The Impact of Sleep Deprivation on Decision Making: A Review

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Few sleep deprivation (SD) studies involve realism or high-level decision making, factors relevant to managers, military commanders, and so forth, who are undergoing prolonged work during crises. Instead, research has favored simple tasks sensitive to SD mostly because of their dull monotony. In contrast, complex rule-based, convergent, and logical tasks are unaffected by short-term SD, seemingly because of heightened participant interest and compensatory effort. However, recent findings show that despite this effort, SD still impairs decision making involving the unexpected, innovation, revising plans, competing distraction, and effective communication. Decision-making models developed outside SD provide useful perspectives on these latter effects, as does a neuropsychological explanation of sleep function. SD presents particular difficulties for sleep-deprived decision makers who require these latter skills during emergency situations.

Most of the studies that examine the effects of sleep deprivation (SD) on behavior and psychological performance have concentrated on measures deemed sensitive to "sleepiness," favoring more basic skills, such as vigilance, reaction time, and aspects of memory (cf. the recent review by Pilcher & Huffcutt, 1996). These tests are usually combined with monotony and lack of environmental stimulation, which, taken together, produce optimum conditions for maximizing the adverse effects of SD. Such monotony is further facilitated by the need to ensure that participants are well trained in the test procedures beforehand to minimize practice effects.

The extent to which these more conventional laboratory-based tests relate to real-world tasks is a matter for debate. A good illustration, and an example attracting much attention, concerns junior hospital doctors (interns) who experience SD with long working hours on a routine basis. Much of the SD research, as of this writing, has focused on cognitive processes that have little to do with the true nature of the job or normal working duties (e.g., serial reaction time, vigilance). Sometimes, the overall picture can be confusing, with findings showing no impairments for certain clinical skills and concurrent deterioration in psychological performance tasks of unknown relevance to these and other medical skills. For example, Beatty, Ahern, and Katz (1977) noted that after a night of being on call, anesthesiologists had no difficulty in monitoring vital signs during a surgical simulation, although they

were impaired on Baddeley's (1968) Grammatical Reasoning Test. Little consistency in these findings is further highlighted in a comprehensive review of this area by Leung and Becker (1992), who concluded that lack of control data, bad methodology, and poorly defined SD criteria provide no clear conclusions, despite the large number of studies. For example, SD findings are usually compared with off-duty days, when the clinician is still recovering from the effects of long work hours, and performance is still impaired. Hence, it is likely that the effects of SD are underestimated and give little insight into performance during a medical emergency. Probably, the only consistent finding has been the effect of SD on the clinician's mood, but the relationship between this and performance remains speculative.

One of the few realistic studies on clinicians, by Deary and Tait (1987), measured work-related performance during the afternoon following a night (a) off duty, (b) on call, or (c) working continuously in an emergency unit. The latter condition gave the worst results, and there were clear adverse effects on mood with increasing SD. In contrast, V. J. Brown et al. (1994) found that sleep-deprived doctors and medical students were able to comprehend learned articles from a surgical journal, even though these were lengthy and complex. However, there are two interesting studies relating to more divergent clinical skills, both showing impairment with SD. The first, by Goldman, McDonough, and Rosemond (1972), noted that sleep-deprived junior doctors were more hesitant and showed less focused planning during a surgical procedure. More recently, Nelson, Dell'Angela, Jellish, Brown, and Skaredoff (1995) found that anesthesia residents who had no more than 30 min of sleep during a night on call had impaired innovative thinking and verbal fluency, whereas complex convergent tasks remained intact. These authors concluded that the former finding could lead to medical shortcomings, such as premature diagnosis and failure to assimilate information about a patient's condition.

Nevertheless, the prevailing view in SD research is that high-level complex skills are relatively unaffected by SD because of the interest they generate and the implicit encouragement for participants to apply compensatory effort to overcome their sleepiness. Hitherto, no SD review has critically examined this assumption.

We now do so, and we challenge aspects of this assumption by drawing on recent SD findings relating to high-level cognitive function. Also, we use an operational perspective of cognitive models of decision making, which is an approach not previously used in an SD setting. To complement this latter perspective, we present a functional neuropsychological explanation that helps to integrate the behavioral and psychological changes resulting from SD. Our review is of an applied nature and covers topics particularly pertinent to the real world, (e.g., to managers, doctors, military commanders, and so forth confronted with prolonged working hours without sleep during crises and emergencies).

Sensitivity to Sleep Loss—Simple Versus Complex Tasks

In regard to the related topics of task complexity and monotony, it remains unclear from the literature whether tasks associated with cognitive speed, psychomotor skills, visual and auditory attention, and short-term memory are so sensitive to 1 night of SD for any other reason than their monotony and lack of novelty (as opposed to the more specific characteristics of these tests). In an often overlooked and elegant series of studies, Kjellberg (1975, 1977) clearly demonstrated how the effect of SD on simple cognitive tests increases with decreasing novelty, such that the greater the tedium, the shorter the test can be before deterioration is evident during SD. For example, after 1 night of SD, a well-rehearsed 10-min simple reaction-time task shows deterioration in the first 5 min (Dinges & Kribbs, 1991; Kjellberg, 1977). This tedium can be further heightened if the test comprises part of a much longer test battery of similarly monotonous tests.

A similar theme was highlighted many years ago by Williams, Lubin, and Goodnow (1959), Wilkinson (1961), and again more recently by Wilkinson (1992), who advocated that "SD reduces the non-specific arousal level of the body, but has no specific effects" (Wilkinson, 1992, p. 254). He went on to argue against using tasks that are "too complex, too interesting, too variable and, above all, too short" (Wilkinson, 1992, pp. 254–256). He, along with many other investigators, had shown that these latter tasks intrinsically encourage sleepy people to apply compensatory effort and perform normally. Hence, these tasks have been deemed to be insensitive to SD. Similarly, with the dull, monotonous reaction-time and vigilance tasks, if participants are suitably encouraged to apply more effort, for example, by giving them knowledge of results (Wilkinson, 1965), financial reward (Horne & Pettitt, 1985), or increasing the rate of stimulus presentation (Corcoran, 1963), then these tasks also lose their sensitivity to SD.

Given this state of affairs, it is generally assumed that under demanding and motivating conditions, SD will have little impact on high-level decision making or complex skills. Such an assumption has been borne out by the few studies looking at some of these tasks, and SD researchers have been reluctant to pursue this avenue further. For example, IQ types of performance tests, critical reasoning, and logical well-practiced tasks are all resilient to 36 hr or more of SD (Horne, 1988a). Similarly, tasks that incorporate complexity by virtue of either multitask or decision-making elements are generally organized around rule-based strategies. For example, Hockey, Wastell, and Sauer (1998) and Linde, Edland, and Bergstrom (1999) devised tasks requiring multiple levels of simultaneous vigilance across different sensory modalities. Although undoubtedly more complex than simple vigilance or

reaction-time tests, these tasks are not particularly taxing in terms of demands for innovation or dealing with the unexpected. Wilkinson (1964) described the effects of 30–60 hr of sleep loss on two decision-making tasks developed with ecological validity in mind. Both involved military-type maneuvers (simulated battle games), and participants were trained naval personnel. One was a tracking and interception task, which showed no sign of impairment, despite being of a relatively long duration—a finding attributed by Wilkinson (1964) to task complexity and considerable participant interest. It should be noted that the SD literature shows that interesting tracking tasks show little effect of short-term SD (Horne, 1988b; Wilkinson, 1965). However, the second task, coded decision taking, required the participant to plan ahead and undertake a cost–benefit analysis of any intended action. Thirty hours of SD led to substantial impairment, which Wilkinson (1964) attributed largely to a loss of participant interest. That is, he viewed task interest to be the salient difference between the two tasks and the cause of the different outcomes following SD. However, even though the latter task was complex in the sense that it required adherence to rules of play, visual monitoring, and so forth, it also relied on substantial planning and mental imagery.

To summarize, complex tasks that are essentially rule-based and interesting for the participant tend not to be sensitive to sleep loss. However, if such tasks are given many times, they become well learned, may lose their novelty, and risk becoming dull and monotonous, which will make them vulnerable to sleep loss unless one is remotivated to perform well. In contrast, real-world decision making can also involve unique and unfamiliar circumstances, necessitating a wide range of other complex skills (e.g., having to appreciate a difficult and rapidly changing situation; assess risk; anticipate the range of consequences; keep track of events–update the big picture; be innovative; develop, maintain, and revise plans; remember when events occurred; control mood and uninhibited behavior; show insight into one's own performance; communicate effectively; and avoid irrelevant distractions). With the inherent interest generated by most of these tasks, together with the likelihood that, of necessity, decision time may be short rather than long and tedious, such tasks should not be sensitive to SD, according to the more classical perspective of SD outlined above. However, there is increasing evidence from recent laboratory studies that even 1 night of SD does lead to significant deterioration in these skills, despite the individual's best efforts to perform well and the task being of short duration (< 10 min). The underlying reason, which we elaborate on, is that unlike the rule-based convergent and logical skills, these latter skills depend heavily on the integrity of the prefrontal region of the cerebral cortex. Recent neuropsychological and brain imaging studies show this region to be particularly affected by a night of SD (Drummond et al., 1999, 2000; Horne, 2000; Petiau et al., 1998).

It may be argued that these latter decrements are due to impairments in lower level aspects of performance that are integral to these higher functions, for example, certain aspects of memory. If this were so, then one might ask why this does not apply to the rule-based complex tasks. Of course, there are probably different combinations of these lower skills to facilitate these two categories of complex skills, perhaps with only certain key components affecting the divergent type of complex task. However, rather than become involved at this level of debate, much of this review takes a more pragmatic view of the findings that SD leads to certain

types of high-level cognitive dysfunction, for whatever reasons, although, not readily accounted for in terms of low-level skills.

Decision Making as an Operational Construct

Higher level decision making not only requires convergent, rule-based skills of logical, critical, and deductive reasoning but also can involve unique and unfamiliar circumstances, necessitating a range of divergent skills, as already outlined. We argue that recent laboratory-based findings strongly suggest that unlike the convergent skills, the following, more divergent skills, are particularly affected by SD.

Appreciating a Complex Situation While Avoiding Distractions

This often necessitates the assimilation of large amounts of information, often within a short space of time. The level of complexity may not be an issue because SD participants perform normally on IQ tests (Percival, Horne, & Tilley, 1982) and reading comprehension (Webb, 1986) for up to 2 nights without sleep. However, there is a lack of focused attention, which is likely to impact on those higher order tasks, requiring the assimilation of rapidly changing information. SD leads to increased visual and auditory distraction (Blagrove, Alexander, & Horne, 1995; Hockey, 1970; Norton, 1970). For example, Norton (1970) found that 2 nights of SD caused a marked deterioration in the detection of target information within a complex visual array. Recently, Blagrove et al. (1995) found similar impairments on an embedded figures task after only 1 night of SD. Blagrove (1994, 1996) has also reported that SD participants are less discriminating in handling ambiguous material, less confident, more open to leading remarks, and more willing to modify recollections of a witnessed event, particularly after negative feedback following their initial account. Harrison and Horne (1999) found with their simulated marketing game (see below) that following 1 night of SD, participants were less appreciative of an increasingly complex situation and responded by applying more effort to pointless areas of their decision making, which had little or no effective outcome.

Keeping Track of Events and Developing and Updating Strategies

In a field study, Banderet, Stokes, Francesconi, Kowal, and Naitoh (1981) simulated a realistic military operation, wherein soldiers participated in team-based operations throughout a maximum period of 80 hr of continuous work. Problems emerged at around 36 hr, when participants lost track of critical tasks, failed to update maps with incoming information, and deferred tasks that had previously received prompt attention. Belenky et al. (1994) drew parallels with a "friendly fire" incident during Operation Desert Storm, in which American military vehicles on the ground were fired at and destroyed by fighter pilots from the same unit who had become confused and spatially disorientated after failing to update positional references. The men involved had previously undergone 48 hr of drastically reduced sleep. Wimmer, Hoffman, Bonato, and Moffitt (1992) and Horne (1988a) reported the effects of 1 night of SD on conventional planning tasks that required participants to ignore previously successful strategies and adopt

alternative approaches to make a successful decision. SD led to significant deteriorations in these skills, marked perseveration, and a failure to revise original strategies in the light of new information. Herscovitch, Stuss, and Broughton (1980) found that partially sleep-deprived people were more likely to perseverate rather than change strategies on a nonclinical advanced version of the Wisconsin Card Sorting Task (Heaton, Chelune, Talley, Kay, & Curtiss, 1993), even when it was apparent that these strategies were no longer appropriate.

Thinking Laterally and Being Innovative

May and Kline (1987) monitored performance across a range of cognitive tasks in military personnel during 2 nights of SD with and without additional physical fatigue. Tests included embedded figures, verbal fluency, ideational fluency, inductive reasoning, spatial ability, short-term memory, basic arithmetic, logical reasoning, and flexible thinking. Participants coped well with convergent tasks (when the solution could be arrived at by logical deduction), whereas innovative thinking and the generation of spontaneous ideas deteriorated markedly. The latter, which tap ideational fluency and flexibility of thought processes, are skills that are essential in dealing with complex and unpredictable events.

Harrison and Horne (1999) developed a marketing strategy simulation game—Masterplanner—devised originally as a realistic training tool for prospective managers and master's of business administration students. The main objective for participants is to promote sales for a hypothetical product and ultimately achieve market dominance and a substantive profit by manipulating various factors; the more innovative the play, the greater the potential gain. Integral to this game is a continuing need to update oneself on and remember changing events. Masterplanner requires an interaction between learned skills necessary for the routine playing of the game and a more innovative capacity to respond to unfamiliar and unusual scenarios. Participants play for 1-hr sessions—at the start of each session, participants review the consequences of their decisions made at the end of the previous session. A further set of decisions is then made on the basis of their understanding for the current position. As with many real-world environments, Masterplanner becomes progressively more difficult to cope with as the game proceeds, and participants have problems with securing a place for their product in a near-saturated market. During this SD study, participants also completed a 30-min complex and critical reasoning task, aimed to assess whether they were able to assimilate and understand large amounts of complex, written information. Following 36 hr of SD, participants were unable to cope with the demands of Masterplanner and became insolvent or near-insolvent. They responded less appropriately, became increasingly reliant on previously successful decisions (which were no longer appropriate), and failed to produce innovative solutions to an increasingly critical situation. Control, non-SD participants performed well and were in a position to continue with further sessions if required. The critical reasoning task was not affected by SD, suggesting that although participants were still able to assimilate the factual material generated by Masterplanner, they were unable to use this material in a constructive and innovative way. The lack of an effect on critical reasoning at this stage of SD is in keeping with the scientific literature on SD

concerning logical or convergent tasks (Blagrove et al., 1995; Horne, 1988a; Naitoh, 1976; Wilkinson, 1965). Unfortunately, although tasks like Masterplanner are more applicable to the real world, they present the investigator with the difficulty of determining suitable outcome measures. This may explain why relatively few tasks of this kind have been used in the context of SD.

Assessing Risk—Anticipating Range of Consequences

Assessing risk in terms of cost–benefit analysis or probable consequence has not been explored in any depth following SD. There is indirect evidence of a greater willingness to take risks with increasing fatigue. For example, I. D. Brown, Tickner, and Simmons (1970) looked at driving behaviors throughout lengthy driving shifts on roads through town centers and along busy major roads. By the end of the session, drivers were more willing to initiate dangerous or hazardous overtaking maneuvers (i.e., when visibility of oncoming traffic was poor or by forcing other drivers to adjust their speed or position to allow them to pass). Although it could be argued that an increase in these maneuvers is indicative of a more general deterioration in driving skills rather than a shift toward high-risk driving in itself, it is not possible to differentiate between these two aspects of driving behavior in the context of this experiment. It is notable, however, that drivers did not adopt an overly cautious driving strategy with increasing fatigue, a strategy that might also be considered indicative of bad driving.

Recent work by Harrison and Horne (1998b), using a complex strategy task adapted from the clinical field (Bechara, Damasio, Tranel, & Damasio, 1997), suggests that SD participants are less concerned with negative consequences when faced with a potentially high reward. The task simulated real-life decision making with variable risks and comprised a self-paced gambling scenario in which participants were presented with four packs of cards face down on a computer screen. They were told that all cards carried a reward and only some carried penalties and that they could pick any card from any pack, with the aim to win as much as possible. There were a total of 120 card selections that had to be completed. Success depends on the ability to select cards on the basis of a cost–benefit analysis, despite a high level of uncertainty. After some experience, the non-SD control group learned to avoid packs with an ultimate no-win value, preferring to adopt the more conservative route of low rewards but attracting an overall net profit. In contrast, the SD group was undeterred by heavy losses and continued to be drawn by high-risk packs. After 80 card selections, and unbeknown to the players, pack features were adjusted, forcing the participants to rethink initial strategies. This move prompted players previously drawn to a high-risk strategy to sample from the more conservative (and ultimately successful) low-risk packs. Again, SD participants were reluctant to pursue this route, whereas the controls soon learned to avoid high-risk (no-win) alternatives and continued to do so even when the situation changed. Neurological studies (Bechara et al., 1997; Damasio, 1996) have shown that this test is particularly sensitive to impairment of the orbital-frontal region of the cerebral cortex, an area responsible for one's concern for the future consequences of one's actions and also vulnerable to SD (see below).

It might be argued that these latter findings are due to loss of interest or a sense of futility rather than risky behavior in itself and that for tasks of a similar level of difficulty but not deemed futile,

the outcome would be different. However, with the gambling task, the action of SD participants was purposeful, as they did not simply pick cards at random. Considerable attention to detail and sequencing was required before any planned action. Furthermore, in addition to ensuring that this task as well as our other tasks were short and stimulating for participants, we did find clear differences in SD effects on divergent and convergent activities, even though loss of motivation might have been expected to generalize across tasks of comparable interest.

Maintaining Interest in Outcome

As noted earlier, in experimental settings, compensatory effort can be effective in maintaining performance for a limited period (Horne & Pettitt, 1985; Wilkinson, 1965). Kjellberg (1975, 1977) proposed that decrements found in lengthy, tedious tasks reflect lack of interest in performing well, with the participants probably having realized the futility of the exercise. Other motivational factors may interact with SD in maintaining vigilance-type performance (Lester, Knapp, & Roessler, 1976; May & Kline, 1987). Kjellberg (1975) gave a series of numerical pattern completion tasks to two groups of participants following 1 night of SD. This was a self-paced task, and participants were under no time restraints. A small number of the problems were insoluble, but only one group was informed about this. Following SD, but not under baseline conditions, the informed group spent less overall time on the task and attempted or completed fewer problems than the naive group. This was the case even for problems that were relatively easy to solve. Kjellberg (1975) argued that following SD, a sense of futility quickly interferes with a willingness to apply effort.

Controlling Mood and Uninhibited Behavior

The recent meta-analysis by Pilcher and Huffcutt (1996) of SD studies published within the period 1987–1996 identified 56 investigations, 37 of which were excluded from the meta-analysis because of insufficient details or methodological reasons. The remaining 19 were explored in terms of consistency of findings and size of effect. The strongest outcome was with mood changes rather than with cognitive or motor performance. However, as the selection criteria excluded studies of high-level processing because of the difficulty in equating outcome measures, the impact of mood in these respects is still unclear, although, Angus, Heslegrave, and Myles (1995) have argued that complex and demanding tasks have a more profound effect on mood during SD. Unfortunately, mood changes have rarely been the focus of these more recent studies and have tended to be reported using either basic measures that restrict subjective accounts or anecdotally (if at all).

Irritability, impatience, childish humor, lack of regard for normal social conventions, and inappropriate interpersonal behaviors have all been described anecdotally in experimental settings of SD (Horne, 1993). The inane humor often shown by SD participants was commented on many years ago by Bliss, Clark, and West (1959) and Kollar, Slater, Palmer, Doctor, and Mandell (1966). The former group noted that "several [participants] passed through periods of giddiness and silly laughter, like addled drunks, when their behaviour became uninhibited" (Bliss et al., 1959, p. 354). These behaviors seem to fall under the rubric of loosening or relaxing social inhibitions and may be the result of SD effects on

the prefrontal cortex (Horne, 1993). Such behaviors could well aggravate other potentially adverse effects of SD, for example, aspects of language and other communication failures between individuals (see below). These uninhibited behaviors tend to occur as outbursts because for much of the duration of SD, participants tend to remain quiet and somewhat withdrawn. For example, Haslam (1984) reported that sleep-deprived soldiers on "early call" trials became more docile and resigned to the situation. Of greater concern to Haslam was that with increasing SD, a few of the junior officers ceased to act as leaders and, instead, concentrated on personal survival. Willingness to engage in forward planning by patrols was reduced, and, following periods of increased tension during these military exercises, heightened behavioral disinhibition often occurred, seemingly compounded by the SD (Haslam, 1984).

Finally, there is a relatively large amount of clinical literature pointing to the rapid mood-enhancing effects of SD in depressed patients (cf. review by Wu & Bunney, 1990). One night of SD can result in significant mood enhancement for 60% of patients so treated. The effect does not necessitate total SD; sleep restriction to 4 hr of sleep per night can be equally effective (Wu & Bunney, 1990). Although these findings could be dismissed as only being relevant to depressed patients, the effect is powerful and suggests that the milder effects found in some normal participants (see above) during SD should be examined further in an applied, nonclinical context. Euphoria as well as outbursts of uninhibited behavior are not desirable attributes in a decision maker attempting to control a crisis.

Showing Insight Into Own Performance

Having insight into performance failure is essential to avoiding recurring errors, as well as acting as a signal to a pressing need for sleep. Feedback on performance is a critical factor in motivating participants to perform well in the laboratory, whereas in the field, information concerning the success, or otherwise, of one's actions is not always immediately available. Consequently, under these conditions, decision makers rely to a great extent on their own assessment of how well they are doing, which raises the obvious question of whether sleep-deprived personnel are in a position to do this effectively. This issue has been addressed in relation to low-level tasks (visual perception, vigilance, reaction time, and mental arithmetic) during SD and has a bearing on mood factors and, more importantly, on the use of some types of psychostimulants to alleviate subjective sleepiness. Dinges and Kribbs (1991) argued that SD participants were aware of performance decrements on a vigilance task, even up to 64 hr of SD, at which point they were unable to do anything about it, despite trying harder. Baranski and Pigeau (1997) found that participants treated with 20 mg d-amphetamine or placebo maintained realistic insight into their performance decline, whereas 300 mg Modafinil (a new, non-amphetamine-based psychostimulant) led to overconfidence in performance ability. In a related study by Bard, Sotillo, Anderson, Thompson, and Taylor (1996), SD participants given Modafinil were also shown to be more blasé during a communication task and demonstrated an unnecessary level of risk by not making full use of confirmatory verbal feedback between themselves. Bard et al. (1996) suggested that their participants overestimated their own competence but without losing sight of their objectives. Of inter-

est, the Modafinil group failed to apply more compensatory effort to the task as SD increased, whereas those from other groups did so. To date, self-monitoring has not been considered in relation to complex tasks, although, in a recent temporal memory task (see below), Harrison and Horne (2000) found that SD led to more confidence about ambiguous responses than was the case with non-sleep-deprived participants. The authors also found that for another SD group given (350 mg) caffeine to alleviate the subjective effects of sleepiness (see below), the treatment had only limited effect on reducing performance decrements and did not lead to improvement in discrimination for monitoring one's own performance.

Remembering "When" Rather Than "What"

Temporal memory (memory for when events occur) deteriorates with SD. G. O. Morris, Williams, and Lubin (1960) were the first to notice this in their observations that participants could remember what they had eaten for meals but could not remember when. The investigators also developed a Temporal Disorientation Scale for rating their participants. Surprisingly, this interesting finding was not pursued for another 30 years or so, when Harrison and Horne (2000) reported that SD participants were unable to recall the timing for recent events ("recency"), whereas their prompted recognition ("recognition") of these events remained intact. Neuropsychological studies outside SD research indicate that this recency element is reliant on frontal lobe functioning (Milner, Corsi, & Leonard, 1991; see below), unlike the recognition component. The implications for real-world tasks are that SD may lead to difficulty or confusion in remembering the serial ordering of facts, events, commands, instructions, and encounters with other personnel.

Communicating Effectively

Interaction between people is likely to undergo subtle changes after SD because of alterations in language processing. Qualitative differences in speech articulation have been observed after just 1 night of SD (Harrison & Horne, 1997). This was also the finding by Whitmore and Fisher (1996), in which four-man bomber crews were monitored throughout 36-hr exercises. Voice recordings of radio messages showed that certain vocal parameters were affected by SD (reduced intonation and speech slowing); however, there was also a strong circadian influence. Schein (1957) used a simulated task of message transmission to explore verbal communication skills. In one phase, participants described a complex visual array in terms of the spatial relations between components. This was to be sent to an unseen partner whose job was to reconstruct the array based on the message. After around 55 hr of SD, problems emerged in both receiving and transmitting messages. The difficulty was most apparent for operators with "high intellectual ability," but no further explanation was offered. However, Schein went on to note that SD participants, "dropped the intensity of their voice, paused for long intervals without apparent reason, enunciated very poorly or mumbled instructions inaudibly, mispronounced, slurred or ran words together, and repeated themselves or lost their place in the sequence" (p. 250). G. O. Morris et al. (1960) made similar observations about their SD participants, who became increasingly difficult to understand and made more

speech errors, repetitions, and mispronunciations, leaving sentences to trail off without endings. Given the similarity between these two reports, it seems surprising that this area has not received greater attention in the intervening years.

Angus and Heslegrave (1985) found increased reaction time in response to incoming messages set against a background of continuous distractions. Very little is known about this topic under applied settings, although Neville, Bisson, French, and Boll (1994) reported increased communication errors (inaccurate or misheard messages), with acute sleep restriction among American military aircrew taking part in the Desert Storm operation.

Impairments to the retrieval of words may be one of the earliest aspects of language decrement during SD (Harrison & Horne, 1997; Horne, 1988a; May & Kline, 1987; Tilley & Warren, 1984). May and Kline (1987) found that soldiers had difficulty with a semantic word-generation task after 2 nights without sleep. In another version of this task, Horne (1988a) and Harrison and Horne (1997) used a simple letter prompt for word generation and found a similar effect after only 36 hr of SD. When generating words, participants perseverated within a semantic category and showed less flexibility or spontaneity in language retrieval. Harrison and Horne (1997) used a second task to look at aspects of speech articulation. Following practice sessions to overcome the inhibitory effect of undertaking such an unusual task, participants read sections from a dramatic story, having to use appropriate intonation. After 36 hr of SD, naive judges were able to detect higher levels of fatigue in the participants' voices, compared with a baseline condition. After SD, voices were also judged to lack normal intonation and to be more monotonic. Again, this effect may be due to prefrontal cortical changes during SD (Harrison & Horne, 1997).

In a study involving spontaneous dialogue rather than scripted material (as used by Harrison & Horne, 1997; Whitmore & Fisher, 1996), Bard et al. (1996) reported communication difficulties during a military-style task throughout 64 hr of SD. Pairs of participants, working from different rooms with a radio link up, were given two versions of the same basic map. Only one of these maps had a route and destination drawn in—the other included basic landmarks but no route or destination. The participant with the route map had to transmit sufficient verbal information to allow the recipient to recreate the route on their map (i.e., as if they were planning to meet at this designation). SD participants produced less spontaneous dialogue and were less successful in performing this task.

In a further SD study, Harrison and Horne (1998a) used a task of language inhibition (the Haylings Sentence Completion task) to explore language flexibility. This task comprises two parts: The first requires the rapid generation of highly predictable single-word endings to verbally presented incomplete sentences. For example, "Father carved the turkey with a sharp . . ." where "knife" is the correct answer. In the second part, participants are again presented with incomplete sentences with highly predictable endings, but this time, they have to suppress this response and generate, as fast as possible, an inappropriate single-word ending. We (Harrison & Horne, 1998a) found that after 36 hr of SD, participants became impaired on the second part of the test when they responded more often with either the meaningful completion or a semantically related completion. Also, SD led to longer response latencies on this latter part of the task.

In summary, SD affects language by reducing verbal spontaneity and word retrieval and alters articulation and other vocal characteristics. Also, SD participants may be less willing to volunteer factual details, may appreciate less the importance of doing so, or may have less empathy with colleagues' ignorance of vital information. All this can impair the accurate transmission of ideas between colleagues and impact conversational flow, which may be particularly relevant to situations described by Flin, Slaven, and Stewart (1996), in which there is a need for effective communication in circumstances where the decision maker cannot be where the action takes place but remains in a control area to receive and distribute information about the emergency and to delegate as necessary.

In the Whitmore and Fisher (1996) and Banderet et al. (1981) investigations, men worked in small groups relying on the coordinated activities of the others. In both cases, each man had extremely specific, well-learned roles within a complex but rule-based task paradigm. In the former study, all the men were trained bomber aircrew, working in four-man groups inside a cockpit simulator. In the latter investigation, similar group sizes were used during a simulated artillery team exercise. Although overall success relied on the effective performance of all group members, neither study reported on the interactions between the men. Future studies of this nature need to assess those communication and language skills critical for social interaction and group dynamics.

Models of Decision Making

Outside the field of SD, there exist various models of decision making that may be particularly relevant to SD, in that they provide another useful perspective on several of the findings just described. Research into cognitive mechanisms underlying decision making has generated many interesting results. Although the influence of particular stressors, such as time constraints, affective state, genuine risks, and high losses, has been the focus of these studies, there has been no research relating the effects of SD to specific models of decision making. In this section, we describe the influential ideas in decision-making research and present a brief review of what are referred to as "rationalistic" and "normative" descriptive models. Much of the research relating to these models took place in the laboratory with naive, nonprofessional participants. However, in recent years, there has been considerable interest in the process of naturalistic decision making, which we consider to be more appropriate to SD. In particular, our attention is drawn to the recognition-primed decision model presented by Klein (1993, 1997), which is derived from findings with professional operatives performing real tasks in applied settings or simulations designed to incorporate essential features of normal working practices. This is covered in detail in the *Naturalistic Decision Making* section.

Rationalistic Decision Making

Early models of behavioral decision making concentrated on rationalistic approaches, as exemplified by the expected utility model (Von Neuman & Morgenstern, 1947). It described decision making in terms of the expected utility or value of all possible outcomes, weighted by their probability. Thus, the quality of decision making is assessed in terms of the value of the outcome,

whereby the optimal choice would be that offering the greatest overall utility. In this sense, decisions are broken down into basic components on the assumption of logical and rationalistic processing of this information. However, it has become clear that decisions are rarely made on the basis of cold, rational, mathematical deduction. In particular, this view of decision making fails to account for evidence of bias or heuristic use in cognitive processing (cf. Kahneman & Tversky, 1996; Payne, Bettman, & Johnson, 1992; Tversky & Fox, 1995), which can lead to systematic deviations from utility-based decisions.

Normative Descriptive Models of Decision Making

A number of factors are now known to influence the way problems are evaluated because it seems that decision makers have difficulty with, or are reluctant to maintain, a rationalistic approach to problem solving, an effect exacerbated by the existence of uncertainty or time constraints in problem scenarios. Also, in many complex situations, decision makers are confronted by ill-defined problems where the calculation of probability or utility is impeded by uncertainty, or they may be forced to decide between alternatives of equivalent utility. Under such conditions, factors such as framing, certainty of risk, affective state, and performance insight (unaccounted for by expected utility theory) are likely to have a considerable influence on the outcome and are discussed in more detail below.

Framing. Prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981) describes the influence of framing, that is, the way problems are initially presented and perceived and how this affects the attribution of probabilities and the desirability of specific outcomes. In a well-known example (Tversky & Kahneman, 1981) in which alternatives of equivalent outcome probabilities were favored disproportionately, depending on the presentation of the problem, decision makers favored risk-seeking strategies when the outcome probabilities were framed in terms of loss of life (negative frame). In contrast, a comparable group adopted a risk-aversion strategy when the outcome probabilities (of equivalent value) were presented in terms of lives saved (positive frame). This finding of risk aversion following positive frame has been observed in many experimental studies, with students and managers alike (cf. recent meta-analysis by Kuhlberger, 1998).

An additional factor in consideration of framing concerns the circumstances of actual decision making. Whereas researchers have tended to concentrate on single-task decision making, in the real world, decisions are often taken in contexts developed as the result of previous decisions (deemed successful or otherwise). Although this factor is also likely to exert a powerful influence on the perception (framing) of problems, as well as on the attractiveness or value of alternative strategies, neither aspect has received much attention. Thaler and Johnson (1990) noted that, following a successful outcome, participants tended toward more risk taking, suggesting that recent gains provided room to maneuver. They also found an increased tendency for participants to go for high-gain options following recent heavy losses, with the authors pointing out that heavy losses reduce the attractiveness or prospect of small, incremental gains (i.e., the conservative or safe route) and that only through gains of a different scale can the original position be restored. Within the context of SD, nothing is known about the

influence of previous experience on decision making, although, the impairments to selective attention and temporal memory (Blagrove et al., 1995; Harrison & Horne, 2000; Hockey, 1970; Norton, 1970) suggest that this is a worthwhile area for future study.

Certainty of risk. Research suggests that people are wary of uncertainty, as is the case when the level of risk attached to a particular response is ambiguous. Tversky and Kahneman (1981) argued that in problem evaluation, probabilities can be assessed in terms of their subjective value (i.e., the desirability of a particular outcome) as well as be weighted according to the level of certainty of that event. That is, as gains become less certain, risk-seeking behaviors (offering high levels of gain) become more likely, whereas high-probability gains reduce risk taking.

The way a problem is approached and assessed has implications for the sleep-deprived decision maker. Only one SD study (Harrison & Horne, 1998b), which we have just described, has investigated risk assessment. With this task, evidence of risk-aversion strategies might be expected for two reasons: (a) The task was positively framed, emphasizing gains (rather than losses) by instructing participants that the overall aim of the task was to maximize profit, and (b) low-risk card packs provided greater certainty in that order of rewards and losses for these packs followed a more stable and predictable pattern. Of interest, SD participants failed to respond to this framing bias, whereas controls responded accordingly and used risk-aversion strategies. SD effects on framing could be explored further by extending this study to modify the protocol toward a more penalty-driven task. The following two subheadings highlight factors that may go some way toward explaining the reduced sensitivity to framing bias that seems to occur during SD.

Affective state. Affective state has been found to have an important influence on risk-taking behaviors, with negative mood leading to significantly more high-risk decisions than positive or neutral mood states (Isen, Nygren, & Ashby, 1988). In contrast, positive mood states tend to elicit risk-aversion behaviors, with the extent of risk aversion further enhanced by positive framing (Isen & Patrick, 1983). These findings have been interpreted in terms of Isen and Patrick's (1983) mood maintenance model. Whereas participants experiencing a positive mood avoid risk rather than jeopardize their current mood, participants in a negative mood state actively seek out gains, despite high risks, to remedy their current affective state. Pilcher and Huffcutt's (1996) recent meta-analysis of SD studies showed that the deleterious effects of mood are frequently underestimated. However, mood in this context is often poorly defined and may be confounded by other factors, such as reduced arousal. Future studies investigating the nature of mood changes following SD and the implications for behavior would shed some light on the area.

Performance insight. Thaler and Johnson (1990) found that high levels of self-confidence led to risk-seeking behaviors, especially for choices considered to be high stake. Assuming self-confidence is influenced by the ability to self-monitor during tasks, then there is some doubt as to the ability of SD individuals to maintain this insight for tasks other than the low-level vigilance type (Harrison & Horne, 2000). It might be argued that under real-world circumstances, when there is high risk, there is much incentive to apply extra effort in resolving problems and that even the SD decision maker is able to benefit from knowledge of how the event develops and the threat of genuine losses. However,

knowledge and expertise are no guarantee of more effective decision making (Payne et al., 1992), and increased effort may not help one to recognize an inappropriate strategy, although, this may increase confidence or strategy perseveration by virtue of the amount of attention given to the problem (Tversky & Kahneman, 1986).

Finally, Payne et al. (1992) described decision making in terms of constructive processing. That is, the active restructuring of problems by simplification and selective focusing, so that uncertainties or inconsistencies between options can be resolved. As the authors pointed out, the crucial factor is how people select the important information and ignore the less important. However, SD may well promote the antithesis to such discrimination, as we have pointed out, in that SD can lead to overemphasis of peripheral concerns, a lack of focused attention, and difficulty in ignoring nonrelevant stimuli.

Naturalistic Decision Making

We now turn our attention to an approach to decision making that has influenced operational thinking over recent years. The appeal of the naturalistic decision making (NDM) approach is that it attempts not only to describe decisions as spontaneous reactions to real events, but also views decision makers to be expert, trained operatives rather than naive experimental participants. The emphasis is very much on putting the decision maker in a realistic context and, in that sense at least, represents a departure from earlier work. Studies rely to a great extent on retrospective accounts of decision-making scenarios, with the aim of revealing key factors in strategy development, particularly where this relates to crisis resolution and handling uncertainty (Flin et al., 1996; Kaempf, Klein, Thordsen, & Wolf, 1996; Lipshitz & Strauss, 1997; Randel, Pugh, & Reed, 1996). Although these conditions may appear to be ill-defined from a traditional psychological perspective, advocates argue that this approach offers greater ecological validity. For this reason, NDM offers a particularly interesting perspective on the likely impact of SD on applied decision making.

It has been suggested that in the majority of time-constrained, dynamic, complex, and high-risk situations, decisions rely on the rapid identification of applicable rule-based strategies following an evaluation of the similarities between the current set of conditions and previous experience (Klein, 1993, 1997). To understand decision making in situ, Klein (1993, 1997) developed a recognition-primed decision model (RPD) to describe executive decision-making processes in high-risk, dynamic, and naturalistic environments (see Figure 1a –c).

At the center of the RPD model is the matching of situational variables with prerehearsed scenarios or training exercises that trigger the typical course of action. In the simplest conditions (see Figure 1a), this comprises a direct match between the situation and a recommended course of action. Following this match, four processes are identified: (a) expectancies (establish the scope of the situation), (b) relevant cues (filter relevant from distracting information), (c) plausible goals (formulate realistic aims), and (d) typical action (identify a response strategy likely to work).

Because complex situations may demand a more flexible and innovative approach, the model also allows for additional features to facilitate situational awareness and recognition, as shown in more complex variants (see Figures 1b and 1c). That is, such situations might be atypical and require more sophisticated diagnostic strategies. Figure 1b allows for the additional process of story building, where the decision maker attempts to build a logical picture of events from an otherwise disparate range of incoming information. In a realistic setting using retrospective self-reports, this approach has been found to be a feature of approximately 12% of decisions, whereas the majority of decisions rely on direct matching of dominant features of the situation with previous knowledge and experience (Kaempf et al., 1996). The model also allows for situations where there is a range of possible actions (see Figure 1c). Following recognition, the decision maker considers potential courses of action and examines each in turn (through mental simulation) until a suitable strategy is obtained. It is important to note that this is not necessarily the optimal response strategy but one that may be sufficient in dealing with the immediate situation. In fact, Kaempf et al. (1996) reported that under critical time restraints and high-risk situations, only a small minority (4%) of decisions are made on the basis of direct comparison between options because serial recall of options is expected to stop at the first option satisfying the minimum criteria for suitability.

From an operational perspective, processes exemplified by the RPD model can work in favor of situations requiring quick decisions and immediate responses. It is important that decision makers are able to establish the facts quickly and effectively and are prepared to act, despite distraction or even chaos. In these circumstances many researchers find that emergency personnel apply the RPD model in one form or another (see Figures 1a–c). For example, the model has been applied to the actions of naval commanders monitoring local aircraft, that is (a) identify as friend or foe and (b) implement defensive strategies as necessary (Kaempf et al., 1996). Here, decisions taken during both training and active maneuvers were found to rely almost exclusively on feature recognition. That is, the current pattern of events was matched against knowledge for potential scenarios, and response strategies were selected on the basis of this recognition. Randel et al. (1996) studied U.S. Naval officers during a complex monitoring task and, again, found that highly trained personnel performing a familiar yet complex task relied heavily on knowledge, with their decisions guided by previous experience. In keeping with the RPD model, both expert and novice operators dealt one step at a time with the assessment of the situation and deciding on the course of action, rather than by using parallel comparison of alternatives. The serial processing of solutions compared with a comparative approach is a key feature of many scenarios described within the RPD framework. For example, Endsley and Smith (1996) reported that pilots rarely compared options in deciding on strategy during a simulated attack. Klein (1989) and Hendry and Burke (1995) found that fire fighters made over 80% of their decisions without direct comparison of options. Flin et al. (1996) reported that over 90% of critical decisions taken by offshore installation managers (oil and gas industry) followed the RPD style, with only 10% involving some comparison of alternative solutions or strategies. Accordingly, the RPD model has attracted considerable support from advocates of a context-based or naturalistic approach to the understanding of decision making.

At this point, it is useful to comment on the similarities in focus between NDM and previous research as it relates to SD. There is considerable debate over whether or not the NDM approach rep-
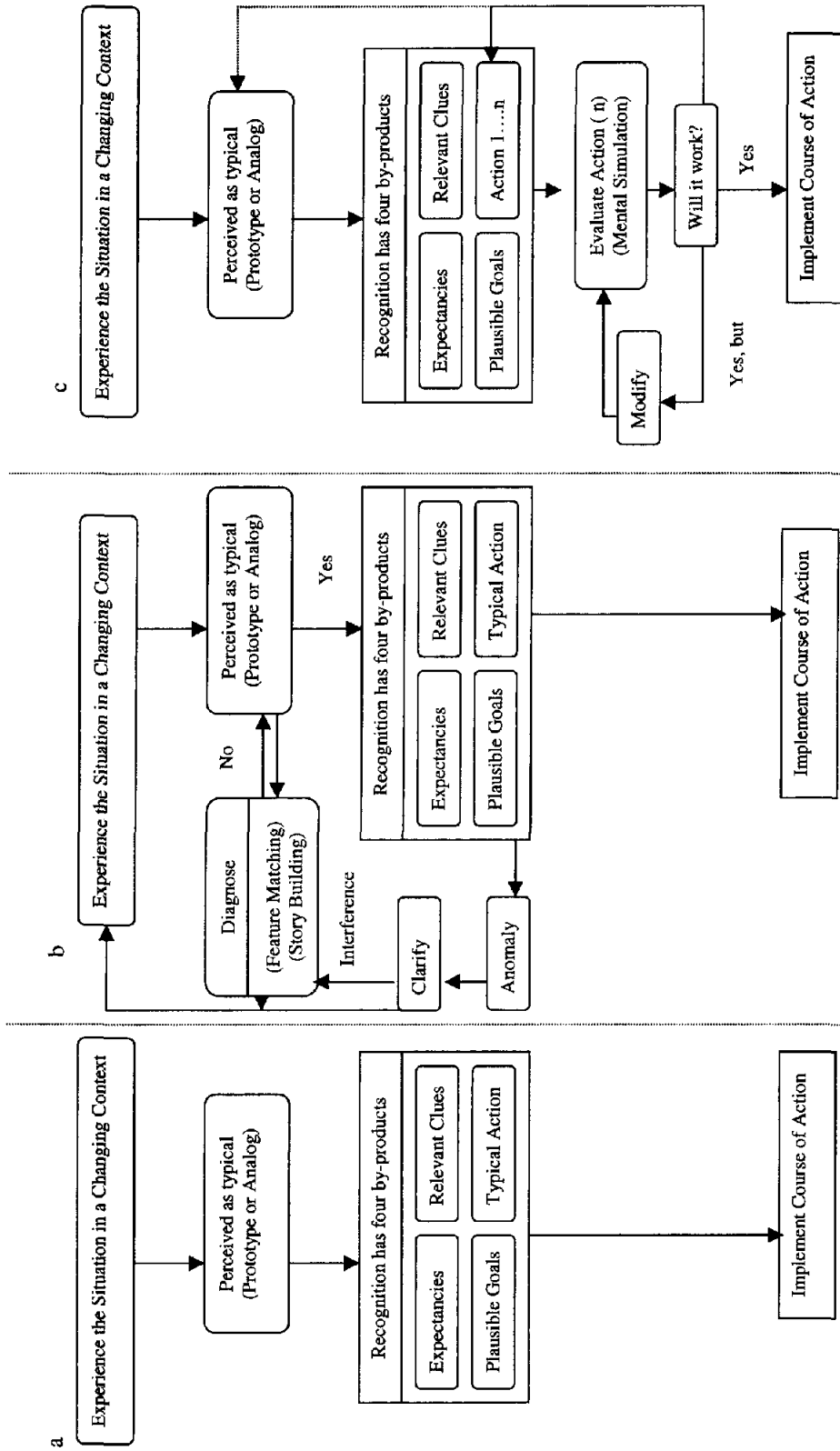
Figure 1. The recognition-primed decision (RPD) model (Klein, 1997) used to describe the decision-making process in a naturalistic setting. At its simplest, decisions are made on the basis of a simple matching of the current scenario with previous experience or training. Recognition then generates four processes to facilitate the generation of a typical course of action (a). Additional diagnostic features are incorporated to account for situations that are not easily reconciled with prior knowledge, training, or experience—story building or feature matching to construct a coherent picture from incomplete information (b) and evaluation of alternative strategies, achieved through mental simulation by the decision maker, of possible actions made in a serial order rather than by direct comparison (c).

resents a paradigm shift away from what is often described as classical decision-making theory (Cannon-Bowers, Salas, & Pruitt, 1996). This is not a major concern for our review, as we focus on certain key processes identified by these models and their relevance to SD. There are areas of considerable overlap in these models; for example, both the NDM and classical models emphasize the importance of how a problem is perceived, exemplified in the latter models by framing and uncertainty biases (e.g., Kahneman & Tversky, 1979, 1996) and in the RPD model by situational awareness. Also, the tendency for decision makers to refrain from further consideration of options after identifying a suitable option (cf. "serial recall of options;" Figure 1c) was described many years ago by Simon (1957).

In the light of the effects of SD, described earlier, it is likely that SD may well act adversely on several processes identified within the RPD model, although, the initial stages of the RPD process would seem to remain robust during SD. That is, the assimilation of information and evaluation of a complex situation. This was the case with our complex business game simulation in which participants remained able to grasp the essential facts of the situation during a 36-hr period of SD (see *Thinking Laterally and Being Innovative*), a finding also reflected by the critical reasoning task. In essence, after 1 night of SD, the decision maker will have a reasonable level of situational awareness and will be able to compare the current situation with previous experience, which, according to Klein (1993), is an essential prerequisite of the recognition stage. However, subsequent stages of the RPD process are likely to be impacted by the effects of SD, which can be illustrated by taking the following aspects of the RPD model.

Expectancies. Establishing the scope of the situation may present difficulties when there is considerable distraction or the situation is changing rapidly. In this case, SD may lead to difficulty with updating information and keeping track of events.

Relevant cues. These may be overlooked because SD participants are easily distracted and tend to become preoccupied with peripheral concerns.

Plausible goals. These also may be overlooked during SD because of an inflexibility of thought processes, together with more rigid thinking, poor planning, and poor appreciation for alternatives. The identification of plausible goals may also be impaired because SD leads to difficulties in risk assessment, monitoring, and having insight into one's own performance.

Typical action. Although this is still feasible during rule-based procedures, SD leads to perseveration in response strategies and a reluctance to give up on a course of action that may no longer be appropriate in the light of recent information or for situations in which a more innovative style of thinking may be required. Again, the identification of a response strategy thought likely to work will rely to a great extent on an individual's ability to assess risk and to have insight into their ability to cope effectively with the task demands.

Feature Matching and Story Building

These are essential in developing a coherent picture of events when information concerning the chain of events may be incomplete. The crucial factor in resolving this ambiguity lies with clarification and updating. Verbal communication skills may be vital to this process. We have described how language spontaneity

becomes impaired at around 30–36 hr of SD, leading to difficulties in word finding and articulation. In terms of operational effectiveness, this is likely to impact on the accurate communication of ideas or requirements. There may also be difficulties in nonverbal aspects of language, in which the absence or reduction of normal rhythms in the voice (as with lack of intonation following SD) may be misconstrued as an indication of indifference or insignificance. The successful resolution of an emergency may well depend on the accurate, concise, and speedy transmission of information between key decision makers. In terms of interpersonal communication skills, it should be remembered that argument and suggestion are more likely to sway SD participants. Moreover, in constructing an overall picture of the situation from incomplete information, pressing issues may become difficult to isolate as memory for the serial ordering of events is lost in the confusion of a dynamic situation.

Temporal memory impairments caused by SD may also affect those situations where there are multiple options that require the internal evaluation of potential actions, necessitating the serial recall of options. It should be noted that the RPD model emphasizes the serial ordering of the deliberation of alternative courses of action rather than direct comparisons. Although the RPD model appears to prioritize the use of serial evaluation of potential strategies in formulating an appropriate action, the use of multiple comparisons has, nevertheless, been estimated to occur in 10–20% of all decisions (Flin et al., 1996; Hendry & Burke, 1995; Klein, 1989). Much valuable research has pointed to how such decisions are made, for example, with regard to framing bias (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981). Although this strategy may be less common than serial evaluation, we would predict that the assessment of risk may well be impaired in such cases following SD.

In the context of SD, there is a dearth of information concerning decision making in situations relying on the ability to generate novel, rather than well-rehearsed, solutions to demanding and difficult conditions. Nevertheless, many of the important features of the RPD model happen also to describe what may fail with complex decision making during SD. That is, the model may be the antithesis for describing decision making during SD when there are unexpected circumstances and surprises not anticipated during prior training. It is questionable whether these adverse effects could be overcome by prior training, as the anodyne is sleep. High subject motivation and attempts by the sleep-deprived participant to apply compensatory effort, as well as the ingestion of some types of psychostimulant, may be ineffective. In the following section, we argue that the RPD model fortuitously describes, from its operational viewpoint, what seems to be occurring in the human brain from the complementary perspective of the role sleep may have with regard to cerebral function.

A Sleep-Based Neuropsychological Perspective

Sleep probably provides an exclusive form of recovery for the cerebral cortex (Horne, 1988b, 1993). The cortical region that works the hardest during wakefulness (i.e., having the highest metabolic rate of all cortical regions) is the prefrontal cortex (PFC), which comprises about 30% of the total cortical mass. The type of sleep that appears to reflect this cortical recovery is slow wave sleep (Sleep Stages 3 and 4; Rechtschaffen & Kales, 1968), manifested in the electroencephalograph (EEG) as slow wave

(delta) activity, which also largely comprises "Process S" (Bor-
bély, 1982). This EEG activity is most intense in the PFC (Werth,
Achermann, & Borbély, 1997), when blood flow in this region is
particularly low (Maquet et al. 1997), suggesting that the putative
recovery is most intense here. One might therefore argue that the
PFC may well be among the first brain regions to suffer as a
consequence of SD. This is indeed indicated by recent cerebral
blood flow-based studies of cerebral activation in young adults
undergoing 30–35 hr of SD. Petiau et al. (1998) and Drummond et
al. (1999, 2000) all reported significant and unique changes in the
PFC in their SD participants, with Drummond et al. (2000) also
demonstrating how the PFC attempts to compensate for its partic-
ular cognitive failings during SD.

The PFC directs, sustains, and focuses attention to the task in
hand by disregarding competing distraction and is the executive
coordinator of many cortical events. In particular, it deals with
novelty and the unexpected. Inasmuch as with practice and training
most complex tasks lose their novelty and become more routine,
then in these respects, they become less dependent on the PFC.
The PFC is responsible for divergent, innovative, and flexible
thinking, as well as memory for contextual details, such as tem-
poral memory (Milner & Petrides, 1984). Neuropsychological
tasks oriented to PFC function show significant impairments with
short-term SD. For example, the Tower of London Test, a non-
verbal task measuring flexibility in planning, which in healthy
individuals causes marked left-prefrontal activation (R. G. Morris,
Ahmed, Syed, & Toone, 1993), is significantly impaired by 1 night
of SD (Horne, 1988a). Language skills showing impairment with
SD (see above), such as word fluency and the Hayling Sentence
Completion task depend particularly on the integrity of the PFC
(Frith, Friston, Liddle, & Frackowiak, 1991; Nathaniel-James,
Fletcher, & Frith (1997).

Returning to the RPD model, it can be seen that several of its
integral processes (see above) appear to rely heavily on the PFC,
as do many of the processes required in effective decision making
under conditions of novelty and the unexpected. Put somewhat
differently, of the various decision-making models just outlined,
by virtue of independent neuropsychological and brain imaging
findings, the RPD model does seem to be particularly relevant
to SD.

Conclusions

We have argued that the traditional view and psychological
measurement of SD have limitations that are not readily apparent
from typical laboratory studies and that may be inappropriate and
misleading when applied to real-world settings. This traditional
view is that sleep loss is dearousing and causes slowing of most
aspects of cognitive function. Accordingly, if the sleepy individual
is given more time to complete a task, which is both motivating
and individually paced, then the slowing can largely be compen-
sated for, with performance returning to normal, at least during
short-term SD. Of interest, this cognitive slowing, which is par-
ticularly evident with dull tasks such as reaction time, is largely
explained by "microsleeps" and "lapses" (Dinges & Kribbs, 1991).
Thus, after a night of SD, when a sleepy person is not lapsing,
reaction times are normal, and for much of a 10-min reaction time
test there is no cognitive slowing. Furthermore, under these cir-
cumstances, lapsing is unusual in the first 5 min or so of testing.

However, we have argued that for some tasks, particularly those
involving the PFC, and as exemplified by the RPD model, decre-
ments are evident at the very beginning of testing. Moreover, these
decrements are found in the first 5 min when it is reasonable not
only to assume few lapses but also when there is also no time
constraint and a high incentive to perform well. That is, these
particular impairments have nothing to do with lapsing.

When any body organ fails because of illness, being over-
worked, aging, and so forth, one could explain these changes in
terms of a generalized slowing down or becoming less efficient in
some way. However, this is a superficial explanation because there
are invariably components of these organs that malfunction or
deteriorate in qualitatively different ways, leading to the overall
slowing down. That is, some components remain working nor-
mally, while others do not. In view of the great diversity in the
structure and function of brain tissue, it is reasonable to propose
that there are some regions more affected by sleep loss and that
these differences might be qualitative rather than quantitative. We
have argued that because the PFC is probably the hardest working
cortical area during wakefulness, it may be more vulnerable to
sleep loss if sleep provides a specific recovery from the effects of
wakefulness. Despite their best efforts to compensate and despite
working at their own speed, sleep-deprived participants still
showed impaired performance at PFC tasks. Thus, although the
cognitive slowing hypothesis argues that during SD, this slowing
is simply greater in the PFC, it does not adequately explain why
sleep-deprived people can not compensate if they work at their
own pace, as seems to be the case for less PFC oriented, rule-based
tasks.

A recent report by Binks, Waters, and Hurry (1999) has claimed
that short-term SD does not selectively impair prefrontal function-
ing. However, all their tests were taken from a neuropsychological
test battery designed for clinical purposes, largely to assess brain
damage. Hence, there was a ceiling effect with these tests, which
were not sufficiently sensitive to be affected by short-term SD,
especially for the participants, who were university students.

Despite the paucity of studies concerning executive-type deci-
sion making following SD, we have highlighted several areas for
concern: impaired language skills–communication, lack of inno-
vation, inflexibility of thought processes, inappropriate attention to
peripheral concerns or distraction, over-reliance on previous strat-
egies, unwillingness to try out novel strategies, unreliable memory
for when events occurred, change in mood including loss of
empathy with colleagues, and inability to deal with surprise and
the unexpected. More cognizance should be given to the unique-
ness of many situations that may necessitate a decision maker
going without sleep, often because of an emergency and under
conditions that may not easily fit within any rule- or knowledge-
based paradigm of decision making. If there is a particular need to
draw on innovation, flexibility of thinking, avoidance of distrac-
tion, risk assessment, awareness for what is feasible, appreciation
of one's own strengths and weaknesses at that current time (meta-
memory), and ability to communicate effectively, then these are
the very behaviors that we feel are most likely to be affected by
SD, not only when people are working alone but also when
working in a team. The impact of SD on these behaviors is likely
to be particularly significant in a situation that changes rapidly and
personnel have to adapt to a wide range of continuous and unpre-

dictable developments. Tasks that demand other than well-learned automatic responses will be most vulnerable.

It is perhaps just a coincidence that some of the most renowned man-made disasters or near disasters concerning nuclear power plants, such as Chernobyl, Three Mile Island, Davis–Beese (Ohio), and Rancho Seco (Sacramento), all occurred in the early morning and involved human error in failing to contain otherwise controllable but unexpected and unusual mechanical or control room malfunctions. With all four, experienced control room managers misdiagnosed and failed to appreciate the extent of the fault and then embarked on courses of action that were inappropriate and continued to persevere in this way in spite of clear indications that their original assessment was wrong. Of course, it is difficult to say how much of this could have been due to SD effects on decision making and not to stress and panic. However, SD certainly played a crucial role in the fateful dawn decision to launch the Space Shuttle Challenger. The report of the *Presidential Commission on the Space Shuttle Challenger Accident* (1986) cited the contribution of human error and poor judgment related to sleep loss and shift work during the early morning hours and stated that the decision to launch "should have been based on engineering judgments. However, other factors may have impeded or prevented effective communication and exchange of information" (p. G-5). Key managers had obtained less than 2 hr sleep the night before and had been on duty since 1:00 a.m. that morning. The report further commented that "working excessive hours, while admirable, raises serious questions when it jeopardizes job performance, particularly when critical management decisions are at stake" (p. G-5).

We have attempted to integrate the experimental findings from SD studies with the current understanding of behavioral decision making. A popular (RPD) model of the decision-making process in applied settings highlights skills likely to cause the most difficulty following SD. Such skills also largely involve the PFC, which is a brain area shown by recent laboratory studies to be particularly vulnerable to SD.

Most SD studies have used young adults, more specifically men, and these young adults are usually from colleges or junior ranks in the forces. Consequently, much of our knowledge is based on people who are neither typical of the normal population nor typical of more senior decision makers or commanders, who may well be men and women over the age of 40 years. Clearly, there is a need to involve older people in future studies of decision making and SD. The only two (related) studies (Webb, 1985; Webb & Levy, 1982) that have looked at older (40–60 years old) versus younger (20–25 years old) participants used only the simpler type of performance tests. Compared with the younger group, the older participants claimed less of a decline in subjective ratings of sleepiness and impaired performance, but this was not borne out by the tests of persistence–attention, precision, and cognitive processing, which all showed a greater deterioration in the latter group.

If, during a prolonged crisis, key decision makers remain awake beyond about 24 hr, then it is reasonably clear that despite their best efforts to perform well, their decision-making ability will become impaired. Whether or not psychostimulants (e.g., caffeine, Modafinil, pemoline) in pharmacological doses can redress the decline in these particular skills remains to be seen; very little published research is apparent. We (Harrison & Horne, 2000) have shown that caffeine in moderate doses (350 mg) fails to signifi-

cantly improve at least some of these impairments following 1 night of SD. This contrasts with the variety of studies reporting on the beneficial effects of psychostimulants on more simple tests of persistence and attention (cf. Buysee, 1991). Clearly, sleep is the best anodyne for the sleep-deprived decision maker. If the crisis persists, then this individual needs to be replaced temporarily by someone equally competent who has had adequate sleep. As to the minimum sleep length necessary for an acceptable return of performance at these tasks, this must also remain a rhetorical question for the time being. However, the quality of this sleep is probably important. For example, because slow wave sleep–Process S is implicated in this recovery (see above) and is most evident during the first 4 hr of sleep (Borbély, 1982; Horne 1988b), a working hypothesis might be that at least this amount of sleep may be needed for adequate performance at these particular skills.

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