Effects of Temperature on Sleep: Manipulating Body Temperature to Improve Sleep Quality, Onset, and Arousal.

David Gaynor, Kelsey Breseman

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Abstract

Core body temperature is a crucial factor influencing how easy it is to fall asleep, ease of awakening, and quality of sleep. This paper reports on research supporting the effects of temperature on sleep and proposes a device to improve sleep quality by manipulating the temperature of a sleeping subject.

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[16]. Finally, the National Sleep foundation's 2008 Sleep in America study reported that 42% of respondents had midsleep awakenings, multiple times a week[15]. 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[3]. To help remedy this situation we propose a system which is both healthier and more effective than medication, which allows for improved sleep onset, arousal and quality without side effects. This system, which we are calling Warm Wake, will allow for a more natural waking experience, quicker sleep onset, increased REM sleep quantity, and few nocturnal awakenings. Its combination of temperature sensing, sleep state monitoring, and temperature control allows it to manipulate the users' core body temperature in order to maintain or terminate sleep depending on the users' needs.

2 Temperature and Sleep Onset

Sleep is easiest to attain during the temperature minimum circadian phase. This phase starts about 5-6 hours before the circadian temperature minimum and extends to about 1-3 hours after it, with sleep propensity increasing the closer you are to the sleep minimum, and decreasing as you approach the maximum [11, 18]. In fact, the sleep initiation process is most likely to occur at the maximum rate of temperature decline [17]. Immediately before the temperature minimum phase is the wake maintenance circadian zone (WMZ), in which sleep is most difficult to attain. Individuals with sleep onset insomnia (SOI), usually exhibit delayed circadian phases, where their temperature minimum phase comes later than their bedtime. As a result they find it very difficult to fall asleep. Studies show that sleep onset is influenced by the rhythm of temperature [18] and can be influenced by the manipulation of a subject's temperature. Lowering core body temperature, for example, through selective warming of skin at the hands and feet, can effectively advance one's temperature minimum, and additionally, release melatonin, both of which increase sleep propensity.[13].

3 Temperature and Sleep Quality

It has been suggested that skin temperature could act as an input signal to the regulation of sleep [13]. Sleep consists of rapid eye movement (REM), in which the brain is very active but the body has a reduced regulatory response; and non-REM (NREM) sleep, characterized by an actively regulating but otherwise inactive brain in a moveable body. NREM sleep is further subcategorized into four numbered stages of increasing depth of sleep. Stages 1 and 2 are light sleep, from which a sleeper can be easily awakened. These typically occur at the onset of sleep. Stages 3 and 4 are termed "slow-wave-sleep" (SWS) and cycle periodically with REM sleep throughout the night [6].

"Good" sleep is typically characterized by high sleep efficiency (amount of time asleep divided by amount of time in bed attempting to sleep), a low number of arousals, and a refreshed feeling upon awakening. Subjective reports demonstrate that subjects feel sleep is "better" when SWS energy is low and sleep occurs near the trough in core temperature [1, 2]. Additionally, the absolute amount of REM sleep a subject experiences at night has been correlated with higher intellectual functioning the next day [6].

Body temperature is highly correlated with the regulation of sleep state. Though many more studies are available on the correlation of core temperature with sleep phase, these studies require rectal probes, and are thus not directly applicable to our device. Instead, we focus on the manipulation of ambient temperature, temperature inside the bed, and skin temperature, all of which have proved strong effects on sleep structure [12, 13, 14]. In particular, the number of arousals reduces significantly when the temperature is maintained at a zone of thermoneutrality within the bed at a temperature of approximately 30 °C. Even slight variations around this thermo-neutral zone can change the structure of sleep. REM sleep is particularly depressed by colder temperatures, while SWS is more depressed with more heat [12].

Sleep structure is also dependent on circadian oscillators, including core body temperature (not to be confused with skin temperature or the temperature of the environment [5]). REM sleep is preferentially distributed toward the later part of the night, which is linked to a circadian oscillator which can be tracked through the oscillation of core body temperature [6, 7, 10, 12]. This means that if sleep does not reach into the peak circadian time for REM sleep, a subject will be disproportionately deprived of REM sleep, causing noticeably lower intellectual functioning the next day [6]. The coupling of REM sleep propensity and body temperature cycle could mean that the two are independently controlled by a different circadian oscillator, or that there could be a direct and manipulable effect of body temperature on the timing of REM sleep and on the sleep-wake cycle [18].

The ability to maintain sleep is also dependent on sleep stage, and thus on temperature. In particular, the body's thermoregulatory responses are sleep stage dependent: during REM sleep, the body reduces its regulation of temperature and of the sweating response. Thus sleep is more easily disturbed during REM sleep, and is more sensitive in general to cooling than to warming. Some sources suggest that the cyclic alternation between SWS and REM may be necessary in order to keep the body within its thermoneutral zone and thus asleep for longer [12, 18].

4 Temperature and Waking

Just as a lower core body temperature is more amenable to falling asleep, a higher one can result in increased alertness upon awakening. In a subjective study, patients who were asked how refreshed and alert they felt when they woke up consistently rated their waking experience higher when awakened near the peak of their temperature cycles [2]. Furthermore, a study by Erin Baerh for NIH found that M-type individuals (morning people) had an earlier sleep minimum, and thus woke up higher on their temperature curve, closer to their maximum [4]. M-types are more active and productive in the morning, after waking than N-types, who have a later temperature minimum. This can be problematic for N-types who, as shown by a study at the University of North Texas in Denton, perform a full letter grade worse than those who have pleasant waking experiences (M-type)[8]. We hypothesize that artificially raising core body temperature near waking will result in a more pleasant arousal, and possibly an overall advanced circadian phase.

Other factors contributing to a refreshed feeling upon awakening include higher sleep efficiency [1] and the amount of SWS sleep present in the night: the more SWS sleep subjects accumulated in the night, the harder it was to arouse them [2] (though notably, it does not seem to matter which phase of sleep a subject is in when they are awakened [2, 7]). All of these factors are controllable, as discussed above, by a device which regulates body temperature.

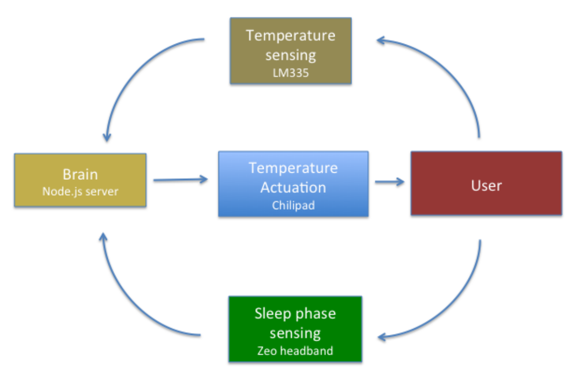

Figure 1: A simple diagram illustrating our current system. It illustrates the 4 major subsystems of our system, temperature actuation, temperature sensing, sleep phase sensing, and "brain".

5 Our System

Our system consists of two sensing subsystems, a temperature actuation subsystem, and a "brain" subsystem. Our first sensing subsystem is for skin temperature sensing. It consists of a strap worn across the chest, which fixes a temperature sensor against the axilla floor. This sensor communicates with the "brain" server, running on a laptop using a wifi enabled microcontroller. The temperature data it posts is useful as a measurement of skin temperature, and is used as feeback for the temperature actuator. The second sensing subsystem is the Zeo (Zeo, Inc.) sleep phase monitoring headband. It is worn throughout sleep and periodically (every minute) returns the user's current sleep state. It communicates with the "brain" via an Android (Google) application, which is connected to the sleep headband by Bluetooth®(Bluetooth SIG). The temperature actuation subsystem consists of a ChiliPad™(Chili Technology) temperature regulating mattress pad. The system circulates water throughout the pad, heating or cooling it as desired. It can be set to temperatures between 46 and 118 degrees fahrenheit. It is controlled by the "brain" via an Arduino (Arduino) connected to the ChiliPad™'s wireless remote. The Arduino communicates with the "brain" server, and can set the ChiliPad™'s temperature anywhere within its range. The "brain" subsystem processes sensor data and runs a simple algorithm to set the ChiliPad™'s temperature. Currently, this algorithm simply increases the temperature by ten degrees fahrenheit during REM sleep, and 20 minutes before waking.

6 Patent Research

Based on a provisional search of patents, no existing device competes with our system. The most similar patent is "Skin Temperature Measurement in Monitoring and Control of Sleep and Alertness" (US 20100100004 A1), which claims a method for monitoring sleep in a subject by monitoring skin temperature and movements and determining whether the subject is asleep or awake. Although it mentions arrangements for manipulating sleep, it does not outline a method involving a blanket, nor does it claim EEG biofeedback. Our system is novel in its integration of temperature sensing, EEG readings, and temperature actuation in the blanket. It is non-obvious in that the systems are not designed to be integrated at present; we added wireless capability to our temperature sensor and programmed actuation of the temperature control. Finally, the system can be used for research purposes to better understand sleep, and eventually as a consumer device to improve quality of sleep.

7 Validation

While we have not yet run a rigorous enough study to fully validate whether our system will be able to effect the sleep improvements seen in the above research, we are confident our eventual results will be promising. Research by Giles Lavigne found that sudden temperature stimulation on the skin during sleep induced a motor reaction only 2.5% of the time, and a cortical reaction only in light sleep[9]. His study tested temperatures ranging from 72.5 to 114 degrees fahrenheit. This means that users of our system will be unlikely to waken simply from sudden changes to the chilipads temperature. Instead we should be able to maintain elevated or reduced temperatures with the chilipad to slowly adjust the user's skin and core temperatures, to induce the effects discussed above.

8 Conclusion

The research detailed above clearly supports the idea that a device which modulates temperature during sleep can have a profound effect on the quality and composition of sleep, as well as easing the onset of sleep and helping the subject to feel refreshed and alert upon awakening. A future version of this paper will include preliminary results of an experiment we design to prove that our device can indeed effect this type of results by imposing active regulation on a sleeping subject.

9 Acknowldegments

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