SLEEP MANAGEMENT: PERFORMANCE, HEALTH AND SAFETY

James M. Gregory and Lloyd Heinze
Texas Tech University

ABSTRACT

Productivity, safety, and health are major concerns for companies attempting to maximize profit and provide safe, healthy work environments. Human performance declines when people receive less than optimal sleep. As performance declines, the risk for accidents and health problems increase. Long hours of work, especially for a week or longer generally lead to increased sleep debt, reduced performance, and increased risk of accidents and health problems. Costs increase as performance declines and risks increase. These changes in human factors associated with sleep management can be especially troublesome for companies attempting six sigma quality standards.

A web-based tool, SLEEP Model, has been developed that allows people to input sleep time and duration, caffeine and alcohol use, and age to evaluate performance and various risk factors, including increased accident and health risks. The presentation will demo SLEEP Model and will illustrate the numeric value of wise sleep management.

INTRODUCTION

Sleep is similar to air, water, and food. It is an essential part of life but often not appreciated until it is in short supply. People even often have a macho attitude that they can function well with limited amounts of sleep and do not seem to understand the various risks associated with poor sleep management. These risks can be long-term, such as many medical problems, or short-term, such as accidents and loss in performance. Medical risk include but are not limited to diabetes, heart disease, cancers, etc. that have a long feedback loop that tends to cause the individual to not make the connection of long-term health issues to sleep management. Short-term risks include some medial responses, poor academic and work performance, and increase in accidents. Even our food choices and occurrences of obesity can be related to sleep management (Spiegel et al., 2004A). Spiegel et al. (2004B) make the following statement in their abstract:

> In conclusion, sleep modulates a major component of the neuroendocrine control of appetite.

Forced reduction in sleep amount tends to be associated with increased hunger and an increased desire for salty foods, starchy foods, and sweets instead of meats, vegetables, dairy, and fruits (Spiegel et al. (2004A). Note that the top three foods choices associated with insufficient sleep are associated with high blood pressure, high calories, high probability of being obese, and an overload on pancreas to process the sugar. In lay terms, we feel tired and want foods with a quick energy fix along with caffeine. Under these conditions, caffeine has the most beneficial effect and the least long-term danger.

Most people appreciate that alcohol reduces performance but are surprised when they learn that going 18 hours without sleep causes about the same decline in performance as 0.05 percent blood alcohol (Lamond and Dawson, 1999; Gregory, et al., 2004; Arnedt, et al., 2005). Thus, a strong need exists for sleep education essentially for all ages of people.

The objective of this paper is to overview the nature of sleep, discuss some of the risks affected by sleep management, and introduce the reader to SLEEP Model, a Web-based tool that simulates changes in performance and risk factors associated with sleep management. SLEEP Model allows individuals to determine expected outcomes from a variety of management decisions. The oral presentation will demo SLEEP Model.

HEALTH

Most people are unaware of the medical risk associated with sleep management. Within the last decade, however, it has become very evident that either too little or too much sleep associates with elevated medical risks. Ayas (2003) provided evidence that risk for diabetes and heart disease was U-shaped as a function of sleep amount and essentially the same function for both medical problems. This function is shown in Figure 1. In a general sense, many medical problems are associated with sleep management and appear to have about the same function.

In 2005, a more comprehensive article was published relating a variety of medical risks to sleep amount (Singh et al., 2005). A somewhat abbreviated list from this work giving percentage risks is given in Table 1. The data in Table 1 were converted to odds ratio by dividing the value at a given sleep amount by the average value for the 6 to 7 hours of sleep and 7 to 8 hours of sleep. The odds ratio was then converted to the fractional increase in medical risk by subtracting 1.0 from the odds ratio. The average increase in medical risk is shown in Figure 2.

Death also is associated with sleep management. Kripke et al. (2002) reported the information shown in Figure 3. Note the U-shaped function for increase in risk of early death as a function of sleep amount. The ages of people in this study were older than the ages in the other medical studies; hence, the shift to a lower sleep amount associated with minimum risk. The risk of death also appears to be roughly one third to one half of the risk for disease.

Sleep obviously, is an important management variable for long-term health and life for people. Proper sleep is essential for the CEO down through all levels of employment and their families.

Reduced sleep for approximately a week causes several changes that can affect health. One change is the response to carbohydrate foods. Sleep debt tends to be associated with increased hunger, especially for sweets, fats, and salts (Spiegel et al., 2004A). The body, however, is slowed in its response to glucose and young, healthy adults have insulin responses similar to people 60 years of age (Spiegel et al., 2004B, Van Cauter [oral presentation at the 2005 Sleep Research Meeting in Denver]). Lepton, a hormone associated with hunger, decreases with the build up of sleep debt (Spiegel et al., 2004A). Gerilin, another hormone associated with hunger, increases as sleep debt increases. The magnitude of these changes with short term sleep debt parallels the magnitude of long-term increased risk for diabetes and heart disease (Ayas, 2003; Singh et al., 2005). The increased medical risks predicted by SLEEP Model are based on data presented by Ayas (2003) and are in close agreement with data from Singh et al. (2005).

The information in Figure 1 also relates to risks for depression shown as the green data points. Risks for hostility not shown but from the same study were very similar to depression. These points were computed from measured data in a Texas Tech University Psychology Department dissertation by Woodson (2004). Thus, there is some evidence that sleep management could affect depression and hostility in the work place. Because these points seem to follow the curve used to calibrate the risks for medical risk in SLEEP Model, the medical risk predictions should also predict the risks for depression and hostility. It seems that sleep is important for behavior health as well as other health issues. These results are especially important for environments where people live and work in crowed or confined spaces or feel that they have no control over their environment.

PERFORMANCE

It is tempting to work people long hours when the project needs to be completed by a certain date or the value of the project is high. Thus, people are often asked to work overtime or double shifts to complete projects. Performance declines with the build up of sleep debt and generally declines with the square of the duration of the overtime period. Peopled generally cheat sleep as they struggle to get everything done when they are worked long hours.

Performance depends on the amount of sleep debt accumulated, the time of day the performance is to be completed, the fraction of sleep needed for a given day that was obtained in the previous night's sleep, and the type of task to be completed: passive (driving) or active and self stimulating (test taking or combat). Artificial stimulates such as caffeine can also affect the passive performance. During periods of fear or excitement, the body secretes adrenaline—a strong stimulate. Thus, it is nearly impossible to predict performance without a mathematical model that integrates all of these factors.

Passive performance or alertness decays exponentially as sleep debt accumulates. Superimposed on this decay function is the circadian cycle that generally accounts for performance to be highest during the day and lowest about four in the morning. Shift work or travel by jet can shift these cycles. A typical passive performance expressed as a fraction of peak performance is shown in blue in Figure 4 for 13 days without sleep. The record for days without sleep with doctor supervision is 12 days by Randy Gardner. Some literature indicates that he hallucinated on the fourth night. Based on SLEEP Model, there is potential for hallucination when the passive and active performance curves come together. Passive performance is often the inverse of response time or reaction time. The calibration data set used in SLEEP Model for passive performance is from Froberg (1977). Calibration details are given by

Gregory et al. (2004). Passive performance is probably the more important of the two types of performance because loss in passive performance associates with increase risk of accidents.

Active performance or test-taking performance is much less sensitive to low levels of sleep debt as shown in red in Figure 4. The data set used for calibration of active performance or test-taking performance is from Weiskkotten and Ferguson (1930) for converting prose to Morse Code. On the third and fourth days of total sleep loss, however, this performance curve declines rapidly (square of sleep debt). After four days of no sleep, some people begin to hallucinate—not a good thing for military operations and probably not a good thing for drilling oil wells.

There are about seven sleep models that are known to exist worldwide. All of these models and especially the Air Force model can predict performance associate with total sleep loss. SLEEP Model also predicts performance well for total sleep loss. All of these models except for SLEEP Model failed to predict performance associated with partial sleep loss. SLEEP Model predicts both well. A simulation for partial sleep loss each night for a couple of weeks is shown in Figure 5. The data set used for calibration of the partial sleep loss function is from Van Dongen et al. (2003). We will present other performance results associated with sleep management as part of the demo with SLEEP Model. Figure 6 illustrates a typical performance prediction from SLEEP Model comparing performance associated with alcohol use to performance associated with going through the night without sleep. It was recently reported in the Journal of the American Medical Association (Arnedt, et al., 2005) that performance of residents after a heavy call was similar to performance with 0.05 percent blood alcohol. Note that this prediction is for a night of no sleep, but we could have obtained a similar result with many combinations, such as several days of partial sleep loss. Based on these predictions of performance and various reports in the literature, a person would be wise to not get sick or have an accident late at night or early in the morning. Better sleep management of residents could certainly help. Also, note the difference in performance in Figures 5 and 6 associated with a night of no sleep. The amount of sleep debt before a night of no sleep has a major impact on the performance and the effect of counter measures, such as caffeine use.

SAFETY

Safety is a dynamic process. It associates directly with the loss in passive performance. The increase in risk for accidents is the product of loss in performance and the duration over which this loss in performance occurs times a calibration factor (Gregory and Xie, 2004). In SLEEP Model, loss in performance can occur from use of alcohol or from the build up of sleep debt. The risk calculator does not care what caused the lost in performance. Once the risk calculator is calibrated to predict risk associated to one cause (alcohol in our case) for loss in performance, it automatically is calibrated to predict the risks associated with the other cause (sleep loss). The risk calculator in SLEEP Model is calibrated from data reported by Vinson et al. (2003) collected from the Emergency Room Center at Boone County Hospital in Columbia, Missouri.

It is more difficult to calibrate or even verify risks associated with lack of sleep using emergency room data. Caffeine has a half life of about 6 hours and can greatly change performance and in turn the risk for accidents. It takes 1.5 to 2.0 hours after drinking or taking caffeine in tablet form to reach peak concentrations of caffeine in the blood. Caffeine gum (available for military use) accelerates the peak concentration to within 30 minutes after consumption. Sleep debt can build up over several days or even weeks. Thus, a much more extensive data collection procedure must be used to have any hope of success to calibrate risk for accidents to sleep condition.

In a rough sense, the increase in risk for accidents associated with sleep management as predicted with SLEEP Model was verified with data from Radun and Summala (2004). This study analyzed fatal accidents in Finland by non-professional drivers over a 10-year period from 1991 to 2001. Caffeine was not considered. The average predictions of increase in risk for simulations using SLEEP Model with and without caffeine closely matched the reported risk of fatal accidents associated with reduced sleep. Thus, the risk predictor in SLEEP Model for sleep management has been roughly verified. From a theoretical point of view, it was verified with the alcohol data set.

Examples of the effects of sleep management decisions on the increased probability of accidents will be provided during the demo of SLEEP Model in the oral presentation. In general terms, it is not unusual to have an order of magnitude increase in the probability of accidents with poor sleep management. While caffeine can have a very beneficial effect to counter lack of sleep, there are combinations, for example a night of no sleep after several weeks of partial sleep, for which caffeine does not have much effect and for which the individual is unsafe to drive or use any device that could cause injury.

NATURE OF SLEEP

While much is now known about sleep, much is still to be learned. Brain functions change during sleep, but the brain does not become inactive. A major advancement in understanding sleep occurred about 50 years ago with the discovery of REM (rapid eye movement). Dreaming most often occurs with REM sleep and the brainwave pattern during REM sleep is most like that of being awake. Thus, it is safe to speculate that mental activity occurs during REM sleep. The body is paralyzed during REM sleep so that we do not act out dreams, sleepwalk, etc. The non-REM fraction of sleep can be subdivided into stages 1, 2, 3, and 4. Stages 3 and 4 are defined as high amplitude low frequency brainwaves. Stage 4 is the most extreme and thought to be the deepest form of sleep. Children are especially difficult to wakeup during this stage of sleep. Stages 3 and 4 are often grouped together and defined as delta sleep. Growth hormone in young people is highly correlated with delta sleep. The amount of delta sleep also appears to be associated with exercise and fitness, but exceptions do occur. Stage 2 appears to be a switch to other stages of sleep. During the sleep process, an individual generally starts in stage 1 (transition to sleep) then experiences stage 2 before stage 3 then moves to stage 4. After a few minutes of stage 4, the individual moves back to stage 3 then to stage 2 then switches to REM sleep to complete the cycle. The individual then switches back to stage 2 and repeats the process. As people age and it appears as people become inactive, the process becomes more disturbed with more wakeup times and longer wakeup periods during sleep. Sleeping at higher elevations tends to remove delta sleep and causes sleep disturbance (Weil, 2005). Mental engagement, worry, or bad news tends to interfere with getting to sleep and also tends to shorten the total sleep period. It seems to amplify the wakeup process. Anything that shortens the total sleep period tends to reduce the REM fraction because the second one-half of sleep is usually rich in REM sleep. The first one-half is rich in delta sleep. For young adults, the fractions of REM sleep and delta sleep are about equal. Age, however, affects the various fractions of sleep components. These changes are shown in Figure 7. In Figure 7, the conception circle is based on modeling boundary conditions. Information in the other circles is based on measurements in sleep labs.

Need for sleep decreases with age as shown in Figure 8. There is some evidence that total sleep need is associated with exercise and fitness and newer data sets for sleep need show less sleep need for children and young adults. This probable effect associated with a change in culture (increased use of TV, computer, cell phones, etc.) and much less physical activity is one explanation of the increasing problem of obesity and related health problems of children and young adults. While there is much to be said about these interactions, it is beyond the scope of this paper. Health officials and researchers now talk about the epidemic of obesity, which seems to be occurring worldwide with enormous risk of disease and cost for medical care. It appears that a major opportunity exists to improve health, quality of life and productive through sleep and fitness education.

SLEEP MODEL

SLEEP (Sleep Loss Effects on Everyday Performance) Model was developed to help students to learn to manage sleep and improve academic performance. SLEEP Model has grown beyond the initial objective and can now be used as a management tool to see the effects of management decisions (sleep amount and use of alcohol and caffeine) on performance and risk for medical problems and risks for accidents. SLEEP Model is available at no cost at the following address:

http://ednet.coe.ttu.edu/development/coe/software/sleepsoft/sleep/

Microsoft languages and tools were used to develop SLEEP Model; therefore, users must use a PC and Internet Explorer for the graphics to work correctly. At the present time, Java is needed as a download to generate the graphics. We do not make up all sleep that is lost. SLEEP Model uses a conservation of REM process to determine the amount of sleep that is made up after a sleep debt is generated. It was reported in an oral presentation by Dr. Jerome Siegel at the 2005 Sleep Research Meeting in Denver that all land-based mammals conserve REM sleep. SLEEP Model, however, appears to be the only sleep model based on the conservation of REM sleep. SLEEP Model is one of only a few models that include caffeine and alcohol as input.

Figures 4, 5, and 6 are example results from SLEEP Model. Figure 9 illustrates the benefits of caffeine use with partial sleep loss. Users can see the results on performance or various risks with their management decisions.

Finally, SLEEP Model is under construction. It is not a perfect or complete model. Two new subroutines have now been developed to be added to the current SLEEP Model: one to consider light input to better manage travel across time zones and one to include fitness and exercise effects on sleep. Predictions shown in Figure 8 are based on this new subroutine.

CONCLUSIONS

One student who improved his academic performance with better sleep management provides a good statement to end this paper. He returned to thank us and said

> Sleep works!

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Table 1
Percentage Risk for Indicated Medical Problem Data from Singh et al., (2005)

	Sleep Amount in hours per day					
	<=5	**>5<=6**	**>6<=7**	**>7<=8**	**>8<=9**	**>9**
Arthritis	36.7	26.0	23.1	20.8	17.4	34.2
Asthma	16.4	15.2	11.2	11.0	11.7	18.8
Cancer	5.5	4.1	4.3	4.8	4.9	8.0
Depression	23.0	17.1	13.5	15.0	15.2	26.8
Diabetes	9.4	5.4	5.0	6.0	4.9	10.7
Emphysema	17.0	8.1	7.3	6.9	10.3	9.8
Epilepsy	4.2	2.3	2.0	1.6	3.4	6.3
Hypertension	33.6	26.4	23.8	22.8	21.6	31.3
Heart disease	9.4	5.1	5.5	6.0	8.0	12.6
Migraines	32.7	26.2	21.9	20.9	20.5	25.5
Stroke	4.5	1.3	0.9	0.8	1.5	2.7
Ulcers	16.1	11.4	9.8	6.2	16.1	12.6

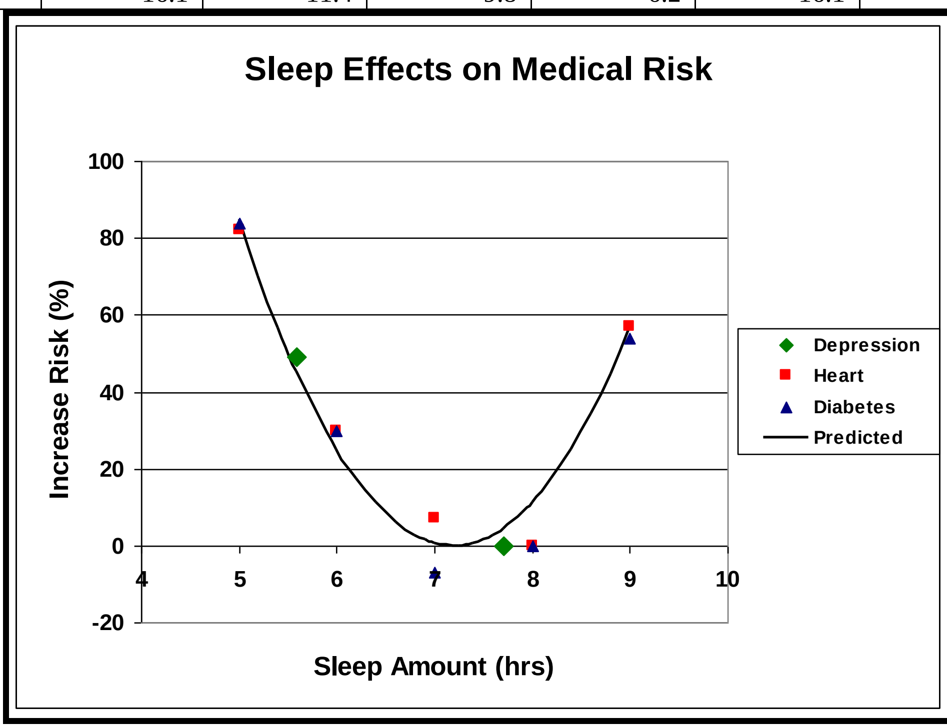

Figure 1 - Risk for Diabetes and Heart Disease and Other Medical Risks
Data for heart and diabetes are from Ayas (2003). Data for depression are from Woodson (2004).

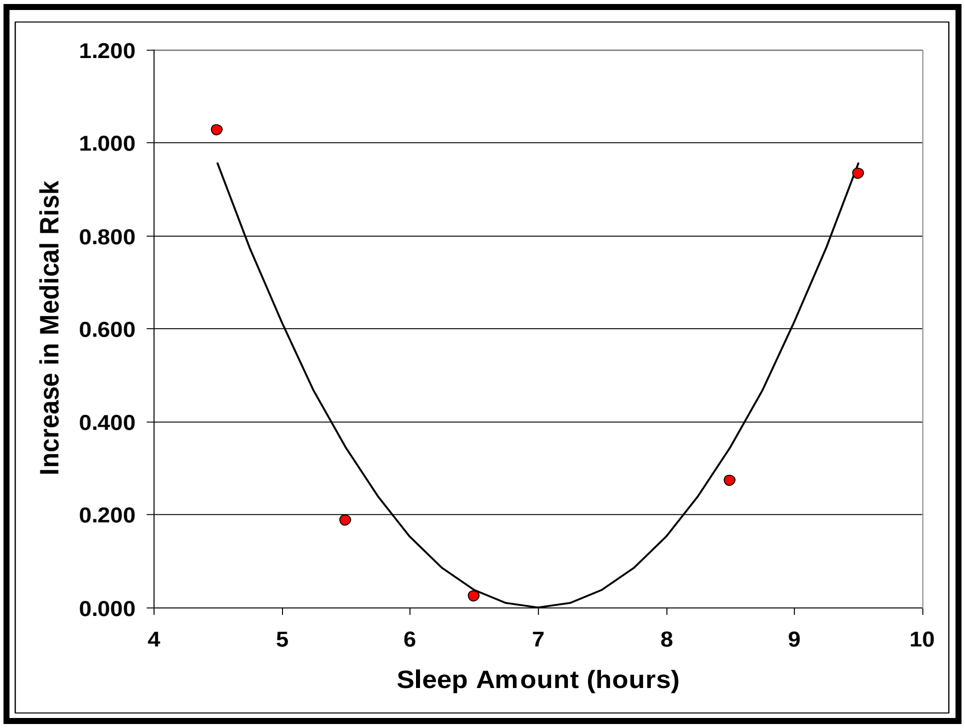

Figure 2 - General Medical Risk Associated with Sleep Amount
Data from Singh et al. (2005).

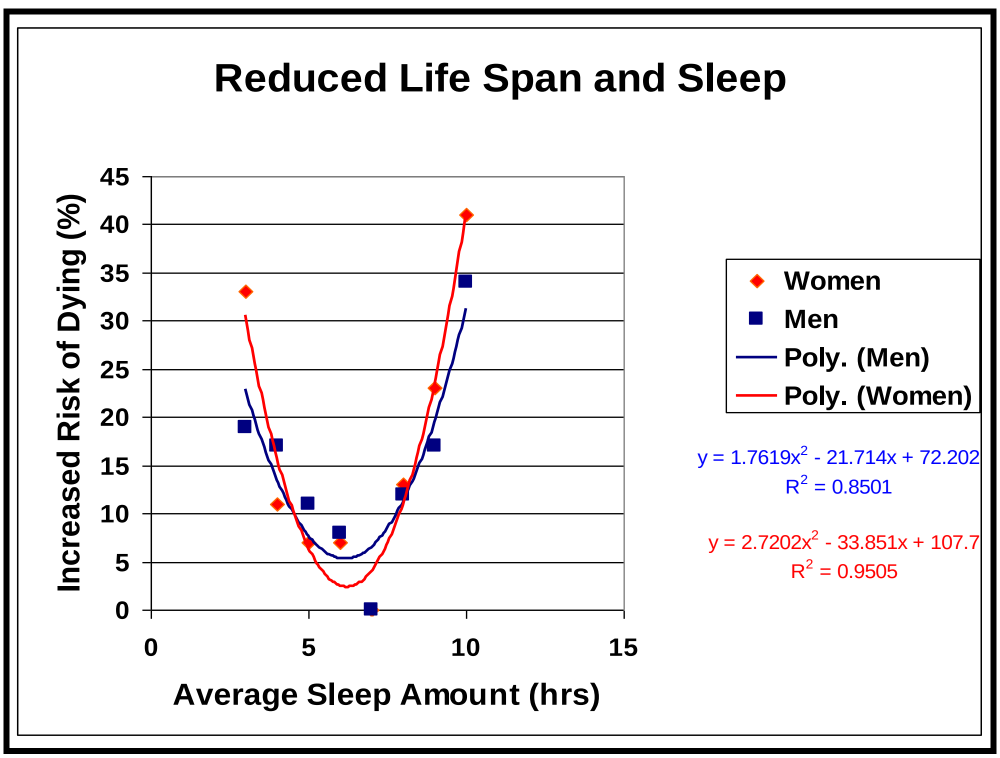

Figure 3 - Sleep Management Effects on Death
Data from Kripke et al. (2002).

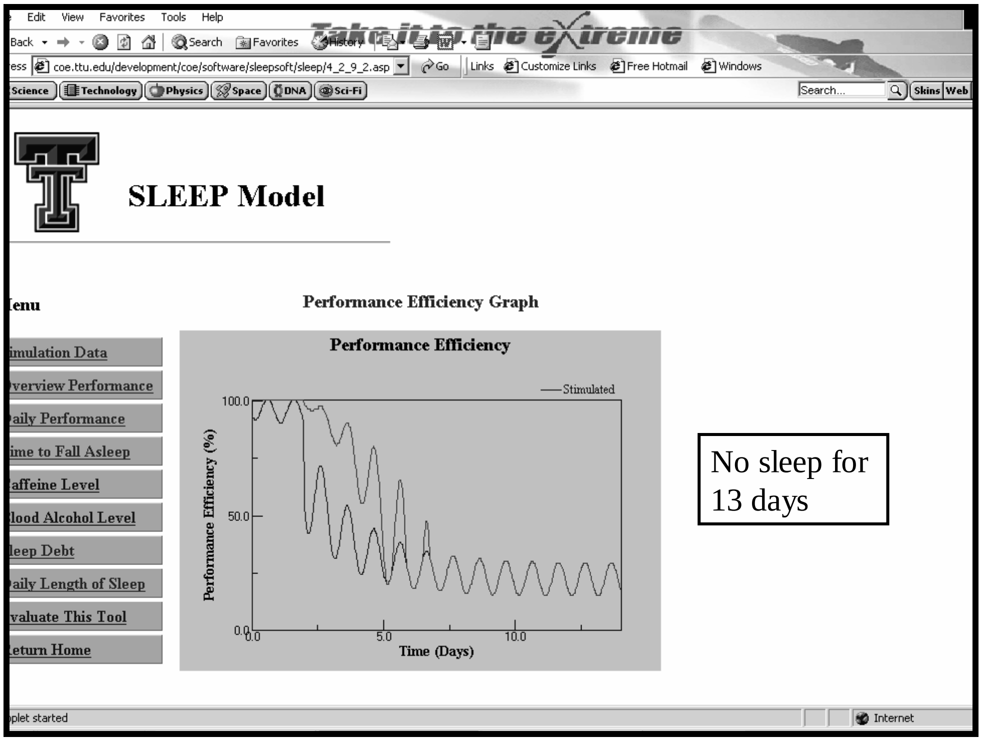

Figure 4 - Typical Passive (blue) and Active (red) Performance Curve
Data for this curve was obtained by simulation of 13 days with no sleep.

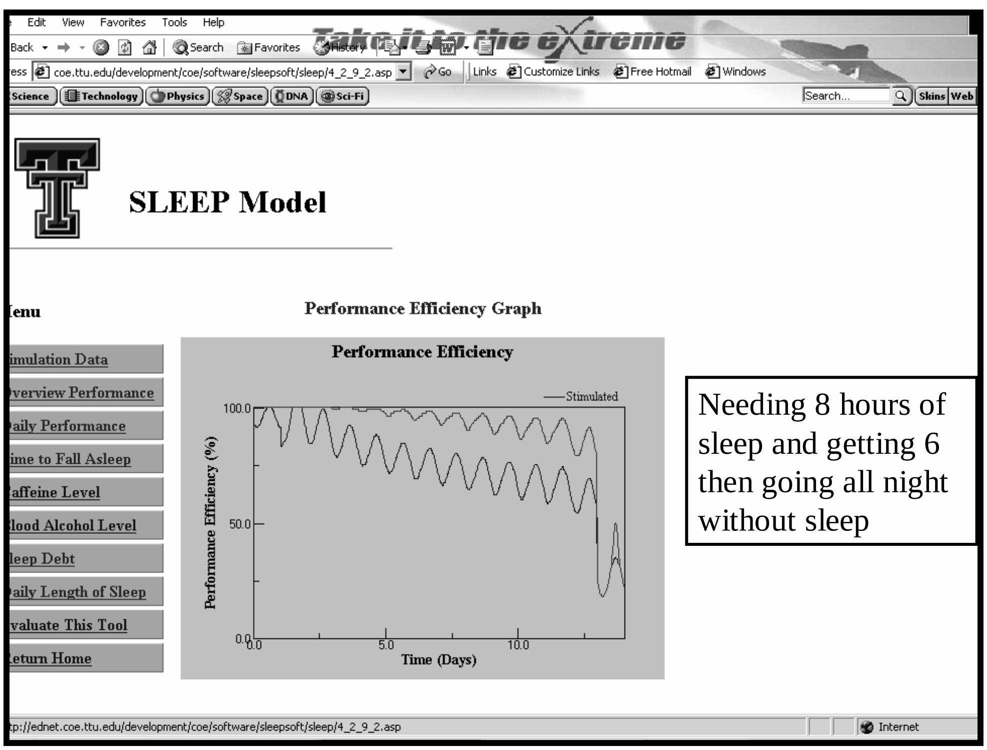

Figure 5 - Simulation of Partial Sleep Loss Followed By a Night of No Sleep
Note the crash in performance associated with the night of no sleep. Also note the difference in performance for this night of no sleep compared to the night of no sleep in the next figure with no sleep debt before the night of no sleep.

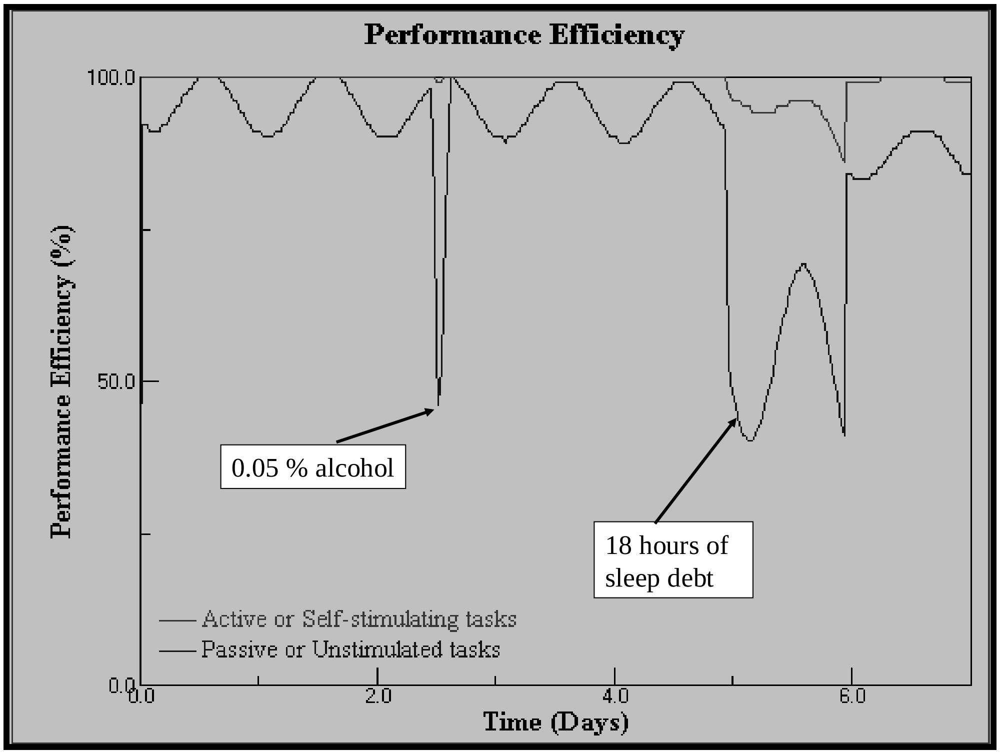

Figure 6 - Predicted Performance From SLEEP Model

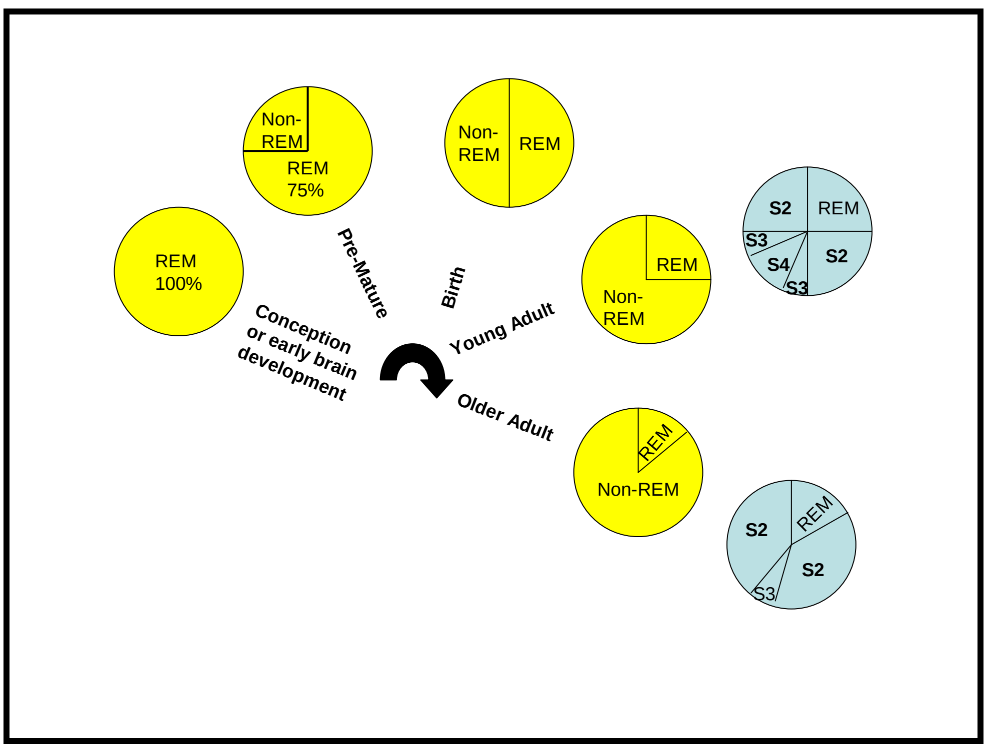

Figure 7 - Change of Sleep Components with Age

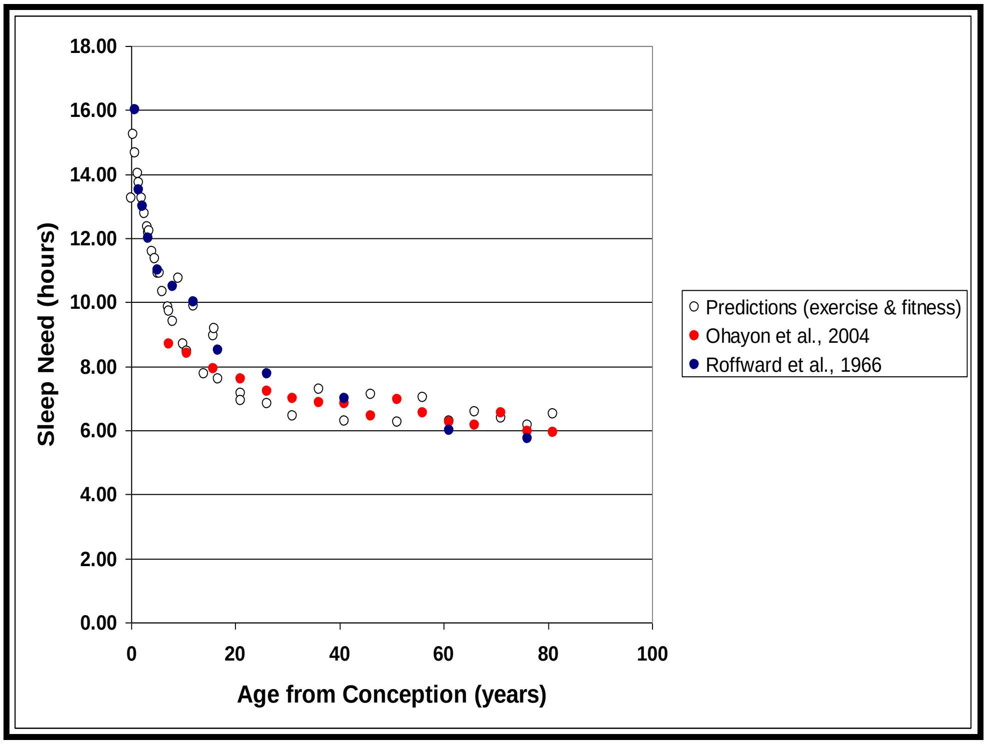

Figure 8 - Change in Sleep Need with Age and With Cultural Changes
Data from Ohayon et al. (2004) and Roffward et al. (1966).
Note that exercise and fitness can account for changes over time.

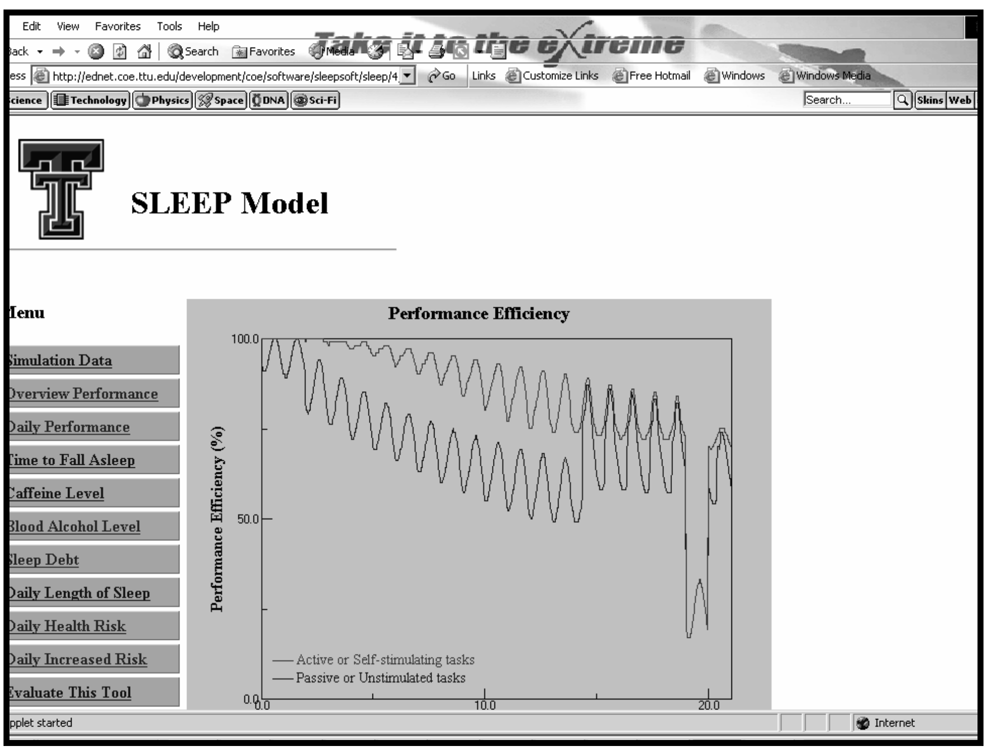

Figure 9 - Illustration of Benefits of Caffeine on Passive Performance During
Third Week of Partial Sleep Loss
Note that caffeine did not help with the night of no sleep for these conditions.