefore be that sleep affects working memory performance only as far as the individual is using fronto-parietal networks to carry out the task. However, this explanation cannot be the whole story, as the studies described above do not represent a pattern of increasing correlation of WM with sleep duration as the participants get older. In addition, there is evidence from studies of rodents (Ruskin et al., 2004) and humans (Van Der Werf et al., 2009) that sleep duration affects hippocampal functioning, so even if children were using hippocampus to undertake WM tasks we might still expect sleep to affect functioning.

It is likely that methodological issues also contribute to the difference in effects seen in children compared to adults. The adult studies included in the meta-analyses largely involved sleep deprivation, either through insomnia or through experimental manipulation, including total sleep deprivation for at least one night. It would be ethically and practically difficult to use these approaches with children, so these studies tend to involve very modest sleep deprivation or extension (up to one hour per night) or naturally-occurring correlations between sleep and cognitive variables. Given that the variation in sleep is smaller with these designs, it is unsurprising that the effect sizes on cognition are smaller.

The current study was designed to further our understanding of the relationship between sleep habits and working memory performance in children. The study design allows for both correlational analysis and experimental effects. Rather than direct manipulation of sleep duration (telling children to restrict or extend their sleep), a sleep education programme was used in order to have a greater chance of long-lasting effects. Children in a single year group were recruited, in order to minimise variation due to age. Year 5 was chosen (age 9-10 years) in order to study children before the onset of puberty (Laberge et al., 2001) but old enough to have an established sleeping pattern without daytime naps (Thorleifsdottir et al., 2002) and to be taking more control of their own behavioural habits (e.g. Such & Walker, 2004).

The key question for this research was, "what are the effects of sleep duration on working memory in children aged 9-10 years?" Specific research questions included:

- Is sleepiness, sleep duration or efficiency correlated with working memory performance?
- Does sleep education improve sleepiness, sleep duration or efficiency?
- Does improved sleep correlate with improved working memory performance?

There were also methodological questions which could be addressed by this study, including:

- Does sleep diary information reflect actigraphy data in this age group?
- Does wearing an actigraph systematically change the information reported in sleep diaries?

Method

Study design

A quasi-experimental design was employed, in which half of the participating classes acted as a control group and half undertook an intervention to improve sleep behaviours. After the study had finished, the classes in the control group were provided with the resources to undertake the intervention if they wished, but as there was no expectation for them to do so they were considered a no-intervention rather than a waitlist control group. This design enabled a cross-sectional analysis at baseline, as well as a longitudinal analysis of experimental effects. The study received ethical approval from University College London (see Appendix 1).

Data collection was designed around the length of the intervention. In the first week (Time 0), baseline sleep diary data were collected. During the following week (Time 1) the pre-intervention data were collected. Post-intervention data were collected five weeks later (Time 2), leaving enough time between data points for the intervention group to carry out the sleep education programme. Follow-up data were collected two to three months after that (Time 3). Only term time weeks were counted, so some classes had an extra week or two weeks between data collection points, if a school holiday fell during that period. See Appendix 2 for the complete project schedule.

At Time 0, only sleep diary data were collected. This information was required in order to give a baseline before the participants knew which of them would be wearing an Actiwatch later in the study. At Times 1, 2, and 3 the full range of data were collected:

- Sleep diaries
- Actigraphy
- Sleep knowledge
- Working memory
- Attention

Sleep diaries were given out on the Monday, to be filled in for seven days and returned. Actiwatches were given out on the Monday, to be returned on the Friday. The author attended the school during the relevant week at the school's convenience, and completed the group-administered measures with the whole class. Over the course of that week, the author and a trained honorary assistant psychologist completed the individually administered measures with each participant. The whole data collection procedure usually took a day and a half for each class. At Time 3 an additional questionnaire was given to participants in the intervention group, seeking their feedback on the programme they had undertaken.

Demographic data on each participating child were collected from existing school records:

- Gender
- Postcode, used to estimate socioeconomic status via the Income Deprivation Affecting Children Index (IDACI, Department for Communities & Local Government, 2011)
- Most recent end-of-year National Curriculum levels in english and maths
- Special educational needs status (on SEN register or not)

Measures

Sleep diaries

Week-long sleep diaries were produced on a single sheet of A4 paper (see Appendix 3). The diary sheets were adapted from those used by Tremaine et al. (2010), including time into bed, time fell asleep, time woke up and sleepiness ratings.

Actigraphy

A set of 10 Actiwatch Spectrum devices and the relevant software with docking station were loaned by the manufacturer (Philips Respironics, Bend, OR, USA) for the duration of this study. Each actigraphy participant was given an information sheet (see Appendix 4) to take home on each of the three occasions that they were asked to wear the Actiwatch. As advised by the Philips representative, the children were instructed to fasten the Actiwatch in the presence of the author onto whichever wrist felt more comfortable, and to leave it there until collection at the end of the week. The epoch length was set to one minute intervals, as this setting was the most commonly used in other studies (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012).

Ideally, participants would have worn the Actiwatch for a full seven days, as recommended by Acebo et al. (1999). However, this was not possible in practice, as the software would not operate with the laptop available and the devices therefore had to be returned to the author's home computer for uploading. Thus, data was collected for four weeknights (Monday to Thursday). These may be the most valid data anyway, since sleep start time and total time in bed differed at the weekend compared to weeknights in Acebo et al.'s (1999) sample of school-aged children during term time.

Each Actiwatch was given out on the Monday and collected on the Friday of the data collection week. The data was then uploaded and the device cleaned ready for the next participant. Occasionally children left their Actiwatch at home, so the parent was asked to bring it into school or, if that was not possible, the author went to the house to collect the device.

The data were viewed using Philips Actiware software version 6.0.0. Sleep onset was defined as 10 minutes of immobility, which is the standard algorithm in this software. To reduce the probability of wake after sleep onset being over-identified (Meltzer et al., 2012) the wake threshold selection was set to “high”.

Sleep knowledge

Children’s knowledge about sleep was measured using a 10-item questionnaire (see Appendix 5) based on Benveniste, Thompson & Blunden’s (2012) tool, which was developed for children aged 9-15 years. Adaptations were made to the original questionnaire. First, item 10 (“how many hours should you sleep every night to be healthy?”) was turned from an open question into a closed one, in line with the other items in the questionnaire. This necessitated a further change so that there were not two questions about sleep length: item 6 (“I need more than 9 hours of sleep each night”) was changed to, “children need less sleep than their parents.” Finally, item 8 (“boys have deeper sleep than girls”) was moved up to become item 2, in order to avoid the existing sequence of five questions with, “true,” as the correct answer.

All of the items in the questionnaire were cross-referenced with the teaching materials provided for the intervention, to ensure that the content needed to answer the questions correctly was included in the lessons. The questionnaire was administered to whole classes at once, and the researcher read each question aloud.

Working memory

Originally the study was designed to capture all cognitive data with group-administered measures, in order to reduce disruption to the classes' schedules and to reduce the total time required for data collection. The Automated Working Memory Assessment (AWMA) 2 was selected, as this web-based version could be completed by groups of children at the same time in the school IT suite or on laptops in the classroom. However, this product was withdrawn by the publisher in September 2013, just before the data collection for this study began. The previous version of the AWMA (Alloway, 2007) therefore had to be substituted, and the publisher would only supply one CD-ROM, necessitating individual testing on a laptop that had the software loaded.

This technical difficulty meant that the working memory tests had to be very selective as there would not be time to undertake extensive testing with each child: the complete AWMA includes three tests each of visual short term memory, verbal short term memory, visual working memory and verbal working memory. One test of visual working memory (Mr X) and one test of auditory working memory (Backward Digit Recall) were chosen, to prioritise tests of working memory rather than short term memory and to cover both visual and verbal modalities since these are theoretically and empirically separable (e.g. Baddeley, 2012). These particular subtests were chosen as the Pearson representative advised that another research group was using them when they required a shorter administration time (this research is now published: Dunning & Holmes, 2014). The switch from group to individual administration also necessitated additional researcher time, and it was extremely fortunate that an honorary assistant psychologist was available and could commit to one day per week of data collection for the duration of the project.

Attention

To enable analysis of whether any effects of sleep on working memory were mediated by attention (as suggested by Steenari et al., 2003), group measures of auditory and visual attention were administered to the whole class at once. Auditory attention was measured using the Score! subtest from the Test of Everyday Attention for Children (TEA-Ch: Manly, Robertson, Anderson, & Nimmo-Smith, 1998). Although the reliability is not quite as high as for the other test of sustained auditory attention in this battery (Code Transmission), it was the only tool that could be adapted for group administration as the responses can be written and do not have to be scored in real time. The Score! test requires participants to listen to a series of tones at varied intervals and keep track of how many were heard. After using this test with the pilot class, instructions were explicitly given each time that the children should keep count in their heads, and that no speaking aloud, tally marks or counting on fingers were allowed. Observation confirmed that children did stick to these rules.

Visual attention was assessed using the d2 Test of Attention (Brickenkamp & Zilmer, 1998), which was developed in Germany. It is a cancellation test, requiring participants to mark all the items fulfilling the criteria (letter d with two marks either above or below it), and none of the distractor items. One child with dyslexia requested to complete his d2 tests individually as he found it difficult, and this was arranged. The Concentration Performance measure from the d2 task was used (rather than Total Number – Errors) in order to ensure that credit was given only for the number of items endorsed and not for skipping over large numbers of items.

Intervention

A universal rather than targeted intervention was used for this study, on the assumption that the prevalence of sleep problems is high so most children would benefit from improving their sleep habits (e.g. Spruyt, O'Brien, Cluydts, Verleye, & Ferri, 2005). A universal programme also had the ethical advantage that all children in a class could participate, without individuals being excluded because their parents had not returned consent forms or because they did not meet criteria on screening for poor sleep.

There are few universal sleep interventions available for primary aged children. Sleep Well Be Well has been trialled in Australia (Quach et al., 2013) but it is targeted at those who report sleep difficulties on a screening questionnaire, and is an individualised programme requiring relatively high levels of resourcing (three 1-1 contacts per family). Moseley & Gradisar (2009) used a group-based universal intervention in schools, but their programme involved older children (15-year-olds). Reut Gruber's group at McGill University have been working for some years on developing their Sleep for Success programme, however only a video has been made publicly available so far; the materials have not been published and there are no articles describing or evaluating the intervention in peer-reviewed journals.

The most relevant intervention for this study was the Australian Centre for Education in Sleep (ACES) programme (Blunden, Kira, Hull, & Maddison, 2013; Blunden, 2007a; Blunden, 2007b; Kira, Maddison, Hull, Blunden, & Olds, 2013). This programme comprises a set of sleep education sessions to be delivered to whole classes. While there is more evaluation data on the adolescent programme, a junior programme for younger children has also been developed. The lead author, Sarah Blunden, kindly allowed these ACES Junior materials to be used in this study free of charge. The materials were adapted for UK use and these adaptations were approved by Dr Blunden (see Appendix 6).

The final intervention consisted of three lessons, a project and a parent booklet. The Theory of Planned Behaviour (Ajzen & Fishbein, 1980) was the theoretical underpinning for promoting behaviour change, as children were asked to consider their current sleeping habits and write down any changes that they intended to make. Lesson 1 covered normal sleep, lesson 2 was about sleep hygiene and lesson 3 looked at sleep problems. The project was less prescriptive but ideas were provided in the teachers' manual and the aim was to consolidate children's learning from the lessons. The parent booklet was provided because the sleep patterns of children 9-10 years old are still very much influenced by their parents (Meltzer & Montgomery-Downs, 2011) and would be unlikely to change without parental support.

A training session for the teachers was held in November 2013. They were taken through the content of the PowerPoint presentations, teachers' manual, student workbook and parent booklet, and discussed together any queries and the details of how they would deliver the intervention in their classes. These materials were then given out to the teachers who were to be in the intervention group, while the teachers in the control group did not receive the materials until after all their data had been collected.

All four teachers in the intervention group reported that they delivered the three lessons and sent the parent booklets home. Some teachers reported omitting some of the practical activities in the lesson plans, but all presented the PowerPoint slides and used the workbooks. Although no observations of the lessons were carried out, lesson delivery was checked by inspecting the children's workbooks, which were completed in all four intervention classes. Two classes did not complete a project, one invited children to complete their project for homework (10 children did so) and one class completed the project in a further classroom session. Treatment fidelity was therefore an issue in this study.

Participants

Recruitment

The key outcome measure used to calculate the number of participants required was extension in sleep time, as this outcome would show whether the intervention had worked to increase the amount of sleep time children were getting. It was not possible to use existing reports of sleep education programmes, as they either had older participants or were not successful in achieving a change in sleep duration. Instead Sadeh et al.'s (2003) study was used as a benchmark, as the children in this study were approximately the same age as the current sample, and they were successful in achieving an extension of sleep time over three successive nights in 62% of participants, as measured by actigraphy. Using G*Power 3.1.3 software, and a test-retest reliability of 0.6 (Sadeh, Dahl, Shahar, & Rosenblat-Stein, 2009), the calculated repeated-measures effect size (dz) for the Sadeh et al. (2003) study was 0.78 (baseline mean = 487.7 minutes, s.d = 43 minutes; extension mean = 516.9 minutes, s.d. = 40.2 minutes). To detect an effect of this size with 0.8 power in this study would require 15 participants in the intervention group (the effect in this case would be pre-post intervention change in sleep duration, rather than comparison to the control group).

This power calculation was cross-referenced with correlational studies. Steenari et al. (2003) found a correlation between sleep duration and the hardest auditory WM task of $r = 0.298$ and for the visual WM task $r = -0.325$. G*Power 3.1.3 software calculated that a total of 83 and 69 participants respectively would be required to detect effects of these magnitudes with 0.8 power. Similarly, Vriend et al. (2012) found a correlation between sleep duration and WM of r = -0.28, an effect size which would require 95 participants using the same parameters.

Given that some dropout from the study is to be expected (e.g. Quach, Hiscock, Ukoumunne, & Wake, 2011, had partial or no data from 26% of the families in their sleep education trial), at least three classes were to be recruited to each group. This would enable actigraphy data to be collected from 30 children in the intervention group (10 children in each class could have an Actiwatch) and give a good chance of detecting an extension in sleep duration of similar magnitude to Sadeh et al. A study of this size would likely involve a total of 150-180 children depending on class sizes (six classes of 25-30 pupils), thus providing enough power to detect correlational effect sizes even with some dropout.

Initial recruitment was carried out in September 2013 via the planning meetings that each school in the author's employing Local Authority holds annually with their link educational psychologist (EP). All the EPs took along a flyer (see Appendix 7) and gave it to each primary or junior school's Special Educational Needs Co-ordinator (n = 50), asking for it to be passed on to the Year 5 teacher(s).

Nine schools contacted the author to express interest in becoming part of the study. Two dropped out soon after receiving the teacher information sheet, in September and November of 2013. This left seven schools who returned a teacher consent form (see Appendix 8) signed by the head teacher, of which one had two parallel Year 5 teachers. After the project schedule had been arranged and the Time 0 sleep diaries completed by the first class in that school, the second class joined the study, making eight participating classes. All eight classes continued to be part of the study until the end of data collection. Although the study design required only six classes, all eight were accepted into the study for ethical reasons and to increase the chances of achieving the numbers of participants indicated by the power analyses.

The eight participating teachers were given information sheets to hand out to each member of their class (see Appendix 9). This sheet explained the study and the child's right to opt out of it. One child in the intervention group opted out of the data collection, and in the control group a teacher decided not to invite one child to join the study as he would not have been able to complete the measures. Both of these non-participants had a diagnosis of autistic spectrum disorder. All the other children remained in the study, although at each time point a small number were not in school on the day of data collection.

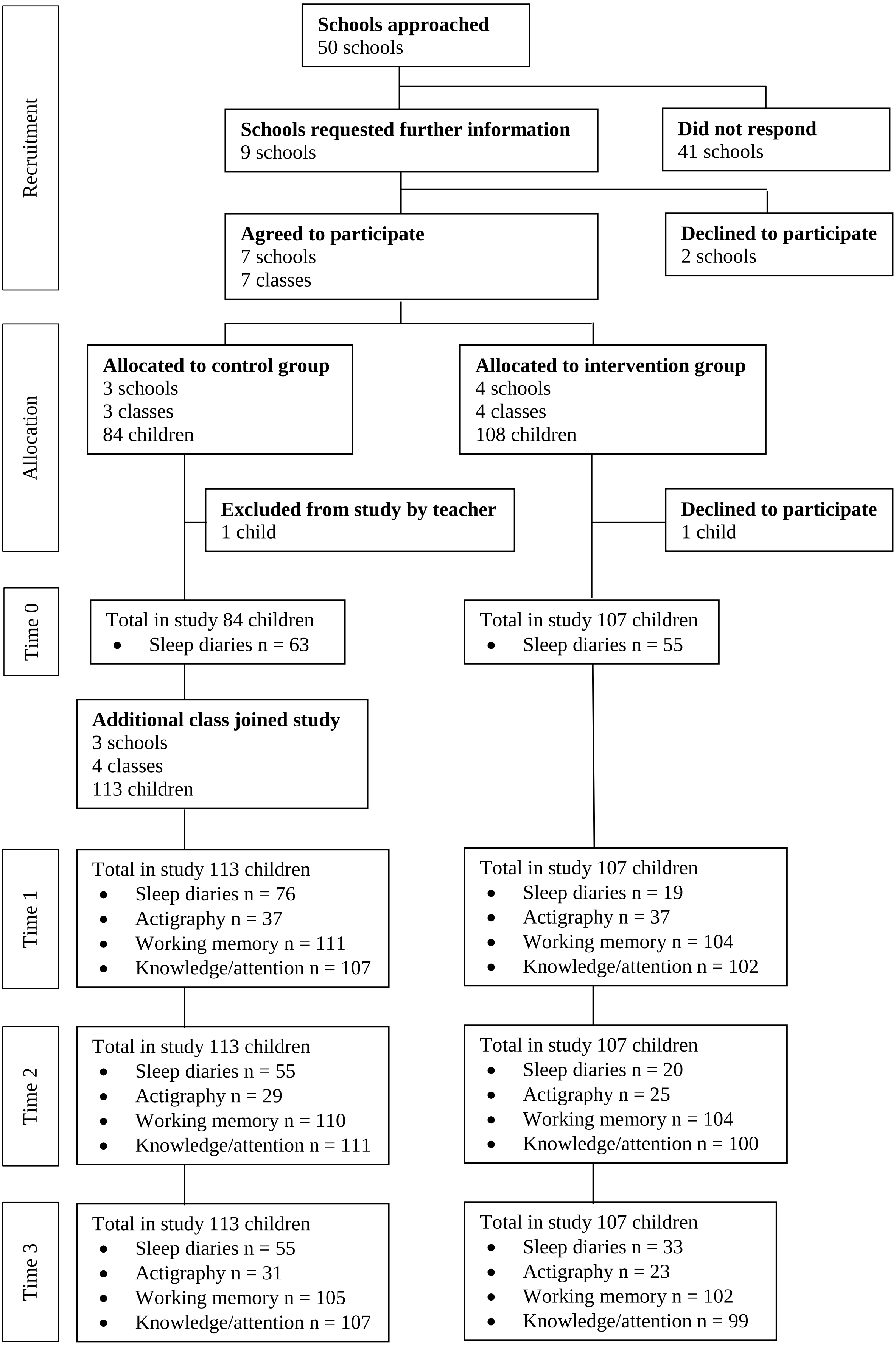

Figure 5: Flow diagram of participation throughout the study

Assignment to control or intervention group

The participating teachers were contacted in October 2013 to ask if any of them would be prepared to act as a pilot class, and one volunteered. This class began their data collection later that month and formed the first class in the control group. At the training session, the participating teachers were shown the schedule and asked to decide among themselves which classes wished to begin on which dates. After this timetable had been agreed, the first three classes were told that they would join the control group, and would have time to deliver the intervention in the summer term after their data collection was complete. The later four classes were told that they would form the intervention group. This approach was taken in order that all classes in the study could deliver the intervention within the academic year. If any of the control classes had started on later dates, they would have finished the data collection phase too late to offer the intervention to the children who had participated.

Characteristics of control and intervention groups

Demographic information about each participating child was provided by the school. An estimate of socio-economic status was made from each child's postcode: the Income Deprivation Affecting Children Index (IDACI) score is the proportion of children aged 0-15 in that area who lived in income-deprived households at the last census in 2010 (Department for Communities & Local Government, 2011). Therefore the higher the IDACI score, the more deprived the neighbourhood where the child lives. These scores were obtained by entering each child's postcode into the UK government's quick checker: http://www.education.gov.uk/cgi-bin/inyourarea/idaci.pl For comparison to national data, deciles have been calculated from the rank ordering given to each IDACI score (Table 4).

Table 4: IDACI scores with corresponding ranks and deciles

IDACI score range	Rank order range	Decile
0 - 0.0344	29232 – 32482	1 (least deprived)
0.0345 – 0.0542	25984 – 29233	2
0.0543 – 0.0766	22736 – 25983	3
0.0767 - 0.1048	19488 – 22735	4
0.1049 – 0.1429	16240 – 19487	5
0.1430 – 0.1921	12992 – 16239	6
0.1922 – 0.2563	9744 – 12991	7
0.2564 – 0.3413	6496 – 9743	8
0.3414 – 0.4564	3248 – 6495	9
0.4565 – 1	1 – 3247	10 (most deprived)

Children's SEN status was also provided by the school. The percentage of children with SEN includes children on the SEN register at any level (School Action, Action Plus or Statement). Attainment scores are based on teacher assessment at the end of the previous school year (summer 2013). The points equate to National Curriculum levels, and in England children are expected to achieve 21 points (also known as Level 3b) at this stage in their education (end of Year 4, aged 9).

Table 5: Participant demographics

	Number of children	% boys	Mean IDACI score	% SEN	Mean reading score	Mean writing score	Mean maths score
Control	113	57.52	0.168	20.35	23	21	23
Intervention	107	49.53	0.372	16.82	21	20	21
Total	220	53.64	0.269	18.64	22	21	22

Overall the participants had relatively low socioeconomic status compared to other children in the UK (mean IDACI score within the 8th most deprived decile), which reflects the geographical area from which they were recruited. Despite this disadvantage, the children in this study were achieving at nationally expected levels.

The intervention group lived in more deprived areas, had a lower proportion of boys, were working at a slightly lower academic level than the control group, and had a lower proportion of children identified as having special educational needs.

The control group included two schools (three classes in this study) which were rated outstanding at their last Ofsted inspection, along with one requiring improvement. The intervention group included two schools rated good, one requiring improvement and one inadequate.

Participation in sleep diary data collection

Table 6: Numbers of sleep diaries completed

Class	Number of children participating	Sleep diaries returned Time 0	Sleep diaries returned Time 1	Sleep diaries returned Time 2	Sleep diaries returned Time 3
Control 1	31	24	27	14	16
Control 2	23	17	14	11	12
Control 3	30	22	21	16	14
Control 4	29	-	14	14	13
Total control	113	63 (75%)	76 (67.2%)	55 (48.7%)	55 (48.7%)
Intervention 1	25	15	0	4	7
Intervention 2	28	21	18	14	25
Intervention 3	27	6	0	0	0
Intervention 4	27	13	1	2	1
Total intervention	107	55(51.4%)	19 (17.8%)	20 (18.7%)	33 (30.8%)
Overall total	220	118 (61.8%)	95 (43.2%)	75 (34.1%)	88 (40.0%)

As Table 6 shows, participation in completing the sleep diaries was highly variable across classes and declined over time. In particular, three of the four intervention classes returned little or no diary data after the first week of the study. For individuals, diary returns were not consistent, for example a child might have completed a diary at Times 1 and 3 but not at Time 2. Complete diary data sets (returns at all four time points) were available for only seven children in the intervention group and 20 children in the control group.

Participation in Actiwatch data collection

The information sheet given to all children in participating classes included an opt-in consent form for children wishing to volunteer to collect Actiwatch data. Where more than 10 consent forms were received, a random selection was made. The participation rates were highly variable, as shown in Table 7.

Table 7: Numbers of Actiwatches used

Class	Consent forms received	Actiwatches taken Time 1	Actiwatches taken Time 2	Actiwatches taken Time 3
Control 1	28	10	10	10
Control 2	15	10	9 (1 withdrew)	8 (1 withdrew, 1 off sick)
Control 3	13	10	10	10
Control 4	8	8	-	7 (1 off sick)
Total control	64	38	29	35
Intervention 1	15	10	9 (1 watch lost)	10
Intervention 2	27	10	9 (1 watch lost)	9 (1 off sick)
Intervention 3	12	9 (1 watch lost)	5 (4 withdrew)	5 (4 withdrew)
Intervention 4	10	9 (1 watch lost)	6 (3 withdrew)	4 (5 withdrew)
Total intervention	64	38	29	28

Control class 4 were unable to collect Actiwatch data at Time 2 because they joined in the schedule with control class 3 (in the same school). It was possible to find a spare week in the schedule at the beginning and end of the programme, but at Time 2 their data had to be collected on the same week as class 3, and there was only one set of

Actiwatches available.

One child in intervention class 2 lost their Actiwatch at Time 2. It took several weeks to replace, and therefore intervention classes 3 and 4 started with only nine Actiwatches.

In three classes, some children chose not to continue wearing the Actiwatch after the first week. They were not asked to give reasons for withdrawing their consent, but several children spontaneously commented that they had found the Actiwatch uncomfortable. One said that she had simply forgotten to wear it.

In addition, sometimes Actiwatches were returned with unusable data for some or all of the nights. This problem may have been caused in some cases by children leaving the watch off-wrist, and in other cases by technical faults with the devices; it is not possible to identify which was the reason in each case. Mean sleep durations were calculated, which in some cases meant a single night of usable data.

Table 8: Numbers of children with usable Actiwatch data

Class	Number of children with usable Actiwatch data at Time 1	Number of children with usable Actiwatch data at Time 2	Number of children with usable Actiwatch data at Time 3
Control 1	9	10	10
Control 2	10	9	8
Control 3	10	10	8
Control 4	8	-	5
Total control	37	29	31
Intervention 1	9	7	8
Intervention 2	10	8	6
Intervention 3	9	4	5
Intervention 4	9	6	4
Total intervention	37	25	23

Results

Statistical analysis

Data analysis was undertaken using IBM SPSS Version 22 software.

Where data were not normally distributed, non-parametric tests were used to compare means. When correlations and partial correlations needed to be calculated for non-normal data, bootstrapping was used to calculate robust 95% confidence intervals (CIs) (e.g. Field, 2013). Bootstrapping was used in preference to non-parametric correlations in order to allow direct comparisons with partial correlations, for which there is no non-parametric alternative in SPSS.

In bootstrapping, the actual data are used as a population from which random samples are drawn and analysed (in this study, the samples were analysed for Pearson correlations, denoted by *r*). The random samples are all the same size as the original, but with replacement (i.e. the same value may appear more than once while another value is excluded from the sample). This process allows an estimation of the sample distribution for non-normally distributed data. The 95% CI tells us the range within which 95% of the results from the random samples of the whole dataset fell. In this study bias-corrected and accelerated bootstrapping was used, with 1000 samples.

As SPSS does not bootstrap the p-values, these are not reported and instead significance is interpreted directly from the correlation CIs. If the 95% CI includes zero, the probability of the null hypothesis being true is greater than 0.05, and the result is therefore taken to be non-significant (Wood, 2005). This approach leads to the same conclusions as conventional significance testing (Smith & Morris, 2015), making it an equivalent way to analyse non-normally distributed data.

Baseline measures

Sleep duration

The sleep diaries yielded three measures of time asleep. Time in bed is the whole period between the recorded time of getting into bed and the recorded time of waking the next morning. Sleep duration is the whole period between the recorded time of falling asleep and the recorded time of waking the next morning. Total time asleep is sleep duration minus the amount of time the child said they were awake during the night (wake after sleep onset).

Actigraphy yielded two measures of time asleep: time in bed and total time asleep, which is time in bed minus time spent awake during the night.

All measures of sleep duration in this study are given as a mean, calculated over the available weeknights (Monday to Thursday) for each time point. Sundays were not included because several weeks within the study included a Bank Holiday Monday, so some Sundays were not a schoolnight.

Table 9: Sleep duration at baseline

Mean duration (first data collection point)	Diary (time in bed)	Diary (sleep duration)	Diary (total time asleep)	Actigraphy (time in bed)	Actigraphy (total time asleep)
N	132	132	132	74	74
Mean	10 hrs 28 mins	9 hrs 41 min	9 hrs 37 mins	9 hrs 26 mins	8 hrs 9 mins
SD (minutes)	42.96 mins	47.17 mins	49.60 mins	33.07 mins	37.40 mins
Less than 7 hours	0	2 (1.5%)	2 (1.5%)	0	3 (4.1%)
7 hrs – 7 hrs 59 mins	0	2 (1.5%)	2 (1.5%)	0	22 (29.7%)
8 hrs – 8 hrs 59 mins	3 (2.3%)	15 (11.4%)	18 (13.6%)	18 (24.3%)	44 (59.5%)
9 hrs – 9 hrs 59 mins	28 (21.2%)	67 (50.8%)	70 (53.0%)	47 (63.5%)	5 (6.8%)
10 hrs – 10 hrs 59 mins	66 (50.0%)	43 (32.6%)	38 (28.8%)	8 (10.8%)	0
11 hrs – 11 hrs 59 mins	33 (25.0%)	3 (2.3%)	2 (1.5%)	1 (1.4%)	0
More than 12 hours	2 (1.5%)	0	0	0	0

The usual recommended amount of sleep for this age group is 9-11 hours (Matricciani, Olds, Blunden, Rigney, & Williams, 2012). In their meta-analysis, sleep duration was operationalised as, "the time between falling asleep and waking," (p. 554). In the current sample, most children were therefore getting enough sleep before the intervention according to their diary data (Table 9). Looking at the actigraphy data, approximately a quarter of children were averaging less than nine hours in bed per weeknight. If night-time wakings are subtracted, giving total time asleep rather than time in bed, less than 7% of children were getting more than nine hours of sleep –

however, actigraphic time asleep is not the metric against which most recommendations are made. The mean total time asleep as measured by actigraphy is almost exactly the same as the baselines reported by Sadeh et al. (2003): their samples had a mean of 8 hours 8 minutes (sleep extension group) and 8 hours 9 minutes (sleep restriction group).

Using independent samples t-tests, no difference was found between the sleep duration of boys and girls on any of these measures at the first data collection point (diary time in bed, t = -1.071, df = 130, p = 0.286; diary sleep duration t = -0.275, df = 130, p = 0.784; diary total time asleep, t = -0.017, df = 130, p = 0.986; actigraphy time in bed, t = -0.318, df = 72, p = 0.752; actigraphy total time asleep, t = -0.373, df = 72, p = 0.463).

Pearson's correlation coefficients between these measures of sleep duration and socioeconomic status were calculated, with higher deprivation being significantly associated with shorter sleep for diary sleep duration (r = -0.25, p = 0.005) and actigraphy time in bed (r = -0.28, p = 0.016), but not for diary time in bed (r = -0.14, p = 0.113) or actigraphy time asleep (r = -0.15, p = 0.197).

As diary-reported sleep duration and total time asleep were so similar, because children reported hardly any wake after sleep onset, all further analyses use total time asleep only. This measure is analogous to the actigraphic measure of total time asleep.

Sleep efficiency

Mean sleep efficiency (percentage of total time in bed spent asleep) measured by actigraphy was calculated across the four weeknights at the first data collection point (n = 74, mean = 86.58%, SD = 4.77%). This finding is consistent with other studies citing sleep efficiency data for this age range (e.g. Steenari et al., 2003, 86.5%; Vriend et al., 2012, 85.5%).The average amount of wake after sleep onset, as measured by actigraphy, was almost an hour, with wide variation between children (n = 74, mean = 57 minutes, SD = 27 minutes). There was no relationship between sleep efficiency and time in bed (r = -0.07, p = 0.540), but a strong relationship between sleep efficiency and time asleep (r = 0.65, p <0.001). These findings are consistent with the correlations between the same actigraphy measures reported by Holley et al. (2009) for 6-11 year olds in the UK.

Working memory

Performance on the two working memory tasks at the first data collection point was similar to that of the standardisation sample (mean = 100, SD = 15).

Table 10: Baseline working memory scores

	Mean raw score	SD raw score	Mean standard score	SD standard score
Visual WM	12.7	4.765	97.58	14.3
Verbal WM	11.6	4.093	101.2	13.76

As the working memory and socioeconomic status measures were not normally distributed according to Kolmogorov-Smirnoff tests (verbal WM D(215) = 0.126, p <0.001, visual WM D(215) = 0.091, p <0.001; IDACI D(215) = 0.123, p <0.001), bootstrapping was used. The correlation between verbal and visual working memory measures at the first time point was surprisingly low (n = 215, r = 0.15, CI -0.018 to 0.307) compared to another study using exactly the same tests of working memory (Alloway, Gathercole, & Pickering, 2006, r = 0.35). Socioeconomic status was correlated with working memory, but in different directions. For visual working memory higher SES was related to higher scores (n = 215, r = -0.13, CI –0.05 to -0.244), but for verbal working memory it was children of lower SES who did best (n = 215, r = 0.236, CI 0.096 to 0.393). The effect sizes are rather small, consistent with other studies showing that socioeconomic status tends not to be strongly related to measures of working memory in children (e.g. Alloway & Alloway, 2010; Engel, Santos, & Gathercole, 2008).

Working memory and sleep

At Time 1, 95 children had returned sleep diaries and also completed tests of working memory. One outlier case (a child reporting less than five hours' total time asleep) was removed from this part of the analysis. Even with the outlier removed, most of the measures reached significance on the Kolmogorov-Smirnoff tests of normality (Table 11) so bootstrapping was used.

Table 11: Tests of normality for working memory and diary data at Time 1

	D	d.f.	p
Diary time in bed	0.073	94	>0.2
Diary time asleep	0.103	94	0.016
Diary sleepiness	0.116	94	0.003
Verbal WM	0.142	94	<0.001
Visual WM	0.123	94	0.001

As shown in Table 12, Pearson's correlation coefficients showed that verbal working memory was negatively correlated with reported time in bed and total time asleep, but not with sleepiness ratings. Visual working memory was not significantly correlated with any diary measure. It is notable that, in this subset of children who had submitted sleep diaries, there was no correlation between their verbal and visual WM scores.

When socioeconomic status was entered as a control variable, all partial correlations between sleep diary and WM measures were non-significant.

Table 12: Correlations between sleep diary and working memory variables at Time 1

	Time in bed	Total time asleep	Sleepiness	Verbal WM	Visual WM
Time in bed	1	r = 0.830 CI: 0.749 to 0.888	r = -0.035 CI: -0.220 to 0.154	r = -0.223 CI: -0.375 to -0.073	r = 0.057 CI: -0.133 to 0.243
Total time asleep	r = 0.820 CI: 0.740 to 0.876	1	r = 0.070 CI: -0.122 to 0.264	r = -0.224 CI: -0.375 to -0.073	r = 0.097 CI: -0.076 to 0.266
Sleepiness	r = -0.004 CI: -0.193 to 0.193	r = 0.095 CI: -0.113 to 0.290	1	r = -0.074 CI: -0.231 to 0.105	r = -0.021 CI: -0.208 to 0.165
Verbal WM	r = -0.154 CI: -0.333 to 0.014	r = -0.174 CI: -0.005 to 0.085	r = -0.104 CI = -0.255 to 0.032	1	r = -0.026 CI: -0.254 to 0.208
Visual WM	r = 0.028 CI: -0.148 to 0.194	r = 0.077 CI: -0.101 to 0.252	r = -0.011 CI: -0.204 to 0.198	r <0.001 CI: -0.237 to 0.271	1

Data in the top right of the table are bivariate correlations; data in the bottom left are partial correlations controlling for socioeconomic status.

Also at Time 1, both actigraphy and working memory data were available for 74 children (Table 13). One child's data showed that they averaged over 11 hours in bed, which is an outlier and was removed from this part of the analysis. This exclusion normalised the data for the actigraphy measures, although the scores for working memory remained non-normally distributed (verbal D(73) = 0.13, p = 0.004; visual D(73) = 0.125, p = 0.006) so bootstrapping was used. Pearson's correlation coefficients showed that none of the actigraphy measures were significantly correlated with either working memory measure, although with SES controlled for, a small but significant correlation was found between sleep efficiency and visual working memory.

Table 13: Correlations between sleep actigraphy and WM variables at Time 1

	Time in bed	Time asleep	Sleep efficiency	Verbal WM	Visual WM
Time in bed	1	r = 0.672 CI: 0.524 to 0.796	r = -0.040 CI: -0.299 to 0.241	r = -0.201 CI: -0.403 to 0.021	r = -0.046 CI: -0.240 to 0.155
Time asleep	r = 0.667 CI: 0.522 to 0.787	1	r = 0.702 CI: 0.579 to 0.801	r = 0.015 CI: -0.219 to 0.256	r = 0.100 CI: -0.068 to 0.260
Sleep efficiency	r = -0.024 CI: -0.258 to 0.246	r = 0.718 CI: 0.593 to 0.814	1	r = 0.206 CI: -0.011 to 0.410	r = 0.185 CI: -0.007 to 0.373
Verbal WM	r = -0.152 CI: -0.356 to 0.059	r = 0.045 CI: -0.205 to 0.278	r = 0.198 CI: -0.057 to 0.437	1	r = 0.103 CI: -0.146 to 0.350
Visual WM	r = -0.129 CI: -0.325 to 0.069	r = 0.067 CI: -0.104 to 0.255	r = 0.212 CI: 0.021 to 0.380	r = 0.176 CI: -0.089 to 0.408	1

Data in the top right of the table are bivariate correlations; data in the bottom left are partial correlations controlling for socioeconomic status.

The baseline data concerning sleep variables and working memory were visually inspected as scattergrams (see Appendix 10) but there were no suggestions of curvilinear relationships. Regression analyses confirmed that no significant quadratic relationships existed between verbal or visual working memory and any of the sleep variables measured:

- diary time in bed
- diary total time asleep
- diary sleepiness
- actigraphy time in bed
- actigraphy total time asleep
- actigraphy sleep efficiency

Overall, the relationship between sleep variables and working memory at baseline in the current sample was not very strong. The diary variables were not significantly correlated with visual working memory, and there was a small but significant negative correlation with verbal working memory (shorter time in bed and shorter sleep were related to higher verbal working memory scores). Including socioeconomic status as a control variable resulted in no significant correlations between any sleep diary and working memory variables. Actigraphy variables were not significantly correlated with visual or verbal WM, although controlling for SES showed a weak positive relationship between efficiency and visual WM.

Measurement issues

Comparison of diary data with actigraphy data

At Time 1, a total of 37 children returned both diary and actigraphy data. Mean time in bed and mean time asleep for weeknights (Monday to Thursday inclusive) was calculated in minutes for each of these children.

Table 14: Descriptive statistics for sleep diary and actigraphy data at Time 1

	Mean time in bed	Standard deviation	Mean total time asleep	Standard deviation
Diary	10 hrs 21 mins	40.5 mins	9 hrs 39 mins	34.8 mins
Actigraphy	9 hrs 27 mins	37.5 mins	8 hrs 8 mins	41.8 mins

Both diary and actigraphy measures of time in bed and time asleep were normally distributed, so Pearson's correlation coefficients were calculated (Table 15). Diary time in bed was significantly correlated with both actigraphy measures, although the confidence intervals are wide and therefore the data do not show a robust relationship.

Table 15: Correlations between diary and actigraphy measures at Time 1

	Time in bed (diary)	Total time asleep (diary)
Time in bed (actigraphy)	r = 0.333 p = 0.044 95% CI r = -0.027 to 0.661	r = 0.243 p = 0.148 95% CI r = -0.075 to 0.535
Total time asleep (actigraphy)	r = 0.359 p = 0.029 95% CI r = 0.098 to 0.580	r = 0.308 p = 0.063 95% CI r = 0.059 to 0.567

Paired-samples t-tests showed that the differences between diary and actigraphy measures of time in bed (t = 7.269, df = 36, p < 0.001) and total time asleep (t = 12.077, df = 36, p < 0.001) were statistically significant, with diary data estimating more time than actigraphy.

The individual night for which most children (n = 36) returned both diary and actigraphy data was Monday at Time 1, so this night was used to compare the times at which children fell asleep and woke up, by diary or actigraphy measure. One child's data for time of waking had to be excluded from the analysis as their diary reported waking at 10.10 am, suggesting that they did not attend school that day. Times of day were transformed using Excel, into the proportion of 24 hours elapsed since the previous midday, so that each time was represented as a number which could be analysed in SPSS. As some of these data significantly departed from the normal distribution according to Kolmogorov-Smirnoff tests (actigraphy time fell asleep: D(35) = 0.155, p = 0.032; diary time woke up: D(35) = 0.155, p = 0.033), Wilcoxon Signed Ranks tests were conducted. The two samples were not significantly different from each other, either in the time the children fell asleep (T = 372, p = 0.54) or the time they woke up (T = 224, p = 0.313). However, because this is a rank order statistical test, it does not compare means and therefore systematic differences would not be detected (e.g. if children fell asleep in the same order by both diary and actigraphy measures, but later by one measure than the other). The mean, median and modal times for falling asleep and waking up were therefore calculated using Excel (Table 16), and suggest that diary and actigraphy measures are indeed in close agreement.

Table 16: Times of falling asleep and waking up at Time 1

	Diary	Actigraphy
Mean time of falling asleep	9.38 pm	9.23 pm
Median time of falling asleep	9.30 pm	9.40 pm
Modal time of falling asleep	10.00 pm	9.40 pm
Mean time of waking up	7.22 am	7.19 am
Median time of waking up	7.20 am	7.18 am
Modal time of waking up	7.00 am	7.27 am

Differences in the amount of time spent asleep on the two measures do occur from the amount of waking during the night. Twenty-nine children reported in their diaries that they did not wake at all during the Monday night of Time 1, five children reported one waking, and two children reported more than one waking. By contrast, the actigraphy data showed that these children experienced between 12 and 44 episodes of waking during that same night (Wilcoxon Signed Ranks T = 666, $p < 0.001$). In terms of total time (wake after sleep onset or WASO), the range reported in children's diaries was 0 to 50 minutes, while the range recorded from actigraphy was 18 minutes to 2 hours 36 minutes, with a mean of 1 hour 1 minute (Wilcoxon Signed Ranks T = 666, $p < 0.001$).

Compared to the actigraphy data, the children systematically overestimated both the time they had spent in bed and the total time asleep when they completed their diaries. The correlations between diary and actigraphy measures of time in bed were statistically significant, but with wide confidence intervals. These results suggest that the diary and the actigraphy data are measuring different phenomena, so diary data cannot be substituted for objective measures of time asleep.

Wearing an actigraph did not affect diary data

A total of 71 children returned sleep diaries at both Time 0 (before they knew who would get an Actiwatch) and at Time 1. At Time 1, 29 of these children were wearing an Actiwatch and 43 were not. The mean time asleep reported by diary (Monday – Thursday nights inclusive) was calculated for both time points.

Kolmogorov-Smirnoff tests showed that the difference (in minutes) between diary-reported time asleep at Time 0 and Time 1 was normally distributed for the group who got an actigraph ($D(29) = 0.096$, $p > 0.2$), but not for the group who remained without an actigraph ($D(43) = 0.153$, $p = 0.013$). One child reported an extremely late night during the week of Time 0 which skewed the data, and removing this outlier normalised the distribution of children in the no-actigraph group ($D(42) = 0.107$, $p > 0.2$). The comparison was therefore made (excluding the outlier) using a t-test. This analysis showed that the children who got actigraphs did not change their diary reporting any more than those who did not get actigraphs ($t = -0.278$, $p = 0.782$). The means for both groups were small (no-actigraph mean = -3.17 minutes, SD = 29.8 minutes; actigraph mean = -1.1 minutes, SD = 32.1 minutes), which hides a variety of differences in both directions: some children reported longer sleep at Time 0 while others reported longer sleep at Time 1.

These findings suggest that future researchers do not need to be concerned that wearing an actigraph will affect how children fill in their sleep diaries. However, the analysis does highlight relatively wide variation between children's reports of their sleep duration from one week to the next: even removing the outlier, the range fell between -96 minutes and +86 minutes' difference in mean sleep duration).

Intervention effects

Sleep knowledge

At the first data collection point, 209 children completed the questionnaire, and, "don't know," responses were coded as incorrect (as per Benveniste et al. (2012). Ceiling effects were less of a problem with the current sample (see Table 17). The mean was significantly lower (mean = 4.81, SD = 1.63) compared to Benveniste's study (mean = 6.36, SD = 1.8) ($t = 11.065$, $df = 850$, $p < 0.0001$). Only two items attracted 60% or higher correct responses, compared to seven items in Benveniste et al. (2012).

Table 17: Responses to sleep knowledge questionnaire at Time 1

Question	% correct Benveniste et al. (2012)	% correct Current study
1. Sleep helps me remember things	69.2	54.1
2. Boys have deeper sleep than girls	23.1	37.8
3. Doing something calm before bed can help me fall asleep	84.6	78.5
4. I should go to bed at the same time every night	72.3	43.5
5. Exercising every day can help me sleep better	70.8	49.3
6. I need about 7 hours' sleep each night (was, "how many hours should you sleep every night to be healthy?")	69.2	34.9
7. Watching TV before bed can make it hard for people to sleep	60.0	53.6
8. Not getting enough sleep can make people overweight	24.6	15.3
9. Doing exercise just before bed can help me fall asleep	32.3	40.7
10. Children need less sleep than their parents each night (was, "I need more than 9 hours of sleep each night")	75.4	73.2

In the current study, the sleep knowledge data were not normally distributed in either the control or the intervention group, at any of the three time points. Visual inspection of the histograms showed that the data were skewed in opposite directions in the control compared to the intervention group. In addition, the intervention group scored significantly lower than the control group at Time 1. Despite this difference at baseline, the intervention group had caught up with the control group at Time 2 (straight after the intervention), and by Time 3 (8-12 weeks after the intervention finished) the intervention group maintained higher scores while the control group fell back to baseline levels (see Table 18 and Figure 6).

Table 18: Effects of intervention on sleep knowledge

	Time 1 knowledge scores	Time 2 knowledge scores	Time 3 knowledge scores
Control group	mean = 5.06 SD = 1.65 Mean rank = 114.59	mean = 5.82 SD = 1.995 Mean rank = 98.07	mean = 5.02 SD = 1.85 Mean rank = 93.01
Intervention group	mean = 4.55 SD = 1.57 Mean rank = 94.94	mean = 6.23 SD = 1.48 Mean rank = 114.80	mean = 5.72 SD = 1.90 Mean rank = 114.84
Mann-Whitney U test of difference between groups	U = 4431 n = 209 p = 0.017	U = 6430.5 n = 211 p = 0.043	U = 6419 n = 208 p = 0.008

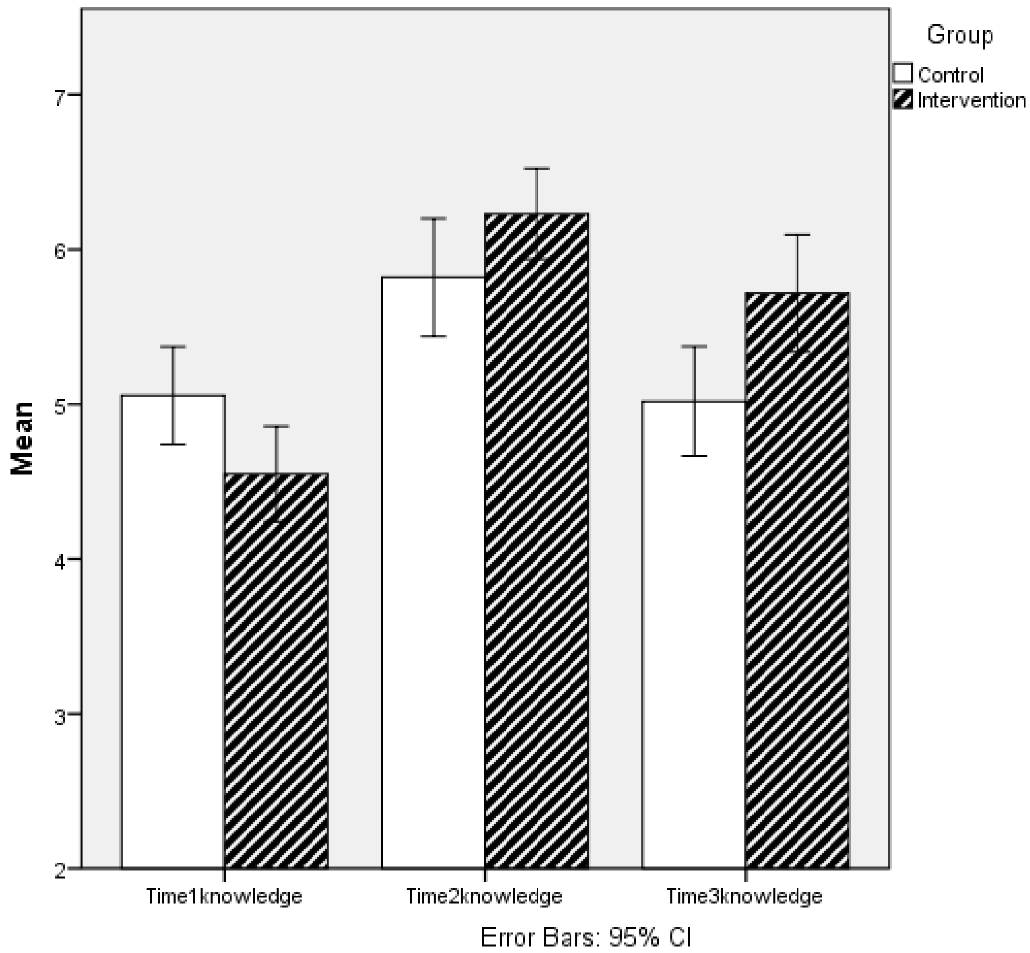

Figure 6: Sleep knowledge at Times 1, 2 and 3

Sleep behaviours

The lack of diary data from the intervention group makes it impossible to analyse whether the intervention group differed significantly from the control group in self-reported measures of sleep. Only 20 children in the control group and seven children in the intervention group returned diary data for all time points. Even if we looked only at the immediate pre- and post-intervention data points (Times 1 and 2), 46 children in the control group and nine in the intervention group submitted diaries at both points. Dropout rates were high, with 40% of the control group and 84% of the intervention group who had submitted an initial diary failing to submit a diary at Time 1, Time 2 or both.

Table 19: Descriptive statistics for actigraphy data at Times 1, 2 and 3

	Time 1	Time 2	Time 3
Time in bed (minutes)	**Control**: n = 37 mean = 573.95 SD = 34.37 **Intervention**: n = 37 mean = 557.05 SD =29.83	**Control**: n = 29 mean = 554.72 SD = 48.07 **Intervention**: n = 25 mean = 558.34 SD =34.73	**Control**: n = 31 mean = 562.84 SD = 31.70 **Intervention**: n = 23 mean = 563.20 SD = 30.32
Total time asleep (minutes)	**Control**: n = 37 mean = 493.36 SD = 32.46 **Intervention**: n = 37 mean = 485.40 SD =41.83	**Control**: n = 29 mean = 474.34 SD = 42.42 **Intervention**: n = 25 mean = 496.56 SD = 30.57	**Control**: n = 31 mean = 491.31 SD = 47.71 **Intervention**: n = 23 mean = 488.53 SD = 48.84
Sleep efficiency	**Control**: n = 37 mean = 86.1% SD = 3.6% **Intervention**: n = 37 mean = 87.1% SD =5.7%	**Control**: n = 29 mean = 85.5% SD = 4.1% **Intervention**: n = 25 mean = 89.0% SD =3.9%	**Control**: n = 31 mean = 88.2% SD = 4.4% **Intervention**: n = 23 mean = 89.0% SD = 4.6%

The actigraphy outcome measures were total time in bed (mean minutes per weeknight), total time asleep (mean minutes per weeknight) and sleep efficiency (mean percentage per weeknight). All of these measures, at all time points, were normally distributed according to Kolmogorov-Smirnov tests, enabling the use of ANOVA.

Looking first at pre- and post-intervention data (Time 1 and Time 2), data were returned from 28 children in the control group and 25 in the intervention group. There is a clear interaction between time point and group for total time asleep as measured by actigraphy ($F(1,51)= 4.675$, $p = 0.035$, partial $\eta^2 = 0.084$). It should be noted that this interaction was contributed to by those in the intervention group increasing their total time asleep *and* those in the control group decreasing it; the interaction does not represent an effect of the intervention compared to no change in the control group.

Focusing just on the intervention group, the amount of sleep increase between Time 1 and Time 2 was not as great as in Sadeh's (2003) study, with a mean extension in this study of 11.16 minutes' total time asleep (Cohen's d = 0.3; Sadeh et al. (2003) achieved a mean extension of 35 minutes' time asleep, Cohen's d = 0.7). A paired-samples t-test showed that the difference between mean total time asleep at Time 1 and Time 2 for those in the intervention group was not significant ($t = -0.970$, $df = 24$, $p = 0.342$). Counting the individuals involved, 14 children reduced their total time asleep at Time 2 compared to Time 1 and 11 children increased their total time asleep. These findings suggest that the intervention did not systematically increase sleep duration.

Staying with analysis of pre- and post-intervention data only, interactions between time point and group were also found for sleep efficiency ($F(1,51) = 4.091$, $p = 0.048$, partial $\eta^2 = 0.074$) but not for total time spent in bed ($F(1,51) = 2.160$, $p = 0.148$, partial $\eta^2 = 0.041$). Again, the control group reduced their mean sleep efficiency at Time 2 while the intervention group increased theirs, so the interaction reflects both changes rather than just an effect of the intervention.

When the time asleep data from Time 3 were added in ($n = 25$ in the control group and $n = 20$ in the intervention group), both groups returned to their baseline sleep durations, and the overall interaction between time point and control/intervention group became non-significant in the ANOVA analysis ($F(2,42) = 2.339$, $p = 0.11$, partial $\eta^2 = 0.052$) (see Figure 7).

Likewise, adding in data from Time 3 to the sleep efficiency analysis rendered the interaction between time point and group non-significant ($F(2,42) = 1.465$, $p = 0.238$, partial $\eta^2 = 0.033$). In this case, the intervention group increased their sleep efficiency between Times 1 and 2 and sustained this improvement, while the control group increased their sleep efficiency between Times 2 and 3 (see Figure 8).

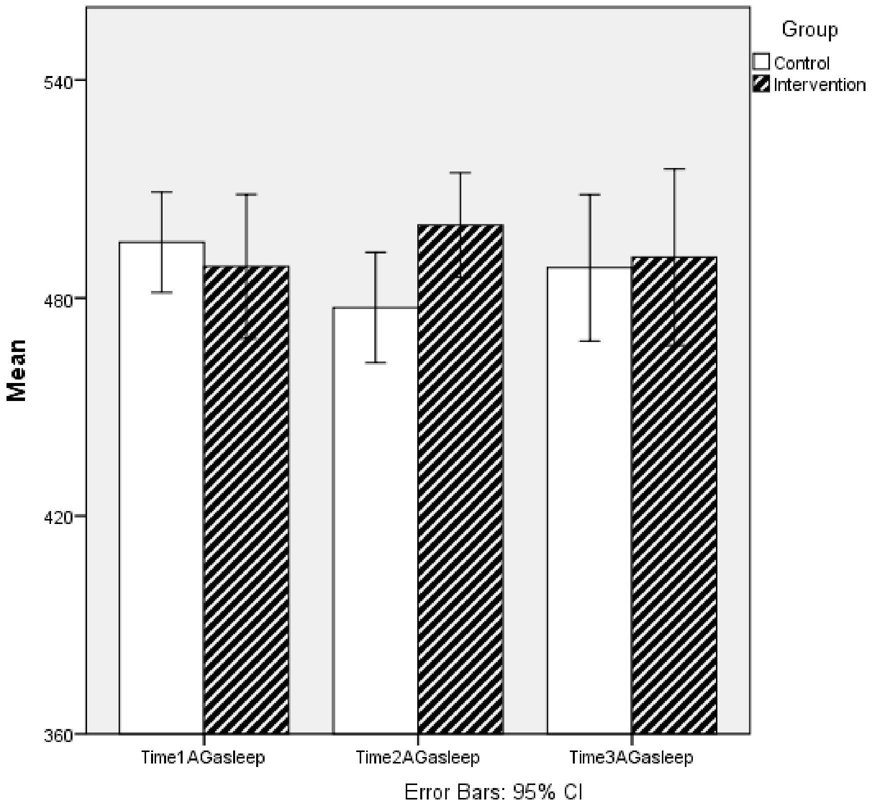

Figure 7: Mean total time asleep (in minutes) as measured by actigraphy at Times 1, 2 and 3

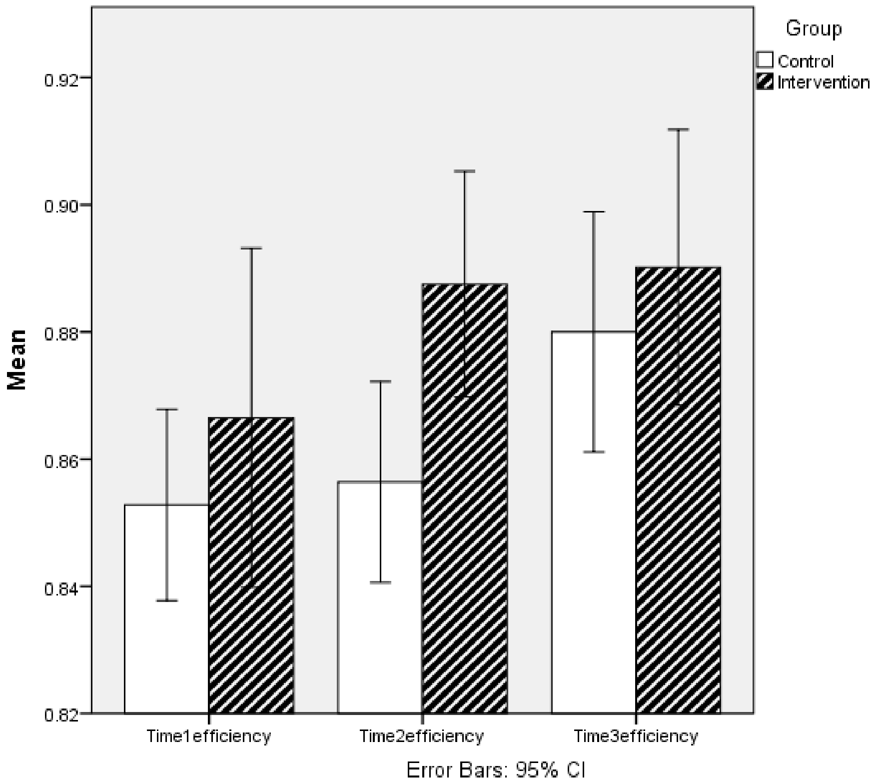

Figure 8: Mean sleep efficiency as measured by actigraphy at Times 1, 2 and 3

Overall, these analyses suggest that the intervention used in this study generated a mean extension of 11 minutes in weeknight sleep duration as measured by actigraphy. The effect was not statistically significant, and more individuals in the intervention group decreased their sleep duration than increased it. This small increase in mean sleep duration was not sustained over time, unlike the gains made by the intervention group in sleep knowledge. Sleep efficiency was also increased in the intervention group compared to the control group, but at follow-up the control group had also increased their sleep efficiency so this change may not be an effect of the intervention itself.

Working memory outcomes

The initial measures of working memory (Time 1) showed that the control and intervention groups differed significantly at baseline. Both verbal and visual working memory scores were not normally distributed, so non-parametric Mann-Whitney U tests were used to compare the control and intervention groups. For verbal working memory the intervention group started with higher scores ($U(215) = 6567$, $z = 1.751$, $p = 0.08$, $r = 0.12$), whereas for visual working memory the control group started with higher scores ($U(215) = 1641$, $z = -2.490$, $p = 0.017$, $r = 0.17$).

For both verbal and visual working memory, the control and intervention groups improved their scores across time points as would be expected with practice and maturation effects. In both cases, the group with the lower scores caught up to the other group (see Figure 9 and Figure 10).

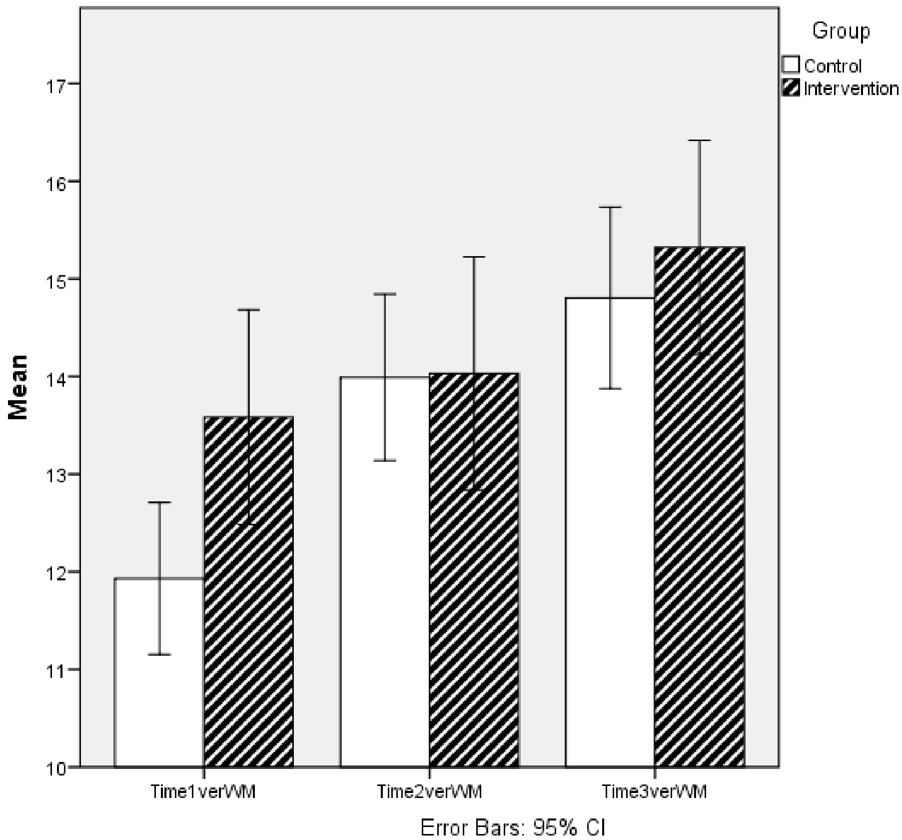

Figure 9: Verbal WM raw scores at Times 1, 2 and 3

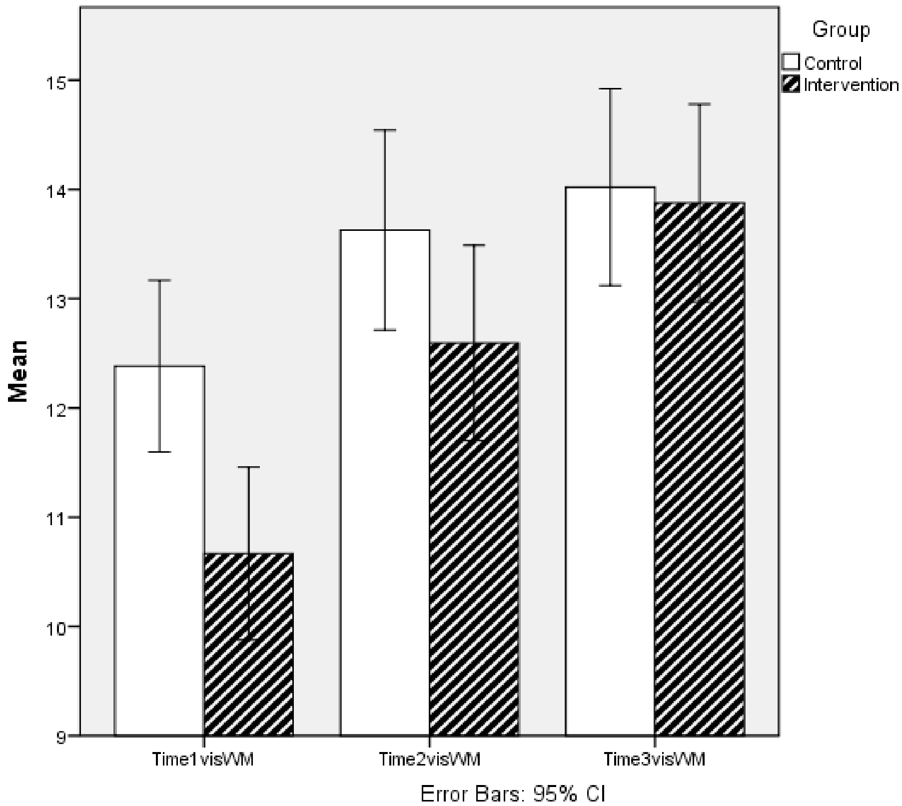

Figure 10: Visual WM raw scores at Times 1, 2 and 3

New variables were calculated for visual WM, verbal WM and actigraphic total time asleep, representing the change scores from Time 1 to 2, from Time 2 to 3 and from Time 1 to 3. Most of these variables were not normally distributed according to Kolmogorov-Smirnoff tests (Table 20), so non-parametric analyses were used.

Table 20: Tests of normality for change scores in sleep diary and WM variables

	D	d.f.	p
Verbal WM change from Time 1 to Time 2	0.115	210	< 0.001
Verbal WM change from Time 2 to Time 3	0.09	202	< 0.001
Verbal WM change from Time 1 to Time 3	0.11	203	< 0.001
Visual WM change from Time 1 to Time 2	0.087	210	0.001
Visual WM change from Time 2 to Time 3	0.101	202	< 0.001
Visual WM change from Time 1 to Time 3	0.076	203	0.006
Actigraphy time asleep change from Time 1 to Time 2	0.099	53	> 0.2
Actigraphy time asleep change from Time 2 to Time 3	0.14	46	0.025
Actigraphy time asleep change from Time 1 to Time 3	0.111	53	0.127

Mann-Whitney U tests of the changes in WM scores between each time point (Table 21) showed that the only significant differences between groups was for verbal WM, where the control group made greater gains than the intervention group between Times 1 and 2, and for visual working memory, where the intervention group made greater gains than the control group between Times 1 and 3.

Table 21: Mann-Whitney U tests of changes in WM scores between control and intervention groups

	Change from Time 1 to Time 2 (n = 210)	Change from Time 2 to Time 3 (n = 202)	Change from Time 1 to Time 3 (n = 203)
Verbal WM	U = 3951 z = -3.548 p < 0.001 r = -0.24	U = 5684.5 z = 1.418 p = 0.156 r = 0.10	U = 4507.5 Z = -1.537 p = 0.124 r = -0.11
Visual WM	U = 6080 Z = 1.314 p = 0.189 r = 0.09	U = 5530 Z = 1.044 p = 0.297 r = 0.07	U = 6231 Z = 2.598 p = 0.009 r = 0.18

Pearson's correlations with bootstrapped confidence intervals were calculated to test whether changes in sleep duration, regardless of the intervention, were related to changes in working memory performance (Table 22). No significant correlations were found between the change in actigraphic time spent asleep and the change in WM scores. One correlation was found between the change in diary time spent asleep and the change in visual WM scores, but the confidence interval was wide which casts doubt on its significance.

Table 22: Correlations between changes in total time asleep and changes in WM scores

	Verbal WM	Visual WM
Diary Time 1 to Time 2 (n = 54)	r = 0.139 CI = -0.148 to 0.397	r = -0.116 CI = -0.312 to 0.095
Diary Time 2 to Time 3 (n = 48)	r = -0.148 CI = -0.430 to 0.145	r = -0.097 CI = -0.344 to 0.159
Diary Time 1 to Time 3 (n = 61)	r = 0.002 CI = -0.126 to 0.485	r = -0.228 CI = -0.437 to -0.117
Actigraphy Time 1 to Time 2 (n = 51)	r = -0.039 CI = -0.183 to 0.217	r = 0.199 CI = -0.126 to 0.485
Actigraphy Time 2 to Time 3 (n = 44)	r = 0.216 CI = -0.289 to 0.552	r = -0.035 CI = -0.428 to 0.352
Actigraphy Time 1 to Time 3 (n = 53)	r = 0.046 CI = -0.193 to 0.273	r = -0.179 CI = -0.501 to 0.162

Overall it is not possible to conclude that this intervention has had any reliable impact on working memory performance. The improvements in both groups suggest that practice and maturation effects had more influence on WM scores than the intervention. Differences between the groups are small, and could be explained by regression to the mean or random effects given that the intervention group did not always show greater improvement than the control group. There is also a lack of correlation between change in sleep duration and change in WM scores, suggesting that those children who did increase their length of time asleep showed no systematic change in WM performance. These findings are perhaps not surprising, given the weak associations between sleep and WM variables at baseline.

Programme acceptability

The four classes who had undertaken the intervention were asked for feedback about their experience of using the modified ACES programme. Teachers and students were asked to complete a brief questionnaire in class as part of the Time 3 data collection, and questionnaires for parents were sent home with the children.

In total 98 children, four teachers and 17 parents returned questionnaires. All of the children and teachers who were present on the day of whole-class data collection completed a questionnaire. The parent questionnaires were largely returned from one class (n = 14), with the other classes returning two, one, and zero parent questionnaires. The feedback questionnaires were anonymous in order to encourage open and honest responses, however this approach does preclude any analysis comparing feedback to other individual data.

The four teachers were unanimous in their views that the programme had been enjoyable, practicable, appropriate for the age range and useful. They commented that it had been worthwhile to raise the profile of sleep as a health behaviour, along with exercise and healthy eating. Their suggestions for improvement all involved additions to the programme: those who had not implemented the project said that they would do so next time, and those who had done the project thought that they would do more activities with the whole class and involve parents more directly.

The sample of parents returning questionnaires is relatively small, and skewed towards one class. Of those 17 parents, all reported that their child learned something and 13 (76%) thought that they had learned something themselves. In terms of behaviour change, 13 parents (76%) reported that their child's sleep had changed as a result of these lessons. Three parents wrote an additional comment, all to say that they thought the programme was useful.

Among the children, the feedback was generally positive, and chi-squared tests confirmed that there were no significant differences between classes. Most children enjoyed the programme, thought that sleep knowledge and habits were important, and said that they had changed their sleep habits as a result of the intervention. In Table 23, the numbers of responses indicating positive feedback have been highlighted by shaded boxes and summarised in the right-hand column.

Table 23: Feedback from children about the intervention programme

	Yes, definitely	Yes, a bit	No, not really	No, definitely not	Positive feedback
The lessons were boring	12	20	41	25	66 (67.3%)
I enjoyed learning about sleep	32	43	15	8	75 (76.5%)
I think other kids should learn about sleep too	72	18	6	2	90 (91.8%)
The programme was a waste of time	4	18	25	51	76 (77.6%)
I think it's important to have good sleep habits	63	20	10	5	83 (84.7%)
I have changed my sleep because of these lessons	18	42	20	18	60 (61.2%)

Of the 98 children completing feedback, 76 wrote a comment about what they had most enjoyed as well as responding to the multiple choice questions. Fifty-three of these comments (70%) indicated that the best thing about the programme was some part of the assessment procedure (TEACh, n = 14; d2 test, n = 6; Mister X, n = 5; Digits Backward, n = 1; sleep knowledge quiz, n = 1; computer tests, n = 5; tests in general, n

= 5; sleep diaries, n = 8; Actiwatch, n = 8). The remaining comments indicated that the best thing was the project (n = 10) or learning about sleep (n = 13).

Twenty-two children also wrote a comment about something they would change if the programme was done with other children. Most suggested making the programme more fun (n = 7) or including more activities (n= 6). Specific suggestions included more group work and more pictures in the materials. Two children suggested that it would be better to have Actiwatches for everyone in the class, and two suggested a more exciting project. The other comments related to changing the workbook or diary sheets (without specific suggestions as to what should be changed) and including more facts in the lessons.

Discussion

Key findings

The original overarching question for this research was, "what are the effects of sleep duration on working memory in children aged 9-10 years?" From this study, the general answer to this question would be that no effects of sleep on working memory were found, although difficulties with the research design and implementation may well have obscured any relationship that does exist.

Within this general research question, specific questions were formulated. The first of these was whether sleepiness, sleep duration or efficiency correlated with working memory performance. The evidence for this question comes from the baseline data, which is relatively good quality information that does not suffer from the dropout and group selection problems encountered with the intervention part of this research. Sleepiness did not correlate with verbal or visual memory scores in any analysis. Sleep duration did correlate with verbal working memory according to diary data (but not actigraphy data), however this relationship became non-significant when controlled for socioeconomic status. Sleep efficiency showed a weak relationship with visual working memory, which became significant when controlled for socioeconomic status. Overall, the evidence for correlations between sleep and working memory variables from this study is not strong but suggests that shorter sleep may be related to better verbal working memory while greater sleep efficiency is associated with better visual working memory.

These cross-sectional findings would be most consistent with those of Geiger et al. (2010) and Van der Heijden et al. (2013). The idea that shorter sleep should be associated with better working memory performance is counter-intuitive and different from the findings in adult studies of sleep deprivation. Geiger et al. (2010) suggest that one hypothesis to explain this pattern is neural efficiency theory (Haier et al., 1988), which posits that people with higher cognitive efficiency can achieve cognitive tasks with lower neural effort, so by extension perhaps those scoring higher on cognitive tests need less sleep. If this were the case we should expect to see the same pattern in adults, however no correlational studies of normal interindividual differences could be found. Another possible explanation given by Geiger et al. (2010) is that children who sleep for a shorter period of time benefit from a longer period of wakefulness, and the extra stimulation they gain from this could accelerate their cognitive development. This hypothesis, although lacking in empirical evidence, would fit with a developmental view of the relationship between sleep and cognition, as prolonged wakefulness might be more beneficial in childhood than in later years when skill development has plateaued.

A further specific research question was whether sleep education improves sleepiness, sleep duration or efficiency. In this study, the intervention was relatively brief (three lessons) and only half of the intervention classes did the project intended to consolidate their learning. Parents were involved through a leaflet sent home. Assessment of sleep knowledge showed that the intervention did produce an increase in children's scores, which was sustained at follow-up, so they had learned and retained information about sleep.

Not enough diaries were returned after the intervention to assess change in self-reported sleep behaviours. Actigraphy data did appear to show a significant difference in sleep duration between the control and intervention groups using repeated-measures ANOVA, however this difference was due to the control group decreasing their mean sleep duration as well as the intervention group increasing theirs. No significant increase in sleep duration was found for the intervention group. Taking into account pre-intervention, post-intervention and follow-up actigraphy data, the intervention group did not increase their sleep duration or efficiency any more than the control group. These findings are consistent with those of other studies of sleep education programmes, which tend to impact upon knowledge but not behaviour (Blunden et al., 2012).

There could be a number of explanations for this lack of effect on sleep behaviours. First, most children were getting enough sleep at baseline, compared to normative data on reported sleep durations (Matricciani et al., 2012). These children would therefore not be expected to change their sleep habits on the basis of education which would inform them that their sleep duration was about right. It would have been useful to analyse just those children with short sleep durations at baseline to see if the intervention changed their sleep behaviours, but not enough data were collected in this study to do that. Second, the intervention may not have been intensive enough to produce behaviour change. Third, more active parental involvement may be required in order to make changes to routines occurring at home. Finally, there may be factors preventing behaviour change even if the child intended to do so, such as perceived importance, locus of control and practical issues such as room sharing or night-time activity of others in the house.

The question of whether changes in sleep correlate with changes in working memory performance cannot be answered by the current study, as the intervention was not successful in altering sleep variables.

The acceptability of the intervention was also assessed. Most children, staff and parents who responded were positive about the programme. Ratings were similar to other sleep education programmes (summarised by Blunden et al., 2012), with over 90% of children in the current study saying that other kids should learn about sleep but only three-quarters enjoying the programme. From looking at other evaluations covered in the review of Blunden et al. (2012), ratings of enjoyment tend to be higher when the programme is delivered by an external professional rather than the regular teacher.

This study was able to answer its methodological questions using baseline data. First, the question of whether sleep diaries reflect actigraphy data in this age group was resolved with findings which are consistent with other studies of child participants (e.g. Holley et al., 2009). There was a systematic over-estimation of sleep duration in diaries compared to actigraphy, which is mainly attributable to a lack of reporting wake after sleep onset (WASO) and a possible over-estimation of WASO by actigraphy. In general there was agreement between the two methods about the times children went to bed and woke in the morning.

A novel question which has not previously been addressed was that of whether wearing an actigraph would affect the way children fill in their sleep diaries. Analysis of the diary sheet completed in the first week (before children knew who would get an actigraph) and in the following week (when some children wore an actigraph) showed that there was no difference in diary reporting between those who did and did not receive an actigraph. Future studies can omit the baseline diary week used in this study, as it added no new information to diary data collected at the same time as actigraphy data.

Key methodological issues

In the current study, allocation of classes to the control or intervention group was not random. The method of allocation was practical and ethical, as it allowed all classes to have the intervention (if they so wished) within the academic year and engaged teachers by giving them control over when to deliver the intervention. However, the keenest teachers wanted to start the project as soon as possible and this introduced bias into the group allocation. The most highly motivated teachers, in the best performing schools, with higher SES populations, volunteered to go first and therefore formed the control group. Random allocation of classes to control and intervention groups would have given a better chance of more comparable groups. In addition, recruitment of teachers in the summer term, ready to undertake the project from the beginning of the new academic year, would have allowed for randomisation of when each class fitted into the project schedule rather than having all the control classes first.

Assessment of working memory relied upon only one test each of verbal and visual working memory. The original study design included three subtests for each, which would have given a more reliable score, but the chosen assessment tool was withdrawn just before the start of the project. While other studies have also used the same single tests of WM as in this research (Cho et al., 2015; Dunning & Holmes, 2014), their validity in this project is questionable. The current sample did show scores comparable to the standardisation sample, however their scores for the visual and verbal WM tests were not correlated with one another which is unusual.

The assessments of attention were not used in the data analysis, since no main effects for working memory were found and therefore no mediator analyses were carried out. The measure of visual attention was valid and reliable, with the current sample showing a normal distribution of scores. However, the measure of auditory attention suffered from ceiling effects, with a skewed distribution and the majority of children scoring 9 or 10 out of 10. A different measure may have been preferable, however no other group-administered auditory attention tests could be found and the resources to test each child individually were not available.

The data collection for sleep variables had good participation at first, but children quickly got bored of filling in sleep diaries and the dropout rate was so high that longitudinal analysis was not possible. A focus group was held, in which six children who had not returned sleep diaries were asked to comment on why they had not done so. This focus group was held after the issue of not returning diaries had become apparent, and was held with the next class to finish their data collection, so that there was no pressure on them to complete diaries in the future. The children all agreed to participate in the focus group and all contributed to the discussion. Their reasons for not returning sleep diaries were:

- Lost the sheet
- Spent time away from home and did not take diary with them
- Living between two homes and did not take diary to the other home
- Spilled a drink on the sheet
- Forgot to do it

The children also had ideas for how to increase the return rate in future:

- Teachers to check who has brought theirs back and remind those who have not
- Teachers to provide incentives for returning diaries
- Remind participants that returning their diaries will help other people
- Put information about sleep on the back of the sheet to remind participants why they are doing the study
- Make the sheet more fun and engaging, with pictures and puzzles on the sheet

Treatment fidelity was also an issue. Two out of the four intervention classes completed the project intended to consolidate and personalise children's learning; the other two could not find the time to do the project. Even within the lessons, which were highly manualised, some teachers reported omitting some of the activities. If the resources had been available, observation of programme delivery would have been ideal. Alternatively, teachers could have been asked to complete a checklist of elements of the intervention, to encourage a complete delivery and to identify any elements not delivered (e.g. Smith, Daunic, & Taylor, 2007). While there is an argument that, for real-world studies, interventions need to be tailored and allow practitioners some freedom in their use, this flexible approach may more useful for programmes which are already well validated so that the research can focus on variations from the established intervention.

Reflecting on the research design, it may be that universal sleep education interventions require much longer-term evaluation in order to detect significant impact, or to be delayed until the prevalence of inadequate sleep is higher. In the 9-10 year old children participating in this study, three-quarters were already getting the recommended amount of sleep and therefore did not require intervention. It is possible that, as they move into adolescence when sleep durations often reduce, those children who have had sleep education may show some behavioural effects compared to those who have not. Alternatively, universal sleep interventions may not be effective until a higher proportion of children are not getting enough sleep and would therefore benefit. A different approach would be to target sleep interventions only at those children already experiencing sleep problems, which have so far shown larger effects than universal programmes (Blunden et al., 2012; Quach et al., 2011).

A further issue for the research design is that of intra-individual variability. While the current study has focused on habitual sleep behaviours, the variability in the same individual's sleep duration on different nights is wide. It is therefore difficult to identify reliable changes in sleep habits, as the standard deviation is so large at baseline.

Perhaps this variability would have been a useful measure in itself, as other studies have found that consistency in children's sleep routines is related to outcomes (Pesonen et al., 2010; Wolfson & Carskadon, 2003).

Finally, there are methodological issues concerning the sample size in the current study. Although previous research was used to calculate an appropriate sample size, different studies have found different effect sizes. Selected studies which were in some way similar to the current research design were used to estimate a sample size which would have detected significant relationships if they existed in similar ways to the reference studies. However, the meta-analysis of Astill et al. (2012) found an effect size for the relationship between children's sleep duration and executive functions of r = 0.07. This effect size mirrors that found for the relationship between children's sleep duration and academic attainments (r = 0.069; Dewald et al., 2010). If the effect in the population was really as small as Astill et al. (2012) suggest, a sample size of 1596 would be required and this was not practicable in the current study. Indeed, if the effect size is that small, it is unlikely to be clinically significant and suggests that sleep is not a very effective target for intervention if the desired outcome is improved executive functioning in children.

Key theoretical issues

The neurodevelopmental perspective may be helpful in understanding the differential effects of sleep on functioning in a range of domains over the lifecourse. The development of the frontoparietal network subserving working memory in adults is incomplete in this age group, both in functional connectivity and in axonal myelination, so we might expect to find that different factors affect WM performance depending on the maturity of these biological systems.

It may also be that children, like adults, have inter-individual differences in their need for sleep. Rather than espousing a recommended sleep duration for children, perhaps it would be more relevant to track children's functioning and suggest changes to their sleep habits only if they are experiencing daytime sleepiness or other functional difficulties. Evidence from Konen et al. (2015) suggests that there are functional losses when children depart from their own usual sleep habits, which would not be detected in a study looking only at group differences in average sleep durations.

There is also a question about the psychology of behavioural change. While the intervention used in this study is based upon the theory of planned behaviour (Ajzen & Fishbein, 1980), there are challenges to the efficacy of this approach to changing people's behaviours (Armitage & Conner, 2001; Hardeman et al., 2002). It may be that sleep education is never going to be an effective way of changing children's sleep behaviours; even if their knowledge is improved and they have intentions to change their behaviours, a range of factors are likely to impede implementation of that change. For example, sharing a bedroom, parental expectations or night-time activity in the home (e.g. adults coming home from work or leisure activities after the child's bed time) may work against a child acting on their intentions to go to sleep earlier. Wake times, at least during the week, are unlikely to be amenable to change as children have to get up in time for a fixed school start. Alternative approaches may be required and some are already being researched, for example changing the start time of the school day to allow for longer sleep in the morning (e.g. Owens, Belon, & Moss, 2010). Later school starts are also being investigated in the UK: the TeenSleep project (https://educationendowmentfoundation.org.uk/projects/teen-sleep/ retrieved 12 August 2015) based at the University of York is due to report in 2018. The US based studies are more likely to find positive results as their standard school start times are usually earlier than in the UK (e.g. Howard-Jones, 2014; Kirby, Maggi, & D'Angiulli, 2011). However, a Norwegian study (Vedaa, West Saxvig, Wilhelmsen-Langeland, Bjorvatn, & Pallesen, 2012) provides some evidence that moving secondary school start times from 8.30 am, which is more similar to UK start times, to 9.30 am improves reaction times (but not sleepiness or mood).

Cognitive psychology may also illuminate the theoretical underpinnings of the current research. Cognitive functions appear to be separable, even in children of this age, and show specificity in their development (e.g. Casey, Tottenham, Liston, & Durston, 2005). Two relevant arguments result from this understanding. First, if the desired outcome is an improvement in working memory performance, the most effective way to achieve that is to train working memory directly. Factors such as sleep, exercise and diet may set the general framework for cognitive development, but specific outcome measures will show large changes only if targeted directly for intervention. Second, development of WM skills may not show generalisation to real-world outcomes of interest. The literature on specific WM training shows that WM performance can be improved by sustained and adaptive training, in a range of populations, however such improvements do not necessarily lead to higher achievements in academic tests (Melby-Lervag & Hulme, 2013). Taking a cognitive psychology perspective might suggest that the effects of even the most effective sleep intervention on specific cognitive functions may be weak, and the effects on real-world outcomes even weaker. This conclusion does not mean that sleep interventions are not worth doing, but that a realistic view of their effects within complex human systems would need to be taken.

Future research

There are some implementation aspects of the current study that would strengthen it if a similar design were to be used again. Programme fidelity could be tracked more closely and a greater emphasis placed on delivering the programme as set out in the materials given. There could also be greater focus on increasing participation rates.

The current study was able to collect large amounts of data from children in class, but the measures requiring home completion suffered high dropout rates. The children themselves gave some useful ideas for increasing participation, such as more attractive diary sheets, teacher tracking of data returns and rewards for participation. In addition, technological solutions to data collection might increase participation, for example mobile phone based prompts to complete diary information as demonstrated by Konen et al. (2015).

Recruitment of a targeted sample could be adopted for future research, to give a greater chance of changing sleep behaviours. For example, initial assessment could be used to target children who are short sleepers or who show problems associated with sleep such as daytime sleepiness. This targeted approach would enable most children to be excluded from the study as they do not need the intervention, and allow a focus on those children who are most likely to benefit from a change in sleep behaviours.

The intervention itself may also need to be adapted in order to produce changes in sleep behaviour. A longer programme may be needed, perhaps with learning spaced over time in order to maintain any changes in behaviour. Parental involvement may need to be more active, particularly in this pre-adolescent age group, in order to support children in changing sleep habits. Alternatively, it may be that a sleep education programme is not sufficient to produce significant changes in behaviour and the intervention needs to have a different focus altogether.

Future research may need to use research designs with multiple outcomes in order to detect the holistic effects of sleep on daytime functioning. If this study had also included measures of other functions, more significant results may have been observed. The existing body of evidence suggests that sleep may have an impact on a range of outcomes including learning, episodic memory, reaction time, obesity and emotional regulation. It would be unhelpful to conclude that children's sleep duration is not important just because it shows no relationship with a single cognitive domain.

Intra- and inter-individual differences in sleep habits will also need to be accounted for in future work. Tracking of changes in sleep behaviours from night to night, weeknight to weekend and school term to school holiday periods would be helpful in order to establish the normal range of variability in children's sleep behaviours. It would then be possible to investigate whether variability itself is an important predictor of daytime functioning and therefore whether it would be a plausible target for intervention. Individual differences in sleep need may also be important, with the effects of sleep deprivation or extension being found only in relation to an individual's usual sleep pattern.

Future studies could elucidate the developmental aspect of the relationship between sleep and WM, by choosing a methodology and applying it to different age groups in order to track the course of the relationship between sleep and WM. Imaging could be part of the research design in order to link directly the development of the fronto-parietal network with the effects of sleep on WM. A useful hypothesis to be tested would be that the effects of sleep on WM get stronger as the neural systems subserving these functions approach maturity.

Critical appraisal

The process of research development

The current thesis was my original research idea, however I also pursued a number of other topics before committing to the project as set out here. The process of exploring research topics is discussed here, as it provides important context for the decisions taken in the current study.

From the start of the doctorate I had some general principles in mind for my thesis, which were that it should further my career aspirations in the field of neuropsychology and that the project should involve some kind of intervention likely to benefit the participants (see section on intervention-led research). I had an early interest in both sleep and working memory, so this was my initial area of focus.

Very early in the research process I considered methods, and from reading the literature about sleep I was convinced that objective measures were important, as so many studies showed differences between self- or parent-report and actigraphy or polysomnography. There was therefore a practical issue of whether I would be able to access the research tools required: if I was not able to get actigraphy devices then I would not be doing a project that measured sleep behaviours. I contacted a range of colleagues in academic, hospital and charity organisations, who confirmed that actigraphs were practical to use but expensive, and they were not able to lend theirs out. At that point, I abandoned the idea of studying sleep as I thought that report methods alone would not give the rigour I wanted to achieve.

At that time, I attended a conference which included an interesting workshop on traumatic brain injury and offending behaviour. I thought that this specific field of research was well covered by the speaker and other teams mentioned in his presentation, but further reading in the field of aggressive offending behaviour led me to Essi Viding's research on callous/unemotional traits in children. I read an article (Dadds & Rhodes, 2008) outlining what neuroscience had to offer in terms of understanding callous/unemotional traits and developing interventions specific to them. As Essi Viding was working in the same department in which I was enrolled as a doctoral student, and she had already collaborated with Norah Frederickson in the educational psychology group, I thought that this could be an opportunity to work with colleagues at the forefront of their field and to be part of a cutting-edge programme of research.

I met several times with Profs Viding and Frederickson, and spent a lot of time reading in this field. I thought about a number of theories which might be relevant, particularly those relating to reactivity as I thought this concept might help to explain the differences between aggressive children with and without callous-unemotional traits and therefore suggest differentiated interventions. I found it increasingly difficult to narrow down ideas to a project that would be manageable and worthwhile. I also experienced some tension between input from different colleagues, as they were drawing on different perspectives, experiences and expectations in their efforts to help guide my thinking. A key turning point came when I brought a shortlist of topics on which I might focus a literature review, and in supervision we crossed out everything related to neuroscience. It seemed as though the project was becoming increasingly complex and moving further away from the core ideas I wanted in my doctoral work: neuropsychology and intervention. A supervision session with my link supervisor gave a fresh perspective from someone outside the specific field, and I made the decision not to pursue a thesis on callous-unemotional traits despite all the work that I and others had put into it.

I got back in touch with Sarah Blunden, a researcher in Australia who had corresponded with me during my initial explorations of a thesis about sleep. She put me in touch with Teresa Arora at Birmingham University, who investigates the relationship between sleep and obesity. During a conversation about the resources needed for doing sleep research, Dr Arora suggested that I approach the manufacturers of actigraphs directly. I took up her idea, and investigated some other topics while awaiting their responses. As soon as I heard that Philips were prepared to loan 10 devices for the 15 months required, free of charge, I committed to developing a study that would use this resource.

In developing the current research further, I drew on my experiences from the work I had done on the previous project idea about callous-unemotional traits. I was sure that my two core principles needed to be represented in the research, as I had learned that I was not comfortable without neuropsychology and intervention as part of the programme. I also knew that I had to narrow down the field in order to generate a manageable project. I felt differently about doing a project where there were no experts in the field in my department (or, arguably, in the country). This would mean that my supervision would be more generic and I would have more control over the content, but perhaps at the expense of having subject-specific ideas suggested, or knowing the most up-to-date information about ongoing studies.

Research questions, methodology and epistemology

Following the structure put forward by Crotty (1998), a coherent thread is identified here linking the research question, the methods used, the theoretical perspective taken and the underlying epistemology.

For the current study, the key question was, “what are the effects of sleep duration on working memory in children aged 9-10 years?” This question was derived from my own interests, and focused by live practice issues as well as a review of the literature. I was drawn into the study of sleep during my first degree, when I undertook a dissertation on narcolepsy and found it fascinating. Postgraduate learning in the field of neuropsychology has developed further my interest in the physiological and cognitive aspects of psychology, as layers in our understanding of how people function. Executive functions have become a particular area of interest, partly due to their apparent vulnerability in brain injury (e.g. Levin & Hanten, 2005) and partly because they have been shown to predict educational outcomes (e.g. Blair & Razza, 2007). In a previous job I helped to develop an extensive set of training and resources to support the assessment and development of executive functions, based on materials which had themselves been part of someone else's doctoral work. Feedback from teachers confirmed that the topic was both novel and useful to them, confirming that it could be a relevant area for my own research.

Initially, I assumed that there is a relationship between sleep and working memory, and that the focus of the research would be on the effectiveness of sleep intervention in changing sleep behaviour and therefore working memory performance. However, as the literature review proceeded I realised that this relationship was far from clear and that the next steps in our collective knowledge would be to find out more about whether sleep duration affects working memory in children at all.

This broad research question led me to a set of methods which would enable some quantification of both sleep and working memory performance. From the literature review I was keen to have an objective measure of sleep behaviour, in addition to sleep diaries kept by participants, and the only practical way to do this without access to a sleep laboratory was through actigraphy. I contacted the manufacturer of a commonly used actigraphic device and was pleased to negotiate the free long-term loan of 10 devices. The availability of this equipment drove the sequential schedule for data collection, as 10 children at a time could be having their sleep behaviours measured in this way. If no actigraphy kit could have been obtained, I would have needed to change the research substantially, perhaps moving away from measuring sleep variables at all. If only one device were available, I might have taken a case-study based approach and looked at a small number of individuals in greater depth. This approach would have been idiographic and would have necessitated a phenomenological perspective. It could have provided information to illuminate the many complex factors involved in children's habitual behaviours and cognitive performance. This sort of research could be helpful in understanding why no clear relationship between sleep and working memory has yet been established in children. However, given that larger-scale research was made possible, an experimental methodology was used, with enough participants to detect correlations in the baseline data and to form two comparison groups for the intervention.

Experimental methodologies like those used in the current study generally derive from a critical realist theoretical perspective (see, e.g. Groff, 2004). An objective reality is assumed, as in positivist views, but in critical realism the researcher accepts that our data and its interpretation can only approximate that underlying reality. In this way, research can be conducted with a view to reducing subjectivity and finding results that can be generalised, while acknowledging that psychological phenomena are unlikely to be characterised by rules or laws which hold in all contexts for all individuals.

Crotty (1998) suggests that there are three main epistemological positions within which a theoretical perspective might sit: objectivism, constructionism and subjectivism. These positions can be viewed in terms of their predictions about the generalisability of findings. Objectivism suggests that meaningful reality exists independently of any individual's experience, and that research should aim to identify aspects of that objective reality. From this position, rules would always hold so long as the theory matches reality. In contrast, subjectivism suggests that there is no independent reality, and that meaning is always created by people through their interactions. This position does not allow for generalisable rules, but focuses on each unique experience. Between these two extremes lies constructionism, which suggests that meaning is created through our engagement with a world which has its own properties but can never be experienced directly. From a constructionist perspective, research can look to find the extent of generalisability for a particular phenomenon, identifying at least some of the factors which exert an influence on the rules.

Using Crotty's (1998) framework, the current research can be summarised as follows:

Research question	• What are the effects of sleep duration on working memory in children aged 9-10 years?
Methods	• Actigraphy • Sleep diaries • Standardised testing • Knowledge questionnaires • Quantitative statistical analysis
Methodology	• Experimental • Cross-sectional + intervention
Theoretical perspective	• Critical realism
Epistemology	• Objectivism

Figure 11: From research question to epistemology

The current research took a generally objectivist approach. An attempt was made to identify a general rule about how sleep affects working memory, with a large enough sample size to uncover some of the objective truth of the matter. Given the difficulties encountered with children returning sleep data which restricted the sample size, the generalisability of the findings in this study are severely limited and the research fails to identify robust relationships between the variables. Even if the research could have been implemented as designed, it would not take into account individual differences in sleep need or other factors which might contribute to working memory performance.

In hindsight, a constructionist approach may have been more useful. Any relationship between sleep and working memory is likely to be mediated by a range of factors far beyond the basic measures in this study (gender and socioeconomic status). A more fruitful approach from a constructivist perspective might have been to focus on individuals' sleep patterns, the reasons for those sleep patterns and a range of outcomes including cognitive, emotional and physical functioning. In this way, factors might be identified which mediate not only the relationship between sleep and WM variables, but also the link between intentions to change sleep behaviour and actual behaviour change (e.g. bedroom sharing). This kind of research could use qualitative or case-study based quantitative methodology.

Intervention-led research

A key driving force for undertaking the whole doctoral programme for me has been to have a positive impact on children and young people. I always wanted to include an intervention in my major research project, so that the act of carrying out the research had a chance of benefiting the participants directly.

In addition, as a practitioner, I often find intervention-led research most helpful in order to inform what might work with the children I serve. Academic research may be interesting but I am usually left asking, "so what?" This problem is particularly true in my special interest area of neuropsychology where there are usually many articles describing a condition and its outcomes but little or no evidence guiding how a psychologist might help someone with that condition. For example, while working in a specialist NHS post I met several children whose posterior fossa tumours had been surgically resected. They showed common difficulties, and I read enthusiastically about posterior fossa syndrome which was new to me. I found many articles describing the possible sequelae of posterior fossa damage, and factors which would make these sequelae more or less likely, but not a single article suggesting how any of these problems could be prevented or reduced.

For my own doctoral research, I was therefore keen to include some element of intervention in the design. I wanted to be able to say that I had found something practical which I could recommend, or steer others away from. Through the course of the thesis, I came to realise that any evidence-based intervention is just the tip of an iceberg formed of theory, practice and research. In the case of sleep interventions, the underlying iceberg is probably not yet formed well enough to support the development of an intervention which stands a good chance of changing sleep behaviours, and still less chance of changing cognitive abilities. Michie, Johnston, Francis, Hardeman and Eccles (2008) clearly explain that evidence-based interventions require a modelling phase which involves, "hypothesising and testing both *what* to target (behavioural determinants) and *how* to do this (techniques to change these determinants)." (p. 661) In the case of sleep interventions, I think that we are still very much in this modelling stage. We are not sure yet which sleep behaviours we need to encourage, how sleep need might change over the course of development or how individuals might differ in the sleep behaviours which would be optimal for them. With a clearer idea of such behavioural determinants, or what we might call, "good sleep," we would be in a better position to start modelling how to change those determinants.

In terms of the ethics of participant benefit, I can now see that this project, although it had an intervention at its core, may not have brought much benefit to the children involved. The reason for using the sleep education intervention was to generate lasting behaviour change rather than temporary sleep extension or restriction, which was a laudable aim that was not met. The design used would have been more robust if an intervention were available that had good evidence of changing sleep behaviours; given that no such intervention exists yet, a different approach would have been more appropriate. To answer the research question, it may have been more effective to use an experimental manipulation as other studies have done (e.g. Sadeh et al., 2003; Vriend et al., 2013), rather than an intervention with a limited evidence base which was much less likely to alter sleep behaviour.

Having set out these self-criticisms, I think that the project is unlikely to have harmed the participants and they have only missed a very small amount of the curriculum they would otherwise have been taught. There may be long-term benefits in terms of sleep habits as those children move into adolescence, and there may have been positive behaviour change not measured by the methods in this study (either due to missing data or variables which were not assessed, such as other cognitive skills or emotional regulation). The acceptability data suggests that most participants thought the programme was enjoyable and worthwhile, so this study is not likely to have caused negative emotional effects. Looking wider than the participants in this particular study, although this research was not aimed at evaluating the ACES programme, it does provide some useful data for practitioners to bear in mind when considering whether such an intervention might be worthwhile.

Risky research

The study undertaken had many risks associated with its implementation, some of which occurred and were managed, and others that would have stopped the project completely. In hindsight, the research design could have been adjusted to reduce some of these risks before starting to implement the project. Table 24 shows the risks which did happen, and how they were dealt with.

Table 24: Realised risks and their management

Risk	Solution
Attention testing using the CPT took much longer than anticipated	Group-administered test of visual attention was found
Group-administered working memory test was withdrawn from the market	Individual tests were found, along with a volunteer research assistant to administer them
Actiwatch software not compatible with new laptop bought for use in this project	Actiwatches collected on a Friday so they could be uploaded on the desktop and reset
Actiwatches not working correctly	One Actiwatch had to be replaced after the pilot group showed it was faulty
Actiwatches not worn correctly	Despite verbal and written instructions, some missing data had to be accepted
Actiwatches mislaid	Researcher visited several homes to collect Actiwatches not brought into school on collection day. One Actiwatch completely lost – replaced by the supplier at no cost
Sleep diaries not returned	Focus group held to find out why and generate ideas for improving return rates, but it was too late to implement the ideas in this study
Intervention not implemented as directed	Information collected retrospectively about which parts of the intervention were delivered; decision made that all classes had done the core elements so would be included in analysis

If I were to repeat the research, I would place more focus on the teachers, who could have helped to reduce many of these risks. For example, some teachers kept track via class lists of which children had returned sleep diaries and reminded those who had not done so: in future I would explicitly ask all teachers to adopt this strategy. In addition I would ensure that some measures of treatment fidelity were included. With the time required for data collection it was impossible to visit each class during delivery of the intervention, however I would at least provide a checklist of intervention elements that the teacher would complete and return.

Other things could easily have gone wrong during this project, which could have derailed it entirely, including:

- Researcher, research assistant or school unable to stick to timetable (e.g. off sick)
- Laptop or software malfunctioning
- Classes withdrawing during the project
- More Actiwatches lost or broken

The research schedule was extremely tight, with no spare weeks in case a delay occurred anywhere in the system. Luckily all the people involved were able to keep to the schedule every week, so the only missing data was from individual children who were off school on the day of whole-class data collection or failed to return sleep data. If I were conducting the same research again, I would aim to use the whole academic year so that some weeks could be scheduled for no data collection, thus providing a cushion in case data collection ever needed to be pushed back a week. In addition to the lack of contingency time, there was no room for error in collecting and delivering the Actiwatches: failing to do this on time would have knock-on effects for the next class in the schedule who would be relying on the devices being transferred to them. A laptop which was compatible with the Actiwatch software would have helped to solve this problem, as the Actiwatches could then have been taken straight from school to school on the same day.

Many difficulties in this research were driven by the use of 10 Actiwatches to gather data from a large group of children. With no funding for this project, and the set of devices being loaned free of charge, using them sequentially seemed to be the best use of this precious resource. However, it may have been more fruitful to use that resource differently. It would have been possible to select 10 children, for example, and track their sleep habits over a longer period of time. This kind of approach would not have the kind of generalisability gained from larger numbers of participants, but it might have enabled a detailed analysis of what factors influenced sleep each night, whether an experimental manipulation changed sleep habits and whether cognitive variables were related to either long term habits or short term fluctuations in sleep.

Using advice from supervisors

Looking back, there were a number of pieces of advice from supervisors which I did not take at the time but which would have improved this research. On reflection, I think my experiences of working on the callous-unemotional topic perhaps made me more resistant to accepting supervisors' advice. The guidance I had received on that project was different between supervisors, so I felt I needed to trust my own judgements rather than accepting advice straight away. Unfortunately, in most cases, their advice was sound in hindsight.

Literature review

A thorough literature review is advised before designing the empirical study. I read widely and did draft a literature review, however I did not get to the point of selecting relevant studies to analyse in detail before implementing my data collection. I designed my study based on authors' own conclusions about their findings, but when I went back and carried out my own analysis I realised that the existing studies showed much less conclusive evidence relating to my specific research question than I had thought. In future I would look at relevant published research in greater detail, including their methodologies and results, to make a more informed judgement about the existing state of evidence.

For example, Sadeh et al. (2003) reported that, “the sleep manipulation led to significant differential effects on neurobehavioural function measures,” (p. 444). They provide graphs of three cognitive measures which showed different changes depending on whether the children had extended or restricted their sleep. What I had not understood until after commencing my own study was that these were the only three significant results: most of their cognitive measures did not show significant differences depending on sleep extension or restriction. The authors had provided the data correctly, but like most reports (Dwan et al., 2008), the article focuses on significant results rather than null results. The significant relationship was between sleep duration and digits forward (usually considered a test of short term memory), whereas the relationship between sleep duration and digits backward (seen as a test of working memory) was non-significant. In addition the authors provided a table indicating which interactions were significant in an analysis of variance. This table included which cognitive measures showed change between the first and second test, as well as the interaction between time point and group. I had not appreciated that the interaction was the important statistic (three out of nine cognitive measures showed significant interactions, and these were the ones presented in graph form). I saw that the change between the first and second times of testing was significant for digits backward, and misinterpreted this result as meaning that sleep had affected this working memory measure. In fact this result only meant that all the children did significantly better when tested a second time.

I have learned a great deal about reading the literature thoroughly and analytically, which I will be using in future to draw my own conclusions about the existing evidence before designing research based upon it.

Dependence on others

Another good piece of advice was to design research which depends as little as possible on others. As the researcher, you are highly motivated to do what needs to be done, to persevere and to do things as intended. The more you rely on others to facilitate your research (e.g. carrying out data collection or implementing an intervention), the greater the chances that the research does not go as planned. This difficulty is rarely pointed out in standard texts on research design (e.g. Brewer, 2000; Robson, 2011).

The current study was highly dependent on others for its implementation, even more so with the introduction of a research assistant to help with data collection which was necessitated by the unavailability of group-administered working memory measures. Some of this dependency was intentional, for example I wanted to know if the intervention would work if regular teachers delivered it, rather than an external professional. However, given that the intervention did not have good evidence of effecting behaviour change even when delivered by a sleep expert (Blunden et al., 2013), this was not a good decision in terms of answering my main research question. Given the scale of this project, some of its dependency on others was purely practical. There was no funding to buy resources or pay staff, so I was reliant on the manufacturer to provide the actigraphy devices and to replace faulty or lost ones (which they did admirably).

If I were doing this research again, I would look for ways of reducing reliance on others. For example, I could have omitted the intervention altogether, or with more resources delivered it myself. Unfortunately studies of sleep will always require some co-operation from home, as the data cannot be directly collected in school. It would have been possible to use a survey to gauge sleep habits, but this questionnaire approach has been shown to be inaccurate compared with diary or actigraphy methods (Werner, Molinari, Guyer, & Jenni, 2008).

Where it is necessary to rely on others, I would in future place much more emphasis on ensuring they knew what was expected and prompting them to undertake their part. For example, I might have met with each teacher just before they were due to begin intervention, to provide refresher training and ensure that they were confident about delivering all aspects of the intervention.

Data input and analysis

I was advised to use SPSS software from the outset, and to generate one master dataset from which all analyses could be done. However, as I was not very familiar with that programme at the time, I decided to use a Microsoft Excel spreadsheet instead. This decision had advantages, for example it made the set-up and data input quicker because I knew how to use the software. It was also available on all the computers being used for this project, whereas SPSS was only available on one laptop. Initial data entry using Excel was not a problem, as data could easily be imported into SPSS directly.

I then decided to set up different SPSS datasets to answer each of my research questions. I did this because each topic needed only a subset of the data, so it seemed more manageable to have small and specific datasets and results pages.

In hindsight this was a mistake. First, the data entry is likely to be flawed, and when a mistake is spotted, having a single dataset would ensure that all future analyses are carried out with the corrected data. The way that I managed my data meant that any errors had to be corrected on the Excel spreadsheet and then on any SPSS datasets which included that datapoint. I did later create an SPSS dataset with all of the key variables included, with which I double-checked my results from the smaller datasets and continued with the analysis. Second, as the analysis progressed I found I wanted to carry out statistical tests involving other variables which I had not initially copied into SPSS. Third, SPSS deals with calculations from empty cells as missing data, whereas Excel treats them as zero values. I realised this after I had calculated variables in Excel such as mean sleep durations, where the means were lowered if a child had not filled in their sleep time for one night in their diary because Excel treated this as if they had got no sleep that night. It took some time to check through all the data and ensure that the calculated variables were all correct. This problem would have been avoided by using SPSS exclusively.

The (un)importance of sleep?

One reflection from both the literature review and the empirical study is that my assumptions about the importance of sleep have been challenged. At the outset of this work, I believed that sleep was a cornerstone of human performance, and with the advent of an, “always-on,” culture (e.g. Park, 2013), we were all likely to be sleep deprived and suffering cognitive decrements as a result. However, recent systematic reviews suggest that over the last 40 years, adults in Britain have actually increased their average sleep duration (Bin, Marshall, & Glozier, 2012) and over the last 100 years, British children have bucked the worldwide trend, also increasing their average sleep duration (Matricciani, Olds, & Petkov, 2012). Perhaps children here in the UK are not sleep deprived after all, on a population level. The literature demonstrating the cognitive impact of lack of sleep in adults is largely based on studies of severe sleep deprivation (Fortier-Brochu et al., 2012; Lim & Dinges, 2010), and there is little to suggest that smaller variations in sleep behaviours are adversely affecting people. In children, the effects of sleep on cognition appear to be relatively small (Astill et al., 2012). From a public health point of view, then, perhaps sleep is not an issue of concern for children in the UK.

Recent studies have shown genetic variation in functional susceptibility to sleep deprivation in humans (Goel & Dinges, 2012; Pellegrino et al., 2013) and in other animals (Thimgan, Seugnet, Turk, & Shaw, 2015). These findings fit with the general theory of differential susceptibility, which posits that a range of genes render people more or less open to being changed by their environment (Belsky & Pluess, 2009; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & Van IJzendoorn, 2011). These genes may act through a range of mechanisms including metabolic, cardiovascular, immune and central nervous system functioning to affect allostasis (the person's ability to achieve homeostasis despite challenges to regulation) (Karatsoreos & McEwen, 2011). It may therefore be that, as well as individual differences in sleep need, there are individual differences in how well people cope when their sleep need is not met.

Even in groups of children with disabilities, who are often assumed to be at greater risk for sleep problems (e.g. Robinson & Richdale, 2004), objective measures may show that their actual sleep duration is no different from typically developing children. For example, several studies have replicated the finding that children with autistic spectrum disorders do not differ from typically developing children in their total time asleep as measured by actigraphy (Allik, Larsson, & Smedje, 2006; Souders et al., 2009; Wiggs & Stores, 2004). Ashworth, Hill, Karmiloff-Smith and Dimitriou (2013) found that children with Down Syndrome and Williams Syndrome slept for the same amount of time per night as a control group, despite parent-reported problems with bedtime resistance and night-time wakings. One explanation for the problems reported in this study might be that the children in both disability groups had an earlier bed time than the control group. Perhaps these children did not need to go to bed any earlier than their age-matched peers, and if they had gone to bed at a, “normal,” time they might have experienced fewer problems.

While there is no doubt that significant sleep deprivation in adults has serious cognitive consequences, the prevalence of both sleep deprivation and of cognitive problems resulting from sleep deprivation may be lower than I had believed. The evidence for children is even less clear. It is hardly surprising, then, that in the current study a sample of the general population of UK children showed no significant relationship between sleep and working memory, and no clear behavioural effects of a universal sleep education intervention.

A distinct contribution

The current research adds to our knowledge about the relationship between sleep and working memory in children, and also to our understanding of methodological issues in this area.

Methodology

This study has confirmed the relationship between actigraphic and diary measures of sleep behaviours. The findings replicate those found in other countries and with children of higher socioeconomic status (e.g. Tremaine, Dorrian, & Blunden, 2010; Werner et al., 2008), showing that diary and actigraphy measures are in good agreement about sleep and wake times, but that diary measures consistently underestimate wake after sleep onset compared to actigraphy.

Problems with using diary measures repeatedly have been found, which have not been reported elsewhere. Qualitative focus group feedback suggests ways in which future researchers might improve the return rate for sleep diaries over time, which is also new to the literature in this field.

A completely novel finding from this study is that wearing an actigraph did not affect how children completed their sleep diaries. It is, perhaps, surprising that no data has been published to date relating to this issue. It would be a reasonable lay prediction that children would be more accurate in reporting their sleep behaviours when they knew that objective assessment was taking place. However, the current study shows that children of this age filled in their sleep diaries with similar variation whether or not they were given an actiwatch to wear.

This study has also provided the field with an adapted sleep knowledge questionnaire which is appropriate for primary aged children and which has better psychometric properties than the one it was based upon (Benveniste, Thompson, & Blunden, 2012). This questionnaire could be used in future research or for practitioners to evaluate sleep education programmes in their settings.

The relationship between sleep and working memory in children

This study adds correlational data to the body of knowledge about sleep and working memory in children. Most variables showed no significant correlation with each other. The only significant results were a negative linear relationship between diary sleep duration and verbal WM (shorter sleep was related to higher verbal WM scores), and a positive linear relationship between actigraphic sleep efficiency and visual WM when socioeconomic status was partialled out. The correlational data is drawn from a large sample of children who were not self-selected, making the findings relatively robust. These results represent a strong challenge to the assertion of Kopasz et al. (2010) that, "most studies support the hypothesis that sleep facilitates working memory as well as memory consolidation in children and adolescents" (p.167).

The intervention failed to produce systematic effects on sleep variables, so the experimental data could not show whether changes in sleep were related to changes in working memory performance.

To explain these findings, a neurodevelopmental perspective may be helpful. The neural mechanisms underlying working memory are at a relatively early stage of development in this age group. If sleep has similar effects on the brain throughout the lifecourse, it is possible that working memory might not be strongly related to sleep until the fronto-parietal networks subserving it are mature. Another way to look at these results is to consider the body's ability for allostasis. Animals including humans have a range of mechanisms to help compensate for challenges to homeostasis (Karatsoreos & McEwen, 2011), and therefore small changes in sleep behaviours may be well tolerated in most people.

The future for sleep interventions

The current sleep intervention was effective in increasing sleep knowledge, an effect which was maintained at the two to three month follow-up point. However, this knowledge did not translate into changed sleep behaviour as far as the data in this study can show. This pattern is a common feature of universal sleep education interventions (Blunden et al., 2012). Indeed, it is not clear what behaviours would constitute a good outcome for a sleep intervention. Our theoretical understanding of optimal sleep, at different developmental stages and for different individuals, is not yet sufficiently developed for us to be able to define behavioural targets. In the current study, average sleep duration and efficiency were measured, but it may be that other variables such as daily variations are more important to target.

While there may be longer-term and wider benefits than were measured in this study, the immediate results suggest that universal sleep education programmes for this age range are not a good use of resources, largely because most children are getting enough sleep without any intervention. Instead, sleep interventions could focus on helping children who are already starting to develop sleep problems (e.g. Quach et al., 2013) and could use other theoretical underpinnings to support behavioural change (e.g. motivational interviewing; see Miller & Rose, 2009) or change in perceptions of problems (e.g. solution focused therapy approaches to changing, “viewing,” as well as, “doing;” see Bannink, 2007).

Since this study was conducted, a small-scale study using motivational interviewing with junior-aged children has been published (Willgerodt, Kieckhefer, Ward, & Lentz, 2014). The research was presented as a feasibility study, and the authors found that using actigraphy to inform motivational interviewing cycles was acceptable to the families in their study. Willgerodt et al. (2014) were able to recruit nine families who wished to improve their child’s sleep (the response rate is unknown as the number of families invited to participate was not reported). These families participated in four episodes of data-gathering using sleep diaries and actigraphy, two of which also included motivational interviewing with parents and child together to set goals based on the data gathered. Three of the children in this study had a disability (attention deficit hyperactivity disorder or learning disability), and all three had problems engaging in both the data collection and intervention procedures. As a feasibility study, it shows that a short intervention using this approach is manageable and acceptable for practitioners and for families with children who do not have a disability. Unfortunately the results are not reported in enough detail to see whether the intervention was effective, even for the six families who participated in the whole protocol.

In terms of targeting children who may benefit from sleep interventions, the Willgerodt et al. (2014) study used a self-selected group of families with a higher than average socio-economic status (all the mothers were educated to degree level). Perhaps a more inclusive way to identify children would be to screen a population and offer intervention to those experiencing sleep problems of some kind. Objective methods such as actigraphy would not be feasible due to the cost of providing large numbers of devices, and using a simple cut-off for short sleep would include children who need less sleep while excluding those with average sleep but with other sleep problems such as bedtime resistance. Perhaps the most practical way to target children for sleep interventions would be a screening questionnaire such as BEARS (Bedtime issues, Excessive daytime sleepiness, Awakenings during the night, Regularity and duration of sleep, Snoring; Owens & Dalzell, 2005) or CSHQ (Children's Sleep Habits Questionnaire; Owens, Spirito, & McGuinn, 2001). Such a questionnaire could help to identify the kind of help that might be appropriate for each individual, for example snoring might require medical attention while regularity of sleep routine would be more amenable to behavioural approaches.

A further issue for sleep interventions is the subjective nature of sleep problems. What parents report as a sleep problem is likely to be highly culturally bound (Jenni & O'Connor, 2005), which means that interventions could focus on perceptions of problems as well as trying to change the sleep behaviours themselves. For example, a child may be a short sleeper but not suffer any functional impairments such as daytime sleepiness or poor vigilance. Interventions could focus on helping such a family to accept individual differences in sleep need, worry less about getting the child to sleep more and find ways to manage the child who wakes early or stays up late. In addition, the behaviours advocated in sleep intervention programmes need to be culturally sensitive. For example, good sleep hygiene in the USA might include a consistent bedtime routine and a low-stimulus sleep environment, but in other contexts this advice would be at odds with most families who allow their children to stay up with the family at night (Ottaviano et al., 1996) or who have several family members sleeping in one room (Oka, Suzuki, & Inoue, 2008).

The future for sleep research

It is difficult ethically to reproduce the sleep research methods commonly used in adults (e.g. severe sleep deprivation) when working with child participants. However, the current study suggests some ways in which research might usefully continue the search for understanding about how sleep affects cognition in children.

Variability within individuals from night to night, and from week to week, was surprisingly wide in the current sample. The sources of this variation would be useful to identify. In addition, these natural variations provide an opportunity to study acute changes in cognitive performance as a function of sleep variables from the previous night. Individual differences could be a useful approach to future research, given the possibility that different children will have different levels of sleep need, which means that there may be no group-level relationship between sleep and cognitive variables.

Another avenue might be to screen participants so that children with short sleep durations can be selected for targeted study. In adults, Grandner, Patel, Gehrman, Perlis and Pack (2010) suggest that people who habitually sleep less than six hours per night would be a helpful group to study, including two groups: those who are short sleepers because they need less sleep than average and those who are short sleepers due to chronic sleep deprivation. Defining short sleep in this way may be a helpful rule of thumb, but it suffers from methodological difficulties (for example, the six-hour cutoff would be likely to include more people if measured by diary or questionnaire than by actigraphy), and includes a large proportion of the population (24.6% in a 1990 survey of over 30,000 US adults; Hale & Do, 2007). In children, the definition of short sleep would vary by age, but within a study it would be possible to identify a group. Gradisar et al. (2008) split their participants into three roughly equal groups according to their sleep duration, but for a targeted study it may be preferable to focus on a smaller proportion than one-third of the population in order to see significant differences between short sleepers and other children. Such an approach might be able to identify group-level correlations between sleep parameters and working memory measures, as it would seem that cognitive functions are resilient to smaller variations in sleep duration. In addition, targeting a group of short sleepers would enable an experimental approach such as a sleep education programme to have a greater chance of changing sleep behaviours than the universal approach used in the current study.

In terms of the neurodevelopmental perspective on sleep and working memory, future research could take a longitudinal approach and include imaging methods in order to track the development of the frontoparietal networks involved in adult working memory performance. It would be useful to investigate the extent of sleep deprivation required before working memory becomes significantly impaired, at different stages of development. Individual differences in vulnerability to sleep deprivation could also be a fruitful avenue for investigation, including whether any such differences are stable traits over the course of development. In addition, it would be helpful to know whether sleep extension can improve working memory performance or change the neural activity underlying working memory tasks, especially in children with habitual short sleep durations. One specific neuropsychological hypothesis to test would be that the relationship between sleep and WM becomes stronger as the individual's brain matures into using fronto-parietal areas that may be more susceptible to the effects of sleep deprivation.

Key messages for educational psychologists

From this literature review and empirical study, a number of key points can be summarised for practitioner educational psychologists:

- There is wide variation in what could be considered normal sleep duration for children. There are differences between individuals, but also within an individual from night to night.
- Brief night-time wakings are very frequent in children. If parents are reporting problems in this area, the psychologist needs to consider the context (e.g. if the parent is in the child's room noticing every movement, they may simply be reporting normal wakings).
- Children with developmental disabilities are not necessarily more likely to have sleep problems. There is a complex interplay between family expectations and child behaviour, for example it may be that a child with a disability such as Down Syndrome is being asked to go to bed earlier than is physiologically needed.
- Assessment of sleep by diary method is likely to give a reasonably accurate picture of sleep onset and offset times, but not of night-time wakings. To take these wakings into account, actigraphy would be a useful method.

Since this study was started, much cheaper and more accessible forms of actigraphy have become commercially available (e.g. FitBit, Jawbone and Garmin brands). Although their accuracy would need to be established, a device of this sort may be helpful for a psychologist to have in their library of equipment.

- Most children of primary school age are relatively resilient to sleep deprivation, although there are likely to be individual differences in this resilience.
- Sleep duration has a weak relationship at best with working memory in children. Advocating that all children get more sleep is unlikely to produce significant gains in cognitive skills of this sort. However, there may well be other benefits of adequate sleep such as reduced risk of obesity and better emotional regulation, which were not addressed in this study.
- Universal interventions may not be an appropriate way to address sleep difficulties in the primary school age range. From the current study, it seems that most children in the general population did not need to change their sleep habits, and for those who did, a short universal education programme may not be enough to alter their sleep behaviours.
- For individual casework, it is worth asking questions about sleep as part of the psychological formulation. If sleep problems are identified, the psychologist needs to consider whether the issues are around family perceptions and expectations, actual sleep behaviours or both. Sleep may only need to be prioritised for intervention if it appears to be affecting daytime functioning in some way.

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Appendix 1: Ethics approval

UCL RESEARCH ETHICS COMMITTEE
GRADUATE SCHOOL OFFICE

Dr Phil Stringer
Educational Psychology Group
Research Department of Clinical,
Educational and Health
Psychology
26 Bedford Way
UCL

21 May 2013

Dear Dr Stringer

Notification of Ethical Approval
<u>Project ID: 4519/001: Sleep and working memory in pre-adolescent children</u>

I am pleased to confirm that your study has been approved by the UCL Research Ethics Committee for the duration of the project i.e. until August 2016.

Approval is subject to the following conditions:

1. You must seek Chair's approval for proposed amendments to the research for which this approval has been given. Ethical approval is specific to this project and must not be treated as applicable to research of a similar nature. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing the 'Amendment Approval Request Form'.

The form identified above can be accessed by logging on to the ethics website homepage: http://www.grad.ucl.ac.uk/ethics/ and clicking on the button marked 'Key Responsibilities of the Researcher Following Approval'.

2. It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. Both non-serious and serious adverse events must be reported.

Reporting Non-Serious Adverse Events
For non-serious adverse events you will need to inform Helen Dougal, Ethics Committee Administrator (ethics@ucl.ac.uk), within ten days of an adverse incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol. The Chair or Vice-Chair of the Ethics Committee will confirm that the incident is non-serious and report to the Committee at the next meeting.

The final view of the Committee will be communicated to you.

Reporting Serious Adverse Events

The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator immediately the incident occurs. Where the adverse incident is unexpected and serious, the Chair or Vice-Chair will decide whether the study should be terminated pending the opinion of an independent expert. The adverse event will be considered at the next Committee meeting and a decision will be made on the need to change the information leaflet and/or study protocol.

On completion of the research you must submit a brief report (a maximum of two sides of A4) of your findings/concluding comments to the Committee, which includes in particular issues relating to the ethical implications of the research.

With best wishes for the research.

Yours sincerely

Professor John Foreman
Chair of the UCL Research Ethics Committee

Cc:
Rebecca Ashton, Applicant
Professor Peter Fonagy, Head of Department

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Appendix 2: Project date planner

Activity	Autumn term	21/10/2014	half term	04/11/2013	11/11/2013	18/11/2013	25/11/2013	02/12/2013	09/12/2013	16/12/2013	06/01/2014	13/01/2014	20/01/2014	27/01/2014	03/02/2014	10/02/2014	17/02/2014	24/02/2014	03/03/2014	10/03/2014
Recruit	x																half term			
Train	x																half term			
Diary week		Control 1									Control 2	Control 3	Intervention 1	Intervention 2			half term			
Diary plus actigraphy and testing				Control 1							Control 4	Control 2	Control 3	Intervention 1			half term			
Lesson 1 & 2					Control 1								Control 2	Control 3 & 4	Intervention 1	Intervention 2	half term			
Lesson 3						Control 1								Control 2	Control 3 & 4	Intervention 1	half term	Intervention 2		
Project week 1							Control 1								Control 2	Control 3 & 4	half term	Intervention 1	Intervention 2	
Project week 2								Control 1								Control 2	half term	Control 3	Intervention 1	Intervention 2
Diary plus actigraphy and testing									Control 1									Control 2	Control 3 & 4	Intervention 1
Diary plus actigraphy and testing																Control 1				

Activity	17/03/2014	24/03/2014	31/03/2014	07/04/2014	14/04/2014	21/04/2014	28/04/2014	05/05/2014	12/05/2014	19/05/2014	26/05/2014	02/06/2014	09/06/2014	16/06/2014	23/06/2014	30/06/2014	07/07/2014	14/07/2014		
Recruit				Easter	Easter						half term									
Train				Easter	Easter						half term									
Diary week	Intervention 3	Intervention 4		Easter	Easter						half term									
Diary plus actigraphy and testing		Intervention 3	Intervention 4	Easter	Easter						half term									
Lesson 1 & 2			Intervention 3	Easter	Easter	Intervention 4					half term									
Lesson 3				Intervention 3	Easter		Intervention 4				half term									
Project week 1				Easter	Easter		Intervention 3	Intervention 4			half term									
Project week 2				Easter	Easter			Intervention 3	Intervention 4		half term									
Diary plus actigraphy and testing	Intervention 2			Easter	Easter				Intervention 3	Intervention 4	half term									
Diary plus actigraphy and testing				Easter	Easter	Control 4	Control 2	Control 3			half term		Intervention 1	Intervention 2			Intervention 3	Intervention 4		

Appendix 3: Sleep diary blank form

Sleep diary

Name .... School: .... Starting date ....

	Monday night	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Time into bed							
Time lights out							
Time I think I fell asleep							
Time I think I woke up	*Tuesday morning*	*Wednesday morning*	*Thursday morning*	*Friday morning*	*Saturday morning*	*Sunday morning*	*Monday morning*
How many times did you wake up during the night?							
How long were you awake altogether during these wakings?							
When you got up in the morning, how did you feel? 1 – Very sleepy 2 – Quite sleepy 3 – OK 4 – Wide awake 5 – Really wide awake							

To be filled in by the child wherever possible – although grown-ups can help if needed!

Appendix 4: Actiwatch wearer’s guide

Thank you for agreeing to wear this Actiwatch to track your sleeping habits.

You should fasten the watch onto your wrist and just leave it there until you need to return it.

Frequently Asked Questions

- **Can I wear it while I wash?**

Yes, the Actiwatch is water resistant so you can wear it in the shower or bath for up to 30 minutes.

- **Can I wear it while I swim?**

It’s best to remove the Actiwatch while swimming, as the Actiwatch would be likely to be in the water for more than 30 minutes. Don’t forget to put it back on afterwards!

- **Can I wear it while I exercise?**

Yes, the Actiwatch can be worn during any activity where you could wear a normal watch. If your school or club has a policy of no watches during an activity, then you should take off your Actiwatch – but don’t forget to put it back on afterwards!

- **What are the buttons for?**

The Actiwatch has some functions which we are not using during this study, so the buttons have been turned off. You can press them if you like, but the buttons won’t do anything.

- **What is it measuring?**

The Actiwatch measures light and movement. So it will record when it goes dark and when you stop moving about at night. It will also record any times during the day when you are very still – this is why we need your sleep diary as well, to make sure we only count your sleep time and not when you are just sitting still! The Actiwatch expects some movement every so often, so if you take the Actiwatch off then it will record that you are not wearing it.

- **Should there be a display on the watch?**

No, the Actiwatch has been set to have a blank screen for this study.

- **Can I clean the Actiwatch?**

There should be no need for you to clean the Actiwatch. It will be cleaned by the researcher before being given to you. If you do wish to clean the Actiwatch during the week you have it, you can wipe it with a soft cloth moistened with water and a mild detergent if needed. Do not use bleach, alcohol or abrasive based cleaners as they may damage the Actiwatch.

- **The display is flashing, what does that mean?**

The display only flashes if the Actiwatch is not fastened properly. It could be too loose or too tight. Refasten the strap so that the Actiwatch is snug on your wrist.

- **The display is showing a battery sign, what should I do?**

When the battery is running low, this sign will show: Keep wearing the Actiwatch for the rest of your week, and tell the researcher when you give it back.

- **The Actiwatch is making my skin red, what should I do?**

First try loosening the wrist strap slightly. If the Actiwatch is still irritating your skin, remove it and give it back.

More questions? You can contact the researcher at rebecca.ashton@ucl.ac.uk or 01254 666980.

Appendix 5: Sleep knowledge questionnaire

Sleep knowledge questionnaire

Please answer the following questions by ticking either true or false

	True or False?	**True**	**False**	**Don't Know**
1	Sleep helps me remember things	T		
2	Boys have deeper sleep than girls		F	
3	Doing something calm before bed can help me fall asleep	T		
4	I should go to bed at the same time every night	T		
5	Exercising every day can help me sleep better	T		
6	I need about 7 hours' sleep each night		F	
7	Watching TV before bed can make it hard for people to sleep	T		
8	Not getting enough sleep can make people overweight	T		
9	Doing exercise just before bed can help me fall asleep		F	
10	Children need less sleep than their parents each night		F	

Appendix 6: Amendments to ACES materials

Changes are in square brackets, original first then amended wording.

Parent booklet

p.2 Added information about the UK adaptation after Sarah Blunden's biography. Contents list added.

p.3 "Eat your veggies" replaced with "eat your greens".

p.8 Removed "repeating grades" as we don't usually do that in the UK. Added "forgetting to take the right kit".

p. 12 Poor sleep in infants - Before [that] [9 months] they actually don't have a memory of that.

p.13 Two additional points in what parents can do to assist children's sleep:

- Too much light in the bedroom, especially in summer time. Windows should have blinds or curtains that will shut out enough light for the child to sleep even if it isn't dark outside. Night lights are fine if the child is scared of the dark.
- Being too hot or too cold. It is very hard for anyone to sleep if they are not comfortable. Children need to have ways to change the temperature, e.g. thicker or thinner pyjamas; a sheet if the duvet is too warm; opening or closing a window.

p.13 Changed "gentle loving and touching bedtime routine" to "gentle bedtime routine".

p.16 what parents can do to assist sleep in adolescents – breakfast outside is unusual in the UK!

[Have breakfast outside in the sun.] [Open the curtains or turn the light on when it's time to wake.] This will give their body the cue to wake up.

p.17 Example – Kelly had to become 18 rather than 16 to reflect UK age for driving.

p.18 point 6 – reference to having to repeat a class removed, as this is not a common practice in the UK.

p.20 sleep questionnaire – removed item "do you have a bedroom clock?" as most people do and having the clock is not the problem. Changed the next item from "Do you anxiously check the clock when you are awake at night?" to "... check the time" – as people may use other devices than a clock.

p.21 getting help for sleep disorders:

4. Allied health care workers (e.g. psychologist) through the [local

association] [school nurse or GP]

Child workbook

p.2 WOW! You are in Year [4] [5].

p.5 Sleep wheel – smaller wheel is labelled “Wheel B – cut this one out” and the instructions relate to Wheel B.

p.8 Examples of sleep patterns –gender neutral names have been assigned. The bed times have been amended to match the total sleep times given. The sleepy scores have been changed to match the direction of the scale used (i.e. 2 is quite sleepy and 4 is wide awake). A question has been added at the end of the page: “whose sleep pattern is better?” to clarify the purpose of the information on the page.

p.9 Sleep hygiene: [You can include a “special time” with mum and/or dad (reading and cuddling).] [You can include relaxing activities like having a drink, a bedtime story and being tucked into bed.]

p.10 Bedroom routine exercise – the example routine has been simplified to make it more realistic for an individual child.

Original example	**Amended example**
Bath or shower- into PJs	Bath or shower- into PJs
Warm milk in lounge	Warm milk in lounge
Into bedroom	Chat quietly with my brother
Spend quiet time	Clean teeth
Time with Dad reading	Into bedroom
Have a quiet talk to my brother	Time with Mum or Dad reading
Listen to quiet music in the dim light	Tucked into bed
Turn out the big light – put on the night light	Turn out the big light and put on the night light
Open the door	Sleep time
Good night from everyone	
Sleep time	

p.12 Cloze exercise has been swapped to boxes with only the correct words available. This is to give the best chance of success through errorless learning and makes more readable sentences if the child comes back to the page at a later date. Also removed reference to “ particularly hard things like science or maths” because different children will find different things harder to learn. Also added sentence: your body finds it harder to know how much ………….. (food) it needs, so you can end up overeating and putting on …..……… (weight)

p.14 So what have we learned – I have added “3 things I can do to improve my sleep” for children to fill in, following the theory of planned behaviour in which intention to change needs to be operationalised.

Just for fun section removed – these quizzes need to be given at set times for evaluation purposes. The relaxation exercise has been moved to just after the bedtime routine exercise.

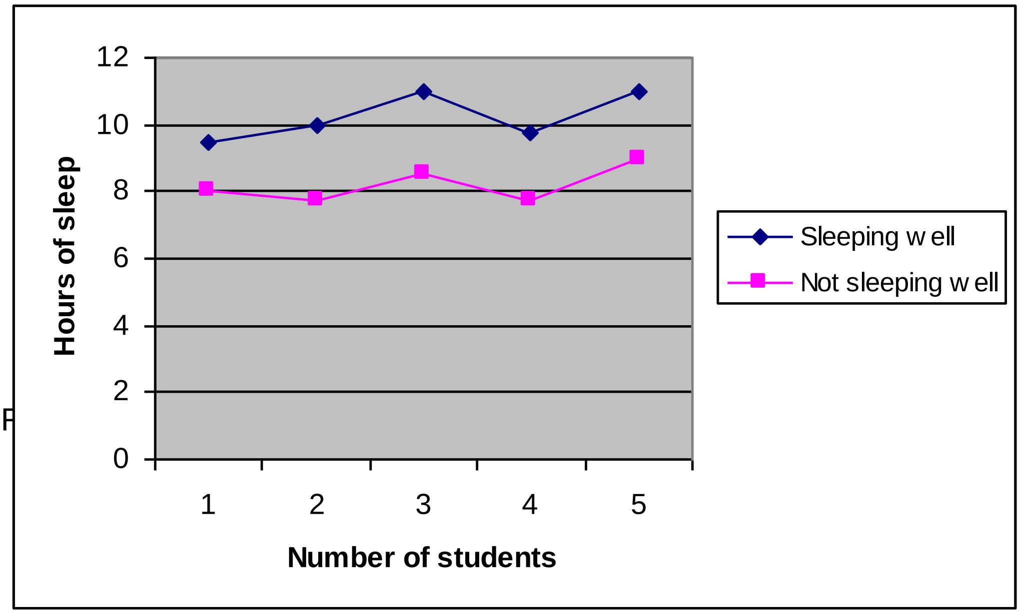
Sleep diary also removed – this will be given as a separate sheet.

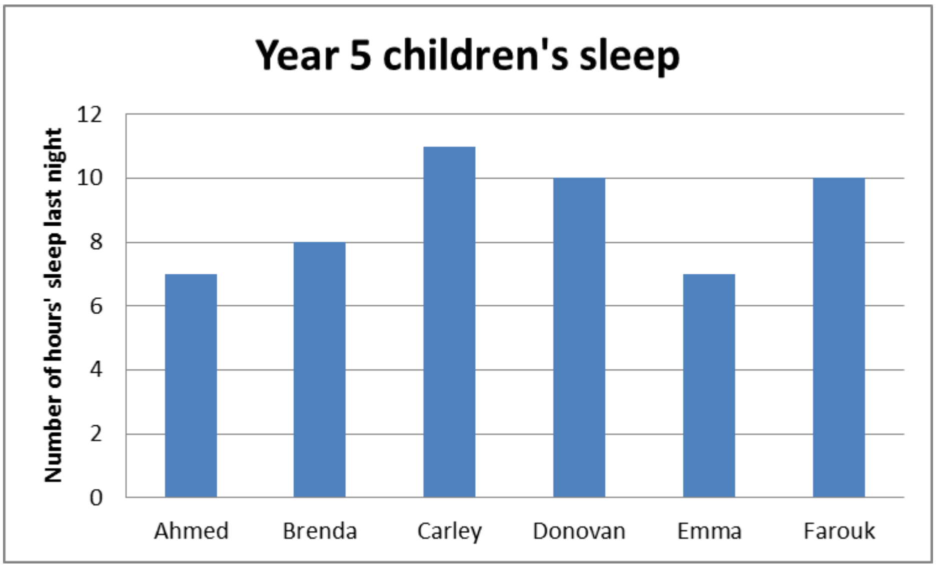
PowerPoint session 1

- Altered page numbers to be consistent with workbooks
- 5 stages of sleep – added “this is when dreams can happen” to Stage 5 description
- Sleep cycle diagram – added “also called Stage 5” to “REM Sleep”
- Removed sleep diary slide – children will already have done this before the first session
- Placed the “complete the blanks” exercise from www.sleepforkids.org as an extension activity after making the sleep wheel.
- Changed final slide from “Australian Sleep Education Programme” to “Australian Centre for Education in Sleep” – just for consistency throughout.

PowerPoint session 2

- Changed “student X” and “student Y” to match page 8 of the child workbook
- Replaced line graph with bar chart because this is an inappropriate use of a line graph (it doesn’t make sense for the data points to be connected because each point is for a different child):





Children are then invited to identify which children are getting enough sleep – making a more interactive experience for the class.

- Altered the “bedtime activities” slide to remove references to their sleep diary, since we are using a simplified diary that does not include activities.
- Also on “bedtime activities”, included clearer instructions for teachers about safely asking children to share information about what they did in the hour before bed time last night.
- Pie chart removed – I felt it could be confusing for a number of children who may not understand percentages or pie charts well enough yet.
- Improving sleep hygiene page – clarified the language: [“Dos “ for good sleep hygiene] [For good sleep hygiene, DO:] and [“Don’ts” for good sleep hygiene:] [For good sleep hygiene, in the hour before bed, DON’T:]
- Added a note for the teacher for clarification on the sleep hygiene page: “Doing exercise during the daytime can help you sleep, as you feel physically tired and ready for sleep. However, exercise too close to bedtime can stop you sleeping. So the message is that exercise is a good thing to do, but not right before bedtime.”
- Looking at bedtime activities again – I have changed the classroom discussion to focus on generating class ideas for good activities that they could include in a bedtime routine. This brainstorm might help them fill in the workbook page on their own routine.
- Own routine is to be done in class rather than at home, to ensure every child completes the activity.

PowerPoint session 3

- Improving sleep hygiene slide removed – it’s a repeat from earlier and children can refer to their workbook page.

- Weblink to sleepsolutions.com removed, internet page no longer exists.
- Added suggestion for a Youtube clip on sleep walking.

Teacher's manual and background information

- Added information about the UK adaptation after Sarah Blunden's biography.
- Paragraph numbering removed.
- Practical guidance placed first, then background information as the appendix (thus reversing the order of the original document).
- Practical guidance includes a session plan for each of the 3 lessons (substantially revised from the original, and teachers are encouraged to set out their own lesson plans using their own school's template during the training session).
- Example of a nightmare is provided, to avoid children having to tell their own personal accounts.
- Relaxation bathtime exercise removed – it's in the children's workbook and doesn't need duplicating.
- Project topic 5 removed, as it refers to adolescent sleep and these are primary children.
- Sleep diary and true/false knowledge questionnaires are placed as an appendix, and the rest are deleted as they are only relevant to adults.

Appendix 7: Flyer to schools

Sleep

Do the children in your class know enough about sleep? Are they getting enough of it?

FREE TEACHING MATERIALS AVAILABLE

Getting a good night's sleep is important for all of us, but especially for children. Sleep helps children to remember things better (Henderson et al, 2012), keep their emotions in check (Simola, 2012) and maintain a healthy weight (Gozal & Kherandish-Gozal, 2012). Crucially for learning, since working memory is a strong predictor of academic performance (Alloway & Alloway, 2010), sleep is related to working memory performance (Steenari et al, 2003).

We all know that lots of children are not getting enough sleep and research demonstrates that children are getting less sleep now than in previous decades (Iglowstein, 2003). But what can we do about it?

A University College London research study is planned for academic year 2013-14, trialling a sleep education programme, and all **Year 5** classes in BwD are invited to take part! Participating classes will receive everything needed to teach 3 high-quality lessons about sleep and a project to consolidate learning. In return we ask you to help us collect the data required to evaluate this trial programme.

For more information please contact:
Rebecca Ashton

Appendix 8: Teacher information & consent form

Information Sheet for Teachers

This information sheet is for you to keep.

Title of Project: **Sleep & working memory in pre-adolescent children**

This study has been approved by the UCL Research Ethics Committee (Project ID Number): **4519/001**

Name	Rebecca Ashton
Work Address	
Contact Details	

We would like to invite Year 5 classes to participate in this research project.

Details of Study:

Getting enough sleep is very important for children, as it affects their learning, health and wellbeing. We are hoping to trial a new sleep programme which will teach children about sleep and how to get into good sleeping habits. The programme involves 3 lessons for the whole class plus a project, with training and all the materials you will need.

Schools who volunteer for this programme will be randomly allocated to one of three groups: classroom programme with classroom project, classroom programme with home project and parent information, or waiting list. Schools on the waiting list will be asked to participate in all the data collection, and will get their copy of the intervention programme at the end. The start date for your intervention can be negotiated with me, within the academic year 2013-14.

If you wish to participate, we would ask you for some data about each child in the class: their gender, postcode, attainment levels and SEN status. Before and after the intervention, and again 3 months afterwards, each child in the class would do a sleep knowledge questionnaire and would take home and complete a week's sleep diary. In addition the researcher would visit school during the week before and the week after the intervention, and again 3 months afterwards, to assess each child in the class using computer-based tests of attention and working memory. At the end of the intervention we have a short questionnaire for you, each child and their parents, to tell us what you thought of the programme.

We need up to 10 children from each participating class to give us some extra data before and after the intervention, and again 3 months afterwards. This will consist of wearing a motion-sensitive Actiwatch while they sleep each night for a week, to record their sleeping patterns electronically. If you volunteer your class for this study, we would write to each child in the class inviting them to do this extra part.

The advantages of participating in this study are that you will receive free training and a free copy of this new sleep intervention programme. We hope, from the existing evidence, that your children will sleep better as a result – but we can't guarantee that will happen.

In return, your commitment will be to deliver the programme in class (and to parents if you are in that group), and to assist us in collecting the data required to evaluate this programme. We will need the use of your ICT suite for a day to do the data collection each time. We don't anticipate that the programme will cause any problems for your children or their parents, but as with any other curriculum area it may raise issues that you would need to manage, with my support as appropriate.

Please discuss the information above with others if you wish or ask us if there is anything that is not clear or if you would like more information.

It is up to you to decide whether to take part or not; choosing not to take part will not disadvantage you in any way. If you do decide to take part you are still free to withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection Act 1998.

Informed Consent Form for Teachers

Please complete this form after you have read the Information Sheet.

Title of Project: **Sleep & working memory in pre-adolescent children**

This study has been approved by the UCL Research Ethics Committee (Project ID Number): **4519/001**

Thank you for your interest in taking part in this research. Before you agree to take part, the person organising the research must explain the project to you. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

Participant's Statement

I **(name) ………………………………. (school) ……………………………………**

- am a Year 5 class teacher.
- have read the notes written above and the Information Sheet, and understand what the study involves.
- understand that if I decide at any time that I no longer wish to take part in this project, I can notify the researchers involved and withdraw immediately without giving a reason.
- consent to the processing of my students' personal information for the purposes of this study.
- understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.
- understand that participating teachers will receive a copy of a programme which is under copyright, and agree not to share or use it outside this school.
- agree that the research project named above has been explained to me to my satisfaction and I agree to take part in this study.

Signed: …………………………………………… Date:

Email: Phone:

I (name of head teacher) ……………………………………………….

- agree to support the above teacher and his/her class to participate in this study.

Signed: ………………………………………………………………………… Date:

Appendix 9: Parent and child information & consent form

Information Sheet for Parents & Children

You will be given a copy of this information sheet.

Title of Project: **Sleep & working memory in pre-adolescent children**

This study has been approved by the UCL Research Ethics Committee (Project ID Number): **4659/001**

Name Rebecca Ashton

Work Address

Contact Details

We would like to invite Year 5 children to participate in this research project.

Details of Study:

Getting enough sleep is very important for children, as it affects their learning, health and wellbeing. Your Year 5 class is going to try out a new programme of 3 lessons and a project which will teach children about sleep and how to get into good sleeping habits.

Everyone in the class will be asked to fill in a sleep diary and a questionnaire as part of this programme. Everyone will also be asked to do computer-based tests of memory and attention skills during school time. These are just part of the curriculum that the school has chosen to provide for Year 5, like any other lessons and like any other homework. However, if you do not wish to take part in this programme please let the class teacher know.

We also need up to 10 children from each class to give us some extra data. This will consist of wearing something called an Actiwatch while they sleep each night for a week before the programme starts, a week at the end of the programme and again 3 months later. The Actiwatch looks like a watch, and is worn on the wrist. It measures how long a child is really asleep, as well as any times when they wake up in the night. This helps us to see how accurate the sleep diary is.

If you would like to be one of the 10 children who wear the Actiwatch, please return the consent form attached. We will pick 10 at random from the forms we receive, and will tell you if you have been selected or not.

The advantages of giving us that extra data are that we will be able to see if the programme makes any difference to children's sleeping habits, and if getting more sleep means that children are better at paying attention and remembering information. You would be helping us to find out whether this sleep programme really works or not, so teachers can decide whether to use it with their children.

In return, you are agreeing to provide that extra data on three occasions. You would also need to give back the Actiwatch at the end of each of the three weeks, as we need them for other children.

Please discuss the information above with others if you wish or ask us if there is anything that is not clear or if you would like more information.

It is up to you to decide whether to take part or not; choosing not to take part will not disadvantage you in any way. If you do decide to take part you are still free to withdraw at any time and without giving a reason. Whether you take part in this extra data or not, we will write to you at the end of the project to tell you our findings. We should be able to let you know whether this sleep programme improves children's sleep and, if so, whether that improves their memory and attention.

All data will be collected and stored in accordance with the Data Protection Act 1998.

Informed Consent Form for Parents & Children

You only need to return this form if you would like to be one of the ten children in your class who wears an Actiwatch.
Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Project: **Sleep & working memory in pre-adolescent children**

This study has been approved by the UCL Research Ethics Committee (Project ID Number):
4519/001

Thank you for your interest in taking part in this research. Before you agree to take part, the person organising the research must explain the project to you.

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

Participant's Statement

I **(student) ………………………………………………. (school) ………………………………………………….**

- am a Year 5 student.
- understand what the study involves.
- would like to be one of the ten children in my class who wears an Actiwatch while sleeping.
- understand that I can change my mind about being in this study at any time.
- know that my Actiwatch information will not be given to anyone else but the researcher.

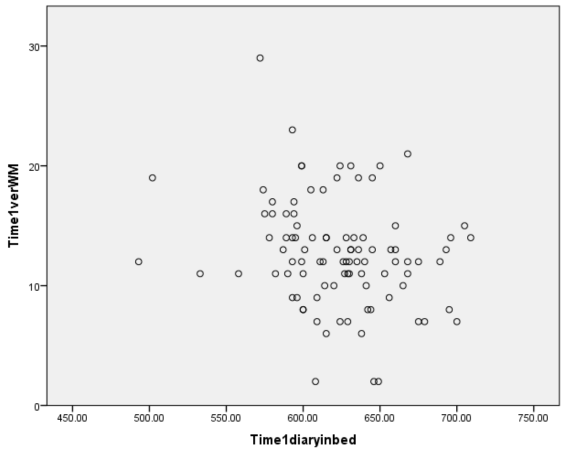
Signed: ……………………………………………………………………………… Date:

I (name of parent) ……………………………………………….

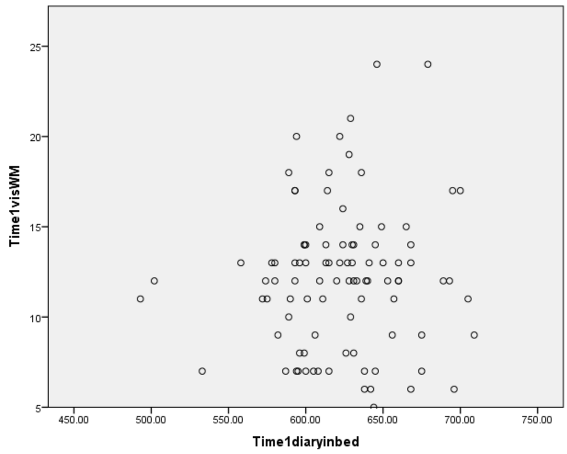
- agree to support the above child to participate in this study.

Signed: Date:

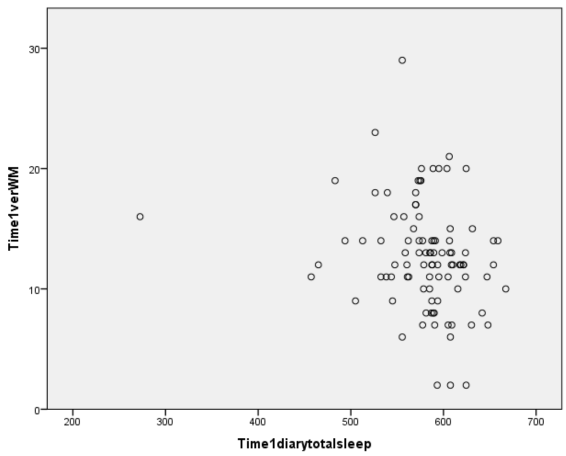
Appendix 10: Scattergrams showing relationships between WM and sleep variables



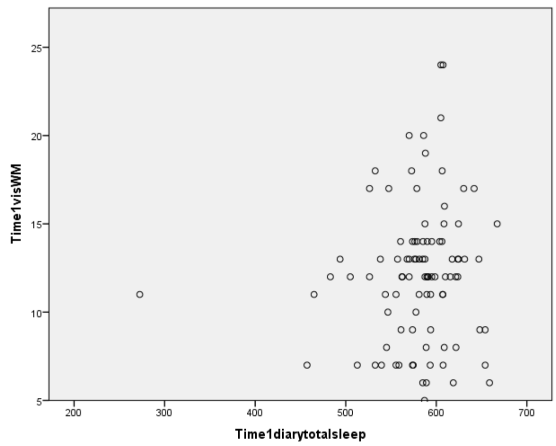
Verbal WM & diary time in bed



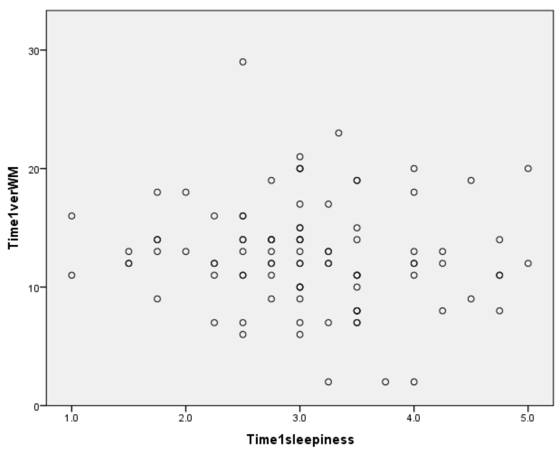
Visual WM & diary time in bed



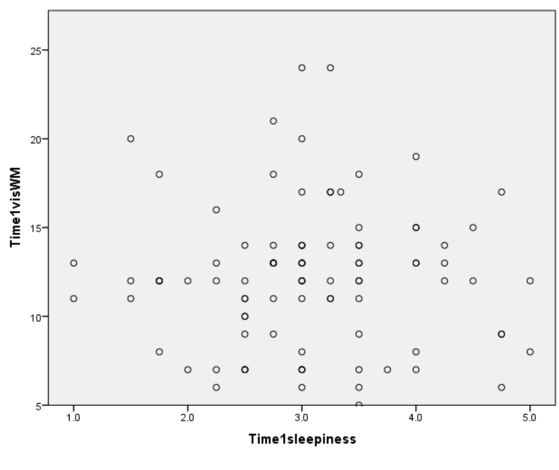
Verbal WM & diary time asleep



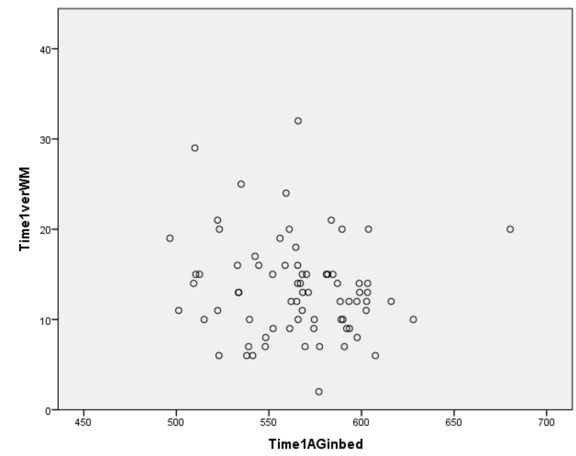
Visual WM & diary time asleep



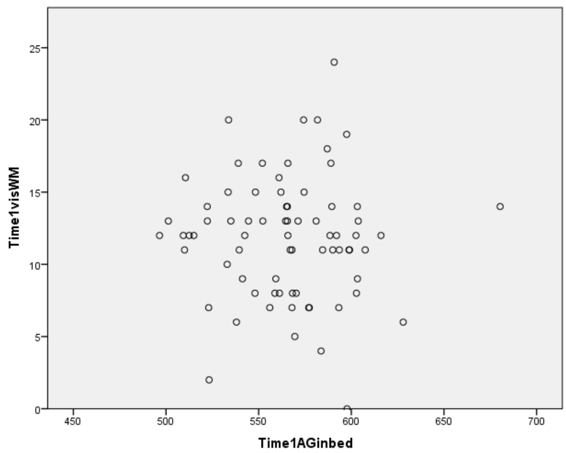
Verbal WM & diary sleepiness



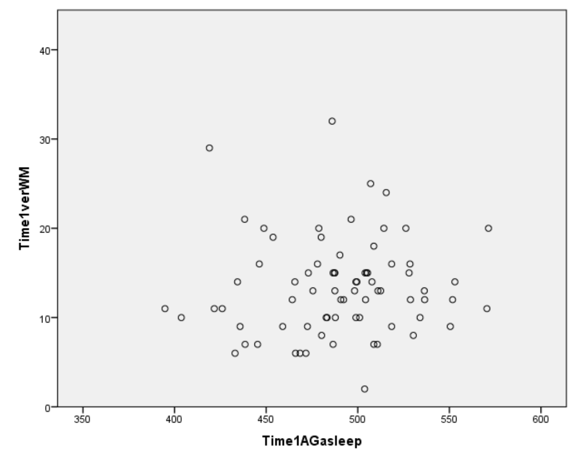
Visual WM & diary sleepiness



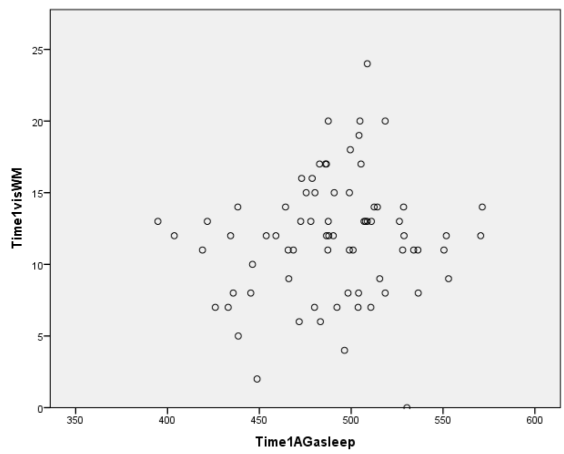
Verbal WM & actigraphy time in bed



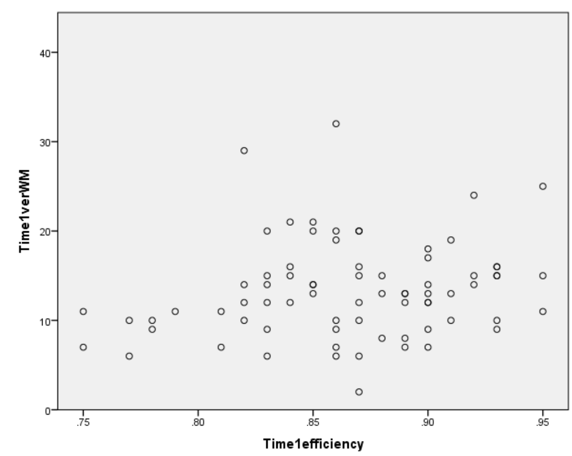
Visual WM & actigraphy time in bed



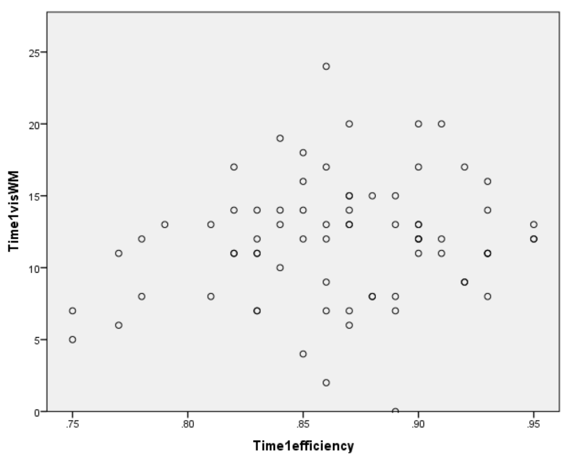
Verbal WM & actigraphy time asleep



Visual WM & actigraphy time asleep



Verbal WM & sleep efficiency



Visual WM & sleep efficiency