Chapter 7

Sleep-related learning

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Introduction

Quality and quantity of sleep are an essential part of health, cognition and well-being; yet, sleep disorders are disturbingly prevalent in neurodevelopmental disorders. The fragility of sleep and its variable sleep architecture between individuals still remains understudied. It is therefore unclear what mechanisms drive these differences. Sleep involves finely tuned multidimensional processes of biochemistry, genetics and psychological processes in response to external environmental cues. Thus, it is important to appreciate the complexity of the sleep state, which involves multiple levels of regulation and directly impacts on one's life. It is now time to move away from the static viewpoint of the sleep state and acknowledge the view of dynamic processes occurring during sleep and identify the impact of sleep on cognitive processing.

Sleep architecture

Our brains go through a variety of different activities during sleep. Sleep is subdivided into five stages (I to V), corresponding to different depths of sleep. As we drift off to sleep, we enter stage I of sleep, which usually lasts around 5-10 minutes. Stage I is marked by a slowing of electroencephalography (EEG) recordings as the fast alpha waves, characteristic of the drowsy wake state, are replaced by lower-frequency theta waves. This stage is considered a transition period between wakefulness and sleep and is also accompanied by slow, rolling eye movements. Stage II lasts for around 20 minutes and involves mixed-frequency brain waves with rapid bursts of rhythmic brain wave activity known as sleep spindles and intermittent high-amplitude K complexes (large positive and immediate negative deflections of the EEG signal). These electrophysiological markers have been associated with memory consolidation and learning. Stages III and IV of sleep are characterised by the slowest electrical waves in the delta frequency (4 Hz), which reflect synchronised depolarisation and hyperpolarisation in large populations of neurons (also termed slow-wave sleep [SWS] or deep sleep). SWS is characterised by a predominance of vagal activity with slowing and regularising of cardiorespiratory rates. Even though the person is deeply asleep, electromyography monitoring shows that tonic activity of the postural muscles is preserved, although in practice whole-body movement is almost entirely absent. It is, however, in this stage of sleep that parasomnias such as sleep walking may occur. Stage V, often known as rapid eye movement (REM) sleep, is when most dreaming occurs. This stage

is characterised by increased brain activity, profound muscular hypotonia and increased sympathetic nervous system activation with irregularity of cardiac and respiratory rates. A distinctive feature of REM sleep is activation of cholinergic neurons to levels seen in the waking state.

Complex activity of hormones such as melatonin, cortisol and many others are secreted into the bloodstream during sleep. For example, growth hormone is related in part to repair processes that occur during sleep. A decrease in growth hormone release during sleep is linked to reduced muscle mass and strength, increased fat tissue and a weakened immune system, among other factors. Follicle-stimulating hormone and luteinising hormone, which are involved in maturational and reproductive processes, are among the hormones released during sleep. Melatonin plays a pivotal role as a major neuroendocrine modulator of circadian biorhythms. In addition to functioning as synchroniser of the biological clock, melatonin also exerts a powerful antioxidant activity and interacts with the immune system. Abnormally high levels of cortisol secretion during sleep have been associated with poorer performance on tasks of declarative memory, executive function and negative emotionality (Li et al., 2006; Scher et al., 2010).

Sleep and cognition

In recent years, a great body of literature has emerged debating the impact of sleep on daytime behaviours and cognition. It has become clear that sleep is essential for numerous functions, including health, mood and cognition, and that even a modest sleep disruption can have severe detrimental effects. In both adults and children, this can impact on daytime behaviour and the ability to maximise potential at school or work. In children, sleep disruption is often associated with symptoms observed in attention deficit hyperactivity disorder (ADHD). Parents often describe their tired children as 'bouncing off the walls'. This is clearly seen in children who snore. Snoring is the most common symptom of obstructive sleep apnoea syndrome (OSAS), which causes sleep disruption by decreasing oxygen levels in the blood (hypoxia) leading to arousal. On average, 27% of young children snore, but this improves with age to around 3-5% in children aged 9-14 years (see Gozal, 2008). Children who snore are reported to display deficits in daytime behaviours such as impaired attention, learning, memory and school performance, have a lower IQ and exhibit increased hyperactivity and problem behaviour. These deficits are often seen to improve after adenotonsillectomy (removal of the tonsils and adenoids), but with some residual long-lasting effects. This may reflect damage to the frontal lobes caused by prolonged apnoeic episodes and disruption to sleep architecture suffered during the critical growth stages of neural development, causing an information processing deficit (Andreou & Agapitou, 2007; Blunden et al., 2005; Gozal & Pope, 2001).

Clinicians disagree on whether daytime behaviour is most influenced by the sleep disruption caused by sleep-disordered breathing or by the hypoxia itself and by hypercarbia (increased circulation of carbon dioxide). Hypoxia refers to the abnormal drop in oxygen levels following apnoeic/hypopnoeic episodes. When this occurs during sleep, oxygen delivery to the brain is diminished. In rat models, this leads to cell death and reduced

long-term potentiation, which can have significant long-term effects for neurocognition in the developing brain. This model is probably generalisable to humans.

In a review paper, Blunden and Beebe (2006) assessed the arguments for each case. A number of studies indicated that hypoxia is the mitigating factor for cognitive impairment in children, evidenced by the observation that children suffering mild levels of oxygen desaturation have associated deficits in neurocognitive and psychosocial domains, and also lower general intelligence, memory and attentional capacity, even without upper airway obstruction or respiratory arousals. Children have also been shown to make an improvement in vigilance and hyperactive behaviour following adenotonsillectomy. By contrast, impairments on sustained attention, vigilance, mental flexibility, memory, intelligence and school performance are most associated with disturbed sleep architecture and observable symptoms of sleep-disordered breathing, rather than hypoxia. Also, sleep problems that create sleep disruption or deficit, such as periodic limb movement disorder (PLMD), insufficient sleep syndrome, sleep fragmentation and experimental sleep disruption or restriction, create problematic cognitive and behavioural effects, even in the absence of sleep-disordered breathing. Blunden and Beebe (2006) concluded that sleep deprivation, sleep disruption and intermittent hypoxia may be independently sufficient to cause daytime deficits in vulnerable children. Further research could elucidate whether early intervention of OSAS could reverse the adverse cognitive effects because adenotonsillectomy is a relatively simple procedure that could have significant beneficial effects for learning and academic performance. This is an important consideration in neurodevelopmental disorders where OSAS is a particular problem, for example Down syndrome (DS). Snoring is relatively common in Williams syndrome (WS) compared with typical individuals (Annaz et al., 2011; Goldman et al., 2009).

In all children, bedtime struggles and early school start times often mean that children's sleep is restricted, and even a modest sleep restriction can significantly impact on daytime behaviour. Sadeh et al. (2003) investigated the neurobehavioural effects of extending or restricting the usual sleep pattern of children aged 9 or 11 years (39 boys, 38 girls) by 1 hour per night for three consecutive nights. Performance on working memory, motor speed, reaction time, vigilance, visual memory and attention tasks was tested. Children in the sleep extension group (n=21) adjusted their sleep by an average of 35 minutes, those in the sleep restriction group (n=28) by 41 minutes; 28 children failed to significantly adjust their sleep and so acted as a control group. As expected, sleep quality improved in the sleep-restricted group, whereas the opposite occurred in the extension group, because physiological compensatory mechanisms act to regulate sleep physiology. In spite of these mechanisms, children in the sleep-extended group improved their performances on a 'continuous performance reaction time' task and a 'digit span forward' task, whereas the sleep restriction group showed no change on these tasks. These improvements, seen even after only a modest extension of sleep, similar to normal life, were similar to, or greater than, the difference seen between the two age groups (9- and 11-year-olds) at baseline. In other words, the neurobehavioural improvements seen after a 35-minute extension in sleep are similar to those gained by 2 years of development, showing how sensitive children are to modest alterations of their natural sleep patterns. Working memory and attention

difficulties have previously been linked with classroom behaviour and achievement, showing how such a modest alteration in sleep habits could have a significant effect in the classroom, especially in children with neurodevelopmental disorders (Gathercole & Alloway, 2006; Gathercole & Pickering, 2000).

In addition to impacting daytime behaviour, sleep is now also known to play a significant role in certain types of memory consolidation. Sleep-dependent learning is the phenomenon whereby information is preferentially consolidated during sleep, leading to improved performance following a retention interval of sleep. This is particularly evident in motor skill learning. For example, using a finger-tapping task where participants are requested to learn a short sequence with the nondominant hand (Karni et al., 1995), speed and accuracy were found to improve over time, especially when retesting occurred following a period of sleep (18.9% improvement) compared with wake (3.9% improvement) (Walker et al., 2002). This improvement was seen regardless of whether initial training takes place in the morning or evening. It is suggested that consolidation of motor memories requires plastic changes in the primary motor cortex. This may occur with cholinergic activity in the neocortex, seen during REM and wake, and is known to enhance attention, learning and memory consolidation and facilitate experience-dependent plasticity in the brain. Plasticity may also occur through reactivation of the brain. Positron emission tomography studies show that this reactivation is most pronounced during post-training REM sleep and occurs significantly more in participants who have trained on a task than in those who have not (Maquet et al., 2000). REM sleep may become increasingly necessary for procedural memory consolidation as task difficulty progresses, for example mirror tracing or word-stem priming as opposed to simple texture discrimination, where processing is thought to take place at pre-attentive levels (Gais et al., 2000). Declarative memory, on the other hand, relies on the hippocampus so may be more reliant on hippocampal consolidation mechanisms replaying most efficiently during SWS when there is little other interfering background electricity in the brain. This is evidenced with tasks such as word pair learning, where performance has been correlated positively with the percentage of non-REM (NREM) sleep and negatively with the percentage of REM sleep (Backhaus et al., 2008), and memory improves following SWS but not REM sleep (Plihal & Born, 1997).

Sleep disruption can therefore have a negative impact on learning because memories are preferentially consolidated during a full uninterrupted night's sleep. This makes it particularly important to assess sleep in children with WS and other neurodevelopmental disorders because their sleep problems could be having a detrimental impact on their daytime behaviour and learning, which are already subjected to lesser cognitive reserve owing to their conditions. It is therefore possible that some of the difficulties they find with cognitive skills could be alleviated if sleep problems could be treated, because the detrimental effects of sleep disruption can be reversed by good sleep hygiene.

Sleep in Williams syndrome

Although parents of children with WS informally report that their children have problems with sleep, research into the specific sleep problems in WS is scarce. However, with growing

awareness, there are now several research groups investigating the issue. Early studies described settling problems and night waking (Udwin et al., 1987), as well as bed wetting and sleep anxiety (Sarimski, 1996).

More recently, polysomnography (PSG) in seven children with WS under 10 years old has shown that these children spent a greater percentage of the sleep period in a wake state (10% compared with 4% in ten typical children; $p<.05$) and SWS (34% compared with 20%; $p<.001$) while spending a smaller percentage in stages I and II (41% compared with 59%; $p<.001$) (Arens et al., 1998).

In Arens et al.'s study (1998), children with WS were selected from an initial sample of 28 children and were diagnosed as having symptoms suggestive of a movement arousal disorder. As predicted, they showed a higher percentage of PLMD than typically developing (TD) controls (total number of leg movements: 158 versus 65; $p<.001$), with more arousals and awakenings because of leg movements. The authors note the significance of finding PLMD in all seven children; however, considering that these children had antecedently been screened and were only studied with PSG, if there was a possibility of a limb movement disorder, then it is not quite so surprising that all showed PLMD. What is perhaps surprising is that 16 of the original sample of 28 children were screened as having possible PLMD, which is considerably more than would be expected in TD children. However, these results should be taken with caution because children without PLMD risk factors were screened out of the tested subsample. Also, with such a small sample the results cannot be generalised, but they are certainly intriguing and require further investigation.

In a later PSG study of nine teenagers and young adults with WS (age range: 14-29 years, mean: 20.76), increased wake time and SWS were found compared with a healthy control group matched for chronological age and gender (Bódizs et al., 2009). The study also reported increased NREM and decreased REM durations and percentages, a shorter total sleep time and a lower sleep efficiency in participants with WS. Moreover, the authors observed increased uni- or bilateral leg movements, largely during NREM sleep, relative to controls and concluded that frequent periodic leg movements lead to sleep disruption in this group, hence supporting the findings of Arens et al. (1998).

The long sleep latencies and night wakings often described in WS are not only apparent in the PSG studies but also in actigraphy data, a form of activity monitoring using a wrist-worn accelerometer to assess sleep quality and quantity. We carried out a series of studies investigating sleep in children and adolescents with WS. In our studies, parental questionnaires (Annaz et al., submitted) and actigraphy (Annaz et al., submitted) were used to examine sleep patterns in children with WS aged 6 to 12 years. Questionnaire data (Children's Sleep Habits Questionnaire, Owens et al., 2000) from 64 children supported previous research findings that the main sleep problems in WS are long sleep latencies, sleep anxiety, bedtime resistance and night wakings. Some 97% of parents reported their children to have problems with sleep. None of the most frequently reported medical conditions associated with sleep disorders, such as recurrent ear infections, constipation, tonsillitis and epilepsy, were reported in this survey. However, asthma (12%) and allergies (20%) showed to be strong predictors of sleep onset delay in the WS group.

The parental reports were supported by a follow-up actigraphy study of 22 children with WS (aged 6-12 years) and showed long sleep latencies—an average of 46 minutes—with six of these children taking more than 1 hour to get to sleep (Annaz et al., submitted). In the control group of 92 healthy children, it was found that any sleep problems decline with increased chronological age. This change was not evident in the WS group, indicating that sleep problems in WS decrease at a much slower rate and may be enduring into adulthood. We also found that 61% of children with WS complained of daytime tiredness, echoing the findings of Goldman et al. (2009), who found that in 23 young adults with WS, almost all reported feelings of tiredness and sleepiness during the day, with over one-third suffering excessive daytime sleepiness based on the Epworth Sleepiness Scale; Johns, 1991). Their actigraphy data suggested a disparity, showing that participants were achieving an adequate amount of sleep—an average of 7.6 hours—but their sleep efficiency was surprisingly low because of long sleep latencies and increased waking after sleep onset, with participants spending an average of 9 hours in bed in order to achieve only 7.6 hours of sleep. The disparity between feeling tired while having adequate sleep is possibly attributable to the sleep disruption caused by multiple factors common in WS, including nocturia, restless legs movement, sleep apnoea or other factors intrinsic to WS.

Sleep-related learning in WS

Little research has investigated the effects of sleep problems in WS. People with WS often have associated disorders such as ADHD, anxiety and other behavioural problems, which are known to be affected by sleep and improve when sleep problems are treated (e.g. O'Brien et al., 2003). Arens et al. (1998) treated five children with WS for PLMD with clonazepam, a drug known to relieve PLMD symptoms so allowing sleep patterns to return to normal in typical adults. Four of the treated children were reported to show an immediate and sustained improvement on sleep and daytime behaviour with parents reporting less irritability during the day. Repeated PSG in three of these children 3-6 months after treatment showed a significant decrease in PLMD and PLMD-related arousals and awakenings, so that their sleep patterns were comparable with the control group. It is probable that fragmentation and altered sleep architecture in this group has an impact on daytime behaviour, as the authors found that clonazepam significantly reduced PLMD, arousals became fewer and shorter, and parents reported their children to be less irritable during the day.

Treating sleep problems in WS would probably also impact on sleep-dependent memory consolidation, attention and ability to learn during the day (for discussion of the attention and memory profiles characteristic of WS, see Chapters 6 and 8). We used the finger-tapping task to investigate the impact of sleep on motor memory (Annaz et al., submitted). In this task, participants use their left hand to repeatedly type a five-digit number sequence on a computer keyboard. Speed and accuracy are recorded and compared across time points (for further details on the task see Walker et al., 2002). Twelve children with WS aged 6-12 years (3 male, 9 female; mean age 8.6 years) were trained on the task in the evening and retested the following morning and afternoon. In line with previous studies, we found a dramatic overnight improvement in the control group but no evidence of sleep-related learning in WS, as illustrated in Figure 7.1. However, the lack of improvement in the WS

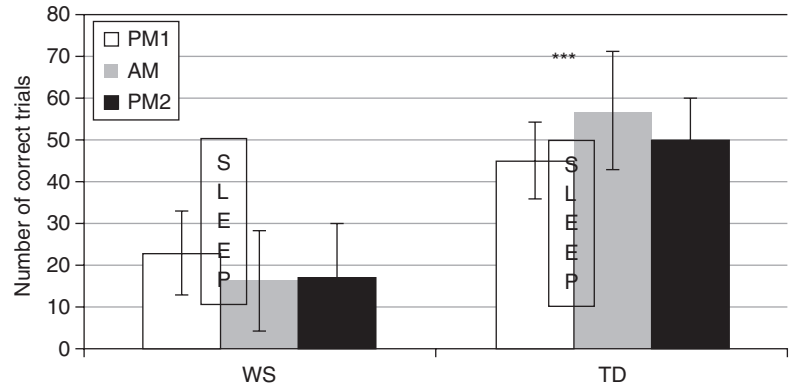

Fig. 7.1 Comparison of performance on the finger-tapping task between typically developing children and children with William syndrome. The error bars show the standard error of the mean. *** p<.001. Abbreviations: TD = typically developing; WS = Williams syndrome. Data from Annaz et al. (submitted).

group cannot be directly associated with sleep problems before we exclude possible problems with fine motor skills that are required to perform the finger-tapping task.

At the time of writing, we are not aware of any other publications on sleep-related learning in WS, but this is an area that requires thorough investigation because the sleep problems evident in WS could be at least in part responsible for many of the cognitive and behavioural deficits that these individuals experience. Sleep problems are often amenable to treatment, so alleviating the sleep problems in WS could have a hugely beneficial effect on their daytime functioning.

Sleep problems in other neurodevelopmental disorders

The neurological and physiological aspects of neurodevelopmental disorders have been well characterised in the wake state. Yet, although it is now well known that sleep problems are common in people with intellectual disabilities, there is relatively little information available characterising exact sleep patterns in these groups.

Autism

Sleep problems rank among one of the most concurrent clinical symptoms in children with autism, with estimates ranging from 40% to 80%. In a recent study using medical history and carer report, it was found that 83 of 160 (52%) children with autism spectrum disorder (ASD) had sleep problems, especially during early childhood, with the most common symptoms being frequent night waking and difficulty initiating sleep (Ming et al., 2008). Sleep problems were found to be associated with mood disorder and also with gastrointestinal problems, which in turn were associated with food intolerances because these could lead to bloating and bowel problems, leading to pain and increased night waking. The authors note anecdotal evidence of improving sleep problems by treating gastrointestinal dysfunction.

Parents of children with ASD tend to report settling problems and long sleep latencies, with some children taking over 1 hour to get to sleep, and night wakings, often lasting 2-3 hours,

where children simply talk, laugh, scream or play with toys. Most children with ASD exhibit abnormal sleep–wake patterns, EEG activity and sleep architecture, although PSG studies disagree on the specifics and differences could be attributable to patient population and methodology issues. Sleep problems are likely to be attributable to a complex interaction between physiological, psychological, environmental and sociological factors (see Cortesi et al., 2010). It is likely that circadian abnormalities play a role in sleep problems in ASD, as hormonal abnormalities have been found in a number of studies. For example, children with ASD have been found to have 42% decreased nocturnal melatonin compared with typical children (Tordjman et al., 2005). As with typical children, sleep problems in autism impact on daytime behaviours and, interestingly, are associated with more severe autistic traits (Schreck et al., 2003).

Down syndrome

It is well established that OSAS is common in the DS population, with prevalence rates estimated to be between 30% and 60%, whereas estimates of the prevalence of any sleep problems in DS are as high as 100% (Marcus et al., 1991). Craniofacial and upper airway abnormalities, obesity, tonsil and adenoid encroachment, and generalised underdevelopment (hypoplasia) of the upper airway have all been associated with OSAS, resulting in sleep fragmentation manifested in frequent awakenings, a higher percentage of wakefulness after sleep onset and therefore lower sleep efficiency.

In a longitudinal PSG study of 56 young children with DS, Shott et al. (2006) found abnormal PSG results in 32 (57%) children, defined by abnormal obstructive indexes (38%), abnormal carbon dioxide retention (hypercarbia; 30%) and/or hypoxia (20%). Some 61% of children had elevated arousal indexes. Parental sleep reports of their children's sleep were relatively inaccurate. In total, 35% of parents reported sleep problems, but only 36% of the children in this group had abnormal polysomnograms; by contrast, 69% of parents reported no sleep problems and yet 54% of their children had abnormal polysomnograms. The high incidence of OSAS and the inaccuracy of parent reports together necessitate that baseline PSG should be recommended for all children with DS. PSG also showed a lower percentage of REM sleep than would be expected in young children, a finding echoed by Miano et al. (2008), who also found increased stage 2 NREM and increased stage 1 NREM percentages compared with a healthy control group and a similar pattern of disrupted sleep architecture in children with fragile X syndrome.

Andreou et al. (2002) found that sleep apnoeas in young adults with DS significantly correlated with their scores on the Raven Progressive Matrices (Raven et al., 2003) test, which examines visuospatial skills. This in turn related with orientation on the Mini Mental State Examination (Folstein et al., 1975) of cognitive functioning, indicating that OSAS may be at least partly responsible for the difficulties that individuals with DS suffer with visuospatial skills and other behavioural or learning abilities.

Attention deficit hyperactivity disorder

Numerous studies show links between sleep disruption and ADHD symptoms. For example, O'Brien et al. (2003) found that in children with severe ADHD symptoms, OSAS was

no worse than in a healthy control group (5% in each group). However, OSAS was present in 26% of children with mild ADHD symptoms, indicating that sleep-disordered breathing may impact on children's daytime behaviour, creating a hyperactive/inattentive behaviour phenotype similar to that seen in clinically diagnosed ADHD. Moreover, increased REM latency and decreased REM percentage were found in children with severe ADHD symptoms; yet, no differences in REM were found in children with mild ADHD symptoms compared with the control group. So although OSAS may be sufficient to cause ADHD-like symptoms, more severe ADHD is accompanied by specific differences in the sleep architecture. In addition, children attending sleep clinics for suspected sleep problems are likely to have ADHD (Chervin et al., 2006). Huang et al. (2007) found that treating sleep problems by adenotonsillectomy in children with ADHD not only relieved the symptoms of sleep-disordered breathing, but also led to an increase in REM sleep, SWS and total sleep time. It further led to better performance scores on a number of ADHD characteristics, such as social withdrawal, delinquency, internalising behaviour, physical symptoms, emotional distress and quality of life, as well as neuropsychological improvements on attention and reaction time tests. These positive outcomes were not seen to the same extent following treatment using methylphenidate, a commonly used treatment for ADHD. Hence, this is an important point, because improvements in attention and concentration indicate that children's performance at school improves following a relatively simple intervention.

Sleep management in neurodevelopmental disorders

The emergence of a 24-hour society and the increasing strain of modern living and its impact on family life have led to a gradual decline of good sleep hygiene habits for children and adults alike. Whether through a lack of bedtime routine or irregular bedtime and getting-up times, this could have a significant impact on children with developmental disabilities, whose fragile sleep patterns are easily disturbed. As outlined in this chapter, sleep problems can have a negative impact on daytime behaviour, learning, attention and other cognitive abilities, as well as problems with motor skills, such as coordination, and other health problems. It is therefore essential that good sleep hygiene is practised in children with neurodevelopmental disorders because their daytime functioning is already inhibited because of their underlying condition. As a sleep loss of as little as 30 minutes can be enough to disrupt neuropsychological functioning in typical children (Sadeh et al., 2003), it is essential that parents are taught good sleep hygiene in order to give their children the greatest possible support and not exacerbate existing sleep problems. Good sleep habits include adding structure to the daytime and bedtime routines to act as *zeitgebers* (time cues) to reinforce circadian rhythms; removing tactile, visual, auditory and olfactory stimulation from the bedroom; scheduling regular bedtimes that do not fluctuate by more than 1 hour at weekends; and relaxing evening routines avoiding overstimulation (Jan et al., 2008). Children also need to learn aspects of when and how to fall asleep, and to unlearn bad habits. This could be particularly challenging for developmentally delayed children, who may not have the intellectual capacity to understand sleeping and so create problems such as bedtime resistance (Richdale & Wiggs, 2005).

In a recent survey of 63 children with WS, parents reported that almost one-third of children had used or currently use medication to get to sleep (Annaz et al., 2011). For almost one-third of these, the medication was melatonin, a hormone supplement often used to regulate circadian cycles. Although there is palpable evidence that melatonin supplementation is a well-tolerated pharmacotherapy to mitigate or eliminate the detrimental effects of poor sleep on children's mood, cognition and daytime function, its effectiveness in children with neurodevelopmental disorders remains inconclusive and has not been studied in WS as yet. In our study, parents reported temporary improvement or no improvement in sleep patterns after melatonin supplementation. Hence, controlled studies with measurement of melatonin secretion, careful developmental and behavioural history, and recordings of children's sleep patterns must be first obtained in order to treat children with disabilities for their sleep disorders.

We recommend that good sleep hygiene should be practised in children with WS, because a structured bedtime routine and suitable sleeping environment could alleviate problems with sleep anxiety and bedtime resistance so common in these children. Although behavioural techniques, tailored to the child's needs, can be effective with developmentally delayed children in order to aid appropriate bedtime routines, research in this area is in its infancy (for a review see Richdale & Wiggs, 2005). Also, good sleep hygiene alone may not be sufficient to treat sleep problems in neurodevelopmental disorders, but it provides a good basis for increasing the success of other interventions, such as behavioural management strategies, medication or treatment of OSAS by continuous positive airway pressure or adenotonsillectomy. This could greatly improve children's daytime functioning and improve quality of life for both the child and the parents.

Conclusion

Cleary, sleep is not only for the brain but also for the rest of the body. Integration of different approaches using parental reports, actigraphy, PSG and genetic and endocrine examination to determine the causality and disorder specificity of sleep disturbances should be considered in future studies. Cognitive studies of children with disorders such as WS should be considering sleep patterns of the child during their investigation because these may have a direct impact on performance scores. More studies on sleep and cognition are greatly needed. These should be carried out as early as from the fetal stage (e.g. Kozuma et al., 1993), through infancy and into adulthood by tracing sleep patterns and interactions between different functions. Notions such as interactivity, compensation, specialisation and localisation can be key in characterising in more depth how atypical sleep patterns affect at the cognitive and behavioural level and implicate on the formation of learning over developmental time (Annaz et al., 2008; Karmiloff-Smith, 1998).

Editor commentary (Emily K. Farran & Annette Karmiloff-Smith)

In this chapter, we learnt three striking facts that, when considered together, have enormous implications for our understanding of development in individuals with neurodevelopmental disorders. First, the authors reviewed evidence from WS, DS, ADHD and autism

that indicated a high prevalence of sleep difficulties in these groups, which one can assume also extends across many other neurodevelopmental disorders. Second, lack of sleep can have a substantial negative impact on many domain-general processes, such as attention. Third, there are syndrome-specific types of sleep disturbance. If we take a neuronstructivist stance and consider the cascading impact that impaired attentional mechanisms can have on the development of domain-specific functions, discussed in Chapters 6 and 18, then an understanding of sleep and sleep-related learning is a key piece of the jigsaw of interacting systems that impact the developmental process.

Sleep is one component in a multilevel interaction, and thus sleep disruption in individuals with neurodevelopmental disorders can have a negative impact on the dynamics of brain development and cognitive processing, in tandem with the syndrome-specific constraints on development. In typical development, parts of the brain are more active during sleep than in wakefulness. Thus, sleep disruption also impacts learning because memories are preferentially consolidated during a full night's uninterrupted sleep. The chapter reported preliminary evidence that sleep-related learning is impaired in WS. This raises the intriguing possibility that aspects of the cognitive profile observed in WS, as well as in other groups that show sleep disturbance such as autism and ADHD, could in part relate to sleep disturbance. The chapter stressed that, given the relative ease at which sleep problems can be ameliorated, further research into the impact of sleep on learning on atypical groups is essential.

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