Effects of Audio Brain Entrainment on Korean People with Mild Insomnia

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Abstract
Sleep health has become an important healthy lifestyle. Research has shown that almost one-fifth of the Korean adult population does not have sufficient sleep. The lack of sleep is associated with significant medical, psychological, social, and economic issues. People are not only yearning for sufficient sleep but the quality of sleep as well. Usually, the obvious choice will be the use of pharmaceuticals however, these often have various side effects, and the lasting use of these medications could become a concern. Therefore, new non-drug alternatives are sought after. Audio brain entrainment is a procedure that modules neural activities by synchronizing brainwave frequency with pulse tones. By producing frequency tones for the deep sleep stage, it promotes a good night’s sleep. In this paper, we developed a pillow integrated with the audio speakers that produce alpha and theta beats that should help improve sleep. Sleep polysomnography was performed on 10 people to compare the effects of the audio stimulus. Initial results showed a positive effect on sleep onset latency, indicating that sleep induction happened. This noninvasive stimulation technique can be a promising candidate for wearable bioelectronics medicine and further neuroscience research.

Keywords Sleep · Brain entrainment · Insomnia · Sleep treatment

Introduction

With humans sleeping for almost one-third of their life, sleep health has become an essential component of a healthy lifestyle (Aminoff et al., 2011; Perry et al., 2013). The timing, duration, and quality of sleep are important indicators of health, and this is further emphasized during the Covid-19 pandemic (Chaput et al., 2018; Xiao et al., 2020a, b). While a good night’s sleep may provide mental and physical recovery (Bonnar et al., 2018; Kim, 2009), sleep disorders are associated with significant medical, psychological, and social disturbances (Cho et al., 2019; Leggett et al., 2017; Vgontzas & Kales, 1999). Different studies had associated people with sleeping disorders with a higher risk of mortality, diabetes mellitus, hypertension, cardiovascular disease, coronary heart disease, and obesity (Im & Kim, 2017; Itani et al., 2017; Jike et al., 2018). For these reasons, good sleep is crucial to a healthy life.

In the United States, more than a third of American adults do not get enough sleep (Perry et al., 2013). However, insufficient sleep is not exclusively a US problem but affects most developed countries (Hafner et al., 2016). According to a report by the Organization for Economic Cooperation and Development countries (OECD), the average sleep time in South Korea was lower than the OECD average (South Korea: 462 min per day; OECD average: 502 min per day) (Chaple & Ladaique, 2009; Kim et al., 2018). Treatment for sleep disorders usually involves pharmacotherapeutics or hypnotics however there are some concerns about the side effects or lasting use of these medications (Lie et al., 2015; Pagel & Parnes, 2001). Possible side effects include daytime drowsiness, cognitive impairments, reduced motor coordination risk of abuse, and long-term dependence (Frandsen et al., 2014; Kripke et al., 2012). Therefore, the demand for low-cost, non-pharmaceutical alternative aids has grown.
In Korea, non-pharmaceutical such as herbal medicine, meditation, acupuncture, exercise, etc. are used (Kwon et al., 2016). One alternative method is the use of audio stimulation (Jespersen et al., 2015; Lai & Good, 2006). Trials have shown that music can be a self-help intervention to improve sleep (Chen et al., 2014; Cho et al., 2019; Feng et al., 2018; Jespersen et al., 2015; Lai & Good, 2006) and a Google search on ‘music’ and ‘sleep’ reveals a huge market promoting its sleep-inducing properties (Jespersen et al., 2015). Besides music, audio pulses can be applied to elicit the brain’s frequency following response, encouraging the brainwaves to align to the frequency of a given beat (Huang & Charyton, 2008). Brainwave entrainment is a procedure that modules neural activities by synchronizing brainwave frequency with that of the stimuli (Dickson & Schubert, 2019). There are four common brainwave bandwidths (delta, theta, alpha, and beta) and the related mental activities have been studied intensely (Thompson & Thompson, 2003). For example, delta frequency (0.5–4 Hz) is dominant during the deep sleep state while theta frequencies (5–8 Hz) are observed in the drowsy or relaxed state. In addition, alpha frequencies (9–13 Hz) are present in various mental activity such as mediation, creativity, calmness, etc. and beta frequencies (13–30 Hz) occurs before reactive psychomotor actions such as intellectual activity and emotional and anxious states. (Tang et al., 2016).

In this paper, we developed a pillow integrated with the audio speakers that produced specifically binaural beats from 2 different frequencies. We hypothesized that the audio stimulation will facilitate EEG slowing (via feedback, entrainment, conditioning, etc.) which may improve sleep induction and maintenance. This study will examine the feasibility of a 30 min administered pulse tone stimulation for sleep promotion in Korean adults with insomnia in a controlled environment. Sleep polysomnography was performed on 10 Korean individuals and sleep data were collected over 2 different nights for everyone. Each night, participants were either exposed to the audio stimulation or not (control). As sound is usually combined with light to create an audio-visual stimulation, a saliva test for melatonin is performed to see if sound alone may affect the circadian rhythm cycle. A survey was also conducted to see the viability of the pillow as a commercial product.

Method

Participants

This sleep study was conducted at the Korea Institute of Standards and Science (KRISS) and people were recruited from the Chungcheongnam-do region.

The Insomnia Severity Index (ISI) was used to determine the people with insomnia (Bastien et al., 2001). This index is a brief self-report questionnaire that measures the patient’s perception of insomnia severity. It has been translated and validated in various languages, demonstrating adequate psychometric properties for several age groups (Cho et al., 2014). The Korean version of the Insomnia Severity Index (ISI-K) was verified (Cho et al., 2014) and applied in this study. Points of 0–7 are interpreted as no clinical insomnia, 8–14 as mild clinical insomnia, 15–21 as moderate insomnia, and 22–28 as severe insomnia. In this experiment, subjects with 8 or more points through self-examination were selected.

Participants who met the criteria were tested after obtaining consent and explaining the purpose, benefits, and risks of the study through the approval of the Ethics Review Committee of the KRISS (KRISS-IRB-2020-5). The day before the experiment, participants were prohibited from drinking alcohol, caffeine, or smoking which are known substances that may influence sleep (Zunhammer et al., 2014).

Experimental Materials (Stimuli)

In this study, a pillow with speakers that generates sound for brain entrainment was designed and fabricated. The pillow material is made of foam and the height of the pillow can be divided into three layers (Fig. 1). Each participant was allowed to select their preferred height. The height chosen was recorded and used for the two nights. For audio brain entrainment, the speaker generated synchronized pulsed tones at an alpha or theta frequency which was provided by GEOMC (Tracy et al., 2007). The sound is a combination of alpha and theta frequencies (4–12 Hz range), beginning with alpha (9–12 Hz), then theta (4–8 Hz), and then ending in alpha. These pulse tones aim to induce changes in the brain waves to functionally activate the brain. The sound comprises the pulse tones and natural sounds (i.e., wave sound, stream sound, rain sound) to optimize sleep induction, and is designed to be applied for 30 min before sleep to induce deep sleep and to improve the sleep quality. The volume of the tone pulses and the background nature sounds were adjusted according to the participant preference while the rate of pulsing tones was fixed.

Experimental Procedures

Experiments were conducted in the lab sleep chamber at KRISS where the temperature, humidity, and illumination were all calibrated and fixed. The laboratory temperature was determined to be at 21.57 ± 0.86°C and humidity at 55.31 ± 5.89% R.H. To provide a constant sleep environment for all subjects, sleep time for both days was...
approximate 7 h with environmental factors such as attire and bed location kept constant.

For this single group cross experimental study, the experiments were conducted two times with each participant (application of sound and the control). Each participant was measured on two different nights and was subjected to a random allocation of treatment (Sound application or no sound application) to see if the pulse tone improved the sleep. All sensors were to be connected 30 min before the participant’s sleep time. Once the sensors are attached, the participant will lie down on the pillow and be subjected to either the sound application or no sound. The sound will be applied for 30 min and for the control, the participant will be on the pillow without activation of the sound.

**Sleep Polysomnography**

Sleep polysomnography is an examination to detect and record various biological signals, electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), airflow signals, and respiratory effort signals that appear during sleep (Ryu & Choi, 2019). This can be defined as a test that detects and records various biological signals such as oxygen saturation, electrocardiogram (ECG), body position, and snoring to determine sleep states or diagnosis of sleep disorders.

The HANDY EEG SystemPLUS Evolution (Micromed S.p.A., Italy) is a portable device that reads sleep conditions by recording biological signals such as EEG, EOG, EMG, and ECG and was used in this study (Ryu & Choi, 2019). The location for the EEG sensors attachment is Fp1, Fp2, C3, C4, O1, O2, and the EOG sensors are PNG1 and PNG2 where the channels are 1 cm up and down from the outer eye angle (Fig. 2A and B). The ECG sensor is attached to the ECG1 channel 5 cm below the Jugular notch and inside the fourth and fifth ribs (Fig. 2C). For the EMG measurement, the electrodes were attached to the skin over both the mentalis muscle of the lower lip (Fig. 2A).

After attaching the various sensors, the experiment commences in the self-governing sleeping room. The data collected were processed and analyzed accordingly. The SystemPLUS Evaluation data collection software was used, and the data analysis was performed twice by two experts (manual reading every 30 s) with the REM brant Analysis Manager. The contents for sleep scoring data of the polysomnography test include light-out clock time, lights on clock time, total sleep time (TST), and total recording time.
Data were further processed to get Total recording time (TRT), sleep latency (SL), wake after sleep onset (WASO), sleep efficiency (SE), duration of each sleep phase (Time in each stage), and the percentage of each sleep stage (Ryu & Choi, 2019).

**Saliva Test**

The amount of melatonin was compared and verified through a saliva test. The saliva test was performed 20 min after the MC Square system was applied or 10 min before sleeping, and immediately after waking up. The saliva samples were collected by chewing on a cotton swab for about 3 min, after which the subject placed the swab into a sterile plastic tube. The tubes were stored in the refrigerator at 4 °C and delivered to the SQLAB institution for analysis. Samples were serial diluted and melatonin was determined by the high sensitivity enzyme immunoassay kit ELISA (Salimetrics Cat No: 1-3402), with an inter-assay coefficient of variation at 3.2% and intra-assay coefficient of variation at 1.2%.

**Subjective Evaluation (Survey)**

A questionnaire was used for a subjective pillow evaluation, and the satisfaction level was determined according to the questions. The questionnaire comprised questions that were answered on 5-grade verbal ratings of overall satisfaction (very dissatisfied to very satisfied), level of comfortability on the neck (very uncomfortable to very comfortable), the height of the pillow (very low to very high), the width of the pillow (very narrow to very wide), length of the pillow (very short to very long), cushion of the pillow (very soft to very hard), the temperature of the pillow (very cold to very hot), the humidity of the pillow (moist to dry), easiness of head-turning (not at all to very easy). The questionnaire was performed after the participant woke up during the first experiment. Results were then tabulated and converted to a percentage.

**Data Analysis**

The general characteristics of the subjects and ISI scores were expressed as mean and standard deviation. The Shapiro-Wilk test was performed to determine whether data is a normal distribution and results of the sleep polysomnography results were compared using the Mann-Whitney U test as some data did not have a normal distribution. All statistical analyses were performed using the SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA) and a p-value of <0.05 was considered statistically significant.

**Results**

**Participants**

15 People met the criterion initially but 5 of them had to be excluded as they were receiving medical treatment which could affect the study. A final group of 10 people proceeded with the sleep experiment. Three men and seven women participated with an average height of 164.7 cm and an average weight of 60.8 kg (Table 1). The average age of the participants was 31 years old with an ISI (score) of 9.37 ± 2.43 which classified them to have a mild case of insomnia.

**Sleep Polysomnography**

Sleep polysomnography results for both application of sound and the control were analyzed and presented in Fig. 3. For this experiment, the following measurements were used: TST, SE, SL, and WASO. In addition, the total sleep time percentages of each stage (Stage 1, Stage 2, Stage 3, and REM stage were also broken down to observe any possible irregularities.

For the sleep quality results (Fig. 3), there was a significant decrease in SL from 24.65 min to 9.7 min when the participants were exposed to the sound. TST and SE showed a slight increase while WASO had a decrease when compared to the control. However, while these results showed improvement in sleep quality, there was no significant difference when compared to the controls and more samples will be needed. As brain entrainment uses similar frequencies to synchronize brain activity, we looked at the different sleep stage percentages to see if there are any changes to the user’s sleep pattern (Fig. 4). When the sound is applied, there was a decrease in stage 1 and stage 2 percentages from 71.63 to 68.92% and 16.63–14.92% respectively. However, there was an increase in stage 3 and REM sleep from 8.73 to 12.46% and 3.04–3.69% when compared to the control. However, as there were no significant differences for all stages in our experiments, more data needs to be collected to give us a better understanding of how the different sound frequencies may play a part in sleep.

| Table 1 General characteristics of subjects |
|--------------------------------------------|
| Variable          | Group          |
| Age (year)        | 31.30 ± 10.70  |
| Height (cm)       | 164.70 ± 8.87  |
| Weight (kg)       | 60.80 ± 9.88   |
| ISI (score)       | 9.37 ± 2.43    |

*ISI* insomnia severity index
Saliva Test

We performed a melatonin test to observe what will happen to melatonin levels when the audio stimulus was only applied (Fig. 5). The results of the saliva test before sleep showed melatonin amounts of an average of 16.66 pg/ml (sound applied) and melatonin amounts averaged 17.03 pg/ml (control). After waking up, the average amount of melatonin was 17.87 pg/ml and if the sound was not applied, the average amount of melatonin was 19.80 pg/ml. Both results are not significantly different indicating that melatonin levels with and without the sound application were quite similar.

Survey

A subjective evaluation survey was conducted to evaluate the sleep pillow satisfaction with the sound system. The resulting values were summarized in Fig. 6. The overall satisfaction of the system was high with, 20% who are in the middle and 80% were satisfied. In terms of neck support, 55% find it comfortable while the rest is just acceptable. For the width (67% neutral), height (100% neutral), length (89% neutral), and thickness (88.9% neutral) of the pillow, most users found it to be acceptable which means that sleep was not affected by the pillow conditions. The temperature of the pillow is about 50% slightly warm and 50% no difference. About 78% of the users found the humidity of the pillow to be reasonable while the other 22% either found it slightly wet or slightly dry. When the question “Is it easy to turn your head around?” was asked, 20% found it neutral while 80% found it to be easy. This shows that the speakers do not affect the movement of the user during sleep. 70% of the participant will consider using the pillow again. The overall results of the customer survey showed that the design of the pillow is widely accepted by most participants. While the survey is encouraging, other ergonomic designs will be needed to improve the pillow.
**Fig. 4** The overall average of subjects' sleep architecture from both nights. There were no significant differences between experimental conditions and the control for all stages of sleep. Data represent mean ± S.E.M

**Fig. 5** Amount of melatonin before sleep and after sleep of the 10 participants when MC Squaresystem is applied and not applied. Data represent mean ± S.E.M
Discussion

Sleep polysomnography popularly known as a ‘Sleep study’ has been used for decades to diagnose and evaluate the severity of sleep disorders (Shrivastava et al., 2014). While there is no standardization of the reporting process, most sleep reports are based on certain sleep characteristics that provide quantitative information regarding the patient’s sleep and its deviation from their normal pattern (Shrivastava et al., 2014).

The TST of all participants was determined to gauge how long they slept. The total sleep time refers to the total amount of time for all sleep stages (Shrivastava et al., 2014). A low total sleep time may indicate that the patient slept for an insufficient period due to non-medical/non-physiological reasons, certain medical or sleep disorders, or because of the effect of medications. For this experiment, the time measured was set when the moment stage 1 of the sleep cycle appears and ends just before the wake-up stage. While there is a slight increase in TST when the sound is applied, it was not determined to be significantly different when compared to the control. The average TST was about 344.15 min or 5.7 h when used with the smart pillow, which is still below the recommended levels (7–9 h) by the National Sleep Foundation (Kim et al., 2019). In Korea, researchers found that about 16.7% of Koreans were sleeping for less than 5 h (Kim et al., 2019). This was supported by the ISI index as well.

Furthermore, the overall quality of sleep various parameters such as SE, SL, and WASO were also analyzed. While the duration of sleep is important, research showed that the quality of sleep is more important (Shrivastava et al., 2014). SE is an important parameter for sleep studies as it gives an overall sense of how well the patient slept. It looks at the total time in bed which was spent in sleep. It is calculated as a percentage of Total Sleep Time (TST)/Total Recording Time (TRT). SE mean was about 84% for all users before the brain entrainment was introduced and when the pulse tones were applied, efficiency rose to 88%. There is an approximately 4% increase in SE when the smart pillow was applied. Sleep latency is the duration time between when the light is turned off (lights out) to the time the patient falls asleep based on the reading of the machine (Shrivastava et al., 2014). The MC Square system showed an average sleep latency period of 9.70 min and when compared to the control sleep latency period of 24.65 min, showed an improvement in the participants falling asleep faster. Wake after sleep onset (WASO) refers to the period of wakefulness occurring after defined sleep onset. WASO results showed a reduced time when the MC system is applied. Participants’ WASO showed a slight decrease of 2 min when exposed to the system, indicating that the GEOMC system may improve the overall sleep quality by reducing the time to go to bed and go back to sleep faster went woken up. While the SE and WASO were not significant, sleep onset latency showed that there is a significant decrease. From these 4 characteristics, we can conclude that while the smart pillow may not increase the duration of sleep, brain entrainment may have a positive impact on sleep latency. This was also reported by Lazic et al. (Lazic & Ogilvie, 2007) that sleep onset latencies tended to be shorter in the tone condition when compared to music or the control.

Normal human sleep is entered through non-REM sleep, which is composed of three stages (I, II, III) ranging from the lightest to the deepest sleep, and REM sleep. Typically, non-REM and REM sleep alternate in cycles across sleep. Stage I sleep is the transition from wakefulness to deeper sleep and is the lightest stage of sleep. Stage II sleep constitutes up to 50% of total sleep time and is a true physiologic stage of sleep. Stages III and IV sleep are the deepest sleep and most restorative for body function. During the different sleep stages, different frequencies of brain waves are active (Carskadon & Dement, 2005). As brain entrainment uses similar frequencies to synchronize brain activity, we looked at the different sleep stage percentages to see if there are any changes to the user’s sleep pattern when the tones are applied. Initial results showed that there may be a positive effect on sleep as there is an increase in both deep sleep and REM sleep (Rama et al., 2005) which explains some of
the profound consequences of insufficient sleep on thinking, emotions, and physical health. However, as there were no significant differences for all stages in our experiments, more data needs to be collected to give us a better understanding.

Melatonin is a reliable indicator of circadian rhythm and has been frequently used in sleep studies (Kazemi et al., 2018). Previous studies have shown a decrease in daytime melatonin levels when audiovisual stimulation was used (Tang et al., 2016). As most brain entrainment experiments with the audio stimulus are combined with visual stimulation, we wanted to determine if audio stimulus may have a role in melatonin levels. Melatonin concentration before sleeping and immediately after waking up was measured to determine if there was any effect on circadian rhythm by the pulsing tones. From the experiment, we showed that light stimulus rather than sound stimulus may be the main initiator for melatonin production during brain entrainment for sleep.

While the survey indicates a positive experience when using the pillow, there are other possible factors to take into consideration for future prototypes to ensure a better sleep quality too (Son et al., 2020):

1. The consideration of other materials to ensure better comfortability, cushioning, and neck support.
2. Depending on the environment, temperature and humidity need to be considered as well.
3. Allowance for movement as people may not be sleeping in the same position (supine, side, or prone, altered by having an arm under a pillow or folding the pillow) all the time.

Limitation

The initial results have demonstrated that audio brain entrainment alone can improve sleep quality, especially for sleep latency. This has also been seen in other studies (Tang et al., 2016; Tang et al., 2015) with different groups of people showing positive effects of audio brain entrainment. However, more experiments need to be done to elucidate exactly how the pulse tones affect the brain. While the results are promising, future studies will be required. Due to the covid pandemic, a small sample size was obtained, and additional precautions were taken to prevent the spread (the use of disinfectant and changing of bed sheets) may create a non-constant environment for the user. As results indicate an effect on the participants with mild insomnia, this research can be expanded to different age groups (i.e. young adults or elderly) or people with different insomnia severity who are either not suitable or reduce their consumption of hypnotic drugs. Future experiments can be performed with a sleep diary and longer trials if there are any long-term effects with larger sample size. The mechanism of audio-visual entrainment and how the neurological response relative to the outcome measures (i.e., sleep) remains to be fully demonstrated. Future studies may consider using neuroimaging to describe the concurrent brain activity changes in responding to the audio-visual entrainment as well.

Conclusion

In this paper, we have shown that a combination of pulse tone at alpha and theta frequencies may have a positive effect on people with mild insomnia. While the pillow design may need further improvements, initial results showed that an audio stimulation system decreases sleep onset latency. Time spent at sleep stages 1 and 2 slightly decreased while time in stage 3 and REM sleep increased. As those results were not significant, more experiments must be performed. Audio stimulation does not affect the melatonin levels. Considering that treatment options for insomnia are somewhat limited, pulse tones could serve as an initial intervention in a stepped-care approach for the management of insomnia in Korea. Therefore, audio brain entrainment pillows can be an easy and user-friendly application treatment for sleep disorders. This noninvasive stimulation technique is a promising candidate for wearable electronics and further neuroscience research.

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Declarations

Conflict of interest The authors declare that this study received funding from GEOMC Co. Ltd. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article.

References

Aminoff, M. J., Boller, F., & Swaab, D. F. (2011). We spend about one-third of our life either sleeping or attempting to do so. Handbook of clinical neurology/edited by P.J. Vinken and G.W. Bruyn, 98, vii. https://doi.org/10.1016/B978-0-444-52006-7.00047-2
Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the insomnia severity index as an outcome measure for insomnia research. Sleep Medicine, 2(4), 297–307. https://doi.org/10.1016/S1389-9457(00)00065-4
Bonnar, D., Bartel, K., Kakoschke, N., & Lang, C. (2018). Sleep interventions designed to improve athletic performance and recovery: A systematic review of current approaches. Sports Medicine, 48(3), 683–703. https://doi.org/10.1007/s40279-017-0832-x
Carskadon, M. A., & Dement, W. C. (2005). Normal human sleep: An overview. Principles and Practice of Sleep Medicine, 4(1), 13–23. https://doi.org/10.1016/j.pmcn.2004.01.001

Chapple, S., & Ladaigue, M. (2009). Society at a glance 2009: OECD social indicators. Organisation for Economic Co-operation and Development. https://doi.org/10.1787/soc_glance-2008-en

Chaput, J. P., Dutil, C., & Sampasa-Kanyinga, H. (2018). Sleeping

Chen, C. K., Pei, Y. C., Chen, N. H., Huang, L. T., Chou, S. W., Wu, K. P., Ko, P. C., Wong, A. M., & Wu, C. K. (2014). Sedative music facilitates deep sleep in young adults. The Journal of Alternative and Complementary Medicine, 20(4), 312–317. https://doi.org/10.1089/acm.2012.0050

Cho, J. H. J., Olmstead, R., Choi, H., Carrillo, C., Seeman, T. E., & Morin, C. M. (2014). Validation of a

Feng, F., Zhang, Y., Hou, J., Cai, J., Jiang, Q., Li, X., Zhao, Q., & Li, H. Y. J., Vitiello, M. V., Perlis, M., & Riegel, B. (2015). Openness of sleep disturbance on the association between chronic medical conditions and depressive symptoms over time. Longitudinal and Life Course Studies: International Journal, 8(2), 138–151. https://doi.org/10.14301/lcvs.v8i2.433

Lie, J. D., Tu, K. N., Shen, D. D., & Wong, B. M. (2015). Pharmacological treatment of insomnia. P & T: a peer-reviewed journal for pharmacists, 40(11), 759–771. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4634348/

Pagel, J. F., & Barnes, B. L. (2001). Medications for the treatment of sleep disorders: An overview. Primary Care Companion to the Journal of Clinical Psychiatry, 3(3), 118–125. https://doi.org/10.4088/pcc.v03n0303

Perry, G. S., Patil, S. P., & Presley-Cantrell, L. R. (2013). Raising awareness of sleep as a healthy behavior. Preventing Chronic Disease, 16, E133. https://doi.org/10.5888/pchd.a.130081

Rama, A. N., Cho, S. C., & Kushida, C. A. (2005). Normal human sleep. In Sleep: A comprehensive handbook (pp. 1–9). https://doi.org/10.1002/0471751723.ch1

Son, J., Jung, S., Song, H., Kim, J., Bang, S., & Bahn, S. (2020). A survey of Koreans on sleep habits and sleeping symptoms relating to pillow comfort and support. Journal of Community Hospital Internal Medicine Perspectives, 4(5), 24983–24983. https://doi.org/10.3402/jchimp.v4.24983

Son, J., Jung, S., Song, H., Kim, J., Bang, S., & Bahn, S. (2020). A survey of Koreans on sleep habits and sleeping symptoms relating to pillow comfort and support. International Journal of Environmental Research and Public Health, 17(1), 302. https://doi.org/10.3390/ijerph17010302

Tang, H. Y. J., Riegel, B., McCurry, S. M., & Vitiello, M. V. (2016). Open-loop audio-visual stimulation (AVS): A useful tool for management of insomnia? Applied Psychophysiology and Biofeedback, 41(1), 39–46. https://doi.org/10.1007/s10484-015-9308-7

Tang, H. Y. J., Vitiello, M. V., Perlis, M., & Riegel, B. (2015). Open-loop neurofeedback audiovisual stimulation: A pilot study of its potential for sleep induction in older adults. Applied Psychophysiology and Biofeedback, 40(3), 183–188. https://doi.org/10.1007/s10484-015-9285-x
Thompson, M., & Thompson, L. (2003). *The neurofeedback book: An introduction to basic concepts in applied psychophysiology.*

Tracy, J. I., Ahmed, N., Khan, W., & Sperling, M. R. (2007). A test of the efficacy of the MC Square device for improving verbal memory, learning and attention. *International Journal of Learning Technology, 3*(2), 183–202. https://doi.org/10.1504/IJLT.2007.014844.

Vgontzas, M., & Kales, M. (1999). Sleep and its disorders. *Annual Review of Medicine, 50*(1), 387–400. https://doi.org/10.1146/annurev.med.50.1.387

Xiao, H., Zhang, Y., Kong, D., Li, S., & Yang, N. (2020a). The effects of social support on sleep quality of medical staff treating patients with coronavirus disease 2019 (COVID-19) in January and February 2020 in China. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research, 26*, e923549–e923549. https://doi.org/10.12659/MSM.923549

Xiao, H., Zhang, Y., Kong, D., Li, S., & Yang, N. (2020b). Social capital and sleep quality in individuals who self-isolated for 14 days during the coronavirus disease 2019 (COVID-19) outbreak in January 2020 in China. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research, 26*, e923921–e923921. https://doi.org/10.12659/MSM.923921

Zunhammer, M., Eichhammer, P., & Busch, V. (2014). Sleep quality during exam stress: The role of alcohol, caffeine and nicotine. *PloS One, 9*(10), e109490. https://doi.org/10.1371/journal.pone.0109490

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