A HUMAN FACTORS ALERTNESS MODULE STUDY VIA BRAIN TOMOGRAPHY

Dr. Li Hsieh
Department of Communication Sciences and Disorders
Wayne State University
Detroit, MI

RJ Ranalli
Beaver Aerospace and Defense, Inc.
Livonia, MI

ABSTRACT

This study investigated the effect of an innovative chilling device that intends to make subjects more alert and less sleepy. Tests were conducted using a variety of methods including electric-encephalography (EEG) brain tomography. A series of behavioral tests showed an increase in alertness, changes of body temperatures, and performance indicators after usage of this device. The device chills specific areas of the body and disrupts the body's ability to self-regulate core body temperature. The induced temperature shifts may reduce the body's capability to go to sleep. Physiological changes and brain wave indicators of alertness were also reviewed in this paper. A full study of alertness indicators in expanded driver simulations is recommended. As for future application of this device to Human Factors aspects, this device may have the potential to enhance alertness in the human dimension of machine operation of manned and unmanned assets with further improvement.

INTRODUCTION

This study has investigated a device that makes people more alert while driving and prevents them from falling asleep at the wheel. A prototype has been tested with alertness and behavioral performance measures as well as electric-encephalography (EEG) brain tomography. The initial tests showed that it is possible to chill specific areas of the body and disrupt the body's ability to self-regulate core temperature. The induced cold temperature may reduce the body's capability to go to sleep. As far as the application of this device to Human Factors aspects, it would enhance the alertness levels in the human dimension of the operation of manned and unmanned systems.

Combat operations, particularly in the low intensity conflicts that have occurred in the past few decades, are insidious in sleep deprivation issues. Although the usage period is not unlimited, during normal use this device prevents users from falling asleep during critical tasks and also increases alertness during the performance of those tasks. Numerous fatigue related accidents and fatalities while driving occur in the armed forces not only during combat, but in all conditions and at all times. The general introduction of this device would perform an important Human Factors function with this life saving potential alone. However, there are other, broader implications for the task alertness module. It can prevent drowsiness during mundane and boring but critical functions requiring close attention. This is important for guard and monitoring duties, but would also be useful for military personnel flying persistent surveillance predatory unmanned aircraft.

This paper describes the background of impact of fatigue driving, preliminary behavioral and brain wave findings, and the correlations between alertness effects and core body temperature shifts.

BACKGROUND

The National Highway Traffic Safety Administration (NHTSA) estimated that police cite driver drowsiness as the precipitating factor of nearly 100,000 motor vehicle crashes reported in the US annually (Royal, 2002). Preventing motor vehicle crashes caused by fatigue and drowsiness has recently become a major focus of researchers interested in improving the safety and well-being of drivers, passengers, and other road users (Lin, et al, 2005). One such tactic is to maintain a cool temperature in the car as a possible countermeasure to reduce sleepiness during prolonged and monotonous drives (Horne & Reyner, 1995). Alertness and sleepiness are strongly coupled to thermoregulation in the distal extremities (Krauchi, et al, 2005). As distal temperatures increase, levels of sleepiness increase and, conversely, as distal temperatures decrease, levels of sleepiness decrease (Krauchi et al, 2005). Empirical research on this issue is lacking, however, and reviews of sleep loss have not addressed the effects of ambient temperatures (e.g., cold versus warm air) on driving performance. Reyner and Horne (1996) asserted that common countermeasures employed by drivers to ameliorate the negative effects of fatigue and drowsiness, such as redirecting cold air directly onto the driver's face via the vehicle's air conditioning system, appear to be of "marginal and transient benefit". However, they also stated that the efficacy of putative in-car countermeasures to driver sleepiness is still largely unknown and more research is required before more definite conclusions can be drawn. Similarly, NHTSA has identified the need for "additional information and research on measures that increase or restore driver alertness or reduce crash risk or incidence."

Advanced imaging research on driving using a surrogate test for driver attention (Hsieh, 2009; Bowyer, 2009) provided a window to look into the brain for frontal-parietal networks while cognitive and attention resources were re-distributed during multitasking. Electroencephalography (EEG) is the most promising among a variety of psychophysiological parameters used in previous research as indicators of fatigue. Some EEG studies found that the combination of EEG alpha (8–11 Hz) and theta (4–7 Hz) power is positively associated with increasing sleepiness (Åkerstedt & Gillberg, 1990; Horne & Baulk, 2004; Rechtschaffen & Kales, 1968). Most research found changes in broad bands, particularly theta and delta bands to be strongly linked to transition to fatigue (Lal & Craig, 2001, 2005). In this study, EEG, ECG, EOG, lane-tracking and behavioral performance measures were used to evaluate the effect of the chilling device on improving driver alertness.

HYPOTHESIS AND PHYSIOLOGICAL BASIS

It was hypothesized that a discrete, sudden reduction of body temperature by introducing cold air to distal extremities of a driver in contrast to the ambient temperature may increase alertness and reduce sleepiness. A prototype of the chilling device developed by Advanced Products and Services (APS) (Milford, Michigan) provided a means to precisely chill the shin area of the lower legs of a driver as a method of decreasing driver drowsiness and subsequently preventing human errors induced by sleepiness (See Figure 1). Since several other factors are involved, a chilling device is designed specifically to eliminate variations in the delivery of chilled air and to be able to adjust the delivery of chilled air as determined by the reception of different inputs. The design intent is to simulate the immediate area surrounding an automotive driver's lower body. The intent of the flow devices, flow shunts, chilling devices, and blowers is to isolate process effects of chilled air to the lower extremities of a normal range of body sizes. The leg temperature to core body temperature can be measured and correlated.

Figure 1. The first generation of the chilling device

SUMMARY OF PRELIMINARY FINDINGS

Alertness was tested in two pilot studies using complementary measures including most or all of the followings: 1) body temperature changes; 2) behavioral performance measures 3) subjective assessment of sleepiness and alertness; 4) EEG physiological measures. The chilling device was designed to temporarily overcome drowsiness and to contribute to a safe driving outcome in the case of a fatigued driver. It is not intended to keep drivers awake on a long term basis due to the inherent dangers of prolonged sleep deprivation. Accordingly, the device was tested only for periods not exceeding one hour.

Pilot Study I: The first pilot study was conducted by Advanced Products and Services of Milford in Michigan based on six subjects (aged 25-60 years old). Results showed that while there was a 100% sustained change in core body temperature, the variance of body temperature was not uniformly down (Figure 2). A 40 year old male subject showed a rise in core body temperature. The temperatures taken in 8 other subjects also showed sustained core body temperature shifts. The range of body temperature change was from 1 to 6 degrees Fahrenheit.

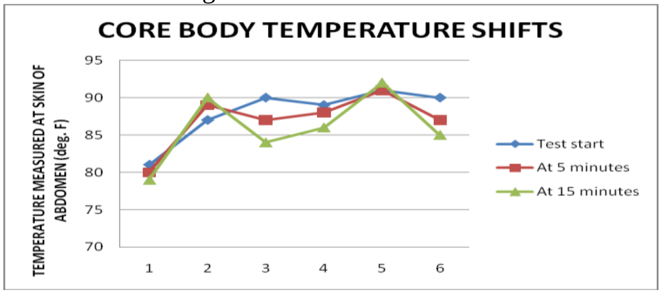

Figure 2. Graph of Core Body Temperature shifts in response to the application of the device

For the examination of microsleep episodes, 8 subjects were tested after a standard day's work schedule and the consumption of an evening meal. Testing was conducted in a room with no windows or other outside distractions and consisted of taking a series of written mathematical tests completed at the subjects' own tempo for one hour periods interspersed with mundane tasks with no particular outcome. The first observations were made without the use of the chilling device (i.e., Baseline). Subjects were observed by monitors for evidence of microsleep episodes. Of the original eight subjects, two were observed to have two episodes of microsleep, two subjects were observed to have one episode of microsleep, and four had no incidents of microsleep. All expressed varying subjective observations of fatigue and boredom.

The second observation was performed with the device attached after the baseline. Sustained changes in core body temperature were observed in all subjects while using the device. Although the most effective temperature at the shin is still under investigation, microsleep might be prevented or reduced when the temperature ranges between 39 degrees and 52 degrees Fahrenheit applied to an area about three inches above the ankle and two inches below the knee. No incidents of microsleep have been observed in any users of the device for up to an hour of tested usage. Subjective report of perceiving temperature changes were given by all subjects within two minutes of application, although sustained core body temperature indications were not present until five minutes into use.

Subjective report also indicated discomfort at chilling levels below 45 degrees Fahrenheit. This discomfort should be individualized when determining the maximum temperature allowable for comfort without sacrificing the effects of preventing or reducing microsleep episodes. The purpose of this application is to prevent or reduce microsleep through disrupting the stability of core body temperature, which has also been improved by shifting the shin chilling temperature up and down to maintain the inability of the body to effectively stabilize thermal stasis.

Based on subject's performance on simple calculations, alertness indicators tracked steadily up to an average of 25% better with the usage of the device than without (Figure 3). All subjects first practiced through samples tests, administered on a computer screen, before the actual experiment. The tests consisted of adding and subtracting 10 sets of numbers with two digits, entering the answer, and continuing to the next problem until all ten were completed. The calculations behind the interpreted increase in alertness were factored between number of correct answers and amount of time to perform simple mathematic calculations. The accuracy would account for a 10% weight of the total score. The time required to completion would count for a 90% weight of the total score as the key determinant of alertness. The estimated shortest time to perform the test was 10 seconds or one second per problem.

Accordingly, the Factored Alertness Score was calculated by using the following formula:

[0.1] x [10 x (number of problems solved correctly per set of 10)] + [0.9] x [2*(50 – total number of seconds required to complete the test in excess of 10 seconds)]

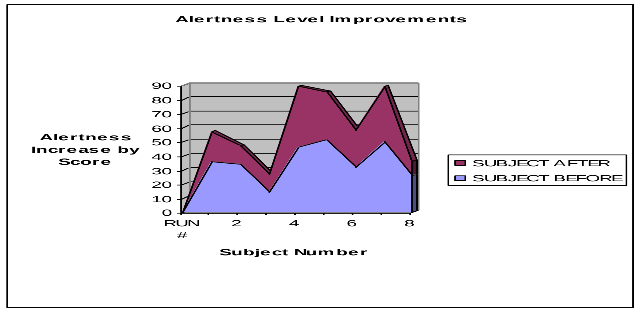

Figure 3. Alertness Indicator Scores showing a 25% increase in alertness, factoring in time per task and number of correct answers per test

Therefore, a perfect alertness score would then be: [0.1] x [10 x (10 correct)] + [0.9] x [2 x (50 – 0 second over the minimum of 10 seconds)] = Factored Alertness Score of 100.

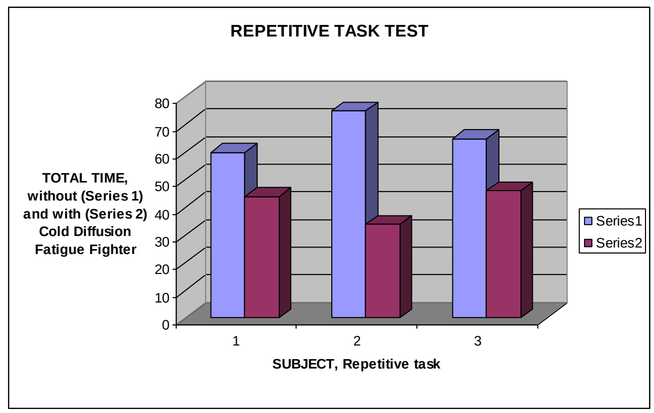

Figure 4. Repetitive Tasks with and without the device showing an increase in scored alertness levels with the device.

To eliminate familiarity being the result of better tests scores, repetitive tests as well as non-repetitive test were conducted throughout all test sessions with and without the device. Three subjects were tested for repetitive tasks and five for non-repetitive tasks.

For the repetitive tests, three subjects performed a series of six repetitive but simple tasks: 3 tasks with and 3 tasks without the device. Time reported for repetitive tests was cumulative (Figure 4). For the non-repetitive skill tests, the dexterity and problem solving ability of five subjects were scored for time of completion based on similar tasks of corresponding complexity. Results of both repetitive and non-repetitive tests showed that the time required to perform these tasks was shorter with the device in use than without for all the subjects (Figures 4 & 5).

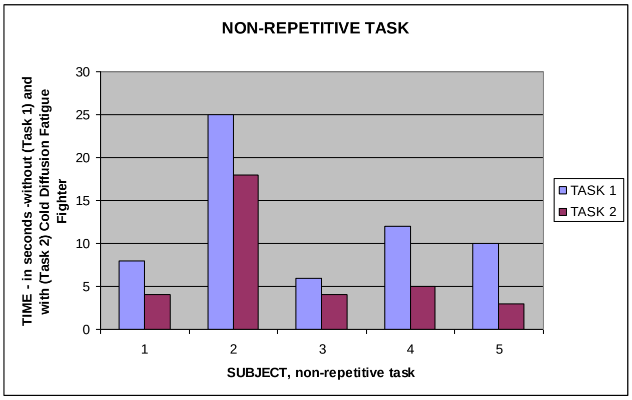

Figure 5. Non-repetitive but similarly complex tasks required less time with the Cold Diffusion Fatigue Fighter in use.

Results of Pilot Study I indicated that the chilling device which may enhance alertness and possibly be beneficial for other machine operator applications. Pilot Study II was conducted to investigate the alertness levels and associated brain activations by using simultaneous EEG recordings when subjects were engaged in a validated driver attention task.

Pilot Study II: Pilot Study II used a simulated driving paradigm to evaluate alertness and reaction time performance with the intervention of this chilling device. At the same time, Pilot Study II also investigated the changes in physiological and neurological signals, resulting from manipulation of air temperature of this device.

Three normal subjects (aged 22-27 years old) without sleep deprivation were screened for handedness, auditory and visual acuity, sleepiness scale (John, 1991) attention disorder scale, depression, driving records and neuropsychological history.

Each subject completed three driving conditions with manipulation of air on specific shin region of the lower legs: driving baseline without air, driving with air, and driving with cold air on the shin of lower legs. Each experimental condition consisted of two 9-minute driving sessions. Therefore, each subject went through six driving sessions on a computer-based driving simulator with the total experimental time about an hour. Throughout the simulated driving task, the subject was asked to keep track at the center of the lane in a real world driving video by steering the steering wheel. The subject was also instructed to detect and respond to red light events by pressing a foot pedal as quickly and as accurately as possible. Behavioral reaction times, accuracy, and EEG recordings were collected simultaneously during the experiment.

Data was recorded using a 64-channel Waveguard cap in Hsieh's lab at the Wayne State University. Data was band pass filtered at 0.5-30Hz, corrected for artifacts, averaged with artifacts removed, and corrected for baseline differences. For the EEG Spectrum analysis, six 9 min segments obtained per subject were processed. The subsequent artifact-free segments were subjected to spectrum analysis after filtering Delta (0.5-3.5 Hz), Theta (3.5-7.5Hz), Alpha (7.5-12.5 Hz), and Beta (12.5-30 Hz)

In addition, core body temperature, self-rating sleepiness scale (Maclean, Fekken, Saskin, & Knowles, 1992), self-rating alertness level (Scale of 1-8), and a set of 10 math questions at the level of 12th grade were measured at pre, between and post driving sessions.

The room temperature during the experiments was 74-75 degrees. The temperature of the air supplied from the device was measured at 71 degrees, whereas temperature of the cold air ranged from 52.3, 55.6, to 59.4 degrees for S1, S3, and S2, respectively.

<u>**Body temperature changes:**</u> Preliminary data showed that all subjects went through 1-2 degrees of the core body temperature shifts measured at the skin of abdomen from the simulated driving baseline to the driving conditions with air and cold air, respectively (Figure 6). Subjects' self-ratings of perceptual temperature changes are consistently lower after the driving condition with cold air (Figure 7).

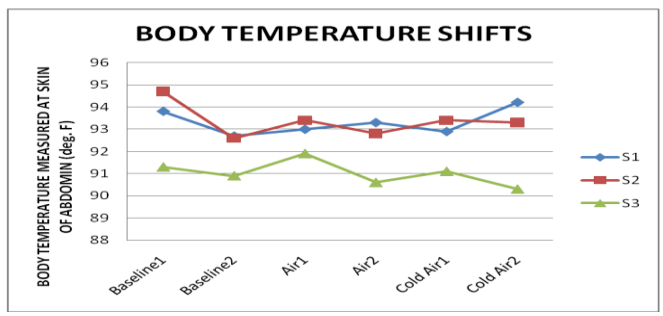

Figure 6. Body temperature shifts throughout the simulated driving task.

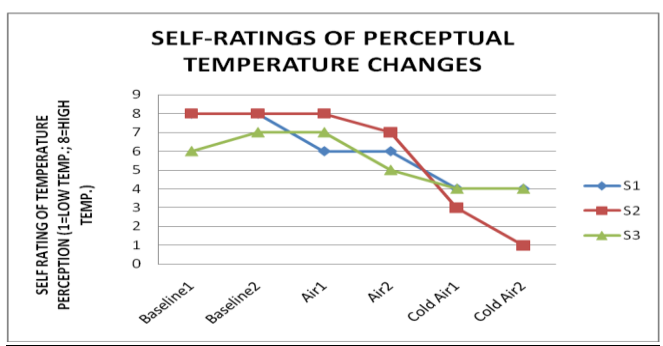

Figure 7. Self-Ratings of Perceptual Temperature Changes throughout the simulated driving task.

Self-Ratings of Sleepiness Scale and Alertness Level: Two healthy, young subjects (i.e., S1 and S3) reported feeling less sleepy and more alert after application of cold air with the device (Figures 8 & 9).

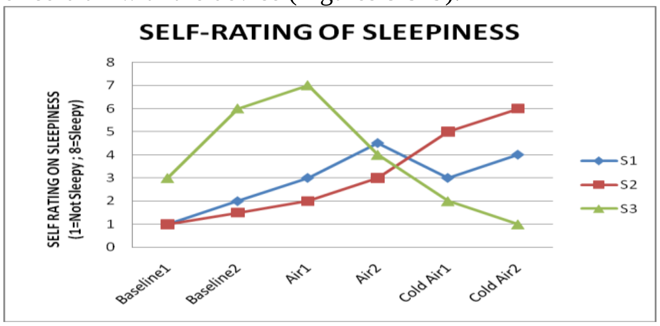

Figure 8. Self-Rating of Sleepiness throughout the simulated driving task.

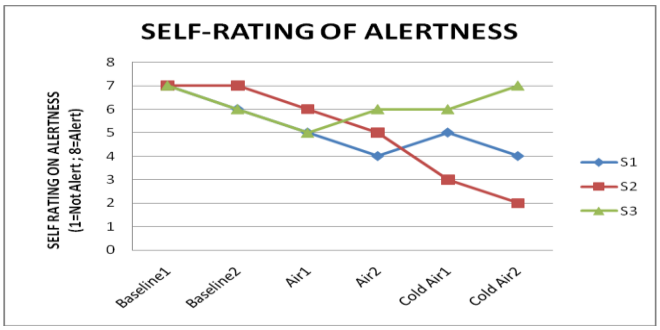

Figure 9. Self-Rating of Alertness throughout the simulated driving task.

Behavioral Performance Findings:

1. ***Alertness Index based on the math tests:*** According to the formula used in Pilot Study I for the Alertness Index, there was an average of 32% increase with the air and an average of 45% increase with the cold air, compared to the no air condition in Pilot Study II (Figure 10).

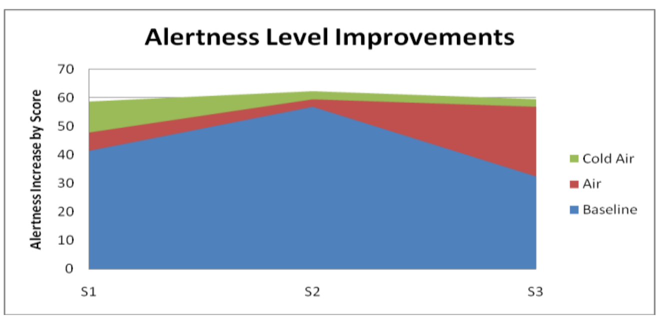

Figure 10. Alertness Indicator Scores showing an average of 45% increase in alertness under cold air condition in Pilot Study II, factoring in time per task and number of correct answers per test.

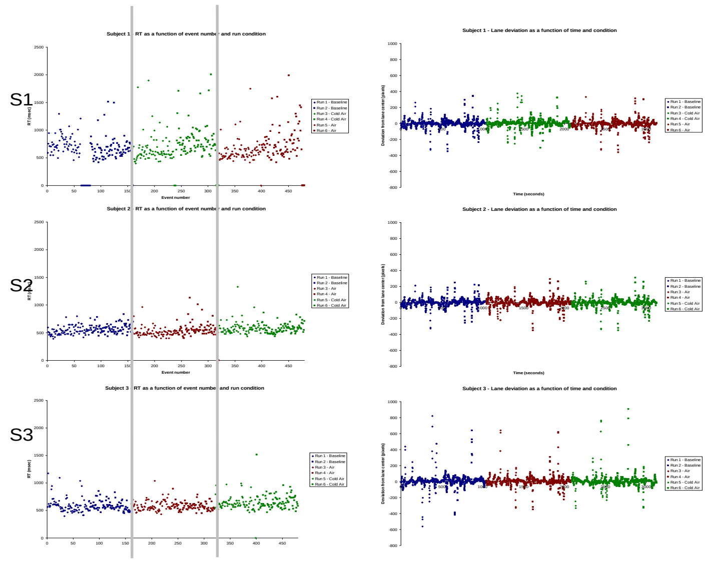

Figure 11. Reaction time performance of visual event detection (left panel) and standard deviations of lane tracking from the center of the lane during simulated driving (right panel) during simulated driving [blue color=baseline driving condition; green color=driving with cold air; red=driving with air].

2. ***Performance during simulated driving:*** Behavioral performance of visual event detection during simulated driving showed slightly faster reaction times after the transition between conditions when applying air (red dots) and cold air (green dots) with the device (See the reaction time distributions after the grey lines on the left panel of Figure 11). On the other hand, the lane tracking data based on the standard deviations from the center of the lane did not show any difference across conditions for all three subjects (Right panel of Figure 11). The driving performance results was not surprising to because the sample size of 3 subjects for Pilot Study II is small and because all of the subjects were healthy young adults without sleep deprivation. The lane tracking results confirmed that lane tracking of all three subjects was consistent with no significant lane deviations/departures which could be signs for crash or near crash incidents at the time of this driving experiment.

Preliminary EEG Physiological Findings: EEG data based on 3 subjects were inconclusive due to the small sample size. However, in the EEG frequencies of S3, beta waves in both left and right hemispheres showed an increase in power with application of the air and cold air, similar to

S3's self-rating alertness level (Figure 12). EEG measures could be promising for future studies as sample size becomes larger with application to the sleep deprived or drowsy drivers.

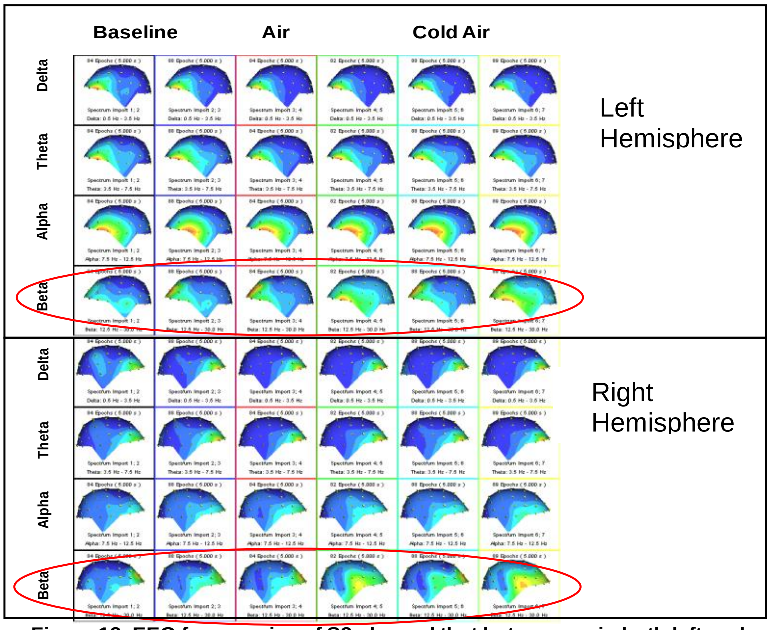

Figure 12. EEG frequencies of S3 showed that beta waves in both left and right hemispheres had an increase in power with application of the air and cold air, similar to S3's self-rating alertness level.

DISCUSSION AND CONCLUSION

This study investigated the effect of an innovative chilling device that intends to make subjects more alert and less sleepy. Tests were conducted using a variety of methods including electric-encephalography (EEG) brain tomography. An initial series of fractional factorial tests during usage showed an increase in alertness, changes of body temperatures, and performance indicators. The device precisely chills specific areas of the body and disrupts the body's ability to self-regulate core body temperature. The induced temperature change may reduce the body's capability to go to sleep. As measured by behavioral tests, the device also improved reaction time performance in fatigued individuals after a short period of application of this device. Laboratory evaluation including brain wave indicators of alertness and physiological changes in Pilot Studies I and II can be summarized as follows:

1. Core body temperature shifts were evident (ranged from 1 to 6 F^o) in response to the application of the device for both Pilot Studies I and II. Pilot Study II confirmed that subjects perceived the temperature changes in correspondent to the air temperature provided by this device.
2. Alertness indicator scores increased after application of this device for both Pilot Studies I and II. These scores were calculated based on a formula factoring time and accuracy for math tests, listed in earlier section;
3. Two healthy, young subjects (i.e., S1 and S3) reported feeling less sleepy and more alert after application of cold air with the device in Pilot Study II.
4. Reaction time performance during simulated driving were slightly faster after the transition between conditions when applying air (red dots) and cold air (green dots) with the device. This finding provides an estimated effective time window for application of this device based on 3 healthy, young participants. With larger subject group and control of sleep deprivation conditions, this testing paradigm may provide more precise and reliable time windows for optimal usage of this device with an individualized and adaptive temperature control.
5. EEG Beta waves may be sensitive to self report alertness.

Suggestions for future studies include:

1. Larger sample size with sleep deprived and control populations.
2. Development of a human perception model to optimize the chilling device operation which senses individual body temperatures and provides adaptive and individualized temperature control with a rapid-onset and portable capability.
3. Development of effective time windows for application of cold air with this device for each decrement of the chilling temperature with the consideration of individual body temperature.
4. More EEG and alertness studies are needed to examine the validity and reliability of this drowsiness countermeasure device.

A full study of alertness indicators in expanded driver simulations with a larger sample size, sleep deprivation and a human perception modeling with an adaptive and individualized temperature control is recommended. As for future application of this device to Human Factor aspects, the device may have potential benefits to enhance the alertness levels in the human dimension of the operation of manned and unmanned assets with further improvement.

A follow-up EEG study will be conducted at Wayne State University to examine drowsiness countermeasure on driving performance and sleepiness during a prolonged and monotonous simulated drive after a night of restricted sleep. Drowsiness will be measured using complementary measures including 1) eye tracking and physiological measures; 2) subjective assessment of sleepiness and alertness; and 3) driving performance measures.

REFERENCES

[1] NHTSA. “Drowsy driver detection and warning system for commercial vehicle drivers: Field proportional test design, analysis, and progress”, National Highway Traffic Safety Administration, Washington, DC. [on-line]. Available: http://www.nhtsa.dot.gov/

[2] D. Royal, “National Survey of Distracted and Drowsy Driving Attitudes and Behavior: 2002. National Highway Traffic Safety Report: DOT HS 809 566”, 2002.

[3] C-T Lin, R-C. Wu, S-F. Liang, W-H. Chao, Y-J. Chen, & T-P. Jung, “EEG-based drowsiness estimation for safety driving using independent component analysis”, IEEE Transactions on Circuits and Systems-I, Regular Papers, Vol. 52, No. 12, December, 2005.

[4] K. Krauchi, C. Cajochen, & A.Wirz-Justice, “Thermophysiologic aspects of the three-process- model of sleepiness regulation”, Clinics in Sports Medicine 24, 287-300, 2005.

[5] JH Horne and LA Reyner, “Counteracting driver sleepiness: Effects of napping, caffeine and placebo”, Psychophysiology, 33, 306-309, 1996.

[6] SM Bowyer, L. Hsieh, JE Moran, RA Young, A Manoharan, C-C Liao, K Malladi, Y-J Yu, Y-R Chiang,& N Tepley, “Conversation effects on neural mechanisms underlying reaction time to visual events while viewing a driving scene using MEG”, Brain Research, 1251, 151-161, 2009.

[7] L. Hsieh, RA Young, SM Bowyer, JE Moran, RJ Genik II, CC Green, Y-R Chiang, Y-J Yu, C-C Liao, S Seaman, “Conversation effects on neural mechanisms underlying reaction time to visual events while viewing a driving video: An fMRI study”, Brain Research, 1251, 162-175, 2009.

[8] T. Åkerstedt and M. Gillberg, “Subjective and objective sleepiness in the active individual”, International Journal of Neuroscience, 52, 29–37, 1990.

[9] J.A. Horne and S.D. Baulk, “Awareness of sleepiness when driving”, Psychophysiology, 41, 161-165, 2004.

[10] A. Rechtschaffen and A. Kales, A manual of standardized terminology, techniques, and scoring system for sleep stages of human subjects, Los Angeles: UCLA Brain Information Service.1968.

[11] S. K.L. Lal and A. Craig, “A critical review of the psychophysiology of driver fatigue”, Biological Psychology, 55, pages 173-194, 2001.

[12] S. K.L. Lal and A. Craig, “Reproducibility of the spectral components of the electroencephalogram during driver fatigue”, International Journal of Psychophysiology, 55 (2), Pages 137-143, February 2005.

[13] M.W. Johns, “A new method for measuring daytime sleepiness: The Epworth Sleepiness Scale”, Sleep, 14, 540–545, 1991.

[14] A. Maclean, G.C. Fekken, P. Saskin, and J.B. Knowles, “Psychometric evaluation of the Stanford Sleepiness Scale”, Journal of Sleep Research, 1(1), 35-39, 1992.