Effects of Temperature on Sleep: Constructing a system to Manipulate Body Temperature to Improve Sleep Quality, Onset, and Arousal.

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1 Introduction

According to a 2010 National Sleep Foundation poll, three in ten Americans report rarely getting a good night's sleep. This perception of insufficient sleep can be due not only to the quantity of sleep recieved, but also the experience of falling asleep and waking as well as the quality of sleep recevied. A recent study performed in the UK found that 62% of respondents reported taking at least 15 minutes to fully wake up in the morning. A study by the the National Sleep foundation in 2009 found that 29% of Americans have difficulty falling asleep at least once a week[3]. Finally, the National Sleep foundation's 2008 Sleep in America study reported that 42% of respondents had midsleep awakenings, multiple times a week[2]. When faced with these sleep difficulties, many turn to prescription or over-the-counter medication; a 2008 Consumer Reports study found that 1 in 5 Americans medicate for sleep at least once a week[1]. To help remedy this situation we propose a system which we believe to be both healthier and more effective than medication at improving sleep quality and quanity. This system, which we are calling Warm Wake, may allow for a more natural waking experience, quicker sleep onset, increased REM sleep quantity, and fewer nocturnal awakenings. Its combination of sleep state monitoring, and temperature control allows it to manipulate the users' skin temperature in order to maintain, manipulate or terminate sleep depending on the users' needs.

2 Our Solution

2.1 Summary

Our system design consists of four major subsystems: a sleep phase monitoring subsystem, a skin temperature monitoring subsystem, a temperature actuation subsystem, and a data processing subsystem.

The sleep phase monitor uses a dry EEG headband (the Zeo) to measure the sleep state of the user, differentiating between light, deep and REM sleep. It is worn throughout the night and passes the user's sleep state to the processing subsystem in ten-second intervals.

The skin temperature monitoring subsystem consists of a small temperature sensor, strapped acrosss the chest, and fixed to the users side, underneath their left arm.

The temperature actuation subsystem consists of a temperature regulating mattress pad. The mattress pad circulates heated or cooled water throughout the pad to maintain a set temperature. It is controlled by the processing subsystem, which interprets the sleep phase data coming from the headband, and the temperature data coming from the temperature probe while also monitoring the time and time since sleep onset. Using this data, it runs a simple algorithm to set the optimal temperature.

This processing subsystem, and the integration it provides is the novel element in our system. There currently exist multiple solutions for sleep state monitoring, including dry EEG solutions such as the Zeo headband and less accurate smartphone apps which monitor movement. There also exists at least one temperature regulating mattress pad, sold by Chili Technologies as the ChiliPad. However, we have been unable to find any system which integrates these technologies, along with a temperature monitor to provide the benefits promised by the aforementioned research.

2.2 Research System

Once we solidified our initial design we constructed a research system. This was necesary in order to confirm that the results found in our literature review could be replicated using inexpensive, consumer grade devices, under nonlaboratory conditions. Our research system has all the same specifications as our full system design described above, but with some additional functionality for monitoring and debugging.

For our sleep monitoring subsystem we use the Zeo (Zeo, Inc.) sleep phase monitoring headband (Figure 2). The headband communicates with an Android (Google) application of our own design which monitors sleep phase data and submits it to a debugging and logging server, as well as the system's data processing server.

Our skin temperature monitoring subsystem consists of a form-fitting shirt, modified to hold a battery pack, wifi enabled microcontroller, and temperature probe (Figure 3). The temperature probe is mounted to the inside of the shirt, which provides insulation while also affixing the probe to the skin. The data processing server determines the corrrect temperature to set at any given time, using an algorithm of our design.

Right now, for our research system, this algorithm is very simple; it is an alarm which changes the temperature at a certain time. This is only for research, so we can observe the effect of changing ambient temperature under consistent and relatively controlled conditions. However, the processing subsystem does have full access to real-time temperature and sleep phase data, so once initial research is complete the algorithm can be easily developed to be more intelligent.

The data processing subsystem communicates wirelessly with our temperature actuation subsystem. This linkage (shown in Figure 4), in our research system, is simply an Arduino connected to a wireless controller. For temperature actuation we use the ChiliPad™(Chili Technology) temperature regulating mattress pad. It can set ambient temperature between 46 and 118 degrees fahrenheit, although our algorithm only utilizes a range between 65 and 95 degrees. This is the range which we've found does not disrupt sleep enough to induce wakefullness. Our system architecture and component specification can be seen in 1.

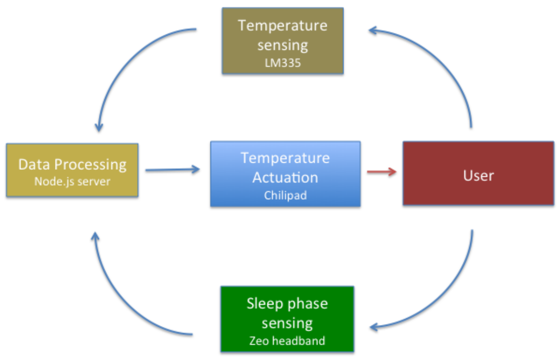

Figure 1: Our system architecture and component specification. The blue arrows indicate data flow and the red arrow indicates actuation.

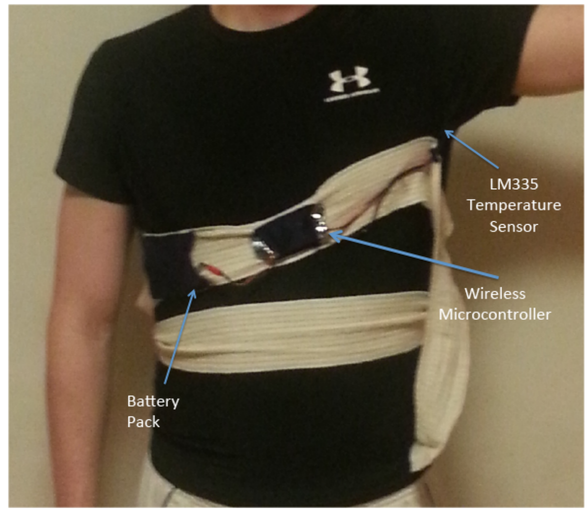

Figure 3: A subject wearing our temperature monitoring subsystem. It commnunicates with our data processing subsystem via the wireless microcontroller.

Figure 2: A subject wearing the Zeo headband, which we used for our sleep monitoring subsystem.

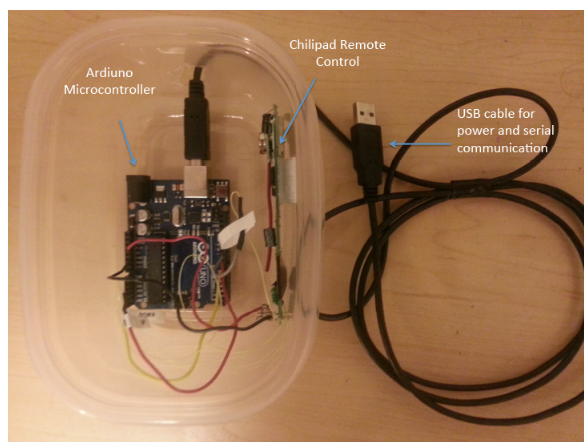

Figure 4: The setup we used to control the Chilipad. We used an Arduino to simulate button presses on the Chilipad remote, which communicated wirelessly with the chilipad

3 Validation

While we have not yet run a rigorous enough study to fully validate whether our system will be able to affect the sleep improvements seen in the above research, we have performed preliminary tests on one team member, which has returned promising results. In our trials, we set the temperature of the mattress pad to ambient temperature for the first half of the night, then approximately half way through the night, at 8:30 AM, the temperature was switched. This allowed us to use the first half of the night as a "control" to which we could compare the second half of the night. This control is flawed, as sleep is not time invariant, and changes as duration increases. However, by comparing these trials to tests run without temperature manipulation we believe we can begin to identify possible effects of changing ambient temperature mid-sleep.

We ran two sets of temperature-switch trials. The first involved a mid-sleep ambient-to-warm temperature change. In these tests, we switched the temperature of the matress pad to 93 degrees Farenheit halfway through the night. 93 degrees is at the upper edge of the thermoneutral zone, the temperature range through which ambient temperature can be manipulated during sleep without inducing wakefulness.

Based on our research, we expected that the subject whould experience more REM, and less deep, sleep. Our results, some of which are shown in Figure 5, appear to validate our expectations. It seems that increasing the temperature to the edge of the thermoneutral zone suppressed deep sleep, which does not appear following the temperature switch in either trial. In addition, the switch may be enhancing REM sleep, which appears to increase in duration and frequency following the 8:30 mark. Of course, REM sleep does naturally increase in duration over the course of a night, so it is difficult to make even preliminary conclusions regarding the effect of temperature on REM sleep frequency and duration with this data alone.

Furthermore, from the temperature data in Figure 5 it is clear that our method of temperature measurement is imprecise, and probably inadequate for observing the effects of changing the ambient temperature. Its 5-10 degree fluctuations are likely due to movement of the probe, and not due to actual changes in skin temperature, as most research we read reported temperature changes no more than +- 1 degree.

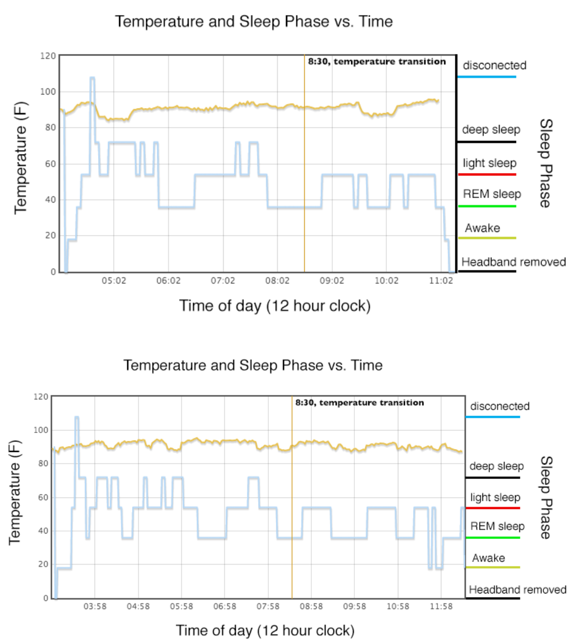

Figure 5: The temperature and phase data from two trials where ambient temperature was increased to 93 degreees Farenheit at 8:30 AM

Our second set of trials involved a ambient-to-cold temperature switch. Based on our research, lowering the ambient temperature during sleep should have the oppposite effect from raising the temperature; the frequency and duration of deep sleep should increase, and REM should reduce. For these trials, we had most of the same environmental conditions as in the aforementioned experiments, but switched the temperature to 68 degrees Farenheit instead of 93 halfway through the night.

It should be kept in mind that all the experiments we ran were both to test our hypotheses, but also to test the system, to identify and address issues. As such, many trials, including these ambient-to-cold tests in particular were plagued by technical difficulties. We were, however, able to collect one sleep session's worth of phase data, shown in Figure 6.

Although we were not able to collect temperature data (due to equipment failures) it is clear that the response to the temperature switch here is different from before. The most obvious difference is that there are two periods of deep sleep following the 8:30 shift. This is markedly different from the warm-to-hot trials shown above, in which no deep sleep was recorded following the 8:30 mark. Unfortunately, the phase monitor fell off an hour after the switch, so we were unable to see if there were additional periods of deep sleep, or reduced REM sleep during the rest of the session.

Although we are not able to draw any statistically significant conclusions about the effect of manipulating ambient temperature on sleep quantity and quality, from our trials, the testing was still immensely useful. Our tests with the system allowed us to identify technical problems with the system, such as our ineffective temperature measurement strategy. They also did demonstrate some possible trends, which warrant further exploration, including the possible increase in deep sleep quantity and duration caused by cold ambient temperatures, and increase in REM duration and quantity caused from warm temperatures.

4 Conclusion

We have designed and constructed a system capable of manipulating ambient temperature during sleep based on skin temperature and sleep phase. Using this system, we have performed experimental trials, testing the effectiveness and reliability of the system, while also identifying areas of exploration. These areas we identified, namely the effect the system has on deep and REM sleep, are worthy of additional research. This research should be aimed at discovering whether the system can really be used to effect sleep in the ways described in various studies, and whether it can use those effects to improve sleep quality and quantity for the average consumer.

5 Conclusion

References

[1] anonymous. How did you sleep last night?, September 2008.

[2] WBA Market Research. 2008 sleep in america poll. Technical report, National Sleep Foundation, 2008.

[3] WBA Market Research. 2009 sleep in america poll. Technical report, National Sleep Foundation, 2009.

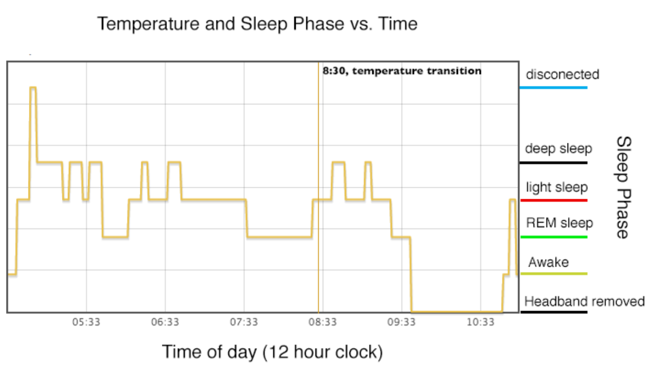

Figure 6: Sleep phase data from a trial where temperature was switched to 68 degrees Farenheit at 8:30 AM. Temperature data was not collected due to technical difficulties.