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Review

Working throughout the night: Beyond 'sleepiness' – impairments to critical decision making

Jim Horne*

Sleep Research Centre, Loughborough University, Leicestershire LE11 3TU, UK

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ABSTRACT

By the end of the first night on a 12 h night-shift, wakefulness may have lasted up to 24 h since the previous sleep. Although most work situations requiring critical decisions are foreseen and effectively resolved by well trained staff, such wakefulness can produce impairments in dealing with unexpected challenging situations involving uncertainty, change, distractions and capacity to evaluate risks. Also compromised can be the ability to engage in and keep abreast of protracted negotiations undertaken throughout the night. These effects, which are not just 'sleepiness', seem due to deteriorations with 'supervisory executive functions' of the prefrontal cortex; a region that appears particularly vulnerable to prolonged wakefulness. Recent research findings are presented to support this case, and some evidence-based recommendations made about practical countermeasures.

Contents

1. Long night shifts

Early morning human errors have been implicated in preventable disasters such as those with the Three Mile Island and Chernobyl nuclear reactors, and the loss of the space shuttle 'Challenger'. Although the Presidential Report on the latter noted that, "working excessive hours, whilst admirable, raises serious questions when it jeopardises job performance, particularly when critical management decisions are at stake" (NASA, 1986), such issues still continue to be overlooked, especially as, nowadays, night shifts have typically increased from 8 h to 12 h, with staff on their first night often having being awake for up to 24 h since sleeping the previous morning. For example, recent reports concerning similar work shifts in the medical profession highlight the increased risk of a variety of medical errors (Barger et al., 2006; Rothschild et al., 2009; Reed et al., 2010; P. Tucker et al., 2010). However, these and other industrial errors may not always simply be due to 'sleepiness', but to more subtle effects on the cortex.

This short review mostly covers recent research findings over the last five years, and focuses on two key aspects of extended wakefulness that may well affect decision making relevant to the world of work:

1. Studies on, or including the effects of a *single night of extended wakefulness* (i.e. excluding those studies that only report on

* Tel.: +44 01509 890463; fax: +44 01509 890463.
E-mail address: j.a.horne@lboro.ac.uk

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longer periods of sleep deprivation, that are not so relevant, here).
2. Tasks involving novelty, unexpected change, and uncertainty with competing distractions, that together are classed operationally as 'higher' or 'supervisory' executive functions (cf. Alvarez and Emory, 2006).

Thus, this account particularly relates to sudden crises and emergencies, or protracted negotiations with 'opposing parties' wishing to bargain or obtain advantage.

However, most research into extended wakefulness has concentrated on 'non-executive' measures that are simple, routine and monotonous and, hence, are very sensitive to sleepiness, such as the psychomotor vigilance test – PVT (Lim and Dinges, 2008; Horne, 2010). Whilst very relevant to tedious work situations, these studies will not be covered here, and neither will the relatively insensitive complex tests relating to logical, non-executive reasoning (Killgore, 2010), including most 'IQ type' tests where the solution is deduced from a logical series. That is, the solutions, here, are 'mechanistic' and involve convergent rather than divergent thinking, including well trained and highly skilled tasks able to be performed virtually 'automatically'.

Although there is some contention over whether certain components of executive function are significantly affected by sleep loss (cf. A.M. Tucker et al., 2010), several of the laboratory tests utilised (cf. A.M. Tucker et al., 2010) are only partly executive in nature, or only assess a single dimension of executive function and are 'non-supervisory' in nature (e.g. Sternberg working memory, Stroop colour test, digit-symbol substitution and simple verbal fluency tests). Furthermore, these tests are given under 'sterile', strictly controlled laboratory conditions without distractions (cf. Alvarez and Emory, 2006), and are somewhat divorced from the real world in not being 'ecological'. Besides, if utilised repeatedly, such tests can lose their novelty, with participants adopting new strategies, to the extent that the test becomes 'automatic' (cf. Jansma et al., 2001). [For example, with the Stroop test, if the participant sub-vocally names the actual colour of the presented word, to see if this corresponds with the word itself, resulting in a simpler 'yes or no' decision, then interference is reduced, allowing a faster, correct response; thus the test loses novelty and is more 'routine'.] Consequently, with repetition, such tests can become less sensitive to executive function and sleep loss (Harrison and Horne, 1999, 2000a; Horne, 2012).

Within the context of sleep loss, and for the findings to be more applicable to the real world, there continues to be a need for these executive tests to be 'ecological', as has been stressed, for example, by Nilsson et al. (2005), who have clearly demonstrated that, by integrating a variety of these tests (e.g. their 'six elements test') into a more realistic and demanding scenario, the adverse effects of a night's sleep loss is clearly evident. In contrast, the approach by A.M. Tucker et al. (2010), in 'dissecting' executive functioning into its 'dissociated components' (as above) the investigators may have overlooked the concept that the 'whole is more than the sum of its parts'.

A further caveat, applicable to the real world, involves additional psychological stress which often accompanies overnight crises but, for ethical reasons, this factor is largely absent from laboratory studies or, at best, is only manipulated in a more benign way (e.g. Minkel et al., 2012). Although little is known about this combined effect, studies outside sleep deprivation certainly point to adverse effects of stress on various aspects of decision making, especially those involving executive decisions and the prefrontal cortex (PFC – see below), as found with the recent study by Plessow et al. (2012), and comprehensively reviewed by Starcke and Brand (2012). The latter authors point out that decision-making is not only affected by external stresses, but that there is also the potential for additional, internally generated stress related to the decision-making itself. Under difficult situations both types of stress could result in suboptimal decisions, even without sleep loss. Interestingly, there are clear stress-related hormonal changes affecting hunger and appetite during sleep loss, often leading to 'comfort eating' (Pejovic et al., 2010), with the latter perhaps providing useful clues to stress levels.

2. Dealing with the unexpected

Usually, most work situations requiring critical decisions in the small hours can be foreseen and effectively resolved, with staff having been adequately trained and well prepared for a variety of eventualities. However, compared with normal waking hours, and in the absence of prepared action plans, this early morning scenario can lead to more mistakes when dealing with unforeseen, uncertain and rapidly changing events, requiring quick decisions, with the individual having to 'fly by the seat of one's pants'. As will be seen, liable to become particularly impaired are the abilities to grasp and continue to update 'the big picture' and rapidly shift between different cognitive tasks according to changing environmental demands (e.g. Couyoumdjian et al., 2009). Deteriorations are also likely to become evident in the abilities to maintain focus on the key issues, keep track of and remember very recent developments, identify and ignore conflicting and irrelevant information, foresee and weigh up potential outcomes from a variety of possible decisions, and be innovative in planning appropriate responses (cf. Harrison and Horne, 2000a; Killgore, 2010). Instead, and during these unexpected crises, staff may be inclined to resort to more routine, albeit highly trained but potentially inappropriate procedures, and then persevere unduly with such actions, even when these are failing.

3. Distraction

Inasmuch that one night of sleep loss impairs focussed attention, people are more likely to become distracted, not simply because they are seeking stimulation in order to remain awake, but also through impairments to executive mechanisms that inhibit distraction. Although this remains a poorly explored area within sleep research, a failure to inhibit distractions is a common finding from studies of executive dysfunction in clinical settings (cf. Burgess and Shallice, 1996). Nevertheless, for whatever reasons, one night of sleep loss leads to increased distraction, not only with more mundane performance (Anderson and Horne, 2006; Anderson et al., 2010), but has also been reported for a demanding, detection task involving screening luggage for weapons (Basner et al., 2008). In another study involving 'searching' for specific objects amongst much 'clutter', overnight sleep deprived participants seemed to adopt random searching rather than create a search strategy having a greater payoff potential (Glass et al., 2011).

4. Protracted negotiations

Even under ostensibly more benign conditions, such as during protracted and delicate discussions in the small hours, as with sleepless politicians trying to resolve deadlocks and negotiate terms, other aspects of executive function can also begin to become affected. The recent study by Libedinsky et al. (2011a,b) declared that "even a single night of total sleep deprivation can have dramatic effects on economic decision making" (Libedinsky et al., 2011b, p. 1). Moreover, negotiators may be more obdurate over intended goals, likely to be sidelined by irrelevent trivia (Harrison and Espelid, 2004; Mander et al., 2008), lose track of when and what was recently said (Harrison and Horne, 2000a; Killgore, 2010), have difficulty in finding the appropriate (and diplomatic) words with which to express themselves (Harrison and Horne, 1997, 1998; Pilcher et al., 2007), become more distrustful and wary of possible exploitation (Anderson and Dickinson, 2010), and fail to detect in other people, subtle changes to facial expression and other non-verbal subtle cues that might otherwise provide useful information (van der Helm et al., 2010). Moreover, with less effective executive functioning people are less able to track and update the underlying meaning being created in a conversation, are more likely to misconstrue another person's perspective, be less able to negotiate (cf. Ybarra and Winkielman, 2012), and in terms of 'theory of mind' (cf. Rizzolatti et al., 2007), will begin to lose the ability to understand the perspective of another person that differs from one's own.

5. Risk taking and emotions

Mood will alter with extended wakefulness, not just because of greater 'irritability'. Such changes can interact with executive function, affecting the ability to weigh up the relative risks and consequences for alternative actions, to the extent that decisions can be influenced unduly by emotions rather than by rational thought (Killgore, 2010; Anderson and Dickinson, 2010), and with participants more vulnerable to those distractions having a particularly emotional content (Chuah et al., 2010). Moreover, if these personnel believe that they are likely to succeed in their actions, then they can become more optimistic and take greater risks (McKenna et al., 2007; Venkatraman et al., 2007; Libedinsky et al., 2011a), even become impulsive (Anderson and Platten, 2011) and unusually euphoric, especially in the early morning hours (Harrison and Horne, 2000a; Killgore, 2010). Clearly, perceived uncertainty and the physical and social circumstances have a major influence, and in some such situations people may become risk averse (Chaumet et al., 2009), especially when thinking of possible failure (McKenna et al., 2007; Anderson and Dickinson, 2010), or they may take the risk anyway (Venkatraman et al., 2007; Pace-Shott et al., 2012) [which may contribute to why casinos are open throughout the night].

6. Task duration

It should be noted that most of the laboratory based findings with executive function that have been described, come from tests that are usually of fairly short duration, typically lasting under 10 min. Such outcomes can seem small, albeit statistically significant, and all too easily dismissed in the light of apparently more impressive findings from the PVT, for example. However, in the real world, over-night critical situations often last much longer than this, in being protracted and necessitating sustained decision making. Thus, effects found within a short experimental period may well portend a worsening of executive decision making under real and more enduring scenarios, especially when there is alarm.

7. Brain mechanisms

The PFC, wherein most of these higher executive functions tend to lie, works particularly hard in waking humans (cf. Fu et al., 2011), and more intensively than do most other cortical regions. Consequently, as the PFC seems especially in need of sleep for its recovery (Werth et al., 1997; Harrison and Horne, 2000a), despite some degree of compensatory back-up by other cortical regions during sleep loss (Drummond et al., 2004; Strangman et al., 2005; Gosselin et al., 2005), all this indeed points to an apparent vulnerability of this brain region to sleep loss. The PFC is particularly involved in decision making when there is uncertainty, especially over short time-spans, and where rapid decisions are required (Huettel et al., 2005; Venkatraman and Huettel, 2012). In contrast, well learned, routine, even complex skills, largely depend on other cortical regions that seem less vulnerable to sleep loss (Harrison and Horne, 2000a; Killgore, 2010; Maddox et al., 2009), which is a reason why we are likely to 'default' to these latter approaches during extended wakefulness, and are less able to suppress rule based strategies, rather than thinking 'out of the box' (Maddox et al., 2009).

Moreover, fMRI studies of short-term sleep loss point to more specific PFC changes relating to higher executive functions, for example, with the orbitofrontal cortex (Venkatraman et al., 2007), that differ from those involved with attention and vigilance (Libedinsky et al., 2011b). Not only do the former changes further indicate that these executive functions can be distinguished from 'sleepiness', but other, non-PFC, brain regions (e.g. insula and nucleus accumbens) that are also linked with decision making rather than to 'sleepiness', also show greater fMRI changes with sleep loss (cf. Venkatraman et al., 2007).

8. Individual differences

Individual differences are apparent in the extent to which personality and cognitive styles seem to cope with extended wakefulness (cf. Maddox et al., 2009; Saksvik et al., 2011). Although this remains a poorly explored area, certainly in terms of executive thinking, there are indications that people having the PERIOD 3 clock gene polymorphism (PER3-5/5), which is associated with being an extreme morning type, show a greater decline in executive function very early morning during extended wakefulness (Groeger et al., 2008). The latter would seem to favour 'evening types', in being 'too early' for morning types. Although this effect of PER3-5/5 seems absent with non-executive tasks (Groeger et al., 2008; Goel et al., 2009), other findings looking at wider aspects of morningness–eveningness (e.g. shift-working) indicate that 'evening types' are indeed better at coping than are 'morning types' (Taillard et al., 2011), as is being high on 'flexibility' and extraversion scores (Saksvik et al., 2011).

Whilst younger adults may seem more able (motivated?) than older people to cope with shift-work, nevertheless, the former are generally more vulnerable to sleep loss (Lowden et al., 2009). One reason may be that, compared with older people, young adults have a greater depth and intensity of sleep (greater amounts of sleep EEG delta activity – Klerman and Dijk, 2008; Dijk et al., 2010), which happens to be more evident in the PFC (cf. Werth et al., 1997). Thus, irrespective of genotype, sleep loss may be more profound in its effects on PFC functions in younger adults. Of course, one might also argue that experience and 'wisdom' of older age might further counteract the potential of any irrational decision making that might be more evident in the younger person. Nevertheless, sleep deprived younger women seem less likely to take risks than younger men (Acheson et al., 2007). And, interestingly, people having a greater cortical white matter density, indicative of greater interconnectivity, seem less 'cognitively vulnerable' to a night's sleep loss (Rocklage et al., 2009).

9. Advice and countermeasures

Whilst people seem able accurately to judge their level of performance decline at simple tasks, at least up to 24 h of continuous wakefulness, little is known about insight into one's own deterioration at higher executive skills (Baranski, 2007). Thus, if and when these particular and unusual crises occur in the early hours of the morning, it is important that front-line decision makers are aware of their potential shortcomings in these respects, which are not necessarily a poor reflection on them personally and, thus, they need to know that that there is more to the 'sleepiness' they experience.

Other advice is that all incoming information ought to be kept under constant and particularly discerning review, with decisions constantly and thoroughly checked for effectiveness. Opinions ought to be taken from a wider range of colleagues than may be the norm, especially as there is evidence that team decision making is beneficial, here (Baranski et al., 2007), even with teams as small as two individuals (Pilcher et al., 2011). Individual attitudes of perseverance, such as, 'it's my watch and I'll see it through', are laudable but inadvisable, especially when there are additional stresses. Instead, if and when possible, a fresh team should be called in. Also, new developments in information technology, especially 'intelligent back-up systems' are promising, such as, 'e-prescribing alerts' for hospital doctors, giving warnings over otherwise unexpected and overlooked drug interactions (Scott et al., 2011).

Whereas 'sleepiness' as revealed by monotony and reflected by simple tasks, can be counteracted to a marked extent by caffeine (cf. Bonnet et al., 2005), and by financial incentives (Hsieh et al., 2010), failings in the more complex executive functions are less responsive to caffeine and increased motivation (Harrison and Horne, 2000b; Killgore, 2010; Killgore et al., 2012). On the other hand, and under laboratory conditions, risk taking having a more logical, deductive basis (without distraction) during sleep loss, can benefit from caffeine (Killgore et al., 2011).

A short (<1 h) nap that may have preceded an unanticipated crisis event is unlikely to be sufficient to rectify problems with executive function. For example, Asaoka et al. (2012) found that even a 1 h nap had little benefit in offsetting the deterioration in error-monitoring functions, especially for the emotional or motivational evaluation of the error, even though the nap improved subjective alertness and response accuracy during the night. Although a nap will help alleviate general 'sleepiness' (Sallinen et al., 1998), a nap longer than about 20 min will generally result in periods of post-sleep inertia before any such benefits become evident. A 10–20 min nap seems to produce the best cost-versus-benefit in these latter respects (Purnell et al., 2002; Brooks and Lack, 2006). In order to overcome 'just sleepiness', a better solution is probably to consume (>80 mg) caffeine immediately before the nap, whereby the 20 min or so delay in its psychostimulant effect is a propitious window for the short nap, with both subsequently having a combined effect in reducing sleepiness (Reyner and Horne, 1997; Schweitzer et al., 2006). However, whether or not this combination is more likely to improve a deterioration in executive function, remains to be explored.

10. Early morning sudden, curtailed sleep

A variant on the present theme of extended wakefulness throughout the night is suddenly being woken up early morning, after about 3 h seep, and confronted with a crisis or challenging task, coupled with sleep inertia. Under laboratory conditions, the latter requires around 20 min to overcome the inertia before the executive centres can fully engage with reality (Balkin et al., 2002), which is a finding also reported by Groeger et al. (2011), following longer (90 min) daytime naps. Nevertheless, in the laboratory, such an awakening may be fairly benign and, as noted, the effects of additional stresses during sleep loss remain little understood.

Arguably, the most realistic 'crisis-driven' study highlighting potential dangers of early morning sleep inertia, following suddenly curtailed sleep during the early circadian trough, and with added stress, comes from the recent study by Horne and Moseley (2011). In a military-type exercise, junior officer reservists were unexpectedly awoken abruptly at 03:00 h after 3 h sleep, and confronted immediately with a 'dummy exercise' of an enemy attack. Each officer had to devise, without consultation, and within 15 min, a feasible plan of engagement with a 'minimal loss of resources'. Of particular importance was that halfway through this planning period they were, without warning, presented with a critical update necessitating a rapid change of tactics, with new and unexpected dangers presented. As they were also being assessed by senior officers, they had to perform at their best, and it is likely that this would have added to the stress of the situation. Compared with a normally sleeping control group, also suddenly confronted with the same scenario, most of the experimental group failed the exercise in being unable to assimilate and effectively react to the new update by revising their plan and, in some case, it resulted in complete military defeat. They generally failed to appreciate the relevance of the new dangers, even though their other, more logical and highly trained skills were unimpaired. This 'worst case scenario', more typical of real world emergencies, involved highly motivated, well-trained individuals determined to succeed. Nevertheless, effective and critical innovative decisions still could not be made in the light of new and changing events.

Although one might view such a scenario as being too extreme and rare under usual work settings, something similar may not be so unusual, domestically. For example, as with new parents suddenly woken by a febrile and very distressed infant, with their having to deal with what might seem to be an alarming and changing situation, and maybe worsened by a previous succession of disturbed nights. What little evidence is available, here, it appears that under these circumstances the parents' flexible thinking and ability to deal with a sudden change in events is indeed compromised (Plessow et al., 2011).

All these various studies point to normal executive function relying on 'adequate' sleep. However, this adequacy should not be seen simply in terms of sleep duration, or 'sleep debt', with adverse consequences largely assessed by laboratory-based sensitive measures of 'sleepiness', but also seen in terms of sleep quality and, especially, more subtle aspects of human behaviour that are likely to be particularly evident in the real world (cf. Horne, 2010, 2011).

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References

Acheson, A., Richards, J.B., de Wit, H., 2007. Effects of sleep deprivation on impulsive behaviors in men and women. Physiology and Behavior 91, 579–587.

Alvarez, J.A., Emory, E., 2006. Executive function and the frontal lobes: a meta-analytic review. Neuropsychology Review 16, 17–42.

Anderson, C., Dickinson, D.L., 2010. Bargaining and trust: the effects of 36-h total sleep deprivation on socially interactive decisions. Journal of Sleep Research 19, 54–63.

Anderson, C., Horne, J.A., 2006. Sleepiness enhances distraction in a monotonous task. Sleep 29, 573–576.

Anderson, C., Platten, C.R., 2011. Sleep deprivation lowers inhibition and enhances impulsivity to negative stimuli. Behavioural Brain Research 217, 463–466.

Anderson, C., Wales, A.W.J., Horne, J.A., 2010. PVT lapses differ according to eyes open, closed, or looking away. Sleep 33, 197–204.

Asaoka, S., Fukuda, K., Murphy, T.I., Abe, T., Inoue, Y., 2012. The effects of a nighttime nap on the error monitoring functions during extended wakefulness. Sleep 35, 871–878.

Balkin, T.J., Braun, A.R., Wesensten, N.J., Jeffries, K., Varga, M., Baldwin, P., Belenky, G., Herscovitch, P., 2002. The process of awakening: a PET study of regional brain activity patterns mediating the re-establishment of alertness and consciousness. Brain 125, 2308–2319.

Baranski, J.V., 2007. Fatigue, sleep loss, and confidence in judgment. Journal of Experimental Psychology: Applied 13, 182–196.

Baranski, J.V., Thompson, M.M., Lichacz, F.M., McCann, C., Gil, V., Pastò, L., Pigeau, R.A., 2007. Effects of sleep loss on team decision making: motivational loss or motivational gain? Human Factors 49, 646–660.

Barger, L.K., Ayas, N.T., Cade, B.E., Cronin, J.W., Rosner, B., Speizer, F.E., Czeisler, C.A., 2006. Impact of extended-duration shifts on medical errors, adverse events, and attentional failures. PLoS Medicine 3, e48.

Basner, M., Rubinstein, J., Fomberstein, K.M., Coble, M.C., Ecker, A., Avinash, D., Dinges, D.F., 2008. Effects of night work, sleep loss and time on task on simulated threat detection performance. Sleep 31, 1251–1259.

Bonnet, M.H., Balkin, T.J., Dinges, D.F., Roehrs, T., Rogers, N.L., Wesensten, N.J., 2005. Sleep deprivation and stimulant task force of the American Academy of Sleep Medicine. Sleep 28, 1163–1187.

Brooks, A., Lack, L., 2006. A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? Sleep 29, 831–840.

Burgess, P.W., Shallice, T., 1996. Response suppression, initiation and strategy use following frontal lobe lesions. Neuropsychologia 34, 263–272.

Chaumet, G., Taillard, J., Sagaspe, P., Pagani, M., Dinges, D.F., Pavy-Le-Traon, A., Bareille, M.P., Rascol, O., Philip, P., 2009. Confinement and sleep deprivation effects on propensity to take risks. Aviation Space and Environmental Medicine 80, 73–80.

Chuah, L.Y.M., Dolcos, F., Chen, A.K., Zheng, H., Parimal, S., Chee, M.W.L., 2010. Sleep deprivation and interference by emotional distracters. Sleep 33, 1305–1313.

Couyoumdjian, A., Sdoia, S., Tempesta, D.D., Curcio, G., Rastellini, E., De Gennaro, L., Ferrara, M., 2009. The effects of sleep and sleep deprivation on task-switching performance. Journal of Sleep Research 19, 64–70.

Dijk, D.J., Groeger, J.A., Stanley, N., Deacon, S., 2010. Age-related reduction in daytime sleep propensity and nocturnal slow wave sleep. Sleep 33, 211–223.

Drummond, S.P., Brown, G.G., Salamat, J.S., Gillin, J.C., 2004. Increasing task difficulty facilitates the cerebral compensatory response to total sleep deprivation. Sleep 27, 445–451.

Fu, X., Giavalisco, P., Liu, X., Catchpole, G., Fu, N., Ning, Z.B., Guo, S., Yan, Z., Somel, M., Pääbo, S., Zeng, R., Willmitzer, L., Khaitovich, P., 2011. Rapid metabolic evolution in human prefrontal cortex. Proceedings of the National Academy of Sciences of the United States of America 108, 6181–6186.

Glass, B.D., Maddox, W.T., Bowen, C., Savarie, Z.R., Matthews, M.D., Markman, A.B., Schnyer, D.M., 2011. The effects of 24-hour sleep deprivation on the exploration-exploitation trade-off. Biological Rhythm Research 42, 99–110.

Goel, N., Banks, S., Mignot, E., Dinges, D.F., 2009. PER3 polymorphism predicts cumulative sleep homeostatic but not neurobehavioral changes to chronic partial sleep deprivation. PLoS One 4, e5874.

Gosselin, A., De Koninck, J., Campbell, K.B., 2005. Total sleep deprivation and novelty processing: implications for frontal lobe functioning. Clinical Neurophysiology 116, 211–222.

Groeger, J.A., Lo, J.C., Burns, C.G., Dijk, D.J., 2011. Effects of sleep inertia after daytime naps vary with executive load and time of day. Behavioral Neuroscience 125, 252–260.

Groeger, J.A., Viola, A.U., Lo, J.C., von Schantz, M., Archer, S.N., Dijk, D.J., 2008. Early morning executive functioning during sleep deprivation is compromised by a PERIOD3 polymorphism. Sleep 31, 159–167.

Harrison, Y., Espelid, E., 2004. Loss of negative priming following sleep deprivation. Quarterly Journal of Experimental Psychology 57A, 437–446.

Harrison, Y., Horne, J.A., 1997. Sleep deprivation affects speech. Sleep 20, 871–877.

Harrison, Y., Horne, J.A., 1998. Sleep loss impairs short and novel language tasks having a prefrontal focus. Journal of Sleep Research 7, 95–100.

Harrison, Y., Horne, J.A., 1999. One night of sleep loss impairs innovative thinking and flexible decision making. Organizational Behavior and Human Decision Processes 78, 128–145.

Harrison, Y., Horne, J.A., 2000a. The impact of sleep loss on decision making – a review. Journal of Experimental Psychology: Applied 6, 236–249.

Harrison, Y., Horne, J.A., 2000b. Sleep loss and temporal memory. Quarterly Journal of Experimental Psychology 53A, 271–279.

Horne, J.A., 2010. Sleepiness as a need for sleep: when is enough, enough. Neuroscience and Biobehavioral Reviews 34, 108–118.

Horne, J.A., 2011. The end of sleep: 'sleep debt' versus biological adaptation of human sleep to waking needs. Biological Psychology 87, 1–14.

Horne, J.A., 2012, Testing of executive function. Chronobiology International, in press.

Horne, J.A., Moseley, R., 2011. Sudden early-morning awakening impairs immediate tactical planning in a changing 'emergency' scenario. Journal of Sleep Research 20, 275–278.

Hsieh, S., Li, T.H., Tsai, L.L., 2010. Impact of monetary incentives on cognitive performance and error monitoring following sleep deprivation. Sleep 33, 499–507.

Huettel, S.A., Song, A.W., McCarthy, G., 2005. Decisions under uncertainty: probabilistic context influences activation of prefrontal and parietal cortices. Journal of Neuroscience 25, 3304–3311.

Jansma, J.M., Ramsey, N.F., Slagter, H.A., Kahn, R.S., 2001. Functional anatomical correlates of controlled and automatic processing. Journal of Cognitive Neuroscience 13, 730–743.

Killgore, W.D., 2010. Effects of sleep deprivation on cognition. Progress in Brain Research 185, 105–129.

Killgore, W.D., Kamimori, G.H., Balkin, T.J., 2011. Caffeine protects against increased risk-taking propensity during severe sleep deprivation. Journal of Sleep Research 20, 395–403.

Killgore, W.D., Grugle, N.L., Balkin, T.J., 2012. Gambling when sleep deprived: don't bet on stimulants. Chronobiology International 29, 43–54.

Klerman, E.B., Dijk, D.J., 2008. Age-related reduction in the maximal capacity for sleep-implications for insomnia. Current Biology 18, 1118–1123.

Libedinsky, C., Smith, D.V., Teng, C.S., Namburi, P., Chen, V.W., Huettel, S.A., Chee, M.W., 2011a. Sleep deprivation biases the neural mechanisms underlying economic preferences. Frontiers in Behavioral Neuroscience 5, 70, October (Epub ahead of print).

Libedinsky, C., Smith, D.V., Teng, C.S., Namburi, P., Chen, V.W., Huettel, S.A., Chee, M.W., 2011b. Sleep deprivation alters valuation signals in the ventromedial prefrontal cortex. Frontiers in Behavioral Neuroscience 5, 70, October (Epub ahead of print).

Lim, J., Dinges, D.F., 2008. Sleep deprivation and vigilant attention. Annals of the New York Academy of Sciences 1129, 305–322.

Lowden, A., Anund, A., Kecklund, G., Peters, B., Akerstedt, T., 2009. Wakefulness in young and elderly subjects driving at night in a car simulator. Accident Analysis and Prevention 41, 001–7.

Maddox, W.T., Glass, B.D., Wolosin, S.M., Savarie, Z.R., Bowen, C., Matthews, M.D., Schnyer, D.M., 2009. The effects of sleep deprivation on information-integration categorization performance. Sleep 31, 1439–1448.

Mander, B.A., Reid, K.J., Davuluri, V.K., Small, D.M., Parrish, T.B., Mesulam, M.M., Zee, P.C., Gitelman, D.R., 2008. Sleep deprivation alters functioning within the neural network underlying the covert orienting of attention. Brain Research 1217, 148–156.

McKenna, B.S., Dickinson, D.L., Orff, H.J., Drummond, S.P., 2007. The effects of one night of sleep deprivation on known-risk and ambiguous-risk decisions. Journal of Sleep Research 16, 245–255.

Minkel, J.D., Banks, S., Htaik, O., Moreta, M.C., Jones, C.W., McGlinchey, E.L., Simpson, N.S., Dinges, D.F., 2012. Sleep deprivation and stressors: evidence for elevated negative affect in response to mild stressors when sleep deprived. Emotion, February (Epub ahead of print).

NASA, 1986. Report of the Presidential Commission on the Space Shuttle Challenger Accident., http://science.ksc.nasa.gov/shuttle/missions/51-l/docs/rogers-commission/table-of-contents.html

Nilsson, J.P., Söderström, M., Karlsson, A.U., Lekander, M., Akerstedt, T., Lindroth, N.E., Axelsson, J., 2005. Less effective executive functioning after one night's sleep deprivation. Journal of Sleep Research 14, 1–6.

Pace-Shott, E.F., Nave, G., Morgan, A., Spence, R.M., 2012. Sleep-dependent modulation of affectively guided decision-making. Journal of Sleep Research 21, 30–39.

Pejovic, S., Vgontzas, A.N., Basta, M., Tsaoussoglou, M., Zoumakis, E., Vgontzas, A., Bixler, E.O., Chrousos, G.P., 2010. Leptin and hunger levels in young healthy adults after one night of sleep loss. Journal of Sleep Research 19, 552–558.

Pilcher, J.J., McClelland, L.E., Moore, D.D., Haarmann, H., Baron, J., Wallsten, T.S., McCubbin, J.A., 2007. Language performance under sustained work and sleep deprivation conditions. Aviation Space and Environmental Medicine 78 (Suppl. 5), B25–B38.

Pilcher, J.J., Vander, Wood, M.A., O'Connell, K.L., 2011. The effects of extended work under sleep deprivation conditions on team-based performance. Ergonomics 54, 587–596.

Plessow, F., Kiesel, A., Petzold, A., Kirschbaum, C., 2011. Chronic sleep curtailment impairs the flexible implementation of task goals in new parents. Journal of Sleep Research 20, 279–287.

Plessow, F., Kiesel, A., Kirschbaum, C., 2012. The stressed prefrontal cortex and goal-directed behaviour: acute psychosocial stress impairs the flexible implementation of task goals. Experimental Brain Research 216, 397–408.

Purnell, M.T., Feyer, A.M., Herbison, G.P., 2002. The impact of a nap opportunity during the night shift on the performance and alertness of 12-hshift workers. Journal of Sleep Research 11, 219–227.

Reed, D.A., Fletcher, K.E., Arora, V.M., 2010. Systematic review: association of shift length, protected sleep time, and night float with patient care, residents' health, and education. Annals of Internal Medicine 153, 829–842.

Reyner, L.A., Horne, J.A., 1997. Suppression of sleepiness in drivers: combination of caffeine with a short nap. Psychophysiology 34, 721–725.

Rizzolatti, G., Sinigaglia, C., Anderson, F., 2007. Mirrors in the Brain. How Our Minds Share Actions, Emotions, and Experience. Oxford University Press, Oxford.

Rocklage, M., Williams, V., Pacheco, J., Schnyer, D.M., 2009. White matter differences predict cognitive vulnerability to sleep deprivation. Sleep 32, 1100–1103.

Rothschild, J.M., Keohane, C.A., Rogers, S., Gardner, R., Lipsitz, S.R., Salzberg, C.A., Yu, T., Yoon, C.S., Williams, D.H., Wien, M.F., Czeisler, C.A., Bates, D.W., Landrigan, C.P., 2009. Risks of complications by attending physicians after performing nighttime procedures. Journal of the American Medical Association 302, 1565–1572.

Saksvik, I.B., Bjorvatn, B., Hetland, H., Sandal, G.M., Pallesen, S., 2011. Individual differences in tolerance to shift work – a systematic review. Sleep Medicine Reviews 15, 221–235.

Sallinen, M., Härmä, M., Akerstedt, T., Rosa, R., Lillqvist, O., 1998. Promoting alertness with a short nap during a night shift. Journal of Sleep Research 7, 240–247.

Schweitzer, P.K., Randazzo, A.C., Stone, K., Erman, M., Walsh, J.K., 2006. Laboratory and field studies of naps and caffeine as practical countermeasures for sleep–wake problems associated with night work. Sleep 29, 39–45.

Scott, G.P., Shah, P., Wyatt, J.C., Makubate, B., Cross, F.W., 2011. Making electronic prescribing alerts more effective: scenario-based experimental study in junior doctors. Journal of the American Medical Informatics Association, 8789–8798.

Starcke, C., Brand, M., 2012. Decision making under stress. Neuroscience and Biobehavioral Reviews 36, 1228–1248.

Strangman, G., Thompson, J.H., Strauss, M.M., Marshburn, T.H., Sutton, J.P., 2005. Functional brain imaging of a complex navigation task following one night of total sleep deprivation: a preliminary study. Journal of Sleep Research 14, 369–375.

Taillard, J., Philip, P., Claustrat, B., Capelli, A., Coste, O., Chaumet, G., Sagaspe, P., 2011. Time course of neurobehavioral alertness during extended wakefulness

in morning- and evening-type healthy sleepers. Chronobiology International 28, 520–527.
Tucker, A.M., Whitney, P., Belenky, G., Hinson, J.M., Van Dongen, H.P.A., 2010a. Effects of sleep deprivation on dissociated components of executive functioning. Sleep 33, 47–57.
Tucker, P., Brown, M., Dahlgren, A., Davies, G., Ebden, P., Folkard, S., Hutchings, H., Akerstedt, T., 2010b. The impact of junior doctors' worktime arrangements on their fatigue and well-being. Scandinavian Journal of Work Environment and Health 36, 458–465.
van der Helm, E., Gujar, N., Walker, M.P., 2010. Sleep deprivation impairs the accurate recognition of human emotions. Sleep 33, 335–342.
Venkatraman, V., Chuah, Y.M., Huettel, S.A., Chee, M.W., 2007. Sleep deprivation elevates expectation of gains and attenuates response to losses following risky decisions. Sleep 30, 603–609.
Venkatraman, V., Huettel, S.A., 2012. Strategic control in decision-making under uncertainty. The European Journal of Neuroscience 35, 1075–1082.
Werth, E., Achermann, P., Borbély, A.A., 1997. Fronto-occipital EEG power gradients in human sleep. Journal of Sleep Research 6, 102–112.
Ybarra, O., Winkielman, P., 2012. On-line social interactions and executive functions. Frontiers in Human Neuroscience 6, 75, http://dx.doi.org/10.3389/fnhum.2012.00075.