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Review

The influence of sleep deprivation and oscillating motion on sleepiness, motion sickness, and cognitive and motor performance

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ABSTRACT

Our goal was to determine how sleep deprivation, nauseogenic motion, and a combination of motion and sleep deprivation affect cognitive vigilance, visual-spatial perception, motor learning and retention, and balance. We exposed four groups of subjects to different combinations of normal 8 h sleep or 4 h sleep for two nights combined with testing under stationary conditions or during 0.28 Hz horizontal linear oscillation. On the two days following controlled sleep, all subjects underwent four test sessions per day that included evaluations of fatigue, motion sickness, vigilance, perceptual discrimination, perceptual learning, motor performance and learning, and balance. Sleep loss and exposure to linear oscillation had additive or multiplicative relationships to sleepiness, motion sickness severity, decreases in vigilance and in perceptual discrimination and learning. Sleep loss also decelerated the rate of adaptation to motion sickness over repeated sessions. Sleep loss degraded the capacity to compensate for novel robotically induced perturbations of reaching movements but did not adversely affect adaptive recovery of accurate reaching. Overall, tasks requiring substantial attention to cognitive and motor demands were degraded more than tasks that were more automatic. Our findings indicate that predicting performance needs to take into account in addition to sleep loss, the attentional demands and novelty of tasks, the motion environment in which individuals will be performing and their prior susceptibility to motion sickness during exposure to provocative motion stimulation.

Contents

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1. Introduction

Many military and commercial transportation operations involve simultaneous exposure to motion and altered work schedules. For example, new military operational situations involving littoral combat ships and amphibious assault vehicles combine sleep deprivation and exposure to provocative motion simultaneously. Some concern has been expressed about how each of these factors affect human performance (McCauley et al., 2007), but systematic studies of their conjoint effects on performance are scarce (Dowd et al., 1975; Collins, 1988). We have investigated the separate and joint effects of provocative motion and sleep deprivation on cognition and motor performance. We have also investigated the effects of motion exposure and sleep deprivation on sleepiness and motion sickness, because there are few systematic studies of the mutual effects of these stimuli on sleep quality and quantity.

Our work extends the literature on the effects of sleep loss. There are many studies of how sleep loss affects psychomotor performance under stationary laboratory conditions and roughly constant motion conditions, i.e. regular railroad or airline flight routes that are relatively routine in nature (Reifman, 2004; Reifman and Gander, 2004; Roach et al., 2004a; Roach et al., 2004b; Rosa, 2004; Van Dongen and Dinges, 2005), but the only studies of sleep in provocative motion conditions are observational (Matsangas et al., 2015). Fatigue studies typically focus on cognitive performance and vigilance tasks (Basner et al., 2013; McCauley et al., 2013; Basner et al., 2015) with less attention to motor tasks (Walker et al., 2002), consequently, we have included tests of motor learning and retention, and balance in our experimental protocols. Interruptions of reaching and of posture from high accelerations during motion exposure have been studied (Matsangas et al., 2014b), but cognitive outcomes less so (Matsangas et al., 2014a), and we have investigated cognitive as well as motor performance. In summary, our study extends the individual literatures on sleep loss and motion exposure and unifies them by utilizing the two factors individually and jointly and by assessing a common set of outcome measures.

Almost all individuals with normal vestibular function are to some extent susceptible to motion sickness (Kellogg et al., 1965; Johnson et al., 1999), although individual susceptibility varies enormously (Money, 1970; Miller and Graybiel, 1972; Golding, 2006). Low grade motion sickness tends not to be recognized as such because with chronic exposure to low levels of vestibular stimulation some individuals experience fatigue, drowsiness, and mood changes for extended periods of time, rather than typical nausea, and this is unrelieved by sleep. This phenomenon is referred to as the "sopite syndrome" (Graybiel and Knepton, 1976; Lawson and Mead, 1998; Matsangas and McCauley, 2014). Some astronauts experience this state for days and even weeks after entry into space flight (Lackner, 2014). With higher amplitudes of vestibular stimulation in a nauseogenic frequency range, such as extreme sea states, and longer exposure, the likelihood of the more familiar signs of motion sickness appearing increases, e.g. stomach discomfort, nausea, cold sweating, vomiting (Kennedy et al., 1968; Lawther and Griffin, 1986). It has never been experimentally determined whether the severity of chronic low grade or acute severe motion sickness is influenced by fatigue. We hypothesized that psychomotor performance, sleepiness and motion sickness would show additive and multiplicative effects of motion exposure and sleep deprivation, because of the cited overlap of motion sickness and sleepiness in response to motion exposure.

To achieve these goals, we designed an experiment with four groups of subjects exposed to four different combinations of two nights normal 8 h sleep or 4 h sleep, combined with testing under stationary conditions or during 0.28 Hz horizontal linear oscillation. All subjects underwent four test sessions per day that included evaluations of fatigue, motion sickness, vigilance, perceptual discrimination, perceptual learning, motor performance and learning, and balance. Studies involving chronic exposure over days to different amounts of sleep per 24 h period have shown measurable performance deficits after the first night with sleep reduced from 8 to 4 h, and the deficits accumulate progressively over the first, second and subsequent 24 h periods (Van Dongen and Dinges, 2005). Thus, 4 h of sleep per night for two consecutive days is experimentally powerful enough for the present purposes. Our choice of a horizontal linear oscillation motion stimulus was designed to be operationally relevant to a broad range of ship, aircraft, rail, and road vehicles. Vertical oscillation at about 0.2 Hz (O'Hanlon and McCauley, 1974; Lawther and Griffin, 1987; Griffin, 1990) is the most provocative component of ship motion. Horizontal linear oscillation is also a component of ship motion and car motion (Guignard and McCauley, 1982; Griffin and Newman, 2004), and it evokes less motion sickness than vertical oscillation under laboratory controlled conditions (Golding and Kerguelen, 1992; Mills and Griffin, 2000; Golding et al., 2001).

2. Materials and methods

2.1. Subjects

Sixty-two healthy adults, 34 males and 28 females, were enrolled in the study after signing informed consent. Subjects could terminate participation at any time, and three subjects (1 male, 2 females) withdrew during the study, two for personal reasons unrelated to the study and one due to severe motion sickness. Inclusion criteria were: age 18–30 years, normal or corrected to normal vision and body mass index (BMI) <30. This was the population of interest to the funding agency, the U.S. Office of Naval Research. Additional exclusion criteria were based on the following self-reported histories obtained in an oral interview: drug or alcohol abuse, sleep disorders, skeletal or muscular problems that impair movement or posture, neuromotor disease or trauma, psychiatric disorder, developmental disorder, severe susceptibility to motion sickness (Golding, 2006), night shift work and/or travel that involved crossing time zones during the three weeks prior to the onset of testing. Only right-handed subjects were enrolled. All subjects gave saliva and urine samples to be screened for the following disallowed substances: narcotics (cocaine, marijuana, opiates, amphetamines, benzodiazepines, and methadone), nicotine, and alcohol. Subjects were required to abstain from caffeine and all caffeinated products starting 3 days before the onset of testing, and for the whole duration of testing. Females were scheduled for tests outside their menstrual periods. Subject screening was conducted via an initial telephone conversation and a follow-up lab visit. Before participating, subjects read and gave their informed consent to an IRB approved description of all screening and experimental procedures.

2.2. Apparatus

To accommodate the multi-day period of residency in the laboratory for two subjects concurrently, two private laboratory rooms were furnished with single beds, night stands, refrigerators, entertainment systems, and other basic amenities. Shared exercise equipment was also available. The total duration of overnight sleep and abstinence from naps were monitored with Actiwatch-2™ and Actiwatch-Spectrum™ devices and associated software (Philips Respironics). The package consists of a small motion sensor worn on a wrist band, a wireless 1Mbit memory data logger to record activity in a 24 h period, a photopic light sensor, an event marker, Actiware™ V5.59 sleep scoring software, and a USB-comm. dock/charger with cable and power adapter.