THE EFFECT OF OPTOKINETIC STIMULATION ON DAYTIME SLEEPINESS

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INTRODUCTION

There is impressive anecdotal evidence to suggest that motion increases sleepiness (13): people become sleepy on planes, boats and trains. Studies involving massive vestibular perturbations, such as prolonged bodily rotation or parabolic flight, not only make people motion sick, but also seem to induce extreme fatigue (Lackner, unpublished observations). Indeed, subjective drowsiness is one of the cardinal symptoms of motion sickness (10), Graybiel and Knepton (9) even noticed that ennui can be the sole sign of motion sickness during chronic exposure to low level nauseogenic stimulation, such as in subjects living aboard a slowly (1 rpm) rotating room for 12 days. Graybiel (8) proposed that unusual activity in the vestibular nuclei leads to sleepiness by spreading through “facultative” links to nearby brainstem arousal centers and elicits other motion sickness signs and symptoms via specific connections to more distant sites such as emetic centers and hypothalamic regulatory centers.

Studies in infants also suggest that vestibular stimulation can promote sleep. Ter Vrugt and Peterson (23) found that the soothing effect of rocking increased with increasing rocking frequency and amplitude. Physiological studies have also demonstrated functional connections between the vestibular system and sleep: the vestibular nuclei are located in the brainstem, adjacent to and integral with the pontine reticular structures (16), some of which control the human sleep-wake cycle (19, 12). Pompeiano and his coworkers (18) have even demonstrated that in the cat, the discharge of vestibular nuclear neurons, particularly those located in the medial vestibular nuclei, increases rhythmically during bursts of rapid eye movement (REM) typical of desynchronized sleep, and that a complete bilateral lesion of the vestibular nuclei leads to the abolition of these REM bursts.

A study by Woodward et al. (24) found that otolithic vestibular stimulation, induced by means of a continuously moving bed, leads to reduced sleep latencies at night, as well as increased REM density. They also looked at daytime sleepiness by performing a Multiple Sleep Latency Test (MSLT), with both moving and stationary bed conditions, and found a non-significant trend towards lower sleep latencies in the motion condition. Although these results are suggestive, to our knowledge, there has been no definitive study to investigate the hypothesis that
vestibular stimulation increases objective sleep tendency, as measured by the MSLT. The current study investigates the hypothesis that unusual vestibular stimulation increases sleepiness by measuring the effect of a nauseogenic optokinetic stimulus (OKS) on subjective drowsiness and objective sleep tendency, as measured by the MSLT. A large OKS, e.g., a moving visual pattern, viewed for several minutes can make stationary individuals feel like they are moving and induce motion sickness symptoms, including drowsiness. OKS activates visual pathways that converge upon the same cells in the vestibular nuclei that receive vestibular afferent signals during real body motion (5). Note that real body motion would make energetic demands whose soporific or arousing effects might be confounded with the potential influences of vestibular nucleus activation.

METHODS

1. Subjects.

Eighteen university students (ten men and eight women) participated in the study. All participants were asked to abstain from medication and other drugs for the duration of the experiment, and to consume no more than two alcoholic beverages per day. Of the original eighteen subjects, four were later dropped from the statistical analysis: three because of life-style induced sleep disruptions, and one because of objective and subjective evidence of persistent insomnia. Hence, fourteen subjects (seven men and seven women) with stable sleep-wake habits and good health were considered in the analysis.

2. Optokinetic stimulus.

Optokinetic stimulation provides an easily controlled means of stimulating the visual-vestibular system and inducing relatively low levels of motion sickness (15). Subjects sat in a stationary chair centered in a 2 meter tall, 1.5 meter diameter, vertical drum covered on the inside with black and white stripes each subtending a 7.6 degree visual angle. Internal overhead lighting maintained normal illumination. For an OKS trial, the drum was rotated about its central vertical axis at 60 degrees/second for ten minutes. Subjects were instructed not to make head movements and to attend to the stripes that were straight ahead. Previous research has shown that subjects would feel themselves rotating for the majority of the trial and would, on average, experience motion sickness of minor to moderate severity (7).

3. The Nightcap sleep monitor.

The Nightcap is a two-channel recording device which distinguishes wake, REM sleep, and non-REM sleep (Fig. 1). One channel of the Nightcap monitors eyelid movements (ELMs) and the other monitors body movements. The eyelid sensor consists of an adhesive-backed piezoelectric film which is fixed to the upper eyelid and detects movements of the eye and lid. The body movement sensor is a cylindrical, multipolar mercury switch taped to the forehead and detects head rotations. These sensors are connected by 1 meter cables to the main Nightcap unit, a 7 cm x 11.5 cm x 2.5 cm case containing signal detectors, A/D converters, a clock, an RS-232 serial port (for downloading data) and a microprocessor with 32 Kbytes of RAM powered by an internal 9-V battery.

The design of the Nightcap is based on several studies which indicate that body movements can be used to distinguish between waking and sleep and that REM and non-REM sleep can be distinguished by the presence or absence of REMs (1, 11, 17). The Nightcap has been demonstrated to be a highly reliable sleep stage monitor, with an agreement of 87% between Nightcap and traditional polysomnographic sleep stage scoring of wake, REM, and non-REM sleep (5).

Previous studies using the Nightcap have demonstrated that sleep onset is coincident with,
Fig. 1 - A subject sleeping with the Nightcap.

By connecting the Nightcap to a Macintosh computer, the experimenter can monitor ELMs and head movements in real time, and immediately identify sleep onset.

and can be identified by, the cessation of ELMs (20). When the Nightcap is connected to a Macintosh computer, it can display both the subject’s eyelid and head movements in real time, and allow for the immediate identification of sleep onset. For the purposes of this study, sleep onset was identified as occurring after 3 consecutive 30-second epochs with less than 3 ELMs per epoch. This roughly corresponds to 90 seconds of stage I sleep. Subjects were then allowed to sleep for an additional 2 minutes before they were woken up and the MSLT trial ended. Note that if subjects did not fall asleep after 20 minutes, they were assigned a sleep onset latency of 21 minutes, to be used in statistical calculations. Figure 2 shows a typical example of Nightcap output from a MSLT trial. Epochs that are scored as sleep are marked with a double asterisk.

4. MSLT sleep room set-up.

The MSLT sleep room consisted of a small (2.4 x 3.0 meter) room with a bed, Nightcap, whitenoise generator, and humidifier. The whitenoise generator was used to mask any transient outside noise. The experimenter sat in an adjacent room and monitored the subject’s Nightcap data on an Apple Macintosh computer. During an MSLT trial, the room was darkened and the whitenoise generator activated, producing a quiet and comfortable sleeping environment.

5. Procedure.

Subjects arrived at the lab prior to the first night of the study, and filled out a physical status questionnaire, and a motion sickness history questionnaire, to screen for any unusual health problems or vestibular disorders. Subjects were given a description of the experimental protocol, and signed a consent form. This was followed by a Nightcap demonstration, in which subjects tried out the Nightcap, and learned how to correctly apply the eye sensor. Each subject received a Nightcap home sleep monitor, as well as a sleep log, to be filled out before and after each night’s sleep during the week scheduled for participation. Subjects were also asked to go to bed before midnight on the nights before they came into the lab, and to avoid caffeine and alcohol on the two days scheduled for MSLTs. Subjects were told that we were investigating the effect of motion sickness on sleep.
Subjects wore the Nightcap each night for seven consecutive nights, beginning on either a Saturday or Sunday. On the third and fifth day of the protocol, subjects came into the lab for MSLTs.

On one of the two MSLT days, subjects followed the NOSTIM protocol; on the other day they followed the OKSTIM protocol. Subjects were randomly assigned to each condition when they arrived at the lab for their first MSLT. Of the fourteen subjects considered in this analysis, half began with the NOSTIM protocol, and half with the OKSTIM protocol.

OKSTIM protocol: Subjects arrived at the lab at either 9:00 am or 10:00 am. Home sleep logs were double-checked, and all Nightcap data collected to date was downloaded. Before the first OKS session, subjects were familiarized with the criteria for diagnosing motion sickness severity developed by Graybiel et al. (10). This included instructions for grading four of the five cardinal symptoms — nausea, sweating, drowsiness, and salivation — as absent, mild, moderate, or major, as well as how to recognize additional qualifying symptoms common to OKS such as dizziness and eye strain. Subjects then sat in the drum for 10 minutes of OKS, during which they were periodically prompted for verbal reports of motion sickness symptoms. When they left the drum after 10 minutes, their pulse (the fifth cardinal symptom) was rated by the experimenter. Subjects then put on the Nightcap, and lay down in the darkened MSLT room for a sleep latency test.

The Nightcap, connected to a Macintosh computer, displayed the subject’s eyelid and head movements for the experimenter, allowing for the identification of sleep onset. If the subjects fell asleep, they were allowed to sleep for a total of three and a half minutes (90 seconds to identify sleep onset, plus two additional minutes sleeping), otherwise the trial was ended after 20 minutes. Subjects were allowed to do whatever they wanted between trials, except sleep. Each trial was conducted four times, at 9 am, 11 am, 1 pm, and 3 pm, or at 10 am, 12 pm, 2 pm, and 4 pm.

NOSTIM protocol: This protocol was identical to the OKSTIM protocol, except instead of spending 10 minutes prior to each MSLT in the optokinetic drum, subjects spent 10 minutes in a quiet room reading.

At the end of the seven nights scheduled for participation, subjects returned their Nightcaps and sleep logs. Subjects were paid $50 for their participation.

RESULTS

A condition (2) x trial (4) repeated measures ANOVA was conducted on all motion sickness and MSLT variables. Note that two MSLT trials were dropped from statistical analysis due to a poor Nightcap recording caused by a bad ground.
1. Measures of motion sickness and subjective drowsiness.

The sum of the values associated with the most severe rating for each cardinal symptom plus the value for any additional qualifying symptoms gave a single motion sickness severity score for each trial, with a maximum possible score of 55. Subjects were significantly more motion sick in the OKS condition (M=9.07) than in the control condition (M=6.82), F(1,13)=33.83, p<0.001. The average score in the OKS condition corresponds to a moderate motion sickness severity score according to the criteria of Graybiel et al. (10). Individual severities ranged from none to severe. There was also an adaptation effect, with less motion sickness over subsequent trials, F(3,39)=3.32, p<0.029, although this could not be separated from possible circadian effects. This pattern of results remained the same even when drowsiness was subtracted from the motion sickness scores.

Subjects were also significantly more drowsy in the experimental condition (M=2.13) than in the control condition (M=0.51), F(1,12)=20.49, p<0.001. Although there was no main effect of trial, there was a significant condition x trial interaction (F(3,36)=3.52, p<0.025); drowsiness tended to decrease on subsequent trials in the control condition, but tended to increase on subsequent trials in the OKS condition (Fig. 3).

2. Measures of objective sleep tendency.

Several measures of objective sleep tendency were used: sleep onset latency, sleep onset frequency, and eyelid movement (ELM) density.

Sleep onset latency is a standard measure of objective sleep tendency. As predicted, there was a trend towards shorter sleep latencies in the OKS condition (M=12.7 minutes) than in the control condition (M=13.6 minutes) F(1,12)=3.53, p=0.085. However, this effect was small at best, especially when compared to the large circadian effect, F(3,36)=5.37, p<0.004, or the increase in subjective drowsiness described above (Fig. 3).

Sleep onset frequency measures the number of times subjects fell asleep on the four trial MSLT (i.e., a score from 0 to 4), and avoids the problem of assigning a mean sleep latency for trials where the subjects failed to fall asleep. There was no significant difference in sleep onset frequency between conditions.

Previous Nightcap studies have suggested that ELM density during wakefulness is a good measure of waking vigilance (21, 22). However, once again, there were no differences in total ELM density between conditions. Overall, opokinetic stimulation did not lead to a measurable increase in physiological sleep tendency.

3. Order effect and sleep tendency.

After looking at the sleep onset data, we noted that subjects were responding differentially to the stimulus, depending on the order of presentation. Sleep onset latencies were subjected to a trial (4) x condition (2) x order (2) mixed repeated measures ANOVA. A significant order effect was observed (F(1,11)=6.75, p<0.025); subjects who received optokinetic stimulation on the first day took longer to fall asleep on both days (M=15.1 and M=16.6 minutes on days one and two respec-
Fig. 5 - OKS produces a significant increase in subjective drowsiness, but only a small decrease in sleep onset latency (sol).

Solid lines: sleep onset latencies in minutes. Latencies with OKS (solid triangles) were marginally shorter (p=0.085) than under control conditions (open triangles). Dashed lines: subjective drowsiness. Subjects rated their drowsiness on a scale of 0 - 6. Drowsiness was rated much higher (p < 0.001) with OKS (solid circles) than under control conditions (open circles).

tively) than subjects who were controls on the first day (M=10.6 minutes), and received optokinetic stimulation on the second MSLT day (M=10.0 minutes). Sleep onset frequencies followed a similar pattern (F(1,12)=6.94, p<0.022).


Home sleep variables for the night immediately following the MSLT trials were subjected to a condition (2) x order (2) mixed repeated measures ANOVA. These variables included: sleep onset latency at night, REM sleep latency, total sleep duration, total REM sleep, total non-REM sleep, the number of REM periods, and REM density. There were no significant effects of experimental condition on any of the home sleep variables.
DISCUSSION

Motion sickness alone did not result in large increases in objective sleep tendency.

Overall, we did not observe a large decrease in sleep latencies in response to optokinetic stimulation. Although there was a trend towards shorter sleep latencies in the optokinetic condition, this effect was small when compared to more robust influences on daytime sleepiness, such as the circadian rhythm or a lack of sleep.

Note that we were intentionally using a threshold-level stimulus, i.e., we only induced a moderate level of motion sickness, and we did not stimulate the vestibular organs directly. It is possible that this stimulus was not strong or long enough to induce increased sleep tendency; a larger and more sustained perturbation of the vestibular system, such as bodily rotation, parabolic flight, or even space flight, may result in changes in physiological sleepiness, in addition to a subjective increase in drowsiness.

Dissociation between subjective and objective measures of sleepiness.

Overall, subjects became drowsy during the optokinetic stimulation, but this subjective sleepiness did not translate into a robust decrease in sleep onset latencies. Recall, however, that this experiment used an optokinetic stimulation, that reliably induces motion sickness. It is possible that vestibular stimulation alone may be soporific, as suggested by both anecdotal and some initial experimental evidence (9), whereas motion sickness arising from visual-vestibular conflict may instead be arousing. Both the nausea and sweating associated with motion sickness may result in sympathetic stimulation leading to increased wakefulness. One way to test this hypothesis would be to examine the effects of prolonged motion without sickness on daytime sleepiness. Nevertheless, these results demonstrate that subjective and objective measures of sleepiness are consistently dissociated by OKS, indicating that they measure at least partially distinct physiological processes.

No effect on nocturnal sleep.

The lack of any significant impact on subsequent sleep variables was surprising. Various researchers have suggested that visual-vestibular perturbations, e.g., wearing inverting goggles, can influence sleep, and most importantly subsequent REM sleep (5, 26). However, subsequent work by Zimmerman, one of the pioneers in the field of spatially rearranged vision and REM sleep, suggests that there is no consistent effect of distorted vision on subsequent REM sleep (27). Our study seems to support this finding, although large individual differences between subjects were observed, raising the possibility that different people may respond differentially to vestibular perturbations, depending on a range of individual physiological variables, e.g., vestibular performance and sensitivity. Recent studies have demonstrated that perceptual learning may require a REM sleep window to consolidate learning (14), and that the amount of REM sleep is markedly enhanced on the night following such learning (25). This experiment does not address the
issue of perceptual learning directly, as subjects were only involved in a short-term adaptation task.

The Multiple Sleep Latency Test (MSLT) may be susceptible to a "first day effect". The pattern of results observed between the control and stimulus groups on the first day is reversed on the second day. This significant and unexpected order effect raises the possibility that we are observing a "first day effect" on the first MSLT day. The "first night effect" is a well-documented phenomenon in sleep labs, and has been demonstrated to influence both REM sleep latency and duration, as well as a range of sleep variables, including dream content. If the MSLT is susceptible to these effects, and if subjects respond differentially to the same stimulus depending on how adapted they are to the NSLT sleeping environment (as they appeared to in our study), then some MSLT studies and even clinical tests may be confounded by a "first day effect." On the other hand, it is also possible that random assignment yielded two groups that were significantly different in their sleep onset profiles, i.e., that the group who were controls on day one were "faster sleepers" than the group who were controls on day two. An adaptation day and a larger sample size would help control for both these possibilities.

The Nightcap can be used effectively to perform MSLTs. The Nightcap has been demonstrated to accurately measure nocturnal sleep onset (20) by recording the cessation of eyelid movements. Initial studies in our lab confirm that the Nightcap can also measure daytime sleep onset by the cessation of eyelid movements, leading to a novel use for the Nightcap as a MSLT monitor. This is the first time, to our knowledge, that MSLTs have been conducted using eyelid movements to measure sleep onset. Although we did not find strong support for the hypothesized effect of motion sickness on objective sleep tendency, the Nightcap was able to accurately measure differences in objective sleep onset. The Nightcap provides a new methodology by which the same simple device can be used to measure sleep in the home, as well as sleep in the lab, using a range of testing protocols, including the MSLT.

SUMMARY

This study examined the effect of optokinetic stimulation on objective sleepiness, as measured by the Multiple Sleep Latency Test (MSLT). The Nightcap, a portable sleep monitor, was used in a novel way to perform MSLTs, as well as record sleep in the home. Subjects wore the Nightcap for seven consecutive nights. On days 3 and 5 of the protocol, subjects came into the lab for an MSLT. On the experimental day, subjects underwent 10 minutes optokinetic stimulation (OKS), resulting in moderate motion sickness prior to each MSLT trial. Although subjects in the OKS condition reported significantly more drowsiness than controls, this did not result in significantly reduced sleep latencies.
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REFERENCES


