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Sleep Deprivation Affects Speech

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Summary: Historical accounts of sleep loss studies have described changes in the content and patterns of speech, although to date these claims have not been systematically studied. We examined the effects of sleep loss on the spontaneous generation of words during a verbal word fluency task and the articulation of speech during a vocalized reading task. Nine subjects underwent two counterbalanced 36-hour trials involving sleep deprivation (SD) and no sleep deprivation (NSD). After SD, there was a significant deterioration in word generation and a tendency for subjects to become fixated within a semantic category. There was a significant reduction in the subjects' use of appropriate intonation in the voice after SD, with subjects displaying more monotonic or flattened voices. These findings are discussed in light of neuropsychological evidence concerning the functions of sleep in relation to the frontal cortex and in light of the implications for interpersonal communication in the event of sleep loss. **Key Words:** Sleep loss—Verbal fluency—Speech intonation—Frontal cortex.

The effects of sleep loss on speech were first noted by Morris et al. (1) during 72–98 hours of continuous wakefulness in young adults, when the investigators reported,

"Alterations in the rhythm, tone and clarity of the subjects' speech were among the most striking observable changes during sleep deprivation. As sleep deprivation progressed, speech usually became slower, softer and contained more unexpected breaks in rhythm. Slurring and softening were often sufficiently marked that the listener could not understand the subject's statements . . . The usual variation in loudness and pitch was attenuated in most subjects, producing a curious flatness" (p. 252).

These observations were based on tape-recorded interviews with subjects about their ongoing personal experiences during sleep loss. The recordings were assessed by two of the experimenters. Clearly, this approach has flaws, especially as the raters were possibly biased, and from what the subjects were saying, the experimenters were not blind to the level of sleeplessness. Nevertheless, Morris et al. (1) were impressed enough by their findings to incorporate them into a five-point cognitive disorganization rating scale, which quantified increasing levels of behavioral impairment during sleep loss. Scale point 1 was "some difficulty thinking of words"; scale point 5 described "rambling incoherent speech for brief periods with failure to recognize errors".

Horne (2) has noted that certain effects (reversible with sleep) seem to mimic aprosodia (loss of intonation), which is a common symptom of frontal lobe deficits (3). If sleep provides some form of cortical recovery in healthy individuals, then the frontal region may be particularly vulnerable to sleep loss because of its especially high rate of activity during wakefulness. There is increasing evidence that neuropsychological tests oriented to frontal lobe function seem to show significant impairment with sleep loss. For example, the "Tower of London Test", which in healthy subjects causes significant left prefrontal activation using brain imaging (4), is significantly affected by one night of sleep deprivation (5). In contrast, non–frontally oriented tasks of similar complexity are not affected (5). Word fluency (the capacity for the spontaneous generation of words to either letter or category prompting), which is another frontal-dominant task as demonstrated by brain imaging (6), is also significantly impaired by sleep loss (5,7), even after one night without sleep (5). The sleep loss studies of Horne (5) and May and Kline (7) have been the only ones to assess

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word fluency. Both required subjects to write down words, not speak them. Nothing is known about the effects of sleep loss on verbal word fluency.

Surprisingly, since the report by Morris et al. (1), no other investigation has followed up their observations concerning sleep loss effects on speech, although Haslam (8) noted "a slowing of speech" (p. 453) in her subjects. Effective verbal communication relies not only on the selective use of speech and vocabulary but also on the capacity to convey information in a style appropriate to the context and content of the intended message. Such impairments during sleep loss can have practical consequences, especially in those situations where sleep-deprived personnel in control rooms, hospital emergency rooms, and the military have to communicate about complex issues, potential crises, etc.

Reviews of the effects of sleep loss on psychological performance (9–12) have pointed out that the adverse effects of one night without sleep are usually not apparent unless the task duration exceeds about 10 minutes, and ideally, the task should be dull, simple, and monotonous. Most of the performance tests given during sleep loss have been oriented towards this maxim. In contrast, both the Tower of London test and the word fluency test described above are completed in under 3 minutes, are stimulating for the subject, and are affected by only one night of sleep loss. Recently, Dinges and Kribbs (13) have argued that performance deficits are apparent in short vigilance-type tasks following one night of sleep loss, if variability in response rather than overall performance is taken into account. They suggested that these errors are indicative of substantial attention difficulties that were undetected at this level of sleep loss using earlier methods of assessment. While the type of task used by Dinges and Kribbs has some frontal lobe involvement, this is not specific to the frontal area (14). It should be noted that the frontal area is associated more with novelty than with well-rehearsed routine tasks.

A few brain imaging studies have now been performed on sleep-deprived healthy subjects, the most substantive by Thomas et al. (15) using positron emission tomography (PET) scans in the course of 72 hours of sleep deprivation. The investigators reported that the most significant decreases in glucose uptake were seen in the frontal region, with the greatest effect appearing after the first night without sleep. This suggests that impairments to neuropsychological tests focusing on this region would probably be evident after only one night of sleep loss, thus supporting the earlier findings by Horne (5).

The present study followed up the work of Morris et al. (1) by concentrating on those aspects of speech that seem particularly affected by sleep loss and by using more refined measures—that is, articulation (features of the spoken voice, especially intonation) and spoken word fluency. One night without sleep was used, as there is good evidence that this would be effective and this amount of sleep deprivation is realistic. This report complements the aspect of this study concerning decision-making abilities, described elsewhere (16).

METHODS

Subjects

Nine subjects (5 male, 4 female, average age 21 years) were selected from respondents to posters around Loughborough University, UK. Initial screening excluded those having sleep difficulties, those who napped regularly in the daytime, and those who were on medication that affected sleep or sleepiness. All were healthy nonsmokers, normally sleeping between 7 and 8 hours a night. None had a history of epilepsy or alcohol abuse. Previous research has highlighted the importance of subjects' motivation in determining their performance capacity following sleep loss (17). In order to enhance the subjects' motivation to perform well throughout all trials, they were paid and were exhorted to put as much effort as possible into all tests.

Design and procedure

Subjects participated in two 36-hour counterbalanced testing periods, with and without a night of sleep. Each condition commenced at 0900 hours and ran until the second night. The interim night was either with sleep [non–sleep deprived (NSD)] or without sleep [sleep deprived (SD)]. Actimeters worn on the wrist (18) and sleep diaries were used for three nights prior to each testing session and on the interim night. These devices also reminded the subjects that they should maintain normal sleep during these nights. Lights out was at 2330 hours; rise time was 0730 hours.

During SD sessions, subjects were confined to the laboratory and supervised throughout the whole period. Between sessions, they remained in a large lounge, watched television, read, played board games, and talked. Noncaffeinated beverages were available ad libitum, and meals were provided at 0800 hours, 1300 hours, and 1900 hours. Snacks (e.g. fruit and toasted sandwiches) were available at other times. At the end of SD sessions, subjects were escorted home. During NSD sessions, subjects followed the same routine, except that they were escorted home at 2300 hours on day 1 and had to retire to bed and remain there until 0730 hours the following morning (day 2). Actimeters were again used. Subjects arrived back at the laboratory at 0830 hours and continued with the experimental schedule until its termination that night.

At the outset of trials, subjects were told that the study was an investigation of the effects of sleep loss on cognitive processes. They were discouraged from discussing with other subjects the nature of the tests or their individual performance. In addition to the tests reported below, subjects took part in a complex, dynamic decision-making task to be reported elsewhere (16).

Word fluency

We used a variation of the Thurstone word fluency test, shown to be sensitive to sleep loss (5). Subjects were given a letter as a prompt and asked to generate verbally in 1 minute as many words as they could beginning with that letter. Their responses were recorded on a tape recorder. As far as possible, the letters used as prompts were controlled for the frequency of use of words having that letter in the English language (19,20). We selected the following letters: F, A, S, C, L, P, R, and W. The letters were counterbalanced across trials.

The test relies on the selective access to information stored in long-term memory, for which various routes may be available, e.g. phonic or semantic cueing. We paid particular attention to recall strategies (i.e. similarities between adjacent words) and qualitative differences (i.e. word types) in the words generated. The test was given three times over two 36-hour testing periods: day 1 (1400 hours) and day 2 (1400 hours and 2000 hours). Three different letters were used for each test, with nine versions being compiled. For each session, the first letter was regarded as a warm-up; the material was discarded without the subjects' knowledge. The data from the other two letters were combined and analyzed by repeated-measures analysis of variance (ANOVA), with two within-subject factors (conditions × trials). Post-hoc paired t tests assessed significant main effects.

Words were also categorized in terms of phonic and semantic similarities. Those sharing similar features with an adjacent word were identified as follows: words having a common ending regardless of meaning were considered phonically similar (e.g. fight and fright), and those referring to the same semantic grouping or category (e.g. fruit = apples and apricots, military = guns and grenades), regardless of the sound of the word, were considered semantically similar. Additionally, all words were further classified in terms of word type (i.e. adjective, concrete noun, verb, etc.). Only unambiguous similarities (100% agreement by independent raters) were scored in this way.

Articulation of the spoken word

We were particularly interested in changes in intonation, volume, and errors. To enhance this potential, subjects read from a short story (21) aimed at children approximately 8–12 years of age. It was a dramatic fairy tale with much dialogue involving whispering and shouting; it required the reader to use a variable pace to convey slow- and fast-moving pieces of the story. Subjects were encouraged to use their voice, vary pitch and intonation, and act out dialogue as if they were reading to an audience of young children. Subjects were given sufficient prior practice so that they were not uncomfortable or self-conscious with this procedure. They read identical passages of text and sat at a fixed distance from the microphone. The recording level remained constant. The story was divided into sections, and each could be read aloud in approximately 3 minutes. The presentation of these sections was counterbalanced across subjects and conditions. There was no obvious imbalance in the emotive content of the sections of the story. The task was undertaken between 1700 hours and 1800 hours on day 1 and day 2.

Assessing voices is a difficult procedure, and we decided to do this by independent judges. Ten graduate students (mean age 30 years, from similar socioeconomic and educational backgrounds to those of the subjects) who were native English speakers were recruited from the campus population and paid for their participation. They assessed the voice recordings using the criteria outlined below. It should be noted that only 25% of the recordings were made after a night of sleep loss. Raters were blind to the identity and experimental condition of the speaker. A total of 36 sessions was recorded (9 subjects × 2 days × 2 conditions). It was considered unrealistic to expect raters to remain attentive through 36 3-minute recordings, so an edited set was made by taking the last 30 seconds from each recording. This allowed the subjects to warm up; it also allowed the possibility that the effects of sleep loss might not be apparent initially. A pilot study had shown that a 30-second section provided sufficient time for raters to judge the five criteria without it being overlong. The ordering of the samples was randomized before the recordings were presented to the raters. Raters were not aware of the identities of the voices, which were simply prefixed by a number.

Raters took part in individual sessions lasting for approximately 1 hour. They were situated in a quiet cubicle with an experimenter who was also blind to the ordering of the samples. To avoid fatigue, the raters were encouraged to take breaks after rating 12 recordings. Raters were told that the voices came from a variety of people, some of whom had been without

TABLE 1. *Mean and standard error for total word count for non–sleep-deprived and sleep-deprived groups*[a]

	Trial 1 (6 hours)	Trial 2 (30 hours)	Trial 3 (36 hours)
Non-sleep deprived	28.4 (1.5)	27.0 (1.5)	29.4 (1.7)
Sleep deprived	29.9 (1.4)	26.7 (1.5)	23.3 (1.4)*

[a] Mean is presented first; standard error follows in parentheses.
* Significant difference between conditions for trial 3. See text for other significant effects.

sleep. They were instructed to listen carefully to each sample in turn and complete a printed questionnaire. They were allowed to rewind the tape and repeat sections of recording if they wished.

Raters assessed each piece under five categories using a five-point scale. These categories, their descriptors, and scales were displayed to the raters throughout the assessment, and were as follows:

Intonation: "makes appropriate use of intonation". 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

Errors: "stumbles and makes errors". 1 = all the time, 2 = quite a few, 3 = some, 4 = very few, 5 = none at all.

Volume: "appropriate changes in volume". 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

Fatigue: "is fatigued". 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

Pace: "appropriate changes in pace". 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

These judgments are within the context of a dramatic story requiring the emotive involvement of the reader.

RESULTS

Word fluency

Unfortunately, owing to a faulty tape, word fluency data from two subjects were lost (thus, for word fluency, n = 7). Total words generated for the three trials in each condition are shown in Table 1. Repeated-measures ANOVA revealed no significant main effect of condition, which was anticipated as the initial day of each condition did not involve sleep deprivation. There were significant effects for trial ($F = 6.83$; df = 12,2; $p < 0.01$) and the interaction ($F = 4.42$; df = 12,2; $p < 0.05$). During SD sessions, the word count declined by about 6 from the first to the last trial, compared with a small increase for NSD (Table 1). Post-hoc paired t tests confirmed that there were no significant differences between SD and NSD for corresponding trials 1 and 2, whereas this was significant for trial 3 ($t = 2.75$; df = 6; $p < 0.05$).

Words were then categorized for substantial phonic (e.g. fright and fight, shiver and sliver) or semantic (e.g. linguist and language, trumpet and trombone) attributes as well as for word type (adjectives, nouns, verbs, and other). This procedure was done blind to the condition of the subject. Table 2 gives the outcome and shows that values for all these categories remained similar throughout NSD. Two-factor (conditions × trials) repeated-measures ANOVAs were calculated for each category. Post-hoc related t tests were used to explore significant interactions as appropriate.

There were significant differences in the use of semantically related words, shown for both main factors (condition: $F = 12.3$, df = 6,1, $p = 0.01$; trials: $F = 4.4$, df = 6,1, $p = 0.04$) and the interaction ($F = 3.39$; df = 12,2; $p = 0.05$). In particular, a larger proportion of the words generated by subjects during the latter two trials of the SD condition were semantically related (Table 2). Post-hoc tests revealed differences between conditions at trial 2 (df = 6; $t = -4.3$; $p < 0.05$) and trial 3 (df = 6; $t = -2.3$; $p < 0.05$) but not trial 1.

For adjectives, there were significant effects for trial ($F = 7.29$; df = 6,1; $p = 0.008$) and significant interaction between trial and condition ($F = 7.38$; df = 12,2; $p = 0.008$), with the latter being particularly apparent during the final trial of the SD condition. Post-hoc tests showed that differences between conditions at this trial were significant ($d = 6$; $t = -2.9$; $p < 0.05$). There were no other significant differences.

For concrete nouns, there were no significant main effects, but a significant interaction was found ($F = 3.92$; df = 12,1; $p = 0.05$). The number of nouns given was greater during trials 1 and 2 of both conditions, but was noticeably diminished during the final trial of SD. Post-hoc tests showed that differences between conditions at this trial were significant ($d = 6$; $t = 3.6$; $p < 0.05$). There were no significant effects for verbs.

Articulation

The mean and standard error for each trial and statement (Table 3) comprise 90 ratings (10 raters × 9 subjects). It can be seen that the NSD data show only minor changes between the 2 days and are similar to day 1 of SD. The most significant finding was with intonation, which had clearly deteriorated by day 2 of SD. There was good consistency between raters; this is reflected in Fig. 1, which shows the distribution of all the ratings for intonation across conditions and days for the five categories. A marked increase of strongly disagree/disagree (for appropriate use of intonation) can be seen for SD day 2, whereas ratings across the

TABLE 2. *Proportions (SE) of words categorized as phonically similar, semantically similar, adjectives, nouns, and verbs*[a]

	Non–sleep deprived			Sleep deprived		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Phonic similarity	0.15 (0.05)	0.16 (0.03)	0.16 (0.04)	0.15 (0.05)	0.19 (0.07)	0.15 (0.04)
Semantic similarity	0.16 (0.02)	0.16 (0.01)	0.16 (0.02)	0.18 (0.02)	0.27* (0.03)	0.27* (0.03)
Adjectives/descriptors	0.18 (0.02)	0.17 (0.02)	0.17 (0.02)	0.16 (0.02)	0.14 (0.03)	0.33* (0.05)
Nouns	0.47 (0.05)	0.45 (0.06)	0.47 (0.05)	0.48 (0.05)	0.45 (0.03)	0.34* (0.03)
Verbs	0.26 (0.04)	0.24 (0.04)	0.23 (0.04)	0.29 (0.06)	0.27 (0.04)	0.28 (0.05)

[a] Trial 1, 6 hours; trial 2, 30 hours; trial 3, 30 hours.
* Significantly different from corresponding trial in non–sleep-deprived condition.

other 3 days are similar, as expected. A repeated-measures ANOVA revealed a significant main effect of condition ($F = 7.3$; df = 8,1; $p < 0.02$) and a significant condition-by-day interaction ($F = 9.1$; df = 8,1; $p < 0.01$). This interaction is illustrated in Fig. 2a and indicates that the differences between conditions were largely confined to differences between day 2. Fatigue showed a significant main effect of day ($F = 10.0$; df = 8,1; $p < 0.01$) and a significant interaction between day and condition ($F = 5.9$; df = 8,1; $p < 0.05$). This interaction is illustrated in Fig. 2b. Overall, fatigue was rated higher during day 2, much more so after SD. There was a significant effect of day for error ($F = 5.3$; df = 8,1; $p < 0.05$), with more rated errors in day 2 but no effect of condition or interaction. Volume and pace showed no significant effects. There was a nonsignificant trend for these latter effects to be worse with SD (Table 3).

DISCUSSION

The significant reduction in word fluency following a single night without sleep is consistent with previous findings (5,7). Also, after 36 hours without sleep, subjects showed a tendency toward repetition within a semantic category. For example, the letter *n* might elicit a string of conceptually similar descriptors such as "nil, nought, none, nothing, and no one", whereas the same letter at the first session was more likely to cue unrelated, concrete nouns such as "netball, nail, nose, nicotine, and newt". On the other hand, subjects did not show an increased reliance on internally generated auditory cues, as there was no change in the production of phonically similar words. Interestingly, following 36 hours of sleep loss, words were frequently produced in bursts, or "chains", separated by lengthy periods of silence. Sleep loss may encourage more rigid thinking, so once a semantic category has been activated within the memory, subjects have greater difficulty transferring attention to unrelated material. This may also result in difficulties in expressing ideas clearly due to changes in word availability and memory cueing.

It does not seem likely that the problems we observed were simply due to a loss of motivation or willingness to perform during the SD condition, as our subjects were well paid and the tasks were relatively short and interesting. We have also recently examined these issues in more depth using caffeine to substan-

TABLE 3. *Mean and standard error ratings scores for selected features of the voice*[a]

	Non–sleep deprived		Sleep deprived	
Feature	Day 1	Day 2	Day 1	Day 2
Fatigue*	2.6 (0.2)	2.8 (0.2)	2.3 (0.5)	3.8 (0.4)
Intonation*	2.9 (0.2)	3.3 (0.2)	2.9 (0.3)	1.9 (0.2)
Errors	2.5 (0.2)	2.1 (0.2)	2.2 (0.3)	1.5 (0.3)
Volume	3.1 (0.3)	3.2 (0.2)	3.2 (0.5)	2.9 (0.2)
Pace	2.5 (0.3)	2.7 (0.2)	2.7 (0.1)	2.9 (0.3)

[a] Each cell contains 90 samples: 10 raters × 9 subjects. Mean is presented first; standard error follows in parentheses.
* Significant interaction between day and condition.

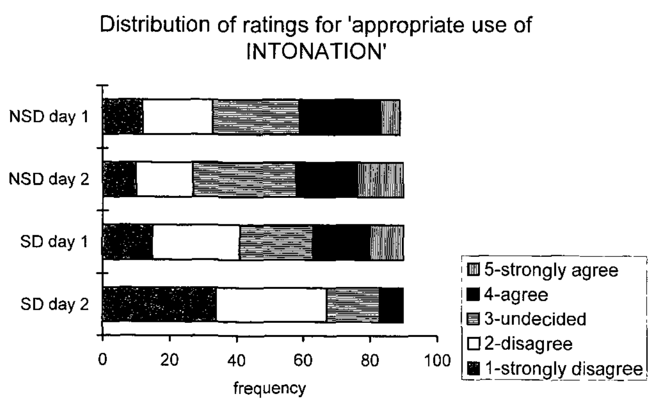

FIG. 1. Distribution of ratings for the appropriate use of intonation throughout the four trials. Frequencies are shown for all 90 ratings (10 raters × 9 subjects) distributed across the five categories. Note the increased use of lower rating categories during sleep-deprived day 2.

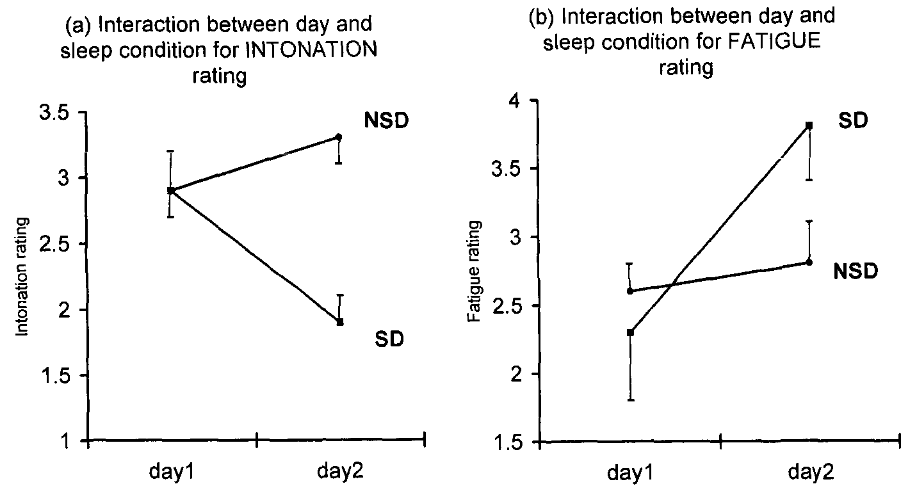

FIG. 2. (**a**) Interaction between day and sleep condition for intonation rating. There was a marked deterioration in rating scores for the sleep-deprived subjects during day 2. (**b**) Interaction between day and sleep condition for the fatigue rating. By day 2, fatigue was rated higher for sleep-deprived subjects than for non–sleep-deprived subjects.

tially reduce subjective sleepiness levels throughout a similar period of sleep loss (22). Despite increased alertness, we found no improvement in performance decrements for language tasks similar to those used in this study but which are known through brain imaging studies to be specific to the dorsolateral prefrontal cortex.

As already noted, recent findings show that the most significant reductions in cerebral metabolic rate following 36 hours of sleep loss occur in the frontal regions (15). A number of brain imaging studies outside the field of sleep loss have reported increased activation in the left prefrontal cortex during word-generation tasks (6,23). However, no brain imaging study has looked at word fluency and sleep loss.

There is also evidence to suggest that the availability of semantically stored knowledge is less likely to be affected by sleep loss. Frith et al. (24) emphasized the importance of the frontal areas in coordinating inhibitory and activation processes during word generation but suggested that temporal lobe processes also provide an important function in the storage of semantic information. They used PET scans to show that although there was increased activation of the left prefrontal cortex during standard word generation tasks, questioning subjects about presented known words (i.e. without the retrieval component of the task) led to increased activation in temporal but not frontal regions (24). We found that despite an overall reduction in the capacity to generate words, there was a significantly increased reliance on semantic information following sleep deprivation. Given the distinction between retrieval processes and storage (24), this apparent shift would be consistent with the study of Thomas et al. (15), which showed that the temporal lobes were less affected by sleep loss compared with the frontal lobes.

This is also in keeping with Martin et al. (25), who used a neuropsychological approach to illustrate the disassociable roles of the frontal and temporal regions in simple letter cueing retrieval versus semantically related retrieval. They found that recall to a simple letter cue is more demanding of frontal lobe capacity than the retrieval of semantic information, which, as shown by Frith et al. (24), is a more temporally oriented task.

We also found that aspects of articulation underwent clear changes following a night without sleep. In particular, raters blind to a subject's previous sleep history were able to detect a loss of intonation usually found in normal speech. This flattening and dullness suggest that the speaker is less interested or involved in what he or she is saying.

The effects of sleep loss on the capacity to generate and articulate speech are likely to have an impact on effective interpersonal communication, as individuals are likely to have difficulty in finding an ideal word or phrase and to be less able to deliver their ideas with the appropriate changes in intonation. In addition, the sleep-deprived person may present the listener with a level of disinterest. Under real-world settings, this could lead to communication failures.

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