Evaluation of Sleepiness in Space Robotics Task Performance and Discussing Sleep with High School Students in a Museum

by
Caroline Lowenthal
B.S. in Aerospace Engineering
Massachusetts Institute of Technology, 2009

Submitted to the Department of Aeronautics and Astronautics and the Engineering Systems Division in partial fulfillment of the requirements for the degrees of

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Abstract

Sleepiness impacts performance in all aspects of life. This thesis addresses the impact of sleepiness on astronauts and adolescents in their everyday tasks. The first part describes the results of an experiment assessing the effect of sleepiness and workload on performance in simulated space telerobotics tasks. The second part describes the results of a forum discussion with high school students about school start time based on information about adolescent sleep biology and various stakeholder perspectives.

Astronauts must maintain a high level of performance during space robotics operations, despite sleep schedules that hinder their cognitive function, response time, and attention. This study aimed to determine the usefulness of secondary tasks to assess sleepiness and workload during simulated space robotics performance. 13 naive subjects were trained to perform two types of robotics tasks and two types of secondary tasks measuring response time. Subjects completed two 2-hour robotics sessions, one at midday after approximately 4 hours awake, and one at night after 18 hours awake. Comparing 18 hours awake versus 4, Karolinska Sleepiness Scale scores increased by at least 2 points. Subjects maintained primary robotics task performance at the night session, but secondary task measures such as inverse response time showed significant changes, with moderate Hedges' g (0.35 to 0.74) effect sizes. For a passive monitoring of arm movement primary task, a simple response secondary task metric proved more sensitive to time awake than a two choice response secondary task, but the converse was found when the primary task involved track and capture manual control. Our visual secondary task was sensitive to changes in primary task workload and sleepiness. Secondary task workload measures are a potentially useful adjunct to primary task drowsiness metrics like PVT and deserve further investigation.

In Part II, we hypothesized that informed high school students can make strong recommendations about school start time after learning about the biology of their sleep needs and participating in a discussion forum to consider various stakeholder perspectives. 26 high school students from Fenway High School participated in a forum at the Museum of Science. Before the forum, they completed a survey about their sleep habits. During the forum, they participated in a role play exercise, taking on the roles of parent, sleep researcher, administrator, student, and teacher and negotiating tradeoffs about school start time. In the post-forum survey, students showed learning about sleep and made good recommendations to share with their peers. They value sleep and think that getting enough sleep is important, yet by their self-reported actions they seem to value other activities more.

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Introduction

Thesis Organization

This thesis is organized into two main parts. The first part describes the experiment conducted to assess the effect of sleepiness on workload and performance. The methodology and results are detailed, followed by a discussion of the experiment and its implications and limitations.

The second part describes the technology and policy analysis of sleepiness effects as assessed by a discussion forum for high school students held at the Museum of Science. At the forum, the impact of sleepiness on the activities of daily life was discussed, along with the issue of school start time considered from different perspectives. The thesis describes the results of the discussion.

The thesis concludes with a section relating the results of the two sections and suggesting future work for each of the topics.

Space Teleoperation

Astronauts are expected to maintain a high level of performance during space robotics operations, despite sleep schedules that potentially hinder their cognitive function, response time (RT), and attention. Long continuous time awake has been shown to have deleterious effects on basic cognitive functions and to impair the performance of human operators performing safety critical tasks, e.g. drivers, air traffic controllers, and medical residents [1-6]. NASA has also been concerned about potential impacts of time awake and circadian shifting on astronauts performing telerobotic tasks on the International Space Station (ISS) [7, 8]. Telerobotic arm operations are performed on the ISS for tasks such as station construction and maintenance, capture of supply spacecraft, and to provide a mobile work platform for spacewalking astronauts [9]. Astronauts average less than 6 hours of sleep per night [10], and are often slam-shifted (sleep-wake periods reversed by 8-12 hours) in advance of robotics operations. This thesis describes the results of an experiment designed to assess the effects of 18-20 hours of time awake on performance, subjective and objective workload of volunteer subjects performing simulated space telerobotics tasks, and whether sleepiness increases subjective and objective workload.

Most studies of fatigue and sleepiness have employed relatively simple tasks, where operator performance is relatively consistent, and so fatigue and sleepiness effects are easily detected. Although performance on complex tasks tends to be more variable and exhibit learning effects, it is also important to understand how fatigue and sleepiness affects them. There is a risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and workload. Cognitive and psychomotor tests were used to monitor these changes, but it is important to determine which tests are best suited to each condition or task. The test should be sensitive to changes in cognitive status, repeatable, reliable, and brief, and most importantly it should predict robotic task performance. This thesis suggests which tests are most appropriate for complex space telerobotics tasks to allow for accurate monitoring of short-term changes in cognitive status. Currently, cognitive and other tests are used to monitor astronaut health over the long term, but there is no definitive way to verify that a particular astronaut is ready to perform at a given time. Impairment of cognitive abilities due to fatigue increases the risk of error during operations, and it is critical to minimize such risks.

Sleep Forum with High School Students

Adolescents require more sleep than either younger children or adults, and their biologically optimal sleep schedule is shifted later in the day than either of the other two groups [11-14]. High schools often start earlier than is ideal for their adolescent students, even as early as 7:00 AM [15]. High school students are the primary stakeholders in the issue of school start times, but there are many other stakeholders with conflicting perspectives, including administrators, teachers, parents, and sleep researchers. Learning through discussion is an effective way of engaging students in a topic [16, 17]. Forums are a particular instantiation of learning through discussion which give students a chance to discuss these various perspectives in small groups. This thesis describes the results of a forum with high school students designed to gather their thoughts on school start time and sleep, having considered the perspectives of the various stakeholders.

Part I: Effect of Sleepiness on Performance and Workload During Space Robotics Tasks

Background/Literature Review

Sleepiness can be defined as sleep propensity – "the speed, ease, or likelihood of falling asleep as opposed to remaining awake" [18], resulting from increased activity in sleep-promoting brain areas due to circadian phase as well as time awake/sleep debt. It should be distinguished from physical or mental fatigue, which is reduced motivation resulting from effort or time on task. Studying operator performance on professional tasks in real world settings can be difficult because operator circadian and sleep debt factors are not always controlled, and tasks are typically cognitively complex. Scientific studies of the effect of sleepiness on operator alertness and performance have traditionally been performed in controlled laboratory settings, and have utilized relatively simple tasks, since learning effects are less complex and the effects of sleepiness and lapses due to micro-sleep episodes are more easily experimentally detected [19]. Results have been used to develop mathematical models [20-22] for circadian and sleep debt effects. Under conditions of chronic sleep restriction (too little sleep per night on an ongoing basis), performance decrements measured in terms of response time (RT), lapses, or accuracy vary based on the type of task [19, 23]. The Psychomotor Vigilance Task (PVT) [24] – which measures sustained attention and simple reaction time to an intermittent visual stimulus – is consistently among the most sensitive and reliable. After 18 hours awake, PVT performance decreased in many subjects, showing both lapses and responses when no stimulus was present [19, 25]. The PVT correlates with the decrease in performance on some types of complex tasks, such as driving performance [26], but is always administered separately as a primary task.

We were interested in measuring the effect of 18-20 hour time awake on robotics performance, as well as operator mental workload. Mental workload can be defined as the fraction of an operator's information processing and attentional capacity used to perform a task [27], and we expected it to be an important determinant of performance on robotics tasks. An operator's capacity in various channels (e.g. visual, auditory) [28] is limited so performance should remain constant until workload exceeds this capacity. Mental workload is therefore typically measured via assessment of spare attentional capacity, either directly by the subject using subjective scales of spare attention, such as the Modified Bedford Workload Scale [29, 30], or it is objectively inferred from performance on a secondary side task. The side task should use the same sensory resources as the primary task, but should be performed only as the attentional demands of the primary task permit. Many neurocognitive functions are thought to be vulnerable to sleepiness, including executive functions which control attention and the ability to regulate perceptual and motor processes for goal-directed behavior. "Distractibility" from this controlled attention has been shown to increase during periods of sleepiness [31]. For this reason, secondary visual tasks are also used to maintain alertness in railroad locomotives [32].

Several researchers have studied the effects of sleepiness on secondary RT tasks using a driving simulator primary task. A study by Baulk and coworkers [33] did not find a reliable association, while a study by Lisper et al. [34] found that changes in response time reflected changes in wakefulness and adequately predicted falling asleep at the wheel. However, the stimulus used in both studies was auditory rather than visual, and arguably cannot be interpreted as a mental workload measure because it didn't compete for attention in the visual channel. Further, auditory stimuli have been shown to be less sensitive to lapses than visual stimuli because it is possible to respond to an auditory stimulus while being too sleepy to maintain visual focus [33]. In contrast to Baulk's results, we found an effect using simple and complex visual secondary tasks. There are several possible reasons for this difference. First, the visual secondary task is arguably a better measure of mental workload when the primary task is also visual. Second, the recent Lim and Dinges meta-analysis suggests 1/RT is a more sensitive and reliable metric [19]. Third, Baulk's driving simulator task was longer and perhaps more monotonous than our two robotics tasks.

An earlier study by Lenné et al. [35] of sleep deprivation and experience effects on driving performance using a visual secondary task did show a significant increase in RT. In contrast to Lenné's research [35], besides the obvious difference in primary tasks, we evaluated 1/RT instead of RT. Also, we used 1/RT to measure mental workload which depends on sleepiness, while Lenné used RT it to measure sleepiness directly. Finally, our shorter inter-stimulus intervals gave us more samples and therefore more robust 1/RT data. Another study by Lenné et al. found that driving tasks become more difficult as measured by a secondary reaction time task late at night and early in the morning (0200 and 0600 hours, respectively), suggesting that task difficulty is a function of time of day and that cognitive resources are fixed [36]. Conversely, we hypothesized that the decrease in performance at night was due to decreased cognitive capacity, rather than increased task difficulty.

Consequently, in our experiment, we hypothesized that as sleepiness increases, cognitive capacity would decrease, and therefore subjective and objective workload should increase. Hence we decided to study the subjects' performance on complex robotics tasks with a visual secondary task to concurrently assess mental workload changes. We evaluated two types of secondary task. One was a "simple" visual response task, requiring only that the subject respond to an intermittent visual stimulus presented on the screen. Subjects responded with a button press when the visual stimulus appeared. The second was a "complex" visual response task, requiring that the subject decide which of two different visual stimuli was being presented and respond accordingly. We anticipated that response times on both types of secondary tasks would be longer than those on a PVT, since they were being performed as a secondary task and the stimuli appeared in the visual periphery. We expected that response time, lapses (missed response rate) and accuracy (percentage of correct responses on the complex task) would be affected by primary task workload due to reduced cognitive capacity as well as by sleepiness. Lapses or very long RTs due to microsleep episodes might be expected from reports in the PVT literature [25], particularly during long and boring tasks. Long response times could also be due to engagement in the primary task during shorter, engaging tasks. Hence we expected that the effect of sleepiness on mental workload might interact with the nature of the primary task. Our experiment was designed to answer the following questions:

- How does performance on primary robotics tasks change when a subject has been awake for many hours? Which metrics of primary task performance show the most consistent changes?
- Can the effects of practice offset the effects of hours awake on primary task performance?
- Do subjective and side task workload metrics show consistent changes when a subject is sleepy? Which metrics show the largest effects most consistently? Does the answer depend on the type of robotic task being performed? If the primary task is primarily vigilance-based, is a simple side task more sensitive? If the primary task is higher workload and primarily based on manual control, is a complex side task more sensitive?

This experiment also served as a pilot study for a longer inpatient study conducted in conjunction with the Brigham and Women's Hospital (BWH). That experiment investigates the effects of chronic sleep restriction and circadian slam shifting on robotics performance, under laboratory conditions where sleep and circadian factors can be very carefully controlled.

Methodology

The experiment used the MIT Robotic Workstation simulator (RWSS),[1] designed to resemble the simulators used at NASA to train astronauts. The virtual arm in the simulation resembled the Space Station Remote Manipulator System (SSRMS) on the ISS, though with some minor differences.[2]As shown in Figure 1, the MIT RWSS user interface consisted of three monitors and two three-axis joysticks mounted on a rolling cart. Subjects controlled translation of the arm end effector using their left hand and rotation with the right hand.

[1] The simulation was developed using Vizard (WorldViz, Santa Barbara, CA), a Python-based virtual reality development scripting language, and employed models developed using AC3D (Inivis Limited, Ely, UK).
[2] The arm moved at somewhat faster rates than the actual arm. It had 6 degrees of freedom instead of 7, slightly different kinematics and no arm dynamics.

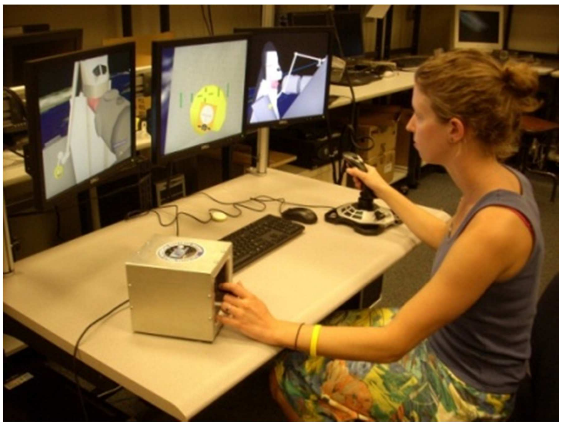

Figure 1: MIT Robotic Workstation Simulator

The virtual environment contains the ISS with the main truss, several modules, and the Shuttle attached (Figure 2). During track and capture trials, the Japanese H-II Transfer Vehicle (HTV) is also represented. The SSRMS is represented as a 17-meter-long arm consisting of 6 joints (Shoulder Yaw, Shoulder Pitch, Elbow Pitch, Wrist Pitch, Wrist Yaw, and Wrist Roll), and 4 links, attached to the truss in the center of the ISS. The arm can move with 6 degrees of freedom (translation up/down, port/starboard, forward/aft, and rotation pitch, yaw, roll), which uses RRG Kinematix (Robotics Research Group, University of Texas) to calculate the inverse kinematics.

Figure 2: A View of the ISS with Shuttle Attached, from Aft

Two types of telerobotics primary tasks were used: 1) track and capture and 2) autosequence. Track and capture was a manual control task where the subject used the central monitor to see a simulated view of a slowly drifting cargo spacecraft from a camera mounted on the arm end effector. Views from two other simulated cameras displayed on adjacent monitors allowed the subject to monitor arm clearance. The subject had a maximum of 90 seconds to maneuver the arm towards the moving spacecraft and capture it by placing the arm's end effector over a grapple pin attached to the spacecraft. Subjects were told to minimize the time to grapple the moving spacecraft, while avoiding both collisions with the spacecraft and the number of failed grapple attempts. These trials were designed to be short, challenging, and require bimanual coordination. In autosequence tasks, the subject entered sequences of prescribed inputs into a menu on the robotic workstation. The inputs consisted of either a series of six joint angle measurements (which could be challenging for a sleepy subject to enter correctly) or an option number to select. After entering the input, the subject released the brake using a keyboard command and then monitored the arm's movement as it automatically executed a sequence of movements determined by the menu entries. The subject did not know the trajectory of the arm, but if the arm moved within 1.5 meters of any structure, the subject was instructed to stop the arm motion by using the brake key. Including data entry, autosequence trials lasted 5 minutes each, imposed a lower physical and mental workload than the track and capture tasks, and were included to challenge the subject's vigilance. Subjects were evaluated on making correct autosequence menu inputs, catching clearance violations before the arm moved within 0.6 meters of structure, and applying the brake appropriately.

Either a simple or complex side task was present during both types of primary task. In both, the side task consisted of the word "Message!" appearing on the left monitor at the middle bottom of the screen, visible in the subject's peripheral vision. In the simple version, the message background and text were green; in the complex version, the color of the message varied randomly between purple and yellow. The subject responded as quickly as possible by pressing the left button on the joystick for the simple version, or the corresponding matching purple or yellow button on the joystick for the complex version; if they did not respond within 10 seconds, the stimulus disappeared and was recorded as missed. The inter-stimulus interval ranged uniformly from 2-10 seconds for both types of tasks. For the simple and complex side task mental workload measures, performance was evaluated on response time (RT), accuracy, and number of missed responses. Subjects also rated their mental workload on a 1-10 point Modified Bedford workload scale[30]after each trial, with ½-point resolution. The questions on this Cooper-Harper-like hierarchical scale assess spare attention.

The experiment sessions were held on three consecutive days. The first 3 hour session was used for training. To pass the training, subjects needed to successfully capture the spacecraft in 5 of the last 6 trials. The second and third sessions were two-hour test sessions on each of the next two days. They were scheduled to manipulate time awake by testing each subject after about 4 hours awake, and in another session after 18 hours awake. Subjects were divided into two groups and tested either "midday-first" (4 hours awake) or "night-first" (18 hours awake) as shown in

Table 2: Experiment Schedule by Group

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We recruited 13 naïve subjects (6 male, 7 female) ranging in age from 21 to 29 (mean 24.7, SD 2.9 years). None of the 13 subjects scored in the evening-type range on the Morningness-Eveningness Questionnaire.[37] It is possible that morning-type people self-selected for the study because they were willing to wake up at 4 AM. The data from 11 subjects (6 female, 5 male) was suitable for inclusion.[3] The midday-first group had 3 females and 2 males, and the night-first group had 3 females and 3 males. The experiment used a repeated measures design within groups. Night test sessions started at 10 PM. Subjects were asked to wake up at 4 AM[4] that day to achieve 18-hour wake time, and to refrain from naps, caffeine, and alcohol for the duration of the study. All subjects denied napping after awakening at 4 AM. Subjects averaged 3.73 hours awake before their midday session (SD=0.89, range 2.25-5.0 hours) and 18.02 hours awake before the night session (SD=0.08, range 18-18.25 hours). In the two nights before their first session, subjects reported an average of 13.9 hours total of sleep (SD=2.0, range 11.0-17.5 hours), as recorded on their sleep logs (Appendix II: Sleep Log). All potential subjects were screened using the Morningness-Eveningness Questionnaire [37] shown in Appendix VI: Morningness-Eveningness Questionnaire. Scores fell into one of the following categories: "Definitely Morning", "Moderately Morning", "Neither", "Moderately Evening", and "Definitely Evening". Subjects whose scores were in the "Moderately Evening" or "Definitely Evening" range were screened out to ensure that subjects would be sufficiently sleepy after waking up at 4 AM and coming in to participate in an experimental session at 10 PM. The experiment was approved by the Massachusetts Institute of Technology (MIT) Committee on the Use of Humans as Experimental Subjects (COUHES) and subjects were paid for their participation.

Each test session began and ended with the subject rating their level of sleepiness using the Karolinska Sleepiness Scale (KSS, Appendix IV: Karolinska Sleepiness Scale). The KSS is a quick, simple and widely used 9-point scale ranging from 1 (very alert) to 9 (very sleepy, fighting sleep). Within each test session, subjects completed 2 blocks of trials, each with 12 track and capture tasks and 6 autosequence tasks in the same order (Table 1). The track and capture tasks were identical in the first and second blocks. (These tasks were all so similar that the subjects could not distinguish between the replications. Analysis showed that track and capture grapple time did not show any significant trend within a block across subjects.) The autosequence tasks were varied slightly between blocks so subjects would not recognize the replications, but were similar enough to be considered replications for the purposes of averaging dependent variables. In the design, side task type was fully crossed with primary task type for every subject. The 2 blocks were used to give subjects a break halfway through the session, to balance each secondary task type for time on task, and to assess early versus late performance. A debrief was performed at the end of the subject's second session (either night or midday), in which subjects were asked whether they fell asleep during either session. The procedure for each session can be found in Appendix I: Experimental Procedure.

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[3] One subject was unable to adhere to the study protocol wake time, and one subject had trouble understanding the use of the ratings scales, rendering the data invalid.

[4] Subjects called in to a voice mailbox at 4 AM to verify that they were awake on time.

Table 1: Experimental Session Robotics Sequence

Number	Primary Task	Secondary Task
Block 1		
6	Track and Capture	Complex attention
6	Track and Capture	Simple reaction time
3	Autosequence	Complex attention
3	Autosequence	Simple reaction time
Block 2		
6	Track and Capture	Simple reaction time
6	Track and Capture	Complex attention
3	Autosequence	Simple reaction time
3	Autosequence	Complex attention

Table 2: Experiment Schedule by Group

	Midday-first Group	**Night-first Group**
Day 1	Training, 3 hours	Training, 3 hours
Day 2	Session 1 Midday, 2 hours	Session 1 Night, 2 hours
Day 3	Session 2 Night, 2 hours	Session 2 Midday, 2 hours

Independent variables were subject, subject group (midday-first or night-first), gender, session time (midday or night), block (1 or 2), session number (first or second session for the subject), primary task type (autosequence or track and capture), and secondary task type (simple or complex response). All independent variables were considered fixed effects except for subject, which was a random effect. Dependent variables for track and capture tasks were grapple time, number of collisions, and number of failed grapple attempts. Dependent variables for autosequence tasks were whether the autosequence menu inputs were correct, fraction of clearance violations caught correctly, late, or missed, and number of times the brake was applied inappropriately. The dependent variable for both mental workload side task types was response time (RT), from which we derived mean inverse RT, the top decile of response times, the number of lapses, and accuracy (number of correct responses/number of stimuli). Bedford workload score and initial and final KSS ratings are subjective dependent measures. For statistical analysis, grapple time was transformed to log of grapple time and RT was transformed to inverse RT. This was done to create variables whose deviations from a linear model (residuals) are normally distributed and have a variance that is stable over the range of values predicted by the model. Bedford workload scale score was standardized for each subject to zero mean and unit standard deviation. Analyses used mixed hierarchical linear regressions, logistic regressions, paired t-tests, and the sign test, in SYSTAT 13 (Systat Software, Chicago, IL).

Independent variables were subject, subject group (midday-first or night-first), gender, session time (midday or night), block (1 or 2), session number (first or second session for the subject), primary task type (autosequence or track and capture), and secondary task type (simple or complex response). All independent variables were considered fixed effects except for subject and group, which are random effects. Dependent variables for track and capture tasks were grapple time, number of collisions, and number of failed grapple attempts. Dependent variables for autosequence tasks were correct autosequence menu inputs, fraction of clearance violations caught correctly, late, or missed, and number of times the brake was applied inappropriately. The dependent variable for both mental workload side task types was response time (RT), from which we derived mean inverse RT, the top decile of response times, the number of lapses, and accuracy (number of correct responses/number of stimuli). Subjective dependent variables included Bedford workload score and initial and final KSS ratings.

Results

Subject performance was evaluated based on the metrics in Table 3.

Table 3: Metrics

Metric	Description	Category
CVs Correct	Fraction of clearance violations correctly caught	Autosequence
CVs Late	Fraction of clearance violations caught late	Autosequence
CVs Missed	Fraction of clearance violations missed	Autosequence
False Positive BA	Number of times the brake is applied when a clearance violation is not present	Autosequence
Correct Inputs	Whether the inputs into the autosequence menu were correct on the first try	Autosequence
Log Grapple Time	Log of the time from brake release to grapple of the HTV	Track and Capture
Collisions	Number of collisions of the arm with the HTV	Track and Capture
Failed Grapple Attempts	Number of times the joystick trigger was pulled when the arm was not within the grapple envelope	Track and Capture
Mean 1/RT	Mean inverse reaction time on the side task	Autosequence, Track and Capture
Slowest 10%	Top decile of reaction times on the side task	Autosequence, Track and Capture
Accuracy	Percent of correct responses on the complex side task on a trial	Autosequence, Track and Capture
Lapses	Percent of side task stimuli missed on a trial	Autosequence, Track and Capture
Standardized MBPWS	Standardized Modified Bedford Pilot Workload Scale rating for each trial	Autosequence, Track and Capture
RT Variance	Variance of reaction time on a side task for each trial	Autosequence, Track and Capture

The measured variables in Table 3 were analyzed in models containing independent variables listed in

Table 4. The numbers in parentheses are the numbers used to code the categories in the data. Analyses were performed using mixed hierarchical linear regressions, logistic regressions, paired t-tests, and the sign test.

Table 4: Variables Used for Evaluation

Variable	Description
Session Time	Midday (0) or night (1) session
Group	Midday-first (0) or night-first (1)
MRT	Score on the Mental Rotation Test for spatial ability
KSS1 and KSS2	Score on the KSS at the beginning (KSS1) and end (KSS2) of each session
Age Category	Category 0 (21-25 years old) or Category 1 (26-29 years old)
Gender	Female (0) or male (1)
Block	First half of a session (Block 1) (0) or second half of a session (Block 2) (1)
MBPWS	Modified Bedford Pilot Workload Scale rating for each trial
Session Number	First (0) or second (1) session for the subject
Task Type	Track and Capture (1) or Autosequence (2)
Side Task Type	Simple (S) or complex (C)

Was perceived sleepiness lower during the midday session than the night session?

Both initial and final KSS ratings during the midday session were lower than ratings during the night session (p=0.001, Sign test). The initial KSS ratings for each subject at the start of their first and second session are shown in Figure 3(midday-first subjects) and Figure 4 (night-first subjects).Subjects consistently rated their sleepiness as higher for the night session at both the initial and final ratings. Most subjects rated their sleepiness at the midday session between 3 (“alert – normal level”) and 5 (“neither alert nor sleepy”); at the night session, most were between 6 and 8 (7 is “sleepy – but no effort to keep awake”). Every subject showed an increase of at least 2 points from the midday to the night session, meaning that the hours-awake manipulation successfully increased sleepiness for all subjects. At the debriefing after each subject’s second session, 6 subjects reported falling asleep during the night session (whether that was their first or second session). No subjects reported falling asleep at the midday session. We looked unsuccessfully for evidence of sleep episodes in the primary task data (such as the arm moving far off course on track and capture or long periods that pass without any secondary task responses on either task). Perhaps subjects who fell asleep did so briefly between trials.

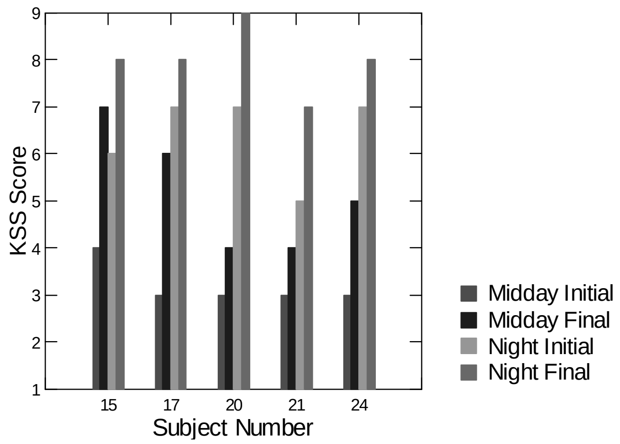

Figure 3: KSS scores for the midday-first group by session

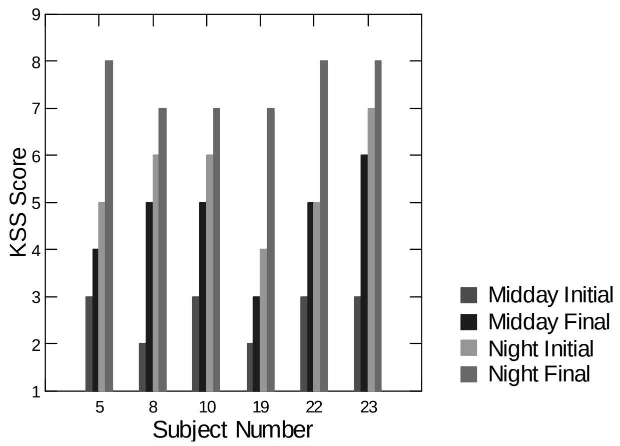

Figure 4: KSS scores for the night-first group by session

How does performance on primary robotics tasks change when a subject has been awake for many hours? Which metrics of primary task performance show the most consistent changes? Can the effects of practice offset the effects of hours awake on primary task performance?

Overall, subjects maintained their individual average performance levels on the primary robotics tasks in both the midday and night sessions (Figure 5). On autosequence tasks, subjects were able to maintain surprisingly consistent performance between midday and night sessions. There were no significant differences between sessions on the fraction of clearance violations caught on time (average across sessions 0.53), caught late (average 0.34), or missed (average 0.14); or the frequency of false positive brake applications (average 0.06) when analyzed by subject, session (midday or night), block, or group (midday-first or night-first). On track and capture tasks, we found a significant effect of session on log of grapple time (p=0.002, Figure 5) among night-first subjects. Those grapple times were on average about 1.5 seconds longer during the night session (about an eighth of one standard deviation in both grapple time (Hedges' g=0.12), and log grapple time (Hedges' g=0.16), calculated within subjects).[5]However, no corresponding session effect was found among the midday-first subjects. Performance is improved at the second session, probably due to practice effects. Performance is reduced at the night session, presumably due to time of day. We suggest that performance and time of day effects sum when the night session is first and tend to cancel when the night session is second. The number of failed grapple attempts and collisions was very small for all subjects, and no significant differences were found. Large inter-subject skill level differences and learning effects limited our ability to detect effects of sleepiness on primary task performance.

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[5]Hedges' g can be defined as$G = \frac{(\overline{x_1}-\overline{x_2})}{s}\left(1-\frac{3}{4(n_1+n_2)-9}\right)$, where 1 represents night and 2 represents the midday session. 38. Hedges, L.V. and I. Olkin, *Statistical methods for meta-analysis*1985: Academic Press New York..

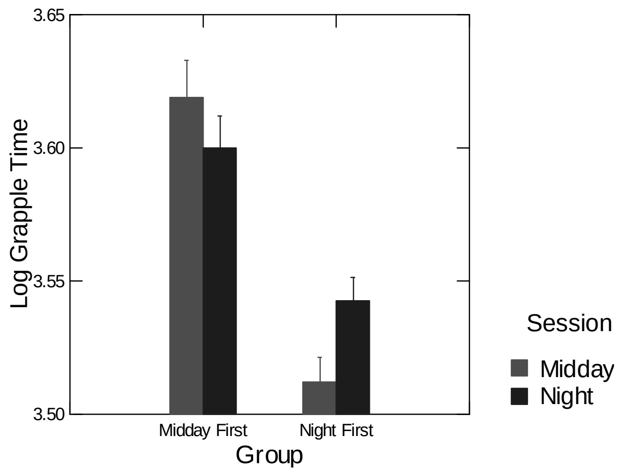


Figure 5: Log grapple time versus group by session with SEM error bars

Do subjective and side task workload metrics show consistent changes when a subject is sleepy? Which metrics show the largest effects most consistently? Does the answer depend on the type of robotic task being performed? If the primary task is primarily vigilance-based, is a simple side task more sensitive? If the primary task is higher workload and primarily based on manual control, is a complex side task more sensitive?

We were unable to demonstrate an effect of task type on standardized Bedford subjective workload, indicating that the subjects were sufficiently trained on track and capture tasks to perceive them to be as easy as autosequence tasks. Standardized Bedford subjective workload was 0.45 points higher at night than during the day for night-first subjects (p=0.012, sign test) and approximately the same for both sessions for midday-first subjects. This suggests that subjective mental workload was affected not only by the session number (first or second), but also by the time of day (midday or night). The results suggest that learning, practice and night session effects combine additively for the night-first subjects and cancel for the midday-first subjects. There was a similar effect on grapple times.

Using session (midday or night) as a proxy for sleepiness and inverse response time as the dependent variable measure, for track and capture tasks, the complex side task was found to be more sensitive to session than the simple side task. The effect of session on inverse response time was significant for the complex side task (p=0.015, mixed hierarchical regression); the midday session had an average 1/RT 0.028 s^{-1} higher than the mean of the two sessions. In terms of RT, responses were 117 milliseconds faster at the midday session (Figure 6, Hedges' g=0.35[6] calculated within subjects). The histograms of RT in midday and night sessions are shown in Figure 7(simple) and Figure 8(complex). Note that the average RT over all sessions is 1.042 seconds in this secondary workload task, much longer than response time in a PVT test (which is always performed as a primary task).The lengthening of average response times is due both to fewer short responses (0-2s) and longer long responses (4-10s) at night as compared to midday (Figure 7 and Figure 8). The session effect was not significant for the simple side task inverse response time data, though the trend was similar. Using initial KSS score instead of session

[6] According to Lim and Dinges (2010), this would be characterized as a moderate effect size, while values over 0.5 can be considered moderate to large.

as an independent variable proxy for sleepiness gave results that further supported the conclusion that the complex side task inverse response time is more sensitive to sleepiness (p=0.026 for initial KSS on complex, insignificant on simple).

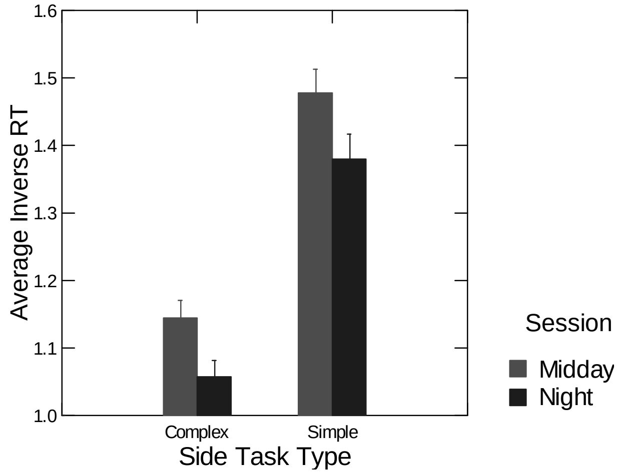


Figure 6: Mean 1/RT for Track and Capture Tasks

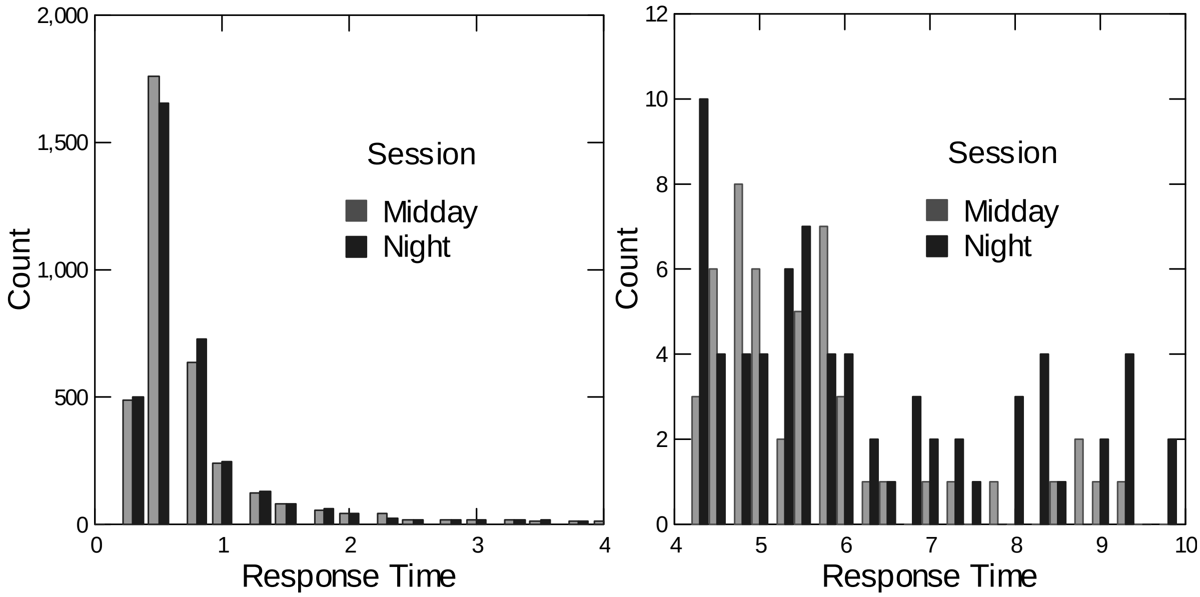


Figure 7: Simple response time at midday and night

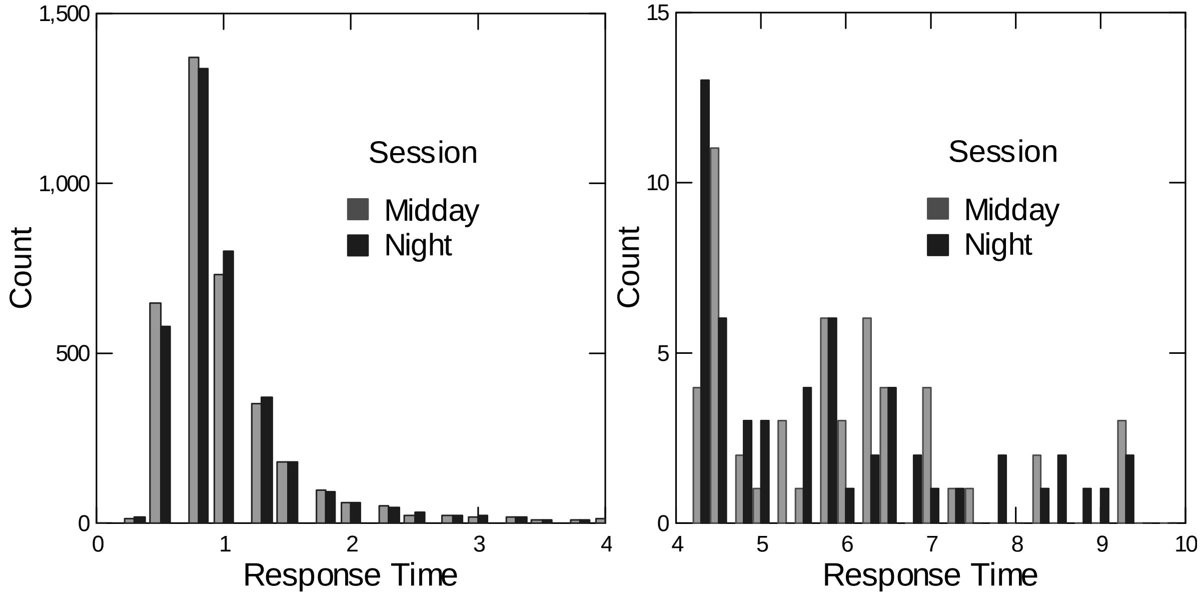


Figure 8: Complex response time at midday and night

In contrast, for autosequence tasks, again using session as a sleepiness proxy and inverse response time as the dependent variable, it was the simple side task rather than the complex side task that was more sensitive to session. The effect of session was significant for both types of side tasks; it was approximately twice as large for the simple side task (0.042s^{-1}difference between average 1/RT between sessions, p=0.01, mixed hierarchical regression) as on the complex side task (0.023s^{-1}, p=0.02, mixed hierarchical regression, Figure 9). The effect on the simple side task corresponds to a 115 ms difference (Hedges' g=0.64), while the effect on the complex side task corresponds to a 68 ms difference (Hedges' g=0.74). Using a mixed hierarchical regression with initial KSS rating(at start of the session)as a sleepiness measure yields a corresponding result: The effect on 1/RT per point on the KSS scale was significant for both and approximately twice as large (-0.023s^{-1}, p=0.026), for the simple side task as for the complex side task (-0.013s^{-1}, p=0.005). In this case, the difference on the simple side task was 24 ms, and 21ms on the complex side task. Using final KSS score instead of initial as the proxy yields a similar result: the effect on RT per KSS point on the simple side task is approximately twice as large (-0.03s^{-1}, p=0.004) as the effect on the complex side task (-0.016s^{-1}, p=0.001). The simple side task had a difference of 24 ms, and the complex side task had a difference of28 ms.

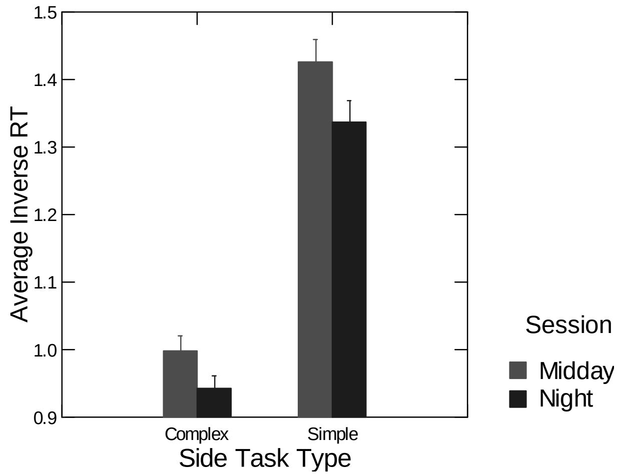


Figure 9: Mean 1/RT for Autosequence Tasks

Taken together, these findings suggest that when assessing mental workload on primary tasks as different as track and capture and autosequence, side tasks vary in their sensitivity to sleepiness effects. In the track and capture task, which involved physically active control, the effect of sleepiness on mental workload was larger if a complex response task was used, whereas for the autosequence task, the effect of sleepiness on workload was larger when measured by a simple response task.

We found no significant effect of KSS or session on the number of lapses, accuracy on the complex side task, or mean slowest 10% of response times, possibly because subjects were insufficiently sleepy and not experiencing enough detectable episodes of falling asleep.

Discussion

This experiment showed:

- The time-awake manipulation produced a significant change in subjective sleepiness. After 18-20 hours awake, Karolinska Sleepiness Scale scores increased by at least two units in all our subjects as expected. Nonetheless most metrics of robotics performance on both autosequence and track and capture tasks were not consistently adversely affected. No reliable effects were found on autosequence task performance. Track and capture performance was affected for the night-first group, but not for the midday-first group, and the effect was not large for the night-first group. Results would probably have been larger if the night session had begun later. It may be that despite drowsiness, subjects rallied in the night sessions to keep performance in the primary task largely constant. This may explain why the most consistently observed effects of sleepiness and session were on mental workload and spare attention.
- It is possible that there were effects of sleepiness on primary task performance but they were masked by practice effects. On track and capture tasks, night-first subjects showed a reduced grapple time at the midday (relative to the night) session, but midday-first subjects showed no such significant effect. We attribute this to practice effects which enhance the differences due to time awake for night-first subjects, but reduce it for subjects tested midday first since they

have more overall practice by the time they begin their night session. A similar reinforcement and cancellation of effects was seen on subjective workload ratings between sessions. Though several subjects reported falling asleep in the night session, we did not see any impact on primary task performance. However, the side task data showed that secondary task performance was affected.

- The inverse response time to a secondary task using complex attention is more sensitive to sleepiness (as measured by session time or KSS score) than that for a task requiring simple attention on more engaging, short-duration tasks requiring active control, such as track and capture. Inverse response time on a simple attention side task is more sensitive to sleepiness on monotonous, longer-duration tasks characterized by passive monitoring, such as autosequence. Secondary task inverse RT proved to be reasonably sensitive to manipulation of time awake (Hedges' g values of 0.35 to 0.74), whereas primary task performance did not. We conclude that after 18 hours awake, our subjects were able to maintain primary task performance largely unchanged, whereas secondary task performance showed more consistent effects of sleepiness. Secondary task workload measures – though perhaps not as sensitive as PVT in terms of Hedges' g – are sensitive to time awake. Because it is imbedded in the primary task, and not administered separately like PVT, use of a secondary task RT may be a useful way of looking for sleep effects during complex tasks, rather than immediately before or after.

It is important to remember that performance on our two simulated tasks may not generalize to other types of robotics tasks. Inter-subject differences in primary task performance in our experiment were larger than any overall differences between sessions or task types. Our subjects doubtless differed in their skill on the primary tasks, as did the quality and duration of their sleep. For example, some subjects consistently had higher variances in performance, while other subjects were more consistent (Appendix VIII: Variance of Reaction Time by Subject). Other sleep research [3] suggests that some of our subjects may have been more vulnerable to the effects of time awake. Moreover, subjects' different strategies for the same task type might have been differently susceptible to sleepiness.

Another concern was that each subject used the two subjective scales (KSS and Bedford workload) differently. Some subjects stated that they had experienced episodes of microsleep during the session, but did not rate their sleepiness at a 9 (extremely sleepy, fighting sleep), when they clearly should have. Others gave the same rating on the Bedford workload scale on every trial, when it was likely that there should have been some differentiation between trials. We standardized the absolute Bedford workload ratings for analysis, but there is no easy way to standardize for differences in the use of the scale. One suggestion was to ask subjects to rate their workload less frequently (e.g. after each set of trials that had the same side task), so that they would use the scale more carefully. Having subjects rate their workload after each trial became less useful as each session went on. It is likely that the results of asking for ratings after each subset of tasks (e.g. after 6 track and capture trials with the simple side task) would probably not be very different from those we found by asking for ratings after each trial.

The next issue with the way this study was conducted is that the sleep schedules of the subjects were not monitored as strictly as those of astronauts, or even as those of subjects in a conventional sleep study. This was impractical in our experiment. As a result, the amount of sleep had and recorded by our subjects might vary greatly among them and contribute to the variability of their levels of sleepiness and their performance. Nonetheless, our time awake manipulation was successful in producing significant changes in KSS scores and mental workload.

Furthermore, astronauts exercise as part of their daily routine, which may affect their sleepiness, but subjects in this experiment did not. To have a lasting effect on alertness, however, exercise must achieve 75% of VO2max for 45 minutes [39-41] – a much higher level than typical exercise. For this reason, astronaut exercise is unlikely to have a lasting effect on alertness, and the impact on our subjects' robotics performance as a proxy for theirs should not be significantly affected.

Time on task as well as hours awake likely affect performance and workload, and these two factors apparently interact. There could also be an interaction between task duration and task type. We tested a short and engaging task and a long and boring task, but not the other two possible combinations. Further, our test sessions were only two hours long whereas typical ISS operations may last up to eight hours. Longer hours performing a complex robotic task are likely to diminish spare capacity and compound the performance and workload decrements that can occur with long periods of wakefulness. Even with our non-slam-shifted subjects and relatively short task times, we found that subjects did take longer to grapple the incoming spacecraft at night and six of eleven subjects reported falling asleep during the night session. While the magnitude of the response time differences in this experiment was not operationally significant, they suggest that countermeasures, such as ensuring ISS robotic operators have adequate sleep prior to long sessions, should be taken to protect mission and astronauts on the International Space Station. Secondary tasks can also serve as useful countermeasures for detecting changes in sleepiness.

Part II: Discussing Sleep with High School Students in a Museum Forum Program

Background/Literature Review

This section discusses the relevant literature and background on adolescent sleep needs, school start times, learning through discussion, and the forum program format.

Adolescent Sleep

Many changes occur during adolescence, physical and otherwise. One change that is often overlooked is the need for increased sleep during the high school years, even as compared to younger teens or preteens. Teenagers need 9 hours and 15 minutes of sleep per night on average [11] (range 8.5 hours to 10 hours [42, 43]), but they get only 8 hours and 33 minutes on school nights (SD=1 hour 56 minutes) [44]. Further, teens' biological sleep drive is characterized by a phase shift, leading them to stay up later at night and wake up later in the morning, which is in conflict with traditional high school start times [12, 13]. This shift is caused by a later onset of melatonin secretion in more mature adolescents, which also turns off later in the morning [14]. It is possible, but not realistic, to use carefully controlled light exposure to shift teen sleep schedules to the desired times [14].

Sleep is crucial in emotional, behavioral, cognitive, and academic development, as well as safety. For teen drivers, sleepiness is the most common cause of accidents, with young drivers accumulating over 50,000 fatigue-related accidents and 1,500 fatalities per year [12, 14, 45]. In 1998, when Fayette County in Kentucky delayed high school start time by an hour, from 7:30 to 8:30 AM, crash rates among drivers 16-18 went down by 15.6%, even while the rates were increasing by 8.9% in the rest of the state [14, 46], though the effect was not statistically significant [47]. However, when Forsyth County in North Carolina shifted school start time from 7:30 to 8:45 AM, the reduction in crash rate among 16- and 17-year-old drivers was statistically significant [47]. Sleep deprived teenagers are more tired, cranky, and argumentative and have more trouble learning and growing [48]. Sleep deprivation in teens is also correlated with poorer grades [49]. These poorer grades are likely related to the increased disciplinary problems, sleepiness in class, and poor concentration caused by insufficient sleep [45]. More research is necessary to determine whether there are lasting effects of insufficient sleep during adolescence [45].

To address these concerns, several attempts have been made to educate parents, teachers, and students about the increased need for sleep during adolescence. Professor James Maas at Cornell made a short film about sleep targeted at teenagers along with a children's book. The National Center for Sleep Disorders Research at the National Institutes of Health released a high-school-level curriculum supplement about sleep for biology classes. There have also been various games and curriculums developed by sleep researchers to help students improve their sleep habits [45].

Finally, a partnership between the Koshland Science Museum in Washington, D.C. and the Hispanic College Fund resulted in 4 projects by 10th-grade students investigating various aspects of sleep in their communities [50]. The projects evaluated the relationship between school start time and grade point average (GPA), the effect of time in bed on test scores, and the effect of technology use before bed on time to fall asleep [50]. They found that a later school start time was associated with a slightly higher

GPA, those who had a longer time in bed had higher test scores, and that the use of technology within the 2 hours before bed resulted in a longer time to fall asleep and shorter overall sleep duration.

School Start Time

High schools in the United States start as early as 7 A.M. [15]. According to a poll by the National Sleep Foundation, 15% of students report falling asleep at school during the year [15]. Some states have considered bills that would prohibit schools from starting before certain times. In 1997, Minneapolis School District became the first school district to establish a later starting time for high schools, moving from 7:15 AM to 8:40 AM, which resulted in students averaging about 5 hours more sleep per week [48]. Students in the school district "reported getting more sleep on school nights, being less sleepy during the day, getting slightly higher grades and experiencing fewer depressive feelings and behaviors" [45]. In 2003, Rep. Zoe Lofgren (D-CA) introduced the "Zzzzz's to A's" bill in the U.S. House of Representatives to provide federal grants of up to $25,000 to school districts to help cover the administrative costs of adjusting school start times [15, 51]. Lofgren argued that the bill "could do more to improve education and reduce teen accidents and crime than many more expensive initiatives" [45]. The bill was referred to the Subcommittee on Education Reform and did not make it to a vote [51].

Despite widespread concern about teenagers' sleep needs and the desire for the positive outcomes associated with later school start times, including better attendance, higher grades, and more sleep on school nights [12], very few schools have changed their start times [52]. Schools cite barriers to changing such as impact on sports practice and after-school activity schedules, as well as the costs of rescheduling the transportation to and from school [53, 54]. Parents also depend on the current schedule for their childcare and carpooling systems, while students worry about having enough time for after-school jobs and extracurricular activities [15, 54]. The National Sleep Foundation (NSF), an independent non-profit, developed a tool kit for stakeholders to use to advocate for later high school start times [55]. The NSF estimates that giving out over 1,500 kits has resulted in 80 school districts changing their start times and another 140 contemplating a change [12].

Policy implications for local, regional, state, and national levels relate to attendance, continuous enrollment, and dropout rates, particularly among "at-risk learners" [56]. Continuous enrollment tracks whether students remain enrolled in a particular school or school district, or whether they are transferring in and out of schools or districts. With later school start times, high schools in the Minneapolis public school district had higher attendance and continuous enrollment, as well as lower dropout rates [56]. Based on the positive outcomes associated with later school start times, policies should be put in place to support schools in starting at more biologically appropriate times. Because school policy is usually handled at the local or regional level, it would be most effective to start by trying to replicate the changes in Minneapolis at other locations, rather than trying to make national policy, as Rep. Lofgren showed [51].

Learning through Discussion

There is extensive literature on the benefits of interactive learning [16, 17, 57]. One particularly effective method is learning through discussion. Learning through discussion facilitates understanding and promotes critical thinking [58]. Collaborative learning encourages students to take responsibility for their own learning [16], leading to higher levels of thought and longer retention [17]. In collaborative learning, students are responsible for each other's learning as well as their own, which helps each student be successful [57].

One method of learning through discussion that has been shown to be both effective and engaging is role playing [59]. Students can take on perspectives of different stakeholders in a given situation to examine the issue from multiple sides. Role playing allows students to examine the different considerations that the stakeholders bring to the discussion. For example, Fox and Loope [60] describe a role-playing exercise to debate the issue of an invasive species in Hawaii from both ecological and social perspectives, drawing on biology, geography, social studies, and political science. Role playing in education has been used for as diverse purposes as learning about weather phenomena [61], animal molting [62], invasive species [60, 63], and history [64, 65]. For role playing to be effective, it is necessary that participants have background knowledge, perspective, situation, and management that are appropriate to their level and topic [65].

Forums

Based on the effectiveness, engagement, and fun of learning through discussion, we decided to hold a forum program at the Museum of Science to engage students on the topic of sleep. Sleepiness can affect students' academic performance, as well as their performance at sports, extracurricular activities, and in daily life.

Role play has been used successfully to help students take on the roles of parents, teachers, and other students for the purpose of conflict resolution [66]. It is important to develop metrics to evaluate the effectiveness of role-playing forums. Many have advocated for partnerships between the community and research institutions about the topic of adolescent sleep [12]. Forums have proven time and again to be effective modes of facilitating discussion among members of the public about controversial topics. One example is PlayDecide, a discussion game developed in Europe to encourage citizens to talk about controversial issues [67]. The goal of PlayDecide is to encourage and facilitate the use of participatory methods at the intersection of the public and science governance individuals and organizations. Measured in terms of participation, PlayDecide has been very successful. Over 15,000 people from 35 countries have discussed 21 topics and uploaded their results to the website [67]. Other examples are the Nanoscale Informal Science Education Network, which hosts forums and science cafés about nanotechnology and its associated issues [68], and the National Issues Forum, which consists of locally sponsored public forums for considering public policy issues [69]. Forum effectiveness is measured by participants' responses on pre- and post-forum surveys, follow-up interviews, observations, videotaping, and attendance tracking at the Nanoscale Informal Science Education Network [68]. The National Issues Forum asks moderators and participants to upload their responses to the website, which they compile into reports to describe what happened in the deliberations [69]. So far, 19 reports have been written [69].

The purpose of this forum was to bring together scientists and high school students to have an informed discussion on the effect of sleepiness on school performance. The forum aimed to give the students a greater understanding of how sleepiness can affect them and tangible steps they can take to reduce the risk of harm due to sleepiness. The forum produced a more informed group of students with brainstormed ideas to improve the problems associated with insufficient sleep and who are mobilized to take action on those ideas. The Museum of Science has a strong and growing forum program designed to address topics of public concern. The impact of sleepiness on thinking, driving, and other parts of daily life fits right in with this program. Taking on this issue in this way can lead to new ideas on how to handle the problems that come with sleepiness for high school students. This thesis aimed to characterize the learning that occurred and the degree to which participants were able to adopt and understand their assigned roles.

This forum was set up to answer the questions of what recommendations informed high school students can make to improve performance at school based on sleepiness concerns and how important they feel it is to make changes to accommodate those concerns. This thesis addresses the following questions:

- Do high school students think getting enough sleep is important?
- How much sleep are high school students getting per night, both on weeknights and weekends?
- What do they know about sleep before participating in a sleep forum and what do they learn from participating? Do they plan to change their behavior as a result of their participation?
- What recommendations can informed high school students make about school start time? How does this relate to what perspectives they consider?
- After participating in the forum discussions, what recommendations do they want to make to their peers?

Methodology

Subjects were 26 minority 10th grade students (16 male, 10 female, mean age 15.8, with range 15-17, predominantly African-American and Hispanic). All of the subjects were in the Fenway High School Museum of Science program, in which the students come to the Museum of Science every Tuesday as part of their standard science curriculum. Of note is the fact that Fenway High School starts at 8:45 AM, since its pilot status allowed the principal to determine the school start time. The students were chosen by the school to participate in the Museum of Science program and the forum. The experiment took place over the course of 2 weeks at the Museum of Science. In the session during the first week, students were told that they would be learning about sleep in the next week's session, and they filled out a Pre-Forum Survey (Appendix IX: Pre-Forum Survey). It is possible that the topic introduction influenced the survey responses, though it is unlikely to have had a significant effect because the introduction was very minimal. The students were also given a homework reading about the effects of chronic sleep restriction and drowsy driving (Appendix XI: Homework Reading) [70]. During the second session a week later, subjects participated in a 2-hour session consisting of a presentation and a pair of discussion blocks, followed by a Post-Forum Survey (Appendix X: Post-Forum Survey).

During the second session, a sleep researcher (Caroline Lowenthal) presented the subjects with age-appropriate background information about sleep, including sleep stages, consequences of sleep debt and sleepiness, age-specific sleep requirements, and methods for falling and staying asleep. The students were encouraged to ask questions during the presentation, and they did so extremely enthusiastically. Then the students watched a 3-minute clip of a video about teen sleep needs [71].

Finally they were instructed to consider the personal experiences and values of each of the various stakeholders by a social scientist (David Sittenfeld). They were reminded to take certain factors into account such as health, independence and personal rights, leisure time, transportation, and the responsibility for quality education felt by teachers, society, and schools.

The subjects then began a role play exercise, which consisted of two discussion blocks. The purpose of the role play was to take on various relevant perspectives on the topic of school start time (student, teacher, parent, administrator, and sleep researcher, Appendix XIII: Roles for the Sleep Role Play Exercise). In the first discussion block, students were divided into 5 groups, each seated at a table with an adult facilitator who was present only to help the students' discussion, not to influence their opinions. Each table of 5-6 students and one facilitator took on one of the 5 roles with a provided character description. Every participant at a table was discussing the same role, but each table had a different role from all of the other tables. Each student completed a discussion worksheet (Appendix XV: Discussion Worksheets) during the block, and at the end they voted by text message on the ideal school start time from the perspective of their adopted role (Appendix XII: Text Message Votes). Students who did not have cell phones or did not want to use their own cell phones were offered the opportunity to use either a classmate's cell phone or a facilitator's cell phone, though ultimately not all students voted. The purpose of the first discussion block was to give the students a chance to familiarize themselves with the role they were playing and to have all of the student playing a particular role to have a common background for the second discussion block. This allowed for a consistent role playing experience across all tables in block 2.

After the first discussion block, students switched tables so that each table had one representative from each role. At each table in block 2 was one student who had previously been at the teacher role table, one who had been at the parent role table, and so on. Each student played the same role in both blocks, but with a different group of students (e.g. in block 1, everyone at the table played the same role, but in block 2, each person played a different role). The facilitators remained at their original tables. During the second discussion block, the students shared their role's perspective and negotiated among themselves to try to determine an optimal school start time. Again they completed a discussion worksheet from the perspective of their role. At the end of the second discussion block, they were given the opportunity to vote about the optimal school start time from their own point of view as a Fenway High School student (Appendix XII: Text Message Votes). Until the second text message vote, the students had maintained their roles.

In both cases, students discussed the importance of sleep and the information needed to make a decision on school start time. Finally, the students completed the Post-Forum Survey.

Figure 10: Participants at the forum

Figure 11: Participants and facilitators at the forum

The experiment was approved by the Massachusetts Institute of Technology (MIT) Committee on the Use of Humans as Experimental Subjects (COUHES). Subjects were not paid for their participation but received course credit as part of their normal curriculum. Parental consent was obtained before the forum.

Results

21 students completed the pre-forum survey and 24 completed the post-forum survey. 26 students participated in the forum and completed the discussion worksheets in both blocks, with the exception of one student in the second block.

Pre-Forum Survey Responses

How much sleep do high school students get on a normal weeknight? On a normal weekend night? (Questions 1 and 3)

According to the pre-forum survey, none of the students are getting enough sleep on weeknights, and 17 of the 21 who completed the survey are not even getting enough sleep on weekend nights. Students reported an average of 6.40 hours of sleep on week nights (SD=0.82 hours) and 6.95 hours on weekend nights (SD=2.13 hours).

How much sleep do they think most of their friends get on a normal weeknight? (Question 2)

The students reported thinking that their friends get 5.88 hours of sleep on week nights (SD=0.67 hours).

How much sleep do they think a teenager needs every night? (Question 4)

Before participating in the forum, students thought that teens need 8.71 hours of sleep per night (SD=0.80 hours).

Do high school students think teenagers need more or less sleep than adults? Than kids? (Questions 5 and 6)

19 of the 21 students thought they needed more sleep than adults, and 18 of 21 thought they needed more sleep than kids.

What do teenagers think happens to their bodies and their brains when they sleep? (Question 7)

Only 4 students could identify that important things happen during sleep. Most students thought that nothing happens during sleep. Responses from the survey included that the brain “goes on standby mode” or “shuts down”, or “you become lifeless,” or “nothing” happens, or you’re “chilling.”

What do teenagers report happens if they don’t get enough sleep? How will they feel? (Question 8)

The students reported that without sleep, they feel drowsy, tired, cranky, unable to concentrate, frustrated, dizzy, in a bad mood, and angry.

Do high school students think getting enough sleep is important? (Question 9, and Question 7 in the Post-Forum Survey)

All of the students who completed the pre-forum survey felt that getting enough sleep is important, and all but one of the students who completed the post-forum survey felt the same way (the one remaining student said getting enough sleep was “sometimes” important). This suggests that it is not indifference that causes students to accumulate sleep debt, since they feel getting enough sleep is important.

Post-Forum Survey Responses

Did the students report trying to get more sleep during the past week? (Question 1)

Of the 17 students who completed both the pre-forum survey and the post-forum survey, 12 said that they had tried to get more sleep in the past week, and 5 said they had not.

How much sleep do they think a teenager needs every night? (Question 2)

After participating in the forum, students reported that teenagers need an average of 8.98 hours of sleep per night (SD=0.66).

Do high school students think teenagers need more or less sleep than adults? Than kids? (Questions 3 and 4)

All of the students who completed the post-forum survey knew that they needed more sleep than adults, and 21 of 24 knew that they needed more sleep than younger children.

What do teenagers think happens to their bodies and their brains when they sleep? (Question 5)

Students also showed a much stronger understanding of what happens during sleep after the forum. Responses mentioned the 5 stages of sleep, including REM, and that the brain is not off during sleep. Students recognized that “your brain processes what you learned that day” and that your body “functions better” when you get more sleep. All of the students who completed the post-forum survey were able to provide answers to the question of what happens to the brain and body during sleep that showed evidence of learning.

What do teenagers report happens if they don’t get enough sleep? How will they feel? (Question 6)

Without sleep, they know “you will perform worse and you will feel tired and drowsy,” that you “can’t think well” and “feel slow and not function as well,” and that “you will fall asleep in school.”

What time did they think high school should start? (Question 8)

The average student response was 8:38 AM, which is in line with their current school start time at Fenway High School (8:45 AM).

What do they think their friends should know about sleep? (Question 9)

In the post-forum survey, subjects were asked what they think their peers should know about sleep. Most students mentioned that sleep is important, particularly getting enough sleep, and that you need sleep. They mentioned some of the effects of not getting enough sleep, such as drowsiness, feeling cranky, and the fact that “your studied things are going to be ‘gone’ (you won’t remember them).” One student mentioned that “if you don’t get enough sleep it adds up to like missing whole days.” Others wrote that “you need all 5 stages of sleep,” and “it helps us to focus in school.” One student summed it up well: “Sleep is good.”

Differences between Pre-Forum and Post-Forum Responses

Before participating in the forum, students thought that teens need 8.71 hours of sleep per night (SD=0.80 hours). Also before participating, 19 of the 21 students thought they needed more sleep than adults, and 18 of 21 thought they needed more sleep than kids. Only 4 could identify that important things happen during sleep. Most students thought that nothing happens during sleep. Responses included that the brain “goes on standby mode” or “shuts down”, or “you become lifeless,” or “nothing” happens, or you’re “chilling.” The students reported that without sleep, they feel drowsy, tired, cranky, unable to concentrate, frustrated, dizzy, in a bad mood, and angry.

After participating in the forum, students reported that teenagers need an average of 8.98 hours of sleep per night (SD=0.66). Of the 17 students who completed both the pre-forum survey and the post-forum survey, 12 said that they had tried to get more sleep in the past week, and 5 said they had not. All of the students who completed the post-forum survey knew that they needed more sleep than adults, and 21 of 24 knew that they needed more sleep than younger children.

Students also showed a much stronger understanding of what happens during sleep after the forum. Responses mentioned the 5 stages of sleep, including REM, and that the brain is not off during sleep. Students recognized that “your brain processes what you learned that day” and that your body “functions better” when you get more sleep. All of the students who completed the post-forum survey were able to provide answers to the question of what happens to the brain and body during sleep that showed significant evidence of learning. Without sleep, they know “you will perform worse and you will feel tired and drowsy,” that you “can’t think well” and “feel slow and not function as well,” and that “you will fall asleep in school.”

Forum Discussion

What recommendations can informed high school students make about school start time? How does this relate to what perspectives they consider?

At the end of each of the two discussion blocks, students voted by text message on what time they thought the high school day should start. After the first discussion block, they were asked to vote from the perspective of the role they were considering in the role play exercise. After the second discussion block, in contrast, they voted from their own personal perspective. The two voting methods produced different results.

Within their roles, the students showed good ability to consider their adopted perspectives. In the role of sleep researcher, all 5 of the students said that school should start no earlier than 8:30 AM, and 3 of 5 said it should start between 9 and 9:30 AM. The 6 subjects in the role of student agreed with those in the role of sleep researcher, all voting that school should start between 8:30 and 9 AM. Students in the role of administrators had been told that the tradeoff for moving the school day later was that the school would have to put off buying new science textbooks that were badly needed. As a result, 4 out of 6 students thought that school should start before 8:30 AM (even as early as 7 AM), and only 2 thought school should start between 8:30 and 9 AM. Both students who voted in the role of parent thought that school should start between 7 and 8 AM, and the three students who voted as teachers thought that school should start between 8 and 9 AM.

After the forum, data from each student's discussion worksheet from each block was analyzed using a set of emic codes, meaning that the codes were developed using the perspectives and words of the participants [72-74]. Emic coding is a technique developed in education and social science research which bases the coding on the participants responses, rather than theory or prior research [73, 74]. Coding for this research was done by the author. Codes were generated based on topics that were mentioned across groups, roles, and the two discussion blocks in the discussion worksheets. The number of codes was determined by the need to have at least one code for each response and to capture the major themes from the discussion. The same response could fall into more than one code category. The codes are intended to convey the frequency of the ideas that came up in the discussion related to values and opinions on school start time and sleep. The codes that emerged from the data are listed in Table 5, along with their frequencies in each of the discussion blocks. The relative frequencies of the codes and the roles of the students who referenced them are discussed in this section, while the implications for these results are addressed in the discussion section.

Table 5: Code frequency by discussion block

Code	Block 1		Block 2	
Prioritization or time management	49	24%	14	12%
Student's responsibility	28	14%	23	20%
Free time activities	28	14%	9	8%
Go to sleep earlier	20	10%	1	1%
Responsibilities	19	9%	0	0%
Recommendation outside of scope	16	8%	1	1%
Money/books/replanning	13	6%	18	15%
Start school later	11	5%	17	15%
Neutral effects of time change	7	3%	6	5%
Change start time	7	3%	5	4%
Keep start time the same	5	2%	10	9%
Negative effects of time change	4	2%	1	1%
Positive effects of time change	0	0%	12	10%

More students mentioned positive effects of changing the school start time (12) than mentioned negative effects (5), though 13 mentioned neutral effects (Table 5). Several students in the role of administrator expressed unwillingness to change the school start time, citing student responsibility as the primary factor in getting more sleep. For example, on the discussion worksheet, one student said, "I would recommend to the Administrator not to change the time because it wouldn't make a difference because the whole sleeping thing is on them." Another student seconded that opinion, suggesting that "even if you moved the school time forward the students would just time their sleeping schedule," meaning go to bed the corresponding amount of time later, rather than using the time to get more sleep.

In the role of teacher, all of the students emphasized the importance of making a plan for the day, suggesting that increased organization could help the teacher get more sleep. In the role of student, they expressed similar intentions. One student specifically recommended “spend[ing] less time on Facebook” and other social media on the discussion worksheet. Another reported that the group discussed “what she should cut down on to get more sleep.”

As shown in Figures 12-16 below, subjects who suggested that the school start time should be the same or earlier (i.e. administrators, parents, and teachers) talked more about the cost of the science textbooks, replanning, and the negative effects of the time change. Subjects who voted for a later school start time (i.e. sleep researchers and students) discussed the fact that it is the student’s responsibility to get more sleep and to manage their time efficiently, but still agreed that school should start later. All groups discussed prioritization and time management, with the exception of the sleep researchers. Another noteworthy point is the relatively few topics discussed by each role group in the first discussion block. In comparison, during the second block, participants talked about many more perspectives and considerations (Figures 17-21). This suggests that they were exposed to a larger range of ideas in the second round, which could impact their opinions on the issue of school start time, even as they continued playing their original role.

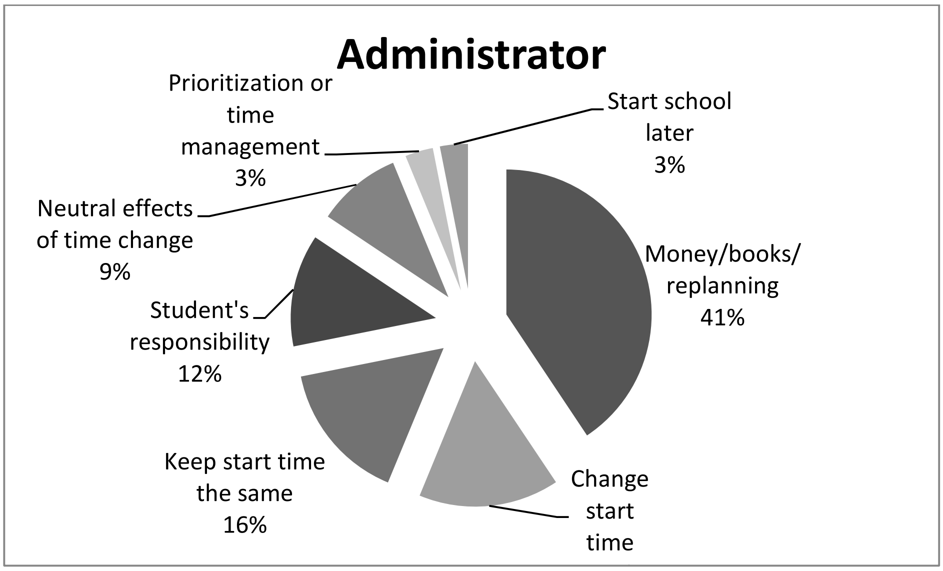


Figure 12: Discussion block 1 topic frequency for administrators

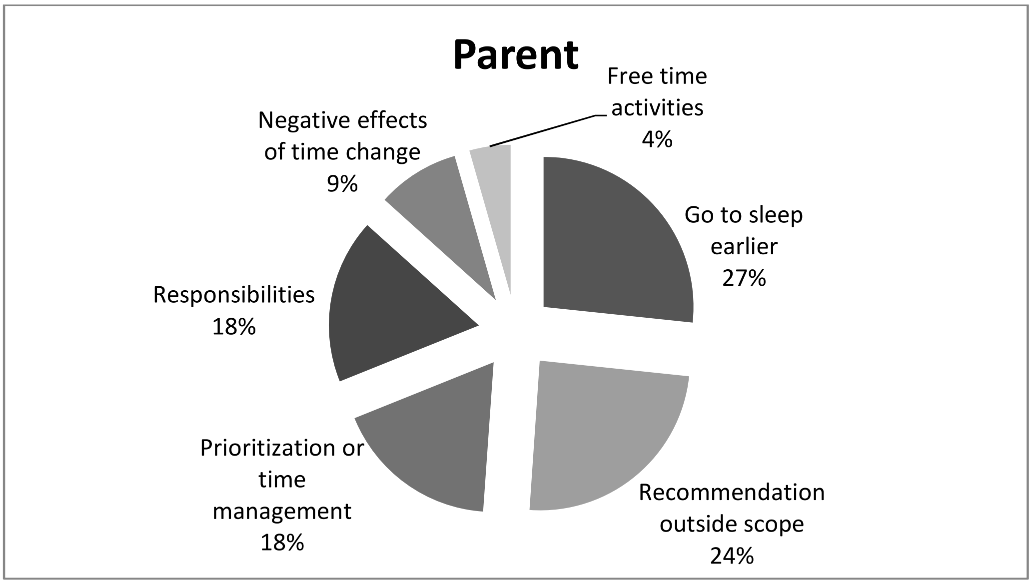


Figure 13: Discussion block 1 topic frequency for parents

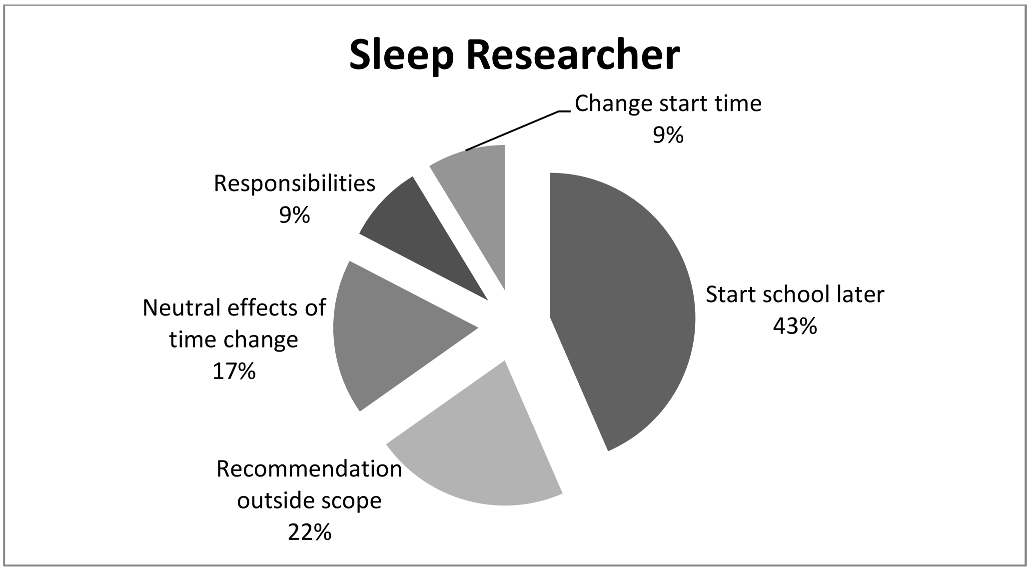


Figure 14: Discussion block 1 topic frequency for sleep researchers

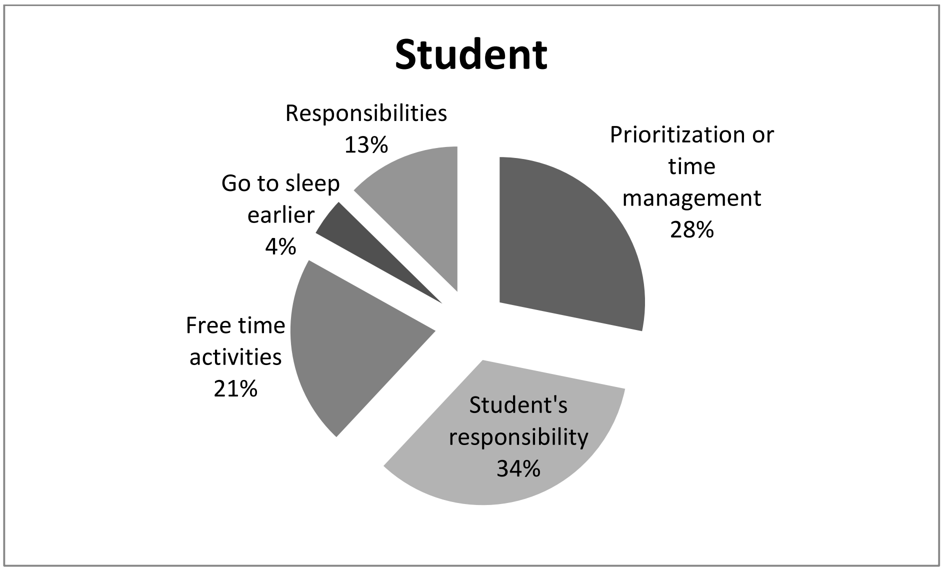


Figure 15: Discussion block 1 topic frequency for students

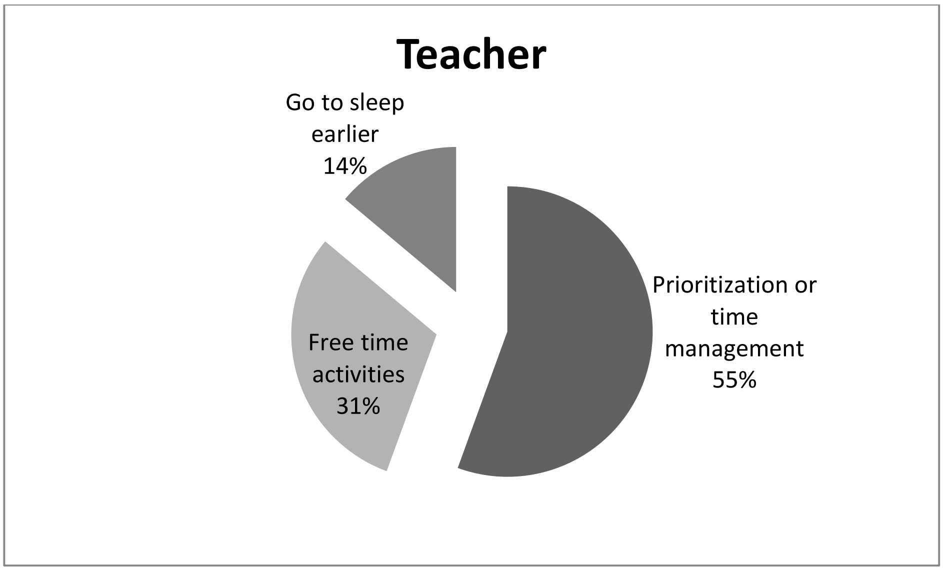


Figure 16: Discussion block 1 topic frequency for teachers

During the second block, participants recorded on their discussion worksheets that they discussed tradeoffs including "cutting extra-curricular activities vs. cutting Facebook to allow for a school day shifted later in the day," "the needs of parents vs. needs of students," and "the solution to the administrator's dilemma" about whether to spend the money on science textbooks or rescheduling the buses. Two subjects in the role of teacher recommended the decision to "make school start later so the kids do better" in school. Students in various roles recognized that the "change of entering school affects everyone" and "affects the whole rest of the day." Unfortunately, one student in the role of administrator said, "the last thing we talked about was it does not matter what time you sleep you're always going to be tired." This comment suggests that that student did not believe that it was possible to get enough sleep to feel well-rested, in contrast with the message of the scientific presentation.

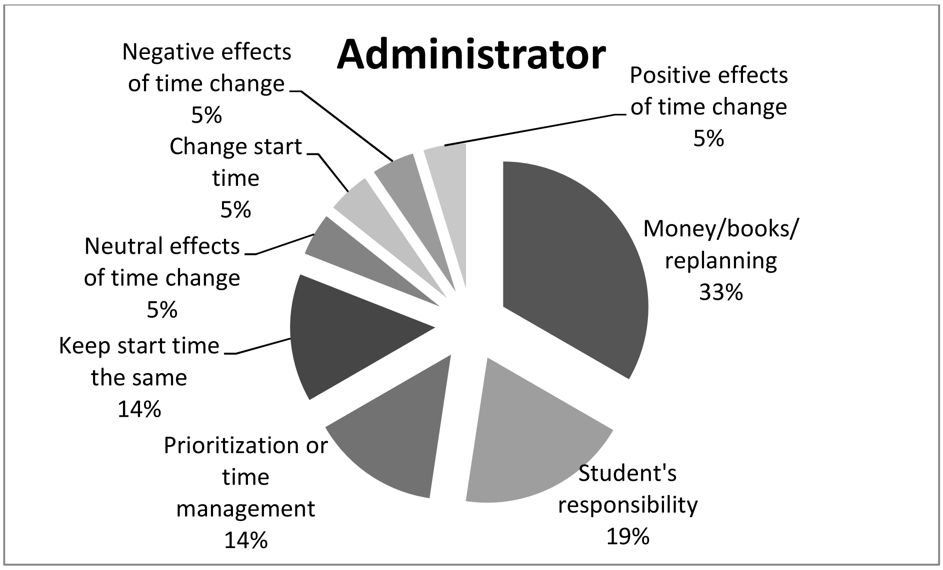


Figure 17: Discussion block 2 topic frequency for administrators

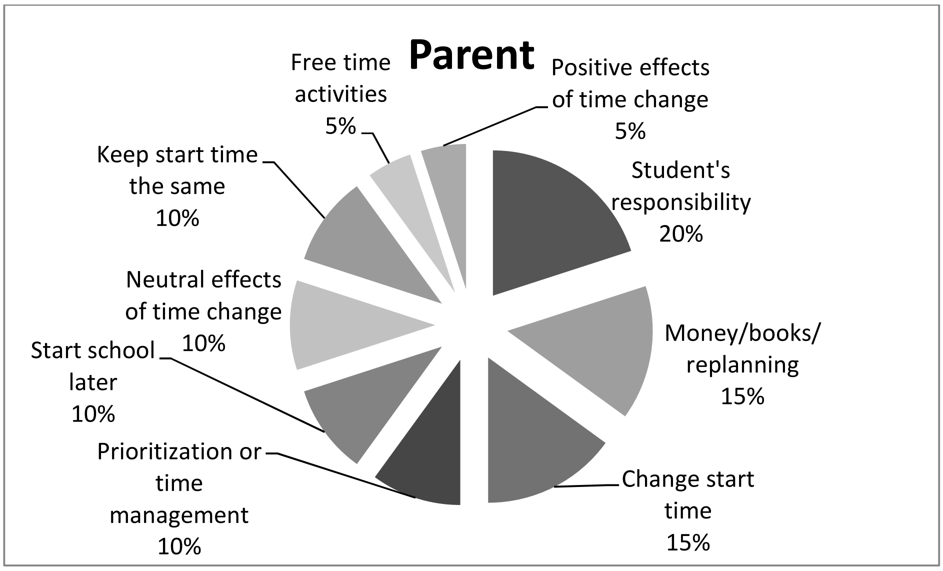


Figure 18: Discussion block 2 topic frequency for parents

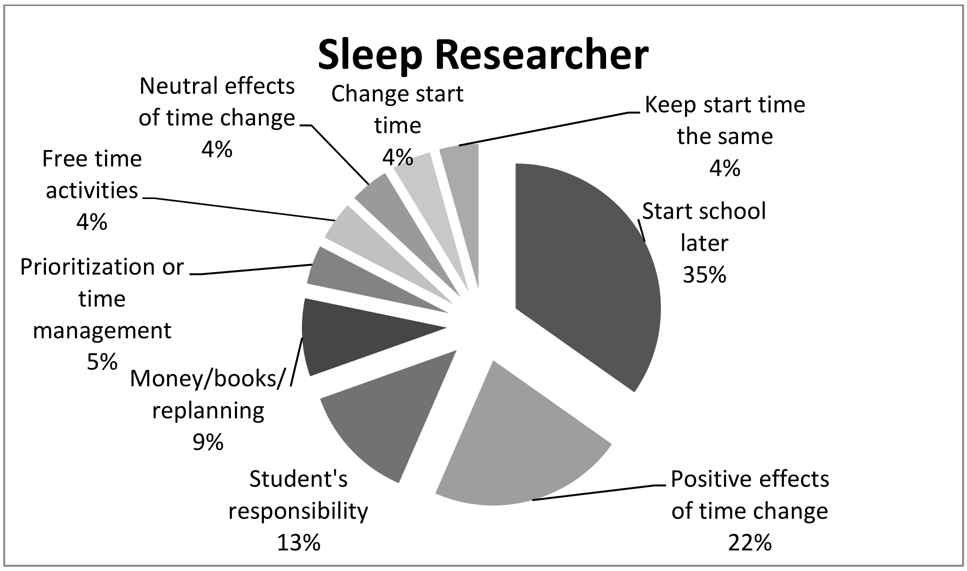


Figure 19: Discussion block 2 topic frequency for sleep researchers

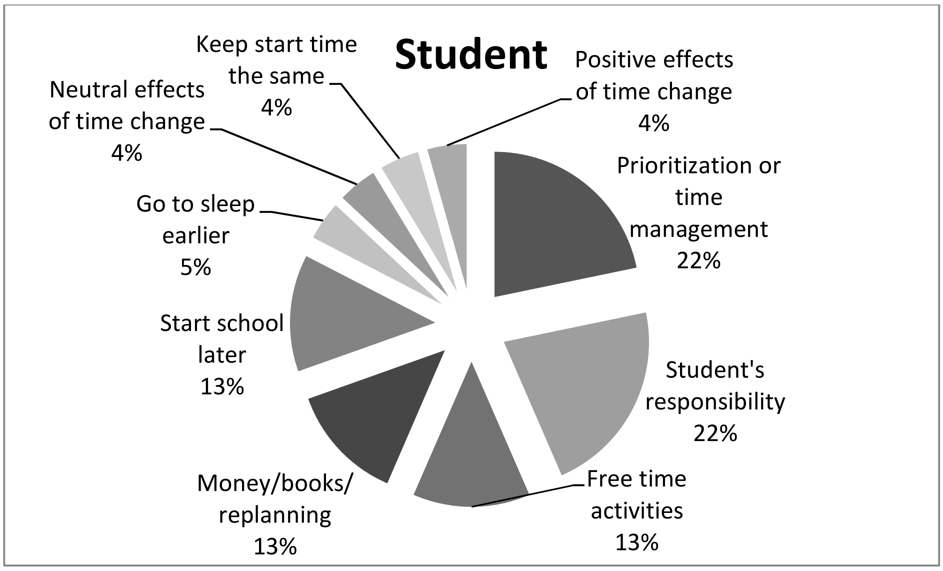


Figure 20: Discussion block 2 topic frequency for students

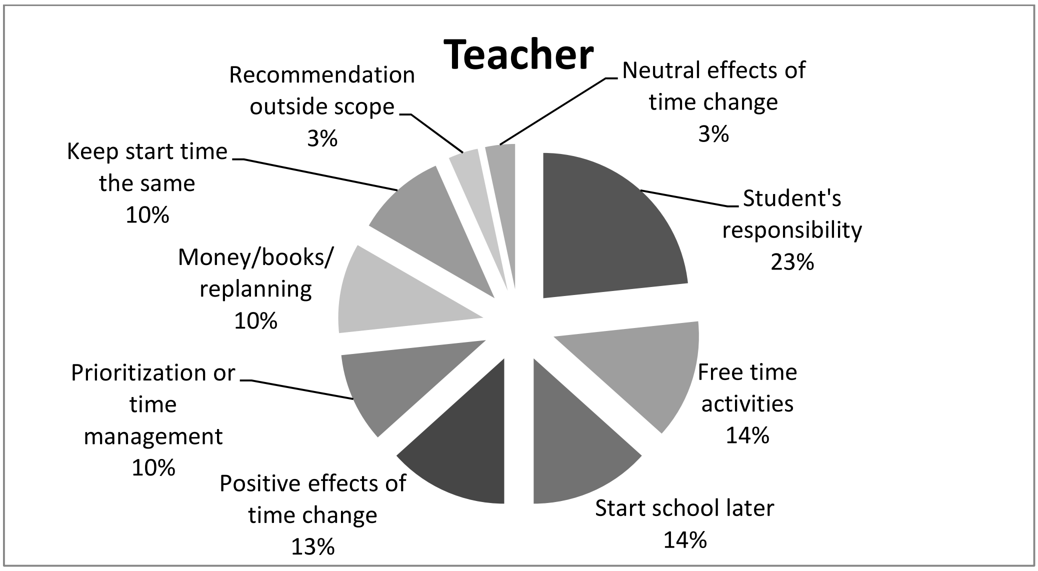


Figure 21: Discussion block 2 topic frequency for teachers

When they were asked to vote as themselves after the second round (Table 6), students generally agreed (10 out of 17 votes) with their peers who had voted as students in the first round, who had all voted that school should start between 8:30 and 9 AM.

Table 6: Student votes on high school start time

Response	As themselves (Fenway HS students)
Between 7 and 7:30 AM	1
Between 7:30 and 8 AM	1
Between 8 and 8:30 AM	4
Between 8:30 and 9 AM	10
Between 9 and 9:30 AM	1

Discussion

Students who participated in the forum universally think getting enough sleep is important, yet they are accumulating almost 3 hours of sleep debt per weeknight. This experiment showed that most students learned effectively about their sleep needs and the biology of sleep between the pre-forum survey and the post-forum survey. Before the forum, only 4 students could articulate that anything important happens during sleep, but after the forum 19 of 24 students who completed the post-forum survey were able to state specific important things that happen during sleep. No students dropped out of the program, but one did fail to complete the discussion worksheet in the second block and two students did not complete the post-forum survey. Further, 5 students gave answers that showed very limited understanding of the sleep process on the post-forum survey. However, the students asked dozens of questions during the scientific presentation, demonstrating engagement and interest, which are important measures of effectiveness. During the discussions, the students actively participated and used terms they had learned from the presentation. It seems that this forum was an effective format to teach high school students about sleep based on voting participation, discussion participation, and increased knowledge demonstrated on the post-forum survey as compared to the pre-forum survey. With a group of subjects who are randomly selected, there will obviously be differences in interest, motivation, and attention. Although only 79% of participants demonstrated this learning, this shows that the vast majority of the randomly selected group was able to muster the necessary interest and attention.

One especially interesting observation was that during the “Who Needs Sleep?” video, there was a section of questions to determine whether you’re sleep deprived. Those questions can be found in Appendix XIV: Questions from “Who Needs Sleep?” When this part of the video came up, without being invited, students began calling out, “Yes!” to each of the questions, growing more enthusiastic with each question. Answering yes to only two of the questions was enough to indicate that a person is sleep deprived, and the students were very excited to learn about something that is so important in their lives.

Students frequently mentioned the topics of prioritization, time management, and personal responsibility in their discussions. This suggests that they view getting enough sleep as their own responsibility. They value sleep and think that getting enough sleep is important, yet by their self-reported actions they seem to value other activities more. An interesting topic for future investigation could be examining different methods of getting students to sleep more. The research conducted by the students in Washington, D.C. in partnership with the Koshland Science Museum suggests that one potential method is having students do their own research projects about sleep. Presumably the research process would get them more invested in the importance of sufficient sleep.

The most obvious limitation to the conclusions drawn from this research is the limited applicability to other populations of students. The students who participated in this forum were almost all minority students in an urban public school in the New England area of the United States. Students in private or suburban schools, in different parts of the country or in other countries, might know more or less about sleep before participating in a forum. To draw stronger conclusions, it would be helpful to run the sleep forum with more diverse groups of students.

One of the other limitations of this particular forum was the poor time management on the part of the author. Too little time was left at the end of the forum for students to finish their discussion in the second block or to completely fill out their second discussion worksheets. With more time to prepare, it might have been possible to run through the process more thoroughly to anticipate that problem and budget the time accordingly. It is possible that the shortened time did not allow participants to discuss the tradeoffs completely in the second discussion block, since they had only 10 minutes for discussion rather than 20 minutes. With the limited time, students might not have given as thoughtful responses on their discussion worksheets, leaving out more detailed information that would have taken longer to write. Facilitators also differed in their abilities to keep the students on track. Some groups seemed to have gotten through sufficient discussion during block 2, while others did not.

Another potential issue with the design of this forum was the discrepancy between Fenway High School's start time (8:45 AM) and the start time of the high school in the discussion scenario (7:30 AM). Students might have been confused or forgotten that they were supposed to be considering whether school should start earlier, later, or at the same time as in the scenario, rather than their actual school. As a group, they seemed to be relatively satisfied with their actual school start time. Remarkably, none of the students in either discussion block voted that school should start after 9:30 AM.

A few students made recommendations that were outside the scope of the information they had learned during the session, such as drinking warm milk, listening to music, or watching TV to help themselves fall asleep. Later in the discussion, one student made the recommendation of blocking some websites to help students use their time better. These strategies were not mentioned during the scientific presentation, nor did they come up as questions. It is possible that some other misconceptions made their way into the discussion but were not recorded on the discussion worksheets. It would have been good to review the worksheets with the students to correct any misconceptions and for them to consolidate the new information, but there was not enough time in the session.

An outstanding question that would be interesting to investigate is whether the students will change their behavior after the forum. The time constraints associated with this research did not allow for follow-up surveys to be administered after some time had passed since the forum.

Based on the results of this research, it is possible to make several policy recommendations. First, high schools should aim to start at a time that is biologically appropriate for teenagers. This might mean starting no earlier than 8:30 AM. In order to accomplish this goal without significant cost, many school districts have considered switching the starting times of elementary schools and high schools, since younger children naturally go to sleep and wake up earlier.

Second, high schools and school districts should consider involving the students in their discussions about school issues. Sleep is only one example of the types of issues that students can have valuable input into under conditions of informed discussion. Allowing students to participate in the discussion about policies that affect them will help them feel more invested in the outcome and more prepared to deal with issues that arise later in their education or careers that require informed discourse.

Third, it would be useful to have high schools teach about good sleep habits, or sleep hygiene, in health classes. This policy would help improve awareness of the problems related to insufficient sleep and help students implement solutions to get more and better sleep.

It would be possible to tackle all of these issues at various levels (e.g. national, state, regional, or local). Since specific school matters are generally handled at the local, regional, or state level, it would make sense for start time policies to begin no higher than the state level, but ideally at the regional level. This would help to ensure compatibility between school districts for after-school sports, competitions, and activities. For involving students in matters that affect them, it makes the most sense to start at the local level, since each school has different considerations and issues they are facing. Students may want to get involved in school start time discussions at one school, while another school might have an appropriate start time but have problems with funding for their music program. By customizing opportunities for student involvement at the local level, schools can include their students in the discussions that are most pressing for them. Introducing sleep topics into health class should be addressed at the school district level, since it is a matter of curriculum and curricular matters are routinely handled at the school district level.

Conclusion and Suggestions for Future Work

Sleep is a serious issue under any circumstance. For astronauts and adolescents, the risks of insufficient sleep can be particularly high. Astronauts can make mistakes that can cost billions of dollars, ruin a mission, or cost their lives. Adolescents can miss out on critical learning opportunities due to sleepiness in high school. Both populations may or may not be aware of the risks, so awareness is a key first step in preventing sleep debt problems. Once awareness is achieved, it is worth investigating countermeasures. In the case of astronauts, countermeasures can include caffeine, blue-enriched white light, or secondary tasks to detect decreases in performance that signal that the astronaut should take a break. For adolescents, countermeasures can include prioritization of tasks and planning a schedule that allows time for sufficient sleep. Another countermeasure is starting school at a time that is aligned with adolescent sleep schedules.

Combining awareness, countermeasures, and attempts by the two populations to get enough sleep should help prevent many of the problems that can arise from sleep debt. This suggests several options for future work:

- Investigate ways to effectively communicate the risks of sleepiness to both astronauts and high school students.
- Hold a forum for the public to raise awareness of the issue of sleepiness in many different aspects of everyday life (scheduled for May 22, 2012 at the Museum of Science).
- Investigate whether a later start time for a night robotics session would result in stronger performance effects, or whether a circadian rebound would start to reduce the magnitude of the performance decrements.
- Try different types of robotics tasks to see whether they are differentially responsive to sleepiness. This thesis focused on autosequence and track and capture tasks, but fly-to and grapple tasks were not evaluated.
- Further research could examine the relationship between practice effects and time of day to determine whether they are actually counteracting each other or whether the results were masking some other effect.
- Time on task is a known factor in performance. Future work could look at the effect of time on task as related to time of day, practice effects, and robotics task types.
- An interesting question to examine would be whether students report any actual changes in sleep duration after attending the forum. A future longitudinal study could conduct a follow-up survey sometime after the forum to see what effect it had on student behavior.

- A similar forum with a student population with different demographics would be useful to determine whether forums are differently effective with different populations or whether different populations have different opinions about school start times.

References

1. Lockley, S., et al., *Effects of health care provider work hours and sleep deprivation on safety and performance.* Joint Commission Journal on Quality and Patient Safety, 2007. **33**(Supplement 1): p. 7-18.
2. Landrigan, C., et al., *Effect of reducing interns' work hours on serious medical errors in intensive care units.* New England Journal of Medicine, 2004. **351**(18): p. 1838.
3. Durmer, J. and D. Dinges. *Neurocognitive consequences of sleep deprivation*. 2005. [New York]: Thieme-Stratton Inc.,[c1981-.
4. Luna, T.D., *Air traffic controller shiftwork: what are the implications for aviation safety? A review.* Aviation, Space, and Environmental Medicine, 1997. **68**(1): p. 69.
5. Philip, P., et al., *Fatigue, sleep restriction, and performance in automobile drivers: a controlled study in a natural environment.* Sleep, 2003. **26**(3): p. 277–280.
6. Philip, P., et al., *Fatigue, sleep restriction and driving performance.* Accident Analysis & Prevention, 2005. **37**(3): p. 473-478.
7. NASA, *Human Research Program Integrated Research Plan.* http://humanresearchroadmap.nasa.gov/evidence/IRP%20Rev%20C.pdf, 2011.
8. NASA, et al., *Risk of Performance Errors due to Sleep Loss, Circadian Desynchronization, Fatigue, and Work Overload.* http://humanresearchroadmap.nasa.gov/evidence/, 2009.
9. Pontillo, T., *Spatial Ability and Handedness as Potential Predictors of Space Teleoperation Performance.* 2010.
10. Barger, L., K. Wright, and C. Czeisler, *SLEEP AND SLEEP-PROMOTING MEDICATION USE IN SHUTTLE CREWMEMBERS.* Aviation, Space, and Environmental Medicine, 2008. **79**(3): p. 266.
11. Maas, J.B., et al., *Power Sleep: The Revolutionary Program That Prepares Your Mind for Peak Performance*1998: Quill/HarperCollins.
12. Wolfson, A.R., *School Start Times And Sleep.* Sleep Review, 2007(March/April).
13. Taylor, D.J., et al., *Sleep tendency during extended wakefulness: insights into adolescent sleep regulation and behavior.* Journal of Sleep Research, 2005. **14**(3): p. 239-244.
14. *Backgrounder: Later School Start Times*. **http://www.sleepfoundation.org/article/hot-topics/backgrounder-later-school-start-times**, Accessed December 14, 2011.
15. *School Start Time and Sleep*. **http://www.sleepfoundation.org/article/sleep-topics/school-start-time-and-sleep** Accessed December 14, 2011.
16. Totten, S., et al., *Cooperative learning: A guide to research*1991: Garland New York.
17. Johnson, R.T. and D.W. Johnson, *Action Research: Cooperative Learning in the Science Classroom.* Science and Children, 1986. **24**(2): p. 31-32.
18. Johns, M., *A new perspective on sleepiness.* Sleep and Biological Rhythms, 2010. **8**(3): p. 170-179.
19. Lim, J. and D. Dinges, *A Meta-Analysis of the Impact of Short-Term Sleep Deprivation on Cognitive Variables.* Psychological bulletin, 2010. **136**(3): p. 375-389.
20. Borbély, A.A., *A two process model of sleep regulation.* Human neurobiology, 1982.
21. Jewett, M.E. and R.E. Kronauer, *Interactive mathematical models of subjective alertness and cognitive throughput in humans.* Journal of biological rhythms, 1999. **14**(6): p. 588.
22. Hursh, S.R., et al., *Fatigue models for applied research in warfighting.* Aviation, Space, and Environmental Medicine, 2004. **75**(Supplement 1): p. A44-A53.
23. Basner, M. and D. Dinges, *Maximizing Sensitivity of the Psychomotor Vigilance Test (PVT) to Sleep Loss.* Sleep, 2011. **34**(5): p. 581.
24. Dinges, D.F. and J.W. Powell, *Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations.* Behavior Research Methods, 1985. **17**(6): p. 652-655.

25. Doran, S., H. Van Dongen, and D. Dinges, *Sustained attention performance during sleep deprivation: evidence of state instability.* Archives italiennes de Biologie, 2001. **139**(3): p. 253-267.
26. Baulk, S., et al., *Chasing the silver bullet: Measuring driver fatigue using simple and complex tasks.* Accident Analysis & Prevention, 2008. **40**(1): p. 396-402.
27. O'Donnell, R. and F. Eggmeier, eds. *Workload assessment methodology*. Handbook of perception and human performance. Vol. 2. 1986. 42-1.
28. Wickens, C.D., *The structure of attentional resources.* Attention and performance VIII, 1980. **8**.
29. Huntley Jr, M., *Flight technical error for Category B non-precision approaches and missed approaches using non-differential GPS for course guidance*, 1993, DTIC Document.
30. Roscoe, A., G. Ellis, and R.A.E. FARNBOROUGH, *A subjective rating scale for assessing pilot workload in flight: A decade of practical use.* 1990.
31. Anderson, C. and J. Horne, *Sleepiness enhances distraction during a monotonous task.* Sleep, 2006. **29**(4): p. 573-576.
32. Sherry, P., *Fatigue countermeasures in the railroad industry: past and current developments.* Association of American Railroads: Counseling Psychology Program, Intermodal Transportation Institute, University of Denver, 2000.
33. Baulk, S.D., L. Reyner, and J. Horne, *Driver sleepiness-evaluation of reaction time measurement as a secondary task.* SLEEP-NEW YORK-, 2001. **24**(6): p. 695-702.
34. Lisper, H.O., H. Laurell, and J. Van Loon, *Relation between time to falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway.* Ergonomics, 1986. **29**(3): p. 445-453.
35. Lenné, M.G., T.J. Triggs, and J.R. Redman, *Interactive effects of sleep deprivation, time of day, and driving experience on a driving task.* Sleep: Journal of Sleep Research & Sleep Medicine, 1998.
36. Lenne, M.G., T.J. Triggs, and J.R. Redman, *Time of day variations in driving performance.* Accident Analysis & Prevention, 1997. **29**(4): p. 431-437.
37. Horne, J.A. and O. Ostberg, *A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms.* International Journal of Chronobiology, 1976. **4**(2): p. 97.
38. Hedges, L.V. and I. Olkin, *Statistical methods for meta-analysis*1985: Academic Press New York.
39. Barger, L.K., et al., *Daily exercise facilitates phase delays of circadian melatonin rhythm in very dim light.* American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 2004. **286**(6): p. R1077-R1084.
40. Buxton, O.M., et al., *Exercise elicits phase shifts and acute alterations of melatonin that vary with circadian phase.* American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 2003. **284**(3): p. R714-R724.
41. Mistlberger, R.E. and D.J. Skene, *Nonphotic entrainment in humans?* Journal of biological rhythms, 2005. **20**(4): p. 339-352.
42. *Teens and Sleep*. **http://www.sleepfoundation.org/article/sleep-topics/teens-and-sleep**, Accessed January 8, 2012.
43. Carskadon, M.A. and C. Acebo, *Regulation of sleepiness in adolescents: update, insights, and speculation.* Sleep, 2002. **25**(6): p. 606-614.
44. *American Time Use Survey (ATUS)*, 2011, Bureau of Labor Statistics: Washington, D.C.
45. Carpenter, S., *Sleep deprivation may be undermining teen health.* Monitor on Psychology, 2001. **32**(9).
46. O'Malley, E.B. and M.B. O'Malley, *School Start Time and Its Impact on Learning and Behavior.* Sleep and psychiatric disorders in children and adolescents, 2008: p. 79.

47. Foss, R.D., et al., *SCHOOL START TIMES AND TEENAGE DRIVER MOTOR VEHICLE CRASHES.* 2010.
48. Gable, L. and K. Kinsella, *Adolescent Sleep Research: Important Findings for Secondary Schools.* San Francisco State University, 2006.
49. Wolfson, A.R. and M.A. Carskadon, *Sleep schedules and daytime functioning in adolescents.* Child development, 1998. **69**(4): p. 875-887.
50. Troy, J., *Youth Research Lab*, in *Koshland Science Museum*2011: Washington, D.C.
51. Lofgren, Z., *H. Con. Res. 135: Expressing the sense of Congress that secondary schools should begin classes no earlier than 8:30 in the morning.*, 2003, 108th Congress: 2003-2004.
52. Wolfson, A.R. and M.A. Carskadon, *A Survey of Factors Influencing High School StartTimes.* NASSP Bulletin, 2005. **89**(642): p. 47.
53. Wolfson, A.R. and M.A. Carskadon, *Understanding adolescent's sleep patterns and school performance: a critical appraisal.* Sleep Medicine Reviews, 2003. **7**(6): p. 491-506.
54. *Eight Major Obstacles to Delaying School Start Times*. **http://www.sleepfoundation.org/article/hot-topics/eight-major-obstacles-delaying-school-start-times**, Accessed December 14, 2011.
55. *School Start Times Tool Kit*, in *National Sleep Foundation*2005: Washington, D.C.
56. Wahistrom, K., *Changing times: Findings from the first longitudinal study of later high school start times.* NASSP Bulletin, 2002. **86**(633): p. 3-21.
57. Gokhale, A.A., *Collaborative learning enhances critical thinking.* 1995.
58. King, A., *Facilitating elaborative learning through guided student-generated questioning.* Educational Psychologist, 1992. **27**(1): p. 111-126.
59. Howes, E.V. and B.C. Cruz, *Role-playing in science education: An effective strategy for developing multiple perspectives.* Journal of Elementary Science Education, 2009. **21**(3): p. 33-46.
60. Fox, A.M. and L.L. Loope, *Globalization and invasive species issues in Hawaii: role-playing some local perspectives.* Journal of Natural Resources and Life Sciences Education, 2007. **36**: p. 147-157.
61. Wilcox, D.R. and D.R. Sterling, *Twisters, Tall Tales, & Science Teaching.* Science Scope, 2006. **29**(8): p. 6.
62. Arce, C., *Molting Mania.* Science and Children, 2006. **43**(7): p. 4.
63. Beck, J.A. and C.M. Czerniak, *Invasion of the Zebra Mussels: A Mock Trial Activity.* Science Activities: Classroom Projects and Curriculum Ideas, 2005. **42**(1): p. 5.
64. Fennessey, S.M., *History in the Spotlight: Creative Drama and Theatre Practices for the Social Studies Classroom*2000: Heinemann, 88 Post Road West, PO Box 5007, Westport, CT 06881 ($19.50). Tel: 800-793-2154 (Toll Free). Web site:(http://www. heinemann. com).
65. McDaniel, K.N., *Four elements of successful historical role-playing in the classroom.* The History Teacher, 2000. **33**(3): p. 357-362.
66. Borbely, C.J., et al., *Sixth graders' conflict resolution in role plays with a peer, parent, and teacher.* Journal of youth and adolescence, 2005. **34**(4): p. 279-291.
67. *PlayDecide*. European Commission 2009 [cited 2011 December 10]; Available from: http://www.playdecide.eu/.
68. *Forums and Science Cafes*. Nanoscale Informal Science Education Network. [cited 2011 December 10]; Available from: http://www.nisenet.org/forums.
69. *National Issues Forums: About NIF Forums*. National Issues Forum Institute. 2000 [cited 2011 December 10]; Available from: http://www.nifi.org/forums/about.aspx.
70. Lenfant, C., *Awake at the Wheel.* Scholastic, 1997.
71. Maas, J.B., *Who Needs Sleep? (DVD)*, 2005.

72. *Emic and Etic Approaches*. President & Fellows Harvard University 2008 [cited 2012 January 2]; Available from: http://isites.harvard.edu/icb/icb.do?keyword=qualitative&pageid=icb.page340911.
73. Harris, M., *History and significance of the emic/etic distinction.* Annual Review of Anthropology, 1976. **5**: p. 329-350.
74. Pike, K., *Language in Relation to a Unified Theory of the Structure of Human Nature*, 1967, The Hague & Paris: Mouton & Co.

Appendix I: Experimental Procedure

Before Training

- ☐ Email MEQ and Consent
- ☐ Verify eligibility
- ☐ Schedule sessions and send Sleep Log
- ☐ Tell subjects to bring Sleep Log to all sessions

Training

- ☐ Welcome and consent
- ☐ MRT
- ☐ Check Sleep Log
- ☐ 1-Introduction PowerPoint, use Familiarization.exp
- ☐ 2-TrackAndCapture PowerPoint
- ☐ CL_TrackandCaptureTraining.exp
- ☐ Offer break
- ☐ 3-Autosequence PowerPoint
- ☐ RWSS_AutosequenceTraining.exp
- ☐ Offer break
- ☐ RWSS_moreTrackAndCaptureTraining.exp
- ☐ Offer break
- ☐ 4-SideTask PowerPoint
- ☐ CL_TrainingFile_SideTask_S.exp
- ☐ CL_TrainingFile_SideTask_C.exp
- ☐ Review any task types that need practice

Sessions

- ☐ Welcome
- ☐ Review PowerPoint
- ☐ Check Sleep Log
- ☐ Introduce MBPWS
- ☐ Introduce KSS
- ☐ KSS 1
- ☐ CL_ExptFile.exp (Offer break at midpoint)
- ☐ KSS 2
- ☐ Debrief if applicable

Appendix II: Sleep Log

Subject Number _____________ Group______________

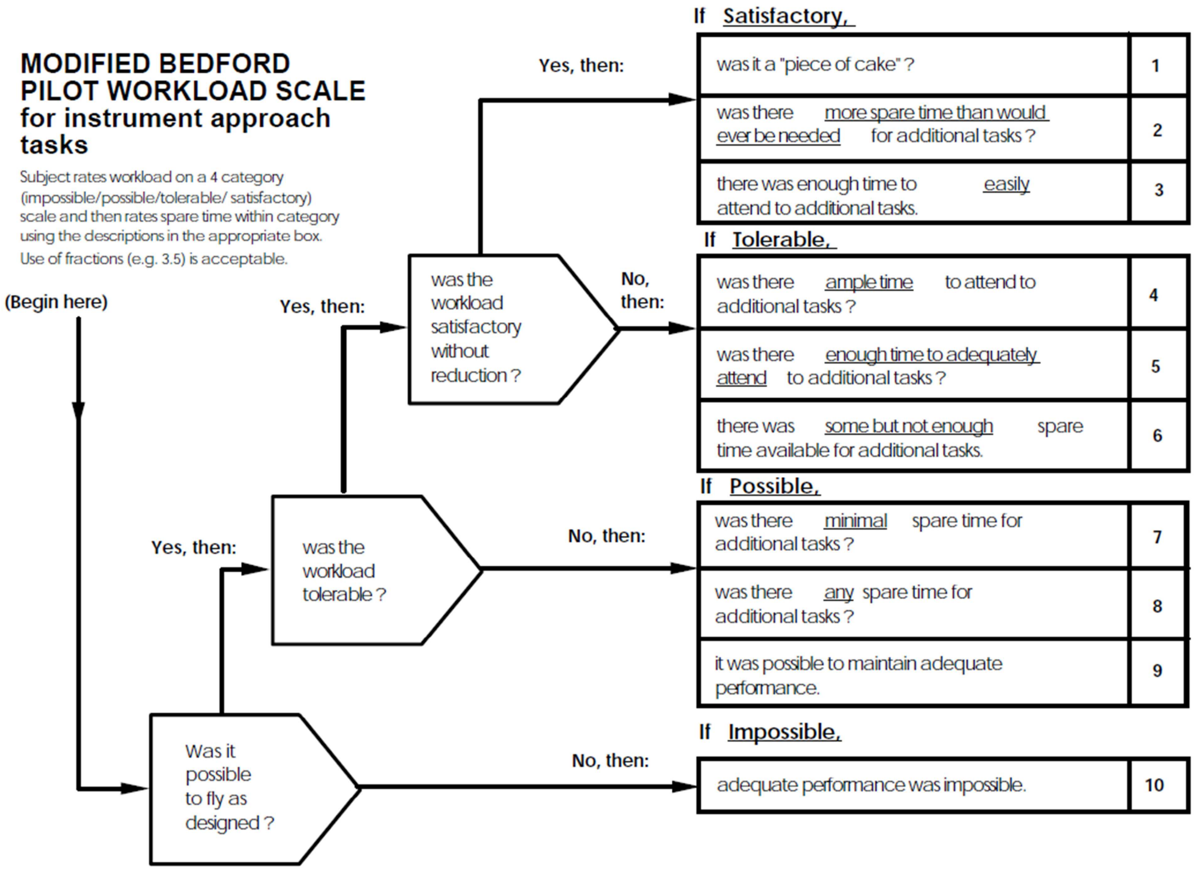
Sleep Log

Session	Date	Wake Time	Sleep Time	Hours of sleep last night
Pre-training		AM / PM	AM / PM	N/A
Training (Day 1)		AM / PM	AM / PM	
Day 2		AM / PM	AM / PM	
Day 3		AM / PM	AM / PM	

Note: The first day on this sleep log should be the day before your first training session.

What time did you call in on your early morning? _______________

Appendix III: Modified Bedford Pilot Workload Scale



Appendix IV: Karolinska Sleepiness Scale

Date___________ Subject Number ______________ Session____________

Please indicate your sleepiness during the 5 minutes before this rating by checking the box next to the appropriate number.
Use also the intermediate steps!

- [ ] 1 –very alert
- [ ] 2 –
- [ ] 3 – alert – normal level
- [ ] 4 –
- [ ] 5 – neither alert nor sleepy
- [ ] 6 –
- [ ] 7 – sleepy – but no effort to keep awake
- [ ] 8 –
- [ ] 9 – very sleepy, great effort to keep awake, fighting sleep

Appendix V: Example Autosequence Procedure Sheet

During the sessions, subjects referenced a binder with the procedures for each autosequence trial. An example procedure sheet is shown below. The procedure sheet lists the trial number, the autosequence mode (FOR or Joint Angle) and the option or joint angle inputs. The MBPWS was propped up for reference at the back of the cart.

Autosequence Scenario #2

Mode:

Joint Angle

Joint Angles:

Shoulder Yaw	-162.2
Shoulder Pitch	134.0
Elbow Pitch	-150.4
Wrist Pitch	-70.2
Wrist Yaw	87.5
Wrist Roll	162.0

Appendix VI: Morningness-Eveningness Questionnaire

1. Please read each question very carefully before answering.
2. Answer all questions
3. Answer questions in numerical order.
4. Each question should be answered independently of others. Do NOT go back and check your answers.
5. All questions have a selection of answers. For each question place a cross alongside ONE answer only. Some questions have a scale instead of a selection of answers. Place a cross at the appropriate point along the scale.

Subject Number:

Score **Date**

1. Considering only your own "feeling best" rhythm, at what time would you get up if you were entirely free to plan your day?

5 AM 6 7 8 9 10 11 12

2. Considering only your own "feeling best" rhythm, at what time would you go to bed if you were entirely free to plan your evening?

8 PM 9 10 11 12 AM 1 2 3

3. If there is a specific time at which you have to get up in the morning, to what extent are you dependent on being woken up by an alarm clock?

- Not at all dependent ☐
- Slightly dependent ☐
- Fairly dependent ☐
- Very dependent ☐

4. Assuming adequate environmental conditions, how easy do you find getting up in the morning?

- Not at all easy ☐
- Not very easy ☐
- Fairly easy ☐
- Very easy ☐

5. How alert do you feel during the first half-hour after having woken in the mornings?

- Not at all alert ☐
- Slightly alert ☐
- Fairly alert ☐
- Very alert ☐

6. How is your appetite during the first half-hour after having woken in the mornings?

- Very poor ☐
- Fairly poor ☐
- Fairly good ☐
- Very good ☐

7. During the first half-hour after having woken in the morning, how tired do you feel?

- Very tired ☐
- Fairly tired ☐
- Fairly refreshed ☐
- Very refreshed ☐

8. When you have no commitments the next day, at what time do you go to bed compared to your usual bedtime?

- Seldom or never later ☐
- Less than one hour later ☐
- 1 - 2 hours later ☐
- More than two hours later ☐

9. You have decided to engage in some physical exercise. A friend suggests that you do this one hour twice a week and the best time for him is between 7:00 - 8:00 AM. Bearing in mind nothing else but your own “feeling best” rhythm how do you think you would perform?

- Would be in good form ☐
- Would be in reasonable form ☐
- Would find it difficult ☐
- Would find it very difficult ☐

10. At what time in the evening do you feel tired and as a result in need of sleep?

8 PM | 9 | 10 | 11 | 12 AM | 1 | 2 | 3

11. You wish to be at your peak performance for a test which you know is going to be mentally exhausting and lasting for two hours. You are entirely free to plan your day and considering your “feeling best” rhythm which ONE of these four testing times would you choose?

- 8:00 - 10:00 AM ☐
- 11:00 AM - 1:00 PM ☐
- 3:00 - 5:00 PM ☐
- 7:00 - 9:00 PM ☐

12. If you went to bed at 11:00 PM at what level of tiredness would you be?

- Not at all tired ☐
- A little tired ☐
- Fairly tired ☐
- Very tired ☐

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following events are you most likely to experience?

- Will wake up at usual time and will NOT fall asleep ☐
- Will wake up at usual time and will doze thereafter ☐
- Will wake up at usual time but will fall asleep again ☐
- Will NOT wake up until later than usual ☐

14. One night you have to remain awake between 4:00 - 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the following alternatives will suit you best?

- Would NOT go to bed until after watch was over ☐
- Would take a nap before and sleep after ☐
- Would take a good sleep before and nap after ☐
- Would take ALL sleep before watch ☐

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own “Feeling best” rhythm which ONE of the following times would you choose?

- 8:00 - 10:00 AM ☐
- 11:00 AM - 1:00 PM ☐
- 3:00 - 5:00 PM ☐
- 7:00 - 9:00 PM ☐

16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 - 11:00 PM. Bearing in mind nothing else but your “feeling best” rhythm how well do you think you would perform?

- Would be in good form ☐
- Would be in reasonable form ☐
- Would find it difficult ☐
- Would find it very difficult ☐

17. Suppose that you can choose your own work hours. Assume that you worked a FIVE-hour day (including breaks) and that your job was interesting and paid by results. Which FIVE CONSECUTIVE HOURS would you select?

12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

MIDNIGHT NOON MIDNIGHT

18. At what time of the day do you think that you reach your "feeling best" peak?

12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

MIDNIGHT NOON MIDNIGHT

19. One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

Definitely a "morning" type? ☐
Rather more a "morning" than an "evening" type? ☐
Rather more an "evening" than a "morning" type? ☐
Definitely an "evening" type? ☐

Appendix VII: Clearance Violations Caught Correctly, Late, or Missed

Table 7: Clearance violations means and standard deviations

Session	Block	Group	Mean Correct	SD Correct	Mean Late	SD Late	Mean Missed	SD Missed
Midday	0	Midday-first	0.57	0.41	0.23	0.37	0.20	0.31
Midday	1	Midday-first	0.48	0.40	0.37	0.41	0.15	0.27
Night	0	Midday-first	0.68	0.40	0.23	0.41	0.08	0.19
Night	1	Midday-first	0.42	0.40	0.42	0.42	0.17	0.33
Midday	0	Night-first	0.53	0.43	0.38	0.42	0.10	0.20
Midday	1	Night-first	0.49	0.44	0.32	0.38	0.19	0.34
Night	0	Night-first	0.60	0.44	0.31	0.40	0.10	0.20
Night	1	Night-first	0.46	0.42	0.42	0.41	0.13	0.28

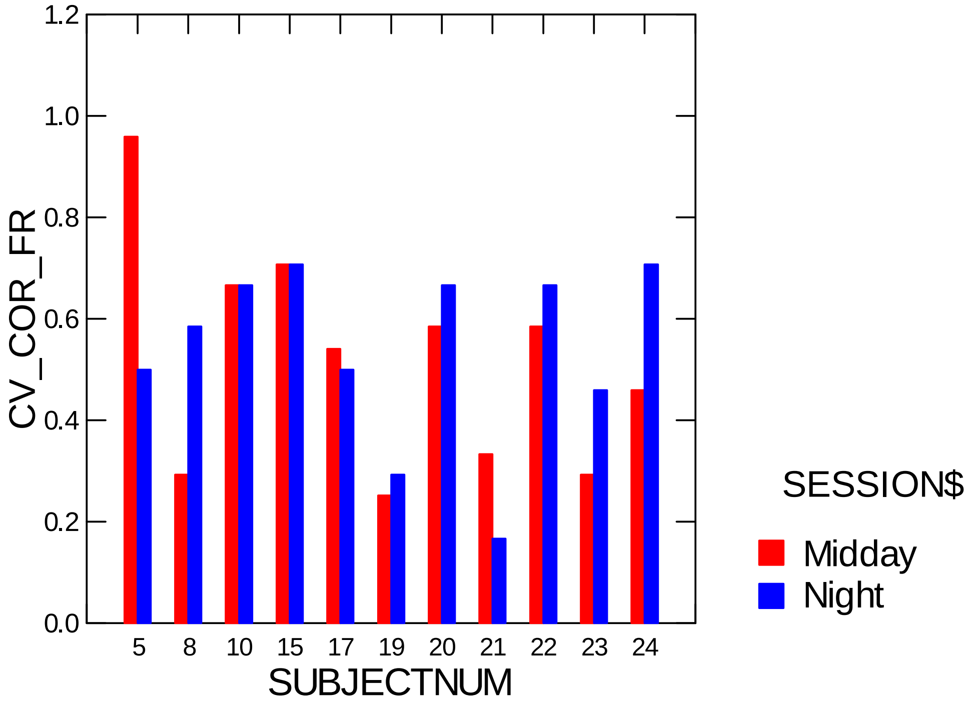


Figure 22: Fraction of clearance violations correctly caught, by subject and session

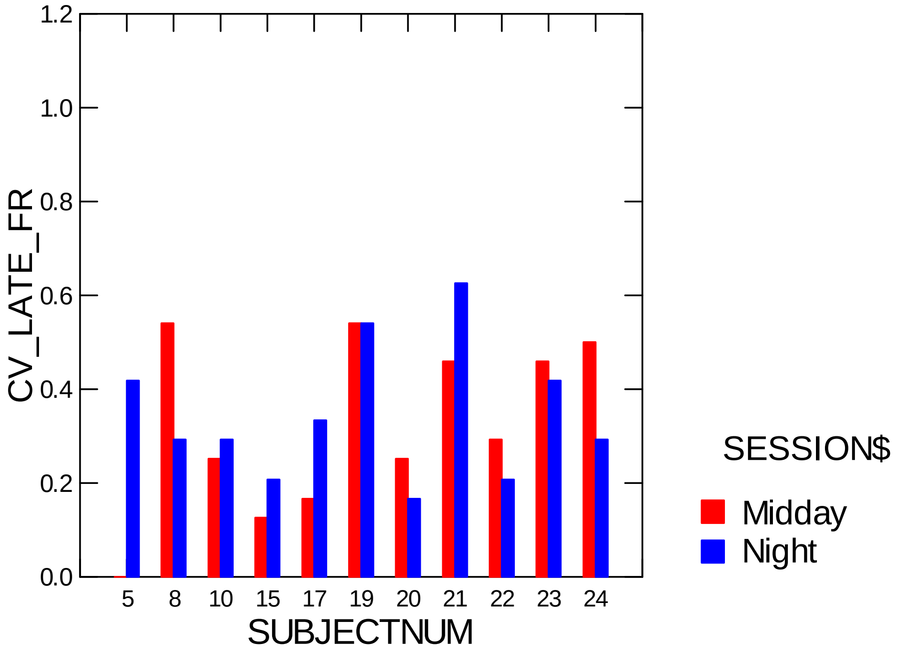


Figure 23: Fraction of clearance violations caught late, by subject and session

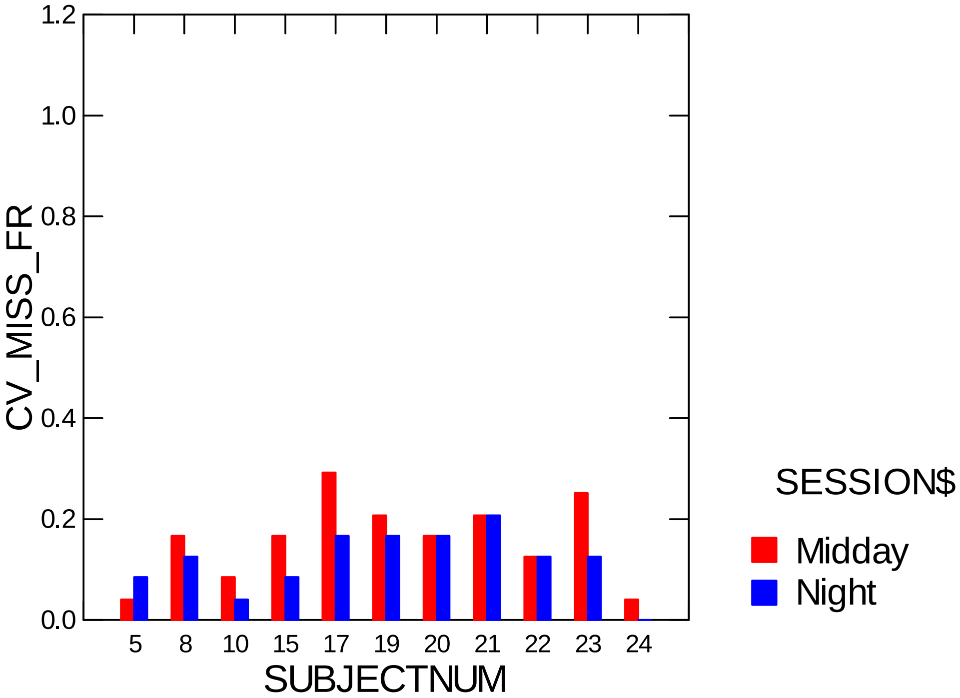


Figure 24: Fraction of clearance violations missed, by subject and session

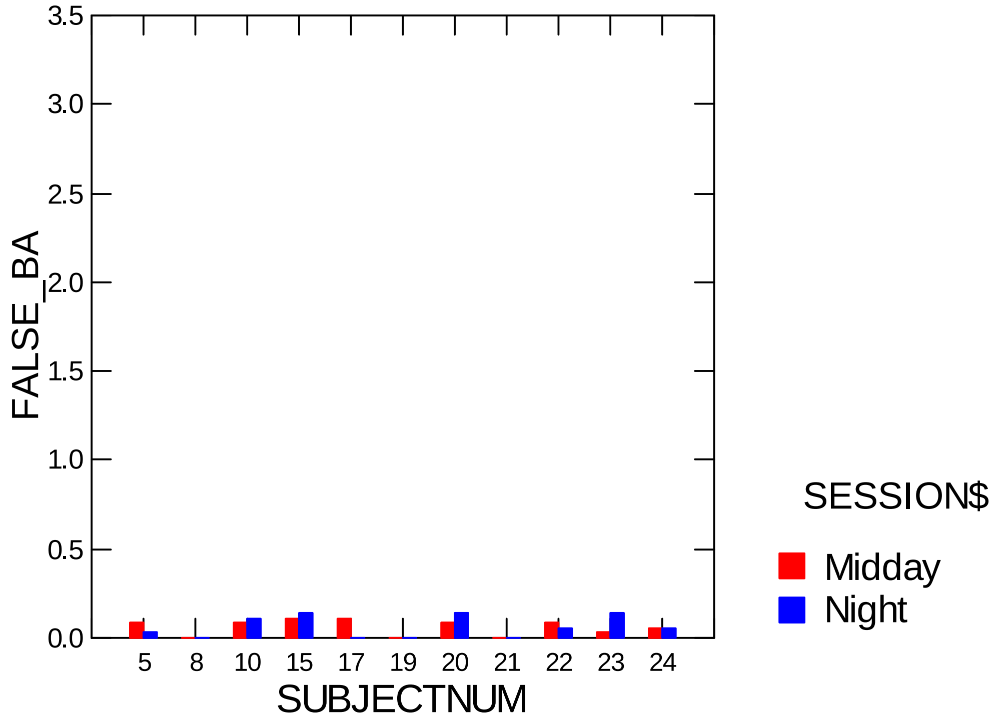
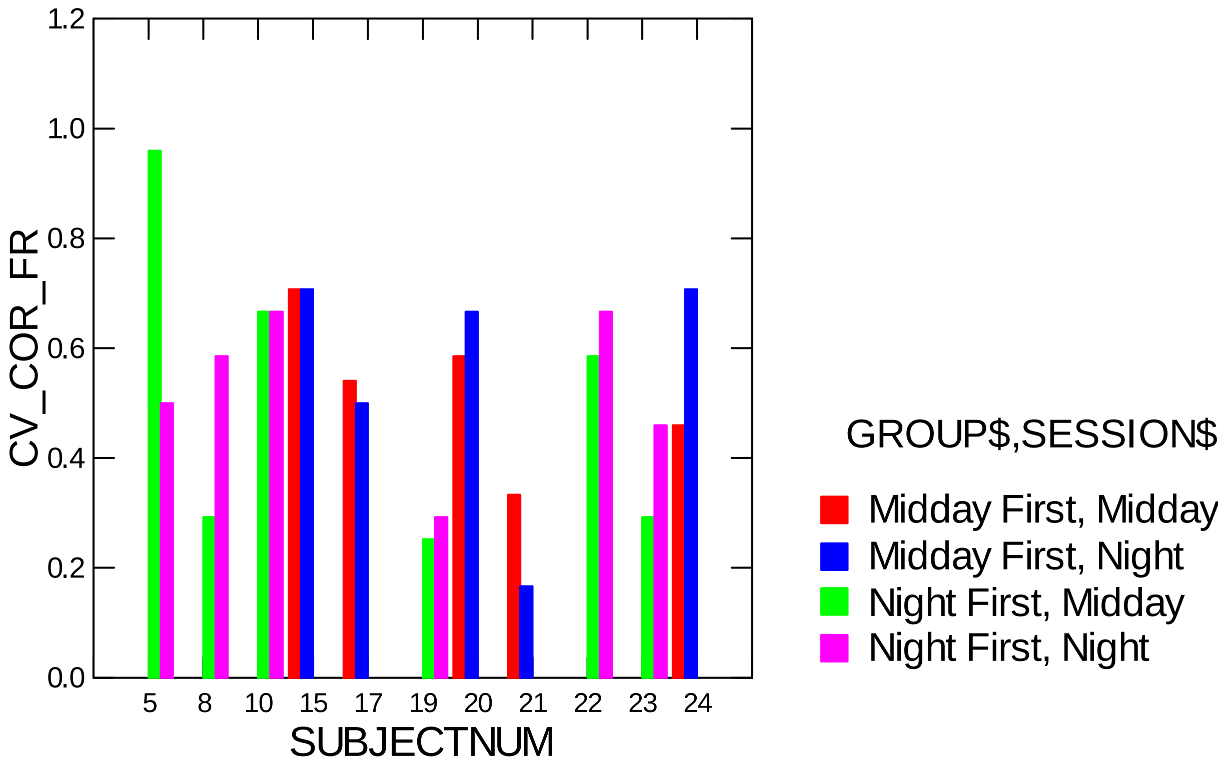
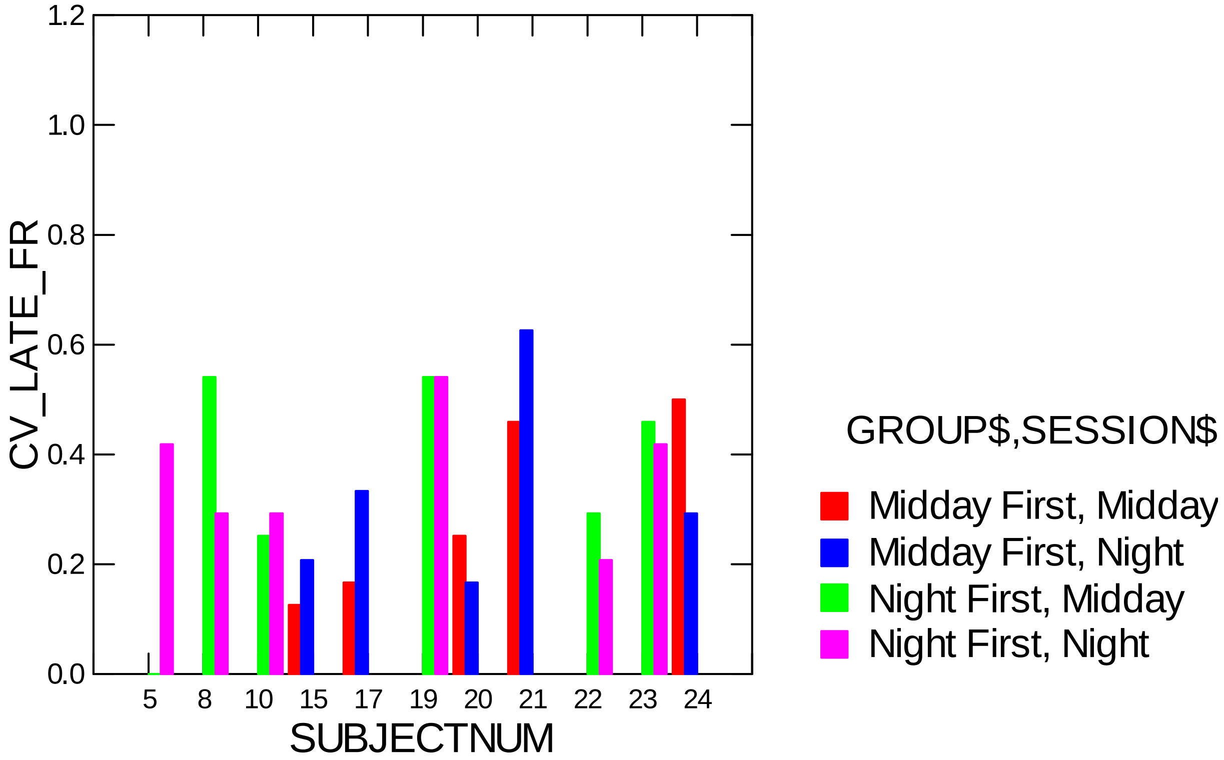
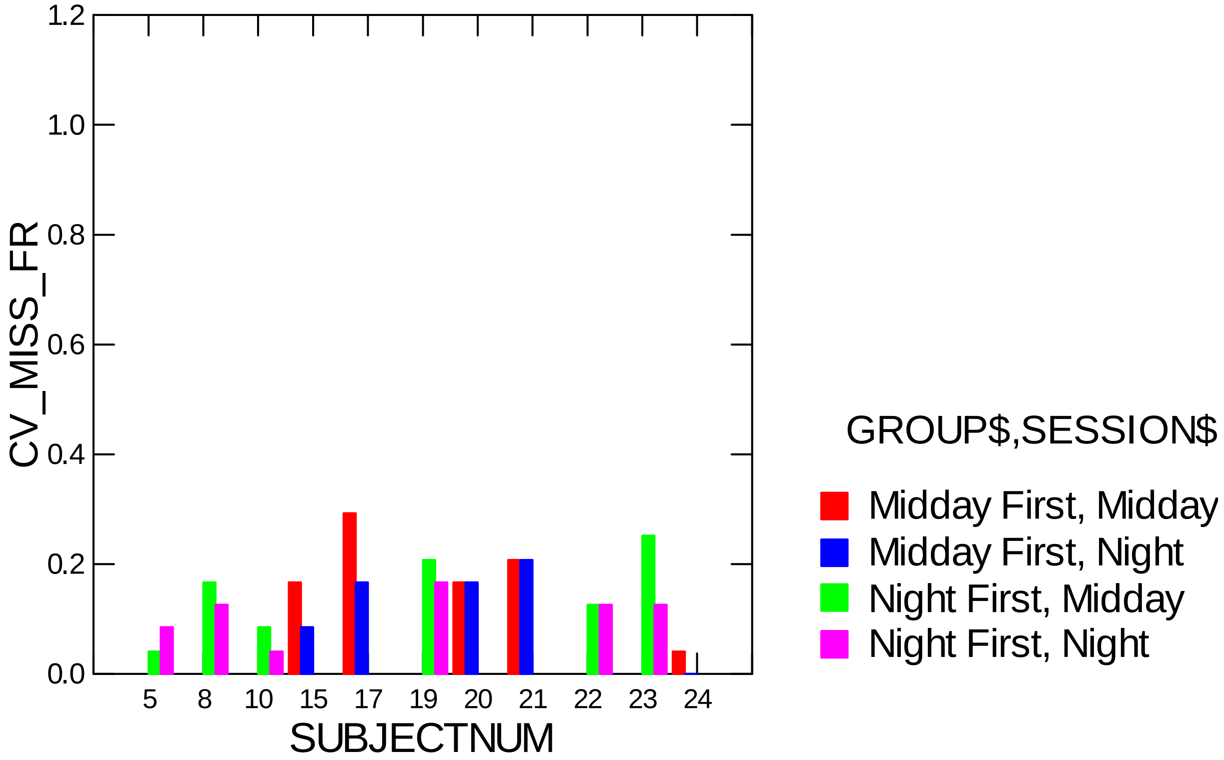
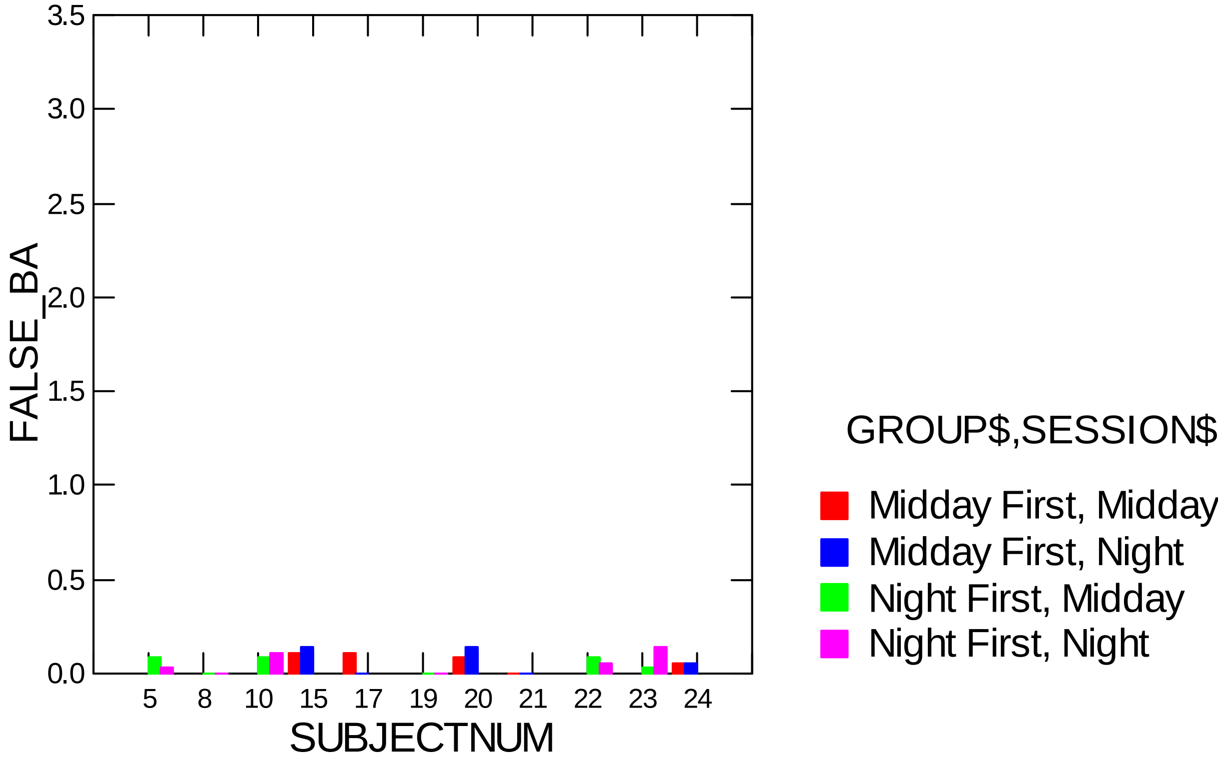


Figure 25: Average number of false positive brake applications per trial, by subject and session




CV_LATE_FR
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5
8
10
15
17
19
20
21
22
23
24
SUBJECTNUM
GROUP$,SESSION$
Midday First, Midday
Midday First, Night
Night First, Midday
Night First, Night


CV_MISS_FR
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5
8
10
15
17
19
20
21
22
23
24
SUBJECTNUM
GROUP$,SESSION$
Midday First, Midday
Midday First, Night
Night First, Midday
Night First, Night



3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
FALSE_BA
5
8
10
15
17
19
20
21
22
23
24
SUBJECTNUM
GROUP$,SESSION$
Midday First, Midday
Midday First, Night
Night First, Midday
Night First, Night

Appendix VIII: Variance of Reaction Time by Subject

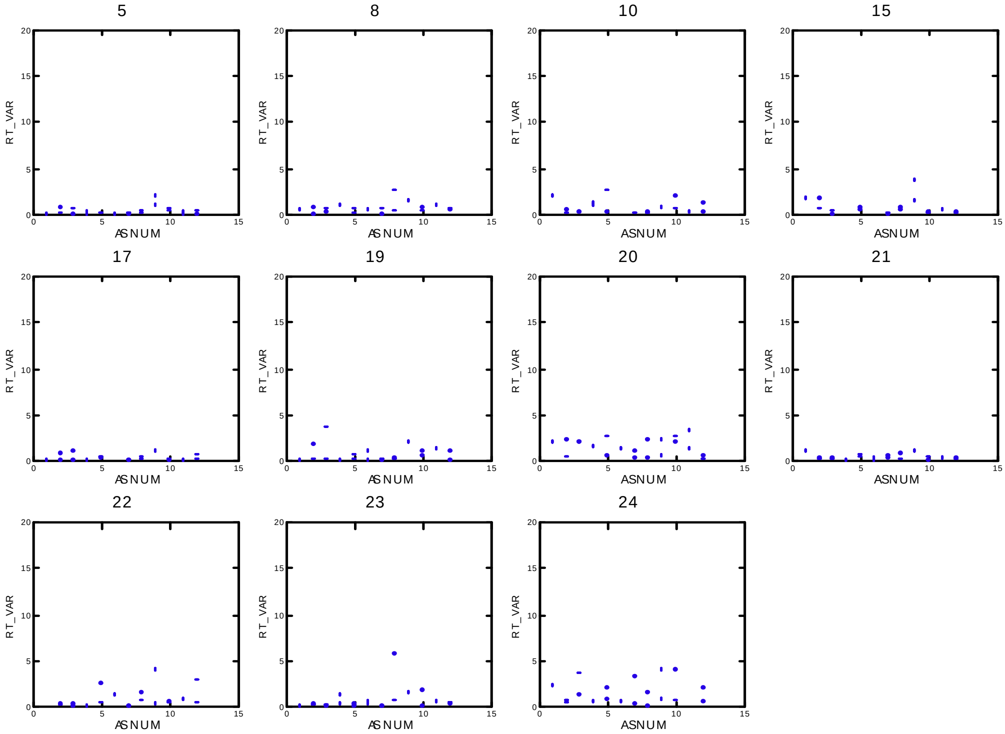


Figure 26: Variance of Reaction Time on Autosequence Tasks by Subject

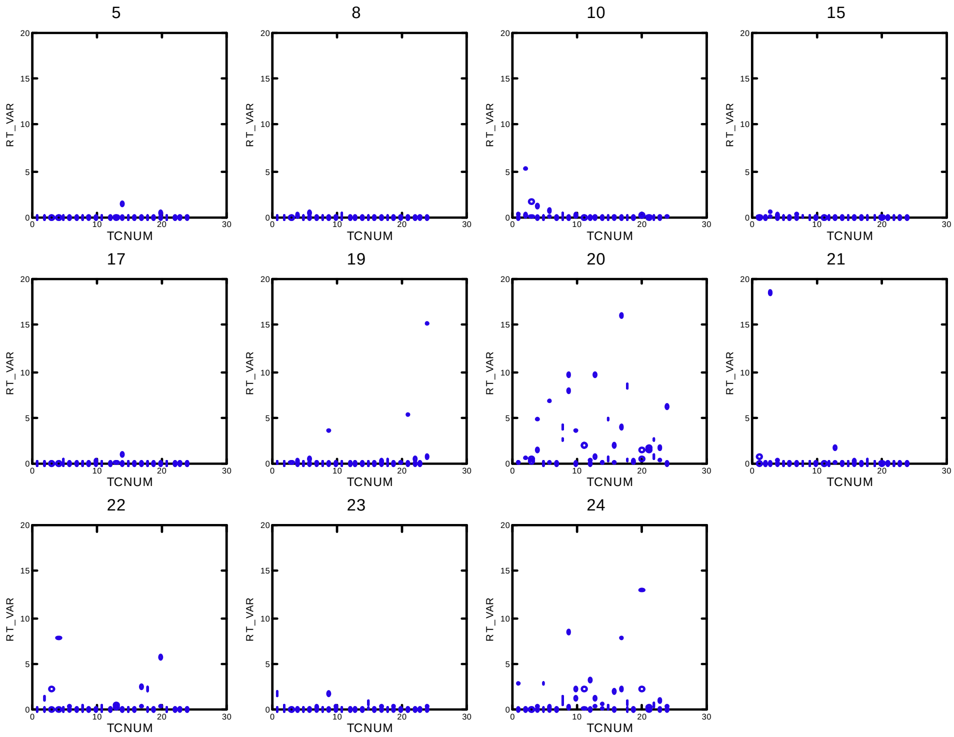


Figure 27: Variance of Reaction Time on Track and Capture Tasks by Subject

Appendix IX: Pre-Forum Survey

1. How much sleep do you get on a normal weeknight? ______________ hours

2. How much sleep do you think most of your friends get on a normal weeknight? ______________ hours

3. How much sleep do you get on a normal weekend night? ______________ hours

4. How much sleep do you think a teenager needs every night? ______________ hours

5. Do you think teenagers need more or less sleep than adults? MORE LESS

6. Do you think teenagers need more or less sleep than kids? MORE LESS

7. What happens to your body and your brain when you sleep?

8. What happens if you don't get enough sleep? How will you feel?

9. Do you think getting enough sleep is important? YES NO SOMETIMES

To help us match up your first and second survey, please write the last 4 digits of your cell phone number below.

____

Appendix X: Post-Forum Survey

1. Have you tried to get more sleep during the past week? YES NO

2. How much sleep does a teenager need every night? ___________ hours

3. Do you think teenagers need more or less sleep than adults? MORE LESS

4. Do you think teenagers need more or less sleep than kids? MORE LESS

5. What happens to your body and your brain when you sleep?

6. What happens if you don't get enough sleep? How will you feel?

7. Do you think getting enough sleep is important? YES NO SOMETIMES

8. What time do you think high school should start? ______________________

9. What's something that you think your friends should know about sleep?

10. To help us match up your first and second survey, please write the last 4 digits of your cell phone number below.

____

Appendix XI: Homework Reading

AWAKE at the WHEEL

DEAR STUDENT:

You have school and homework. Sports and clubs. Friends and family. And an after-school job. **Who has time for sleep? Who needs sleep anyway?**

Believe it or not, you do. As a teen, you actually need more sleep than younger kids: about nine hours every night. Like most teens, you probably sleep only about six. You wake up tired, and you stay that way. Do you think that's okay — that you'll be fine, just like everyone else? No way! Here's why: **When you don't get the sleep you need, you start to get drowsy in class, at work, at parties, and behind the wheel of your car.** That's where lack of sleep can really hurt you and others.

The solution is simple—**crash in bed, not on the road.** Go to bed earlier. Take a nap if you're sleepy. Sleep late when you can.

Remember, when you're short on sleep, stay out of the driver's seat.

Sincerely,

Claude Lenfant, M.D.
Director
National Heart, Lung, and Blood Institute

TOP 5 REASONS TO GET ENOUGH SLEEP

- Drowsy drivers can crash their cars. Crashes disfigure, disable, and kill drivers, passengers, or pedestrians.
- Drowsy teens react more slowly and perform worse in sports than well-rested teens.
- Drowsy teens do poorly in school and have problems socially.
- Drowsy teens have trouble making good decisions.
- Drowsy teens don't look their best.

SCHOLASTIC

FEELING SLEEPY? HERE'S WHY!

- Many teens need at least 9 hours of sleep per night. More than younger kids, and more than adults. But most teens get less than 6.5 hours of sleep. If "most teens" is you, you're probably sleepy most of the time.
- When kids hit puberty, their internal clocks change: that's why teens just naturally want to go to bed late and sleep late in the morning!
- Teenagers have more responsibilities than younger kids. And, between school, homework, jobs, sports and a social life, it is difficult for them to get enough sleep.

WHAT WOULD YOU DO?

HOW WOULD YOU HANDLE THESE SITUATIONS?

(For ideas, check out the **YOU SHOULD KNOW** section.)

1

Brianne is a 17-year-old junior who lives in the suburbs. She's a good student, a member of the high school basketball team, and is very socially active. She stayed up late studying for mid-terms, got to school at 7:30 a.m., finished basketball practice at 4:00 p.m., then drove a friend home from practice. Now it's 6:00 p.m., and she's heading home on the freeway. After a 20-minute drive, she suddenly realizes she missed the exit to her house and doesn't remember driving the last few miles.

What could have happened to Brianne while she was on "auto-pilot"? How could she have avoided this dangerous situation?

2

Pete is 18, and thinking about graduation. He works after school at the mall to make money for college. His older brother is at the state university, about two hours from home; and Pete's planning a weekend road trip starting tonight. After a short night of sleep he goes to school, works for about 4 hours at his job, and grabs a bite to eat. Then, he and his girlfriend, Shelley, jump in the car and head toward the university. It's already 8:00 p.m. Shelley falls asleep and after about 30 minutes, Pete realizes that he's exhausted, too. A few minutes later, he's startled into alertness as he hits the rumble strips along the shoulder of the highway.

How could Pete have avoided this dangerous situation? What should he do now?

3 **Adam** is 17, and has just received his license. His parents have given him a strict 11:00 p.m. curfew. It's now 1:30 a.m., and after a long day, he's about to leave a party at a friend's house. Feeling alert, he jumps behind the wheel of the family car with his best friend Chris in the passenger seat. A few minutes later, Chris yells, "Hit the brakes!" just as Adam, with his eyes closed, is about to drift through a red light.

How could Adam have avoided this dangerous situation? What should he do now to get home safely?

YOU SHOULD KNOW...

1. ...the only way to prevent drowsy driving is to get enough sleep on a regular basis.
2. ...it's possible to build up a big "sleep debt" by sleeping too few hours for too many days on end. You can't "pay off" the sleep debt in just one night—or day. It can take days to get back to normal.
3. ...most sleepiness-related crashes happen between 2 a.m. and 6 a.m. (during normal sleeping hours).
4. ...there is only one sure-fire way to wake yourself up when you're sleepy: take a 15-20 minute nap before driving.
5. ...getting a good night's sleep before a long drive can save your life.
6. ...traveling with a friend who's awake can help keep you awake. But, a sleeping friend is no help at all.
7. ...rolling down a window to get some air, stretching your legs, or even cranking up the radio are almost useless when you're trying to stay awake.
8. ...one beer, when someone is sleep-deprived, will hit as hard as two or three beers when one is well rested.
9. ...drinking caffeine (a caffeinated soft drink, coffee, or tea) before hitting the road may help for a short time, but it can also be a problem. Caffeine can make you lose sleep, which leads to more sleepiness!

opinion poll

Some high schools across the country have decided to start classes about one hour later, to allow teenage students to get extra sleep. **Do you think this will make a difference?**

In many families, parents get even less sleep than their kids.

How could you help convince your family members of the importance of getting more sleep?

Teenagers are under a lot of pressure—preparing for college, playing sports, working after-school jobs, and trying to have a social life.

How can kids lighten their load without losing out on important parts of their lives?

opinion poll

WAKE UP CALL!

RATE YOUR SLEEP HABITS

1. Most nights, I sleep

(a) under 6 hours.
(b) 6 to 8 hours.
(c) 9 or more hours.

2. I blow off sleep to

(Circle any that apply)
(a) study.
(b) party.
(c) work.
(d) watch TV.
(e) talk with friends.
(f) I don't blow off sleep.
(g) other

3. I drive when I'm sleepy because

(a) I know I can keep myself awake.
(b) I don't want to ask for a lift—it's embarrassing.
(c) I love my car.
(d) I don't think about sleepiness until I'm actually falling asleep.
(e) I don't drive when I'm sleepy.

4. When I get sleepy while driving, I

(a) count on highway rumble strips or passengers to wake me up.
(b) stop and call for a lift.
(c) stop for caffeinated soft drinks or coffee.
(d) stop and take a nap.
(e) open a window to get some air.
(f) turn the music up.
(g) just keep driving.

Score points for your answers as follows:

1. (a) 0; (b) 1; (c) 2
2. (a) to (e) 0; (f) 1; (g) 0
3. (a) to (d) 0; (e) 3
4. (a), (e), (f), (g) 0; (c) 2; (b), (d) 3

What your score means:
9 points—Wide Awake
6-8 points—Waking Up
4-5 points—Asleep at the Wheel
Less than 3 points—Hear the Alarm

Appendix XII: Text Message Votes

1. Considering your role in the game, what time should the high school day start?

    a) Before 7am
    b) Between 7am and 7:30am
    c) Between 7:30am and 8am
    d) Between 8am and 8:30am
    e) Between 8:30am and 9am
    f) Between 9am and 9:30am
    g) After 9:30am

2. From your own perspective (as a Fenway HS student), what time should the high school day start?

    a) Before 7am
    b) Between 7am and 7:30am
    c) Between 7:30am and 8am
    d) Between 8am and 8:30am
    e) Between 8:30am and 9am
    f) Between 9am and 9:30am
    g) After 9:30am

Appendix XIII: Roles for the Sleep Role Play Exercise

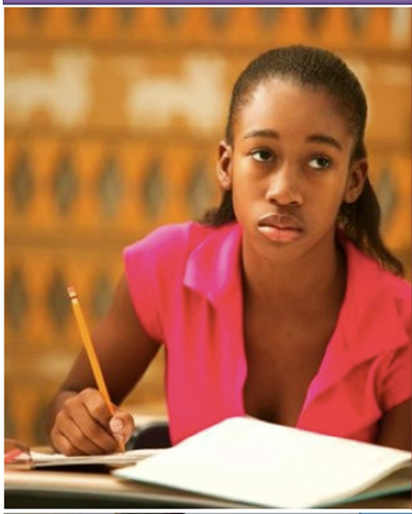
Teacher

Mr. Lewis gets to school at 6:00 AM to get his classroom set up for the day. At 7:00 AM every day, some students come into his classroom for extra help on their math homework. School ends at 2:30 PM. He stays at school until 4:30 PM to grade students' work, and then he leaves. He likes that he is able to pick up his son, who goes to a different school, from high school football practice at 5 PM. He is very tired during the school day because he goes to sleep at 11:00 PM and gets up at 5:00 AM.

5 AM	6 AM	7 AM	7:30 AM	2:30 PM	4:30 PM	5 PM	11 PM
Wakes up	Gets to school	Helps students	School starts	School ends	Leaves school	Picks up son	Goes to sleep

Sleep researcher

Dr. Lee has been studying the sleep patterns of high school students for 20 years. He knows that high school students have trouble going to bed early and waking up early. Based on his research, he knows that this is caused by biology and that the students are doing their best to adapt to the school schedule. His research has shown that when school starts later, students are more alert, less irritable, and learn better. The school board has asked him to make a recommendation for the best school start time. Many people want the time to stay the same because it would disrupt their schedules to change.



Student

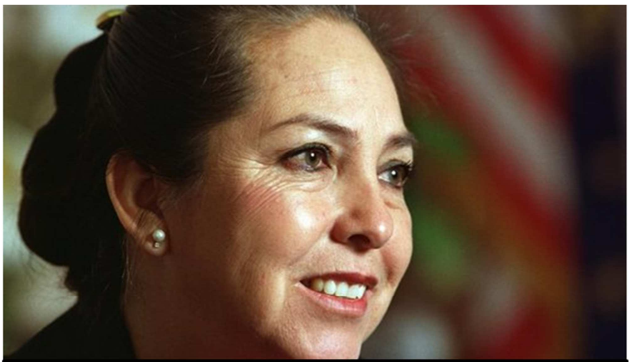
Lissandra gets to school at 7:15 AM to talk to her friends before first period. She wakes up at 5:30 AM to get ready for school, and she usually goes to bed at 11:00 PM after she finishes her homework. On Mondays, Wednesdays, and Fridays she stays after school for soccer practice. On Tuesdays and Thursdays she has to go straight home to take care of her younger brother and sister. She spends 2 hours per day on Facebook, texting with her friends, and watching TV.

5:30 AM	7:15 AM	7:30 AM	2:30 PM	11 PM
Wakes up	Gets to school	School starts	School ends	Goes to sleep

Parent

Sana has two daughters. Ayisha is in high school and Rashida is in middle school. Ayisha takes care of Rashida after school from 3:30 PM until Sana gets home at 6:30 PM. Ayisha has also been working at McDonald's in the evenings 3 nights per week to help out at home. Sana has noticed that Ayisha is very tired every day but still has trouble going to sleep early. Sana has to be at work at 8:30 AM, but she can't leave until Rashida leaves for school. She wants her daughters to get a good education, but she also wants them to get enough sleep.

7 AM	7:30 AM	8:30 AM	6:30 PM
Ayisha goes to school	Rashida goes to school	Sana starts work	Sana gets home



Administrator

Ms. Rodriguez is the superintendent of the school district. She has heard from many students that high school starts too early. She thinks that students might do better in school if it started later. Unfortunately, there have been budget cuts at the school. The cost of shifting the schedule for all of the schools to a later time would be $25,000 because they would need to reschedule all the buses and do a lot of replanning. She doesn't think there is enough money in the budget to make the switch. The only way she could squeeze the money out of the budget would be to put off buying new textbooks that the science department really needs.

Appendix XIV: Questions from “Who Needs Sleep?”

1. Does a warm room or a boring class make you drowsy?
2. Do you fall asleep the instant your head hits the pillow?
3. Do you need an alarm clock to wake you up?
4. Do you repeatedly hit the snooze bar?
5. Do you sleep extra hours on the weekends? [71]

Appendix XV: Discussion Worksheets

Discussion Worksheet – Round 1

Role______________________________

What were 3 issues your group discussed about your role?

1.

2.

3.

What recommendations would you make to your character?

Did everyone in your group agree on everything?   YES   NO

If not, what were some things you disagreed about?

Discussion Worksheet – Round 2

Role_______________________________ Table Letter____________

What were 3 tradeoffs your group discussed during the negotiation?

1.

2.

3.

What recommendations would you make to the school district?

Did everyone in your group agree? YES NO

If not, what were some things you disagreed about?