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5

THE EFFECTS OF SLEEP AND SLEEP LOSS ON PERFORMANCE

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5.1 Introduction

The associations between sleep loss and poor health are mentioned in Chapter 3 (see also Möller-Levet *et al.* 2013); these are long-term consequences, but sleep loss has consequences in the very short term. Although most people will have noticed a difficulty in concentrating, or just staying awake after a bad night, or when experiencing jet lag, we might not always be so aware of how much our performance is impaired by as little as one night's poor sleep. This chapter therefore emphasizes the importance of sleep by focusing on the psychological and performance deficits that result from sleep deprivation. It shows why it is important to take patients' sleep problems seriously and provides the evidence for advising caution when sleep is impaired – even if an individual does not complain of poor sleep.

The mechanisms by which sleep deficit affects cognitive function are complex, but Alhola and Polo-Kantola (2007) suggest a broad two-way classification of theories whereby there are 'general effects on alertness and attention or selective effects on certain brain structures and function' (p.554). These theories are explored briefly before a more detailed look at some of the key performance areas that are affected by sleep loss: alertness in driving and similar tasks, and cognitive performance in memory and learning. Lastly, implications for clinical practice are considered.

5.2 Mechanisms

According to the wake-state instability hypothesis, lapses of attention result from the homeostatic pressure to sleep causing microsleeps* which have the characteristic electroencephalogram (EEG)* activity of sleep. This is in line with the synaptic homeostasis hypothesis (see Chapters 3 and 6), which suggests that if the brain is deprived of the chance to go offline in an orderly fashion in night-time sleep, certain parts will go offline in a more haphazard manner as wakefulness persists (Lucassen *et al.* 2010; Tononi and Cirelli 2006). The continued instability of the wake state and fluctuations in alertness leads to the variability of performance.

Doran, Van Dongen and Dinges (2001) trace the history of research on performance in the context of sleep deprivation from early experiments by Patrick and Gilbert in the 1890s where 90 hours without sleep resulted in motor and cognitive deficits in three participants. Research in the following decades showed that people could often perform at baseline levels after extended periods of wakefulness, but that in longer tasks performance was affected. By the 1930s evidence suggested that 'sleep deprivation affected neurobehavioural functions by initially destabilizing performance rather than by eliminating capacity to perform' (p.253). Subsequently, it was found in the 1950s that lapses in performance were most likely when the EEG showed evidence of transition to sleep onset, leading to development of 'the "lapse hypothesis", which posited that performance during sleep deprivation was punctuated by brief moments of low arousal during which subjects appeared to be unable to respond to the task at hand' (Doran *et al.* 2001, p.254).

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According to Doran *et al.* (2001) when the drive to sleep is overpowering, lapses and slower responses occur, whereas if there is compensatory effort, performance may appear relatively normal for a short time at least. Their experiment, in which participants repeated reaction time tests over a period of 88 hours of wakefulness, showed increasing variability in performance as time went on (with normal responses even after 80 hours awake). They conclude that their findings provide support for the state-instability hypothesis which creates 'an unstable state which fluctuates within seconds and cannot be characterized as either fully awake or asleep' (p.265). It could be argued that it is adaptive to be able to function at baseline after no sleep, but in the modern world that can present a hazard, where it is possible for someone to believe that their ability to drive, for example, remains satisfactory, but where it is in fact impaired because of the variability of performance. As a parallel to this, analysis of lapses has been examined in on-the-road tests of driving as a result of drug-induced impairment (Verster *et al.* 2014).

The major alternative mechanism that has been suggested is the 'sleep-based neuropsychological perspective' (Babkoff *et al.* 2005, p.8) where sleep loss is said to have a variable effect in different parts of the brain. According to one theory – the prefrontal vulnerability hypothesis (Horne 1993) – sleep loss principally affects functions that are associated with the prefrontal cortex. Reviewing evidence of blood flow and EEG activity during sleep, Harrison and Horne (2000) suggest that the prefrontal cortex could be among the first regions of the brain to be affected by sleep deprivation. They go on to note that it is the area that deals with novelty and the unexpected (and therefore routine tasks are less dependent on it) and is responsible for divergent thinking and for memory for contextual detail. Not surprisingly, sufferers of disturbed sleep may put off difficult tasks including planning and problem solving which are key aspects of frontal lobe function (Tucker *et al.* 2010; Ward *et al.* 2013). Similarly, their emotional control may be affected (Killgore 2013).

5.3 Staying alert, reactions and driving

Driving is an activity that many adults do as part of their daily routine without much thought and which others do for their living. It is important for all, but especially the latter, to be alert and able to concentrate on the task, but sleepiness is a significant cause of road traffic collisions, injuries and deaths: it accounts for around 20% of traffic accidents in industrialized countries (Alford 2009; Philip and Åkerstedt 2006). Sleepiness can lead to anything from a driver having a fright on being alerted harmlessly when passing over a rumble strip (or sleeper line) to leaving the road and causing a major incident (see, for example, MacKinnon 1994 or Oliver 2002).

The scale of the problem was assessed in a study in New Zealand by Connor *et al.* (2002). They interviewed 571 drivers who had been involved in a road crash where at least one person had been admitted to hospital or died from their injuries (or interviewed a proxy, if the driver had been killed or seriously injured); they also interviewed 588 randomly selected drivers in a control group designed to represent the population of road users in the Auckland area. Respondents were asked about levels of alertness before the crash (or at the time of the survey for the control group), their sleep times in the preceding 24 hours and the number of nights in the preceding week when less than 7 hours of sleep had been taken. They also completed the Epworth Sleepiness Scale* to measure usual levels of sleepiness. Controlling for other factors, such as alcohol consumption, the researchers found an eightfold increased risk if drivers reported sleepiness and a threefold increase if driving after 5 hours of sleep or less. They summarized their findings as follows:

> Driving while feeling sleepy, driving after five hours or less of sleep, and driving between 2 a.m. and 5 a.m. were associated with a substantial increase in the risk of a car crash resulting in serious injury or death. Reduction in the prevalence of these three behaviours may reduce the incidence of injury crashes by up to 19%. (Connor *et al.* 2002, p.5)

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It would be easy to dismiss the idea that driving on insufficient sleep is something that responsible people would do; however, it is common to get up early ahead of a long journey, or to get to work early, but it is unlikely that anyone rising at 4 a.m. for an early start would have gone to sleep at 8 p.m. the previous evening. Furthermore, it is a common experience to have a disturbed night's sleep anticipating a 'big day' or through worrying about waking up in time, but few of us are likely to cancel a trip because of a poor night's sleep and will push on regardless. Evidence for this is provided by Philip and Åkerstedt (2006) who cite their own work showing that there is an association between long-distance driving and curtailing sleep. They had found in a study in 1993 at a motorway rest area in France during the summer holiday period that as many as 50% of drivers had reduced sleep in the preceding 24 hours and that 10% had taken no sleep in that time. In a subsequent study, with a larger and more varied sample of car drivers (n = 2196) carried out at toll booths (avoiding the selection bias towards fatigued drivers at a rest area), they found that 50% of the drivers had slept less in the previous 24 hours than their usual sleep time; 10% of the sample had slept for less than 5 hours (Philip *et al.* 1999). Philip and Åkerstedt (2006) report that in tests comparing the sleep-deprived drivers with controls there was a reduced level of vigilance and shorter sleep latency* among the drivers.

If it is a matter of concern that vacation drivers and more regular car drivers are sleep deprived and showing signs of reduced performance, it would be yet more worrying if professional drivers' performance were impaired by lack of sleep. Mitler *et al.* (1997) investigated the sleep of 80 male truck drivers in the US and Canada working on different routes and schedules. They found that during the study period the drivers spent an average of 5.18 hours in bed per day and slept for 4.78 hours per day. It was recorded that two of the drivers had stage 1 sleep* while they were driving and also picked up that two others had undiagnosed sleep apnoea. More recently, Sharwood *et al.* (2011) reviewed the literature on sleep problems and the risk of commercial vehicle crashes. It was found that the evidence was somewhat inconclusive because of small sample sizes, for example, but it was concluded that there is an association between crashes and both daytime sleepiness (as measured on the Epworth Sleepiness Scale) and sleep debt.

The association between sleep loss and vigilance has been examined in controlled laboratory conditions by Van Dongen *et al.* (2003) where the neurobehavioural performance of 48 adults (aged 21–38 years) was monitored every 2 hours during wakefulness. Participants were randomly assigned to one of four groups in which different sleep durations were imposed: 8, 6 or 4 hours of sleep for 2 weeks or no sleep at all for 3 days. It was found that restriction to 6 and 4 hours of sleep progressively eroded performance in a battery of tests measuring vigilance, working memory and cognitive throughput (using a serial addition/subtraction task). The researchers conclude that there is no evidence therefore that humans can adapt to chronic sleep restriction; the performance after 14 days of 4 or 6 hours of sleep per night was comparable to that after 1 or 2 days of total sleep deprivation.

A further finding by Van Dongen *et al.* (2003) was that sleep restriction led to increased subjective sleepiness in the first days but increased only slightly as time went on (never approaching levels equivalent to those after two nights of complete sleep deprivation). At the end of the 14 days, participants in the 4- and 6-hour sleep groups performed at their worst in the tests but reported feeling only slightly sleepy. It is suggested that, after chronic sleep restriction, if people are having at least 4 hours of sleep, they do not experience sleepiness as they would after total deprivation; they therefore have a subjective impression that they have adapted to short sleep because they do not feel sleepy. The meaning of this is worth reflecting on: people with chronic partial sleep loss might be less aware of the need for sleep and believe that they can manage with less sleep than others, whereas their performance is on a par with someone who is totally sleep deprived. This gives further reason for concern with the 2005 'Sleep in America' poll reporting a rise to 16% in those sleeping less than 6 hours on weeknights (Banks and Dinges 2007).

Cohen *et al.* (2010) provide more evidence that individuals are not the best judge of their need for sleep and challenge the belief of many that they adapt to chronic sleep loss or that only a single extended period of sleep is necessary for recovery. In a study that manipulated sleep schedules to

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include extended periods of wakefulness over 3 weeks, they found that a chronic sleep debt can develop despite apparent full recovery from acute sleep loss. The relatively common practice of having short sleep on work or school days and longer sleep at weekends could lead someone with chronic sleep restriction to have a false sense of recovery from sleep debt because of performing well in the early part of their usual waking day. The authors point to the vulnerability of shift workers to accidents and errors after extended wakefulness, combined with the tendency towards worse functioning when operating at times when one would usually be asleep (at the circadian performance nadir).

A further observation by Cohen *et al.* (2010) is that acute sleep loss alone is hazardous, reminding us that 19 hours of continued wakefulness from 8 a.m. to 3 a.m. is linked with deficits in performance that are equivalent to a blood alcohol concentration (BAC) that would be illegal in most European countries (0.05%): after 24 hours awake, the deficit is equivalent to a level (0.10%) that exceeds the legal limit in the UK and the US. A study reported by Verster *et al.* (2011) provides support for such observations. Drivers were allowed to sleep between the hours of 11 p.m. and 7 a.m. on the night before driving the following night. Accompanied by professional driving instructors in dual-control vehicles, they drove on a two-lane highway for different lengths of time finishing at 5 a.m. and their performance was monitored by use of a video camera that measured deviation from the lane markings. It was found that the impairment observed in 2 hours of continuous driving at night was comparable to that seen with a BAC of 0.05%, and after 3 hours it was equivalent to a BAC of 0.08% (which is the UK 'drink-drive' limit). As Verster *et al.* (2011) conclude, it is important that drivers take sleepiness at the wheel seriously. Furthermore, our own data reveal that combining extended waking with driving in the early morning between 2 and 5 a.m. (the peak time for sleep-related accidents) can show impairment equivalent to 0.1% BAC, well over the legal driving limit (Alford 2009).

Although the discussion here focuses mainly on driving, a great deal of research has been done in other areas where vigilance is essential (for example, for guidelines on sleep to promote safety in aviation maintenance see Hobbs *et al.* 2011, and for a military perspective see Lindsay and Dyche 2011). However, there are two particular circumstances in which sleep and performance are compromised: shift working and obstructive sleep apnoea.

Shift working is a significant problem because of the interaction between circadian and diurnal rhythms of alertness with sleep duration and extended waking. Daytime sleep is shorter and more disturbed than night-time sleep, resulting in poorer performance and the need for recovery sleep (Gillberg 1995; Häkkänen *et al.* 1999; Kecklund and Åkerstedt 1995; Mawdsley, Grasby and Talk 2014). Those people who are adapted to day working feel more sleepy during night shifts, and rotating shifts result in extended waking, with more than 16 hours of work being associated with performance impairment (Rosa 1995; Van Dongen *et al.* 2003). The overall risk of traffic accidents may be doubled by shift working and extended waking (Barger *et al.* 2005; Ftouni *et al.* 2013; Mets *et al.* 2009).

Sleep apnoea is a clinical condition that results in chronic sleep disturbance affecting over 2–4% of the population, although other estimates are higher (Bearpark *et al.* 1995; Young *et al.* 1993). The condition is defined by the cessation of breathing during sleep and consequent arousals when breathing is restored, resulting in chronic sleep disruption (Chugh, Weaver and Dinges 1996). There are currently no drug treatments available with the standard treatment being continuous positive airway pressure (CPAP) delivered through a mask, although these are often only worn for about 5 hours per night, again resulting in reduced sleep (Gay *et al.* 2006). Worse still, untreated apnoea patients may turn to sedative drugs, such as alcohol, in an attempt to sleep, but this further exacerbates their condition through respiratory depression (Scrima *et al.* 1982). Marked daytime sleepiness is a major consequence and can be picked up by diagnostic tools such as the Epworth Sleepiness Scale (Johns 1991). Whilst it is not surprising that diagnosis may result in withdrawal of the driver's licence until effective treatment has been established and performance restored (Krieger *et al.* 1997; Turkington *et al.* 2004), this may make suffering drivers less likely to come forward, just as they may be reluctant to admit the offence of falling asleep at the wheel. Apnoea represents a particular example of the adverse consequences of

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chronic sleep disturbance on waking performance (Adams *et al.* 2001; Dinges *et al.* 1998). Consequently, an increased risk of driving accidents has been reported (Howard, Jackson and Baulk 2009).

5.4 Learning and memory

To make sense of the research on sleep and memory, it is necessary to appreciate the different types of memory. A declarative memory is something that can be called to mind and may be a *semantic* memory, such as the name of the capital of France, or an *episodic* memory of a particular event, such as last night's dinner. Non-declarative memory, which includes *conditioning* and *procedural skills*, involves memory of how to do things without conscious recollection, such as riding a bicycle (Stickgold 2005).

Wamsley and Stickgold (2011) suggest that one of sleep's functions is to consolidate new memory traces – conceptualized previously as a process of 'strengthening' a fragile trace and making it resistant to interference. They go on to point out that recent research has shown that, in sleep, new information is integrated into established memory networks, meaning is extracted and insight is developed. It is beyond the scope of this chapter to explore in any detail the mechanisms by which memories are retained, and readers are referred elsewhere; for example, Mednick *et al.* (2011) provide a review of theories to explain the role of slow-wave sleep (SWS) in the consolidation of declarative memory. They note that non-declarative memory is thought to be enhanced by rapid eye movement (REM) sleep*, whereas the facilitation of declarative memories is related to the period of non-REM sleep* consisting of both stage 2 sleep* and SWS; they point to a long history of research that shows that a period of SWS is more beneficial for memory than a similar period of REM sleep or waking activity. Mednick *et al.* (2011) outline hypotheses to explain the role of SWS in memory consolidation; the unique-to-sleep hypothesis suggests that memory consolidation depends on mechanisms that exist only in SWS, whereas other theories suggest that SWS eliminates interference that might disturb the process, whether or not SWS is the *only* means by which interference is reduced. Recent research suggests that SWS may also help prepare the brain to encode or form new memories following sleep (Antonenko *et al.* 2013; Wamsley 2013).

Research on sleep and memory can be traced back to the 1880s (Payne *et al.* 2012), but Wamsley and Stickgold (2011) note that it is 'well established that post-learning sleep is beneficial for human memory performance' (p.97). A suggestion by Vertes (2004) that there was insufficient evidence that a function of sleep is memory consolidation brought a response from Stickgold and Walker (2005) who noted that 83% of published articles on the subject in the previous 3 years supported a role for sleep. In a more detailed review Stickgold (2005) concludes that 'each stage of sleep seems to contribute differently…and we have proposed that the multiplicity of sleep stages has evolved, in part, to provide optimal brain states for a range of distinct memory consolidation processes' (p.1273; see also Walker and Stickgold 2006).

Stickgold and his colleagues at Harvard University, and elsewhere, have continued to provide further evidence of the role of sleep, typically in experiments involving learning of information which has to be recalled after a period of sleep or a similar period of wakefulness. Box 5.1 provides an illustration of the range of work that has been done.

BOX 5.1 Examples of sleep and memory research

- Ellenbogen *et al.* (2006): participants learned word pairs at either 9 a.m. or 9 p.m and half of each group (wake and sleep) were given a further set of words (an 'interfering list') to learn just before testing on the first list. The better performance of the group that slept led the researchers to conclude that 'sleep protects declarative memories from associative interference in the subsequent day' (p.1292) and that sleep has an active role in the consolidation of declarative memory.

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- Tamminen *et al.* (2010): participants learned novel (made-up) words, such as 'cathedruke', and were tested for recall after 9–10 hours. The performance of the group that learned the words in the evening and slept before the first test was superior to those who learned the words in the morning and remained awake before testing. Because the study involved use of polysomnography*, the researchers were able to identify an involvement of sleep spindles (see Chapter 3) in the integration of new information into the existing framework of knowledge.
- Payne *et al.* (2012): tested for learning of sets of related and unrelated word pairs, where participants underwent training periods at different times of day and were tested after a variety of intervals. Retention after 12 hours was enhanced if there was a period of sleep, although a period of wakefulness had no impact on retention of related word pairs. Where there was a longer delay before retesting (24 hours) sleep had a beneficial effect if it came soon after learning (and not after 16 hours awake). Finally, 'when sleep shortly follows declarative task learning, it actually slows the subsequent rate of deterioration during the post-sleep wake period, suggesting that an important function of sleep is to stabilize newly learned declarative memories' (p.6).
- Wamsley *et al.* (2010) explored the role of dreaming in memory consolidation. Participants took part in an exercise involving navigating a virtual maze before taking a daytime nap or having a period of wakefulness. Sleep during the nap period was monitored with polysomnography and participants were woken on entering REM sleep. Participants in both the sleep and wake groups were asked to record what was going through their mind during the interval – including the dreams of the sleepers. It was found that dreaming of the maze task predicted better performance on subsequent testing, whereas thinking about the task while awake did not help. The researchers do not suggest that the experience of dreams cause memory consolidation, rather that dreaming might reflect the brain processes that support memory processing.

There is some evidence that memories that are likely to be of future relevance are selectively processed in sleep. Wilhelm *et al.* (2011) demonstrated this in a simple experiment where participants learned three tasks involving both declarative and non-declarative memory that have been found to be sensitive to sleep-dependent memory consolidation: learning of word pairs, object location and tapping a sequence on a keyboard. Groups performed each task and memory consolidation was tested after a period of wakefulness or after a similar period of sleep. A further distinction was that one subgroup of sleepers was told that there would be an additional test, whereas the others did not expect the retesting. It was found that when participants were informed of retesting, consolidation during sleep was enhanced in both declarative memory and procedural memory tasks. Furthermore, the researchers observed that there was also enhancement of sleep-related consolidation among participants who *suspected* there would be a further test. The inference is that 'sleep preferentially consolidates memories to be retrieved in the future' (Wilhelm *et al.* 2011, p.1569).

Although the focus here has been on the effect of sleep on the memory process, there is also some evidence of an effect on other cognitive processes, such as insight, as well as decision-making and judgement of risk. For example, a study by Wagner *et al.* (2004) suggests that sleep is involved in the process of developing insight, or the 'mental restructuring that leads to a sudden gain of explicit knowledge allowing qualitatively changed behaviour' (p.352). Volunteers (aged 18–31 years) took part in an experiment involving a mathematical puzzle where they had to convert a sequence of eight numbers into another sequence according to two simple rules. Unknown to the participants, there was a third hidden rule, which, once they had discovered it, meant that the puzzle could be solved more quickly. This enabled the researchers to identify the point at which the participants gained insight. After a training period, three groups of participants had an 8-hour interval in which they slept at night, remained awake at night, or remained awake during the day. The period of sleep was found to double the probability of spotting the hidden rule. Wagner *et al.* (2004) concluded that sleep 'not only strengthens memory traces quantitatively, but can also "catalyse" mental restructuring' (p.354).

It is noted in Chapter 1 that many major incidents have occurred when people are sleep deprived; this is likely to reflect impaired judgement. As in the case of memory and learning, there is a great deal of research on decision-making (see Harrison and Horne 2000 for an early review). For example,

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Drummond, Paulus and Tapert (2006) found that after two nights of total sleep deprivation, people were able to respond normally in a task when it was appropriate, but they had difficulty withholding inappropriate responses. In a gambling task, Killgore, Balkin and Wesensten (2006) observed that after 49.5 hours of sleep deprivation, participants made riskier decisions than they had done at baseline: they noted that the pattern of decisions reflected a pattern seen where there is damage to parts of the prefrontal cortex. In a subsequent study, Killgore, Kamimori and Balkin (2011) found that after three nights of total sleep deprivation, research participants showed an increase in risk-taking behaviour (in a laboratory exercise) but without a corresponding change in self-reported risk-taking propensity. (See Venkatraman *et al.* 2007 for a study using brain imaging that provides further evidence that sleep deprivation threatens decision-making ability in gambling tasks.)

Venkatraman *et al.* (2007) note that one reason why it is important to understand why we make poor decisions when sleep deprived is that 'there are now unprecedented opportunities to incur damaging losses by means such as online gambling' (p.603). However, while many people might gamble online or on interactive television programmes late at night and threaten their own financial stability, others are involved in work that affects the safety of themselves and others. These few examples from the research suggest that without sufficient sleep people might be able to take routine decisions but are less quick to react when a different response is necessary. They are also more likely to take risks but without the awareness of the increased likelihood of danger. When impaired judgement is coupled with decreased vigilance and increased reaction times, as described in the previous section, the potential for harm is increased greatly.

5.5 Conclusions and implications for practice

To summarize, deficits in performance as a result of sleep deprivation can be as dangerous as those caused by alcohol consumption. Accordingly, sleep loss is associated with increased risk of road traffic crashes (as is driving at night), but people often sleep less before a long journey, and many professional drivers may also be sleep deprived. Continuing sleep restriction has been shown to erode performance, but there is no evidence that humans can adapt to chronic sleep restriction although, as it goes on, people are less aware of being sleepy and may therefore believe that their performance is unimpaired. Sleep is necessary for learning and memory but also appears to have an important role in decision-making, risk-taking and insight.

Research into the effects of sleep loss continues, but there is sufficient existing evidence to conclude that sleep contributes to a range of cognitive functions that we depend on for the performance of daily activity. The evidence supports our everyday experience (that is, what we know without being told by scientists): we need sleep in order to be alert to carry out tasks such as driving, and sleep is necessary to facilitate learning and other cognitive processes. However, the evidence also suggests that we might underestimate the importance of sleep and, for example, forgo sleep before driving in order to get ahead of the traffic. Occupational therapists involved in driving assessments might routinely include screening questions for sleep problems.

If a patient is sleeping badly, it is our duty to warn them of the risk (and document it) that they pose to themselves or others; a therapist may have to decide at which point safety concerns outweigh the imperative of confidentiality (see Chapter 7). We cannot assume that a patient experiencing poor sleep will concentrate fully in any kind of assessment or, for example, that they will be able to fully comprehend instructions. Furthermore, they will not consolidate learning without sleep. Lastly, while the evidence presented in this chapter emphasizes the need for sleep, it cannot be assumed that patients will be able to make effective plans to improve their sleep without being given explicit instructions and guidance.

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