Preliminary research of a specific noise vibration environment impacting on sleep

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ABSTRACT:

This experiment is based in an extremely silent room where the background noise is lower than 5dB(A). The experiment is mostly concerned about the sleep quality and evaluated by the subjective and the objective elavations between the noisy environment and the extremely silent environment. The objective evaluation is based on a series of participants‘ sleeping data and the ratio of different sleeping stages which are considered the most important factors. The subjective evaluation is completed by the subjective sleep questionnaire which participants filled in. The purpose of this experiment is to discuss the importance of sleep in a quiet environment. The experiment is conducted during an afternoon nap which is different from other experiments involving all-night sleep. It is also explained how to make an afternoon nap more efficient and is to explore a good mode for it.

Keywords extremely silent room, noisy environment, afternoon nap, sleep quality

1. INTRODUCTION

The experiment is mostly concerned about the sleep quality between the noisy environment and the extremely silent environment. Sleep is one of the most important and the most basic human life activities. When sleeping, people can eliminate fatigue and restore mental and physical strength, so as to keep generic and sober state in work and study. The sleep quality is very important to every person. If sleep quality declines, all aspects of personal life will be affected. Sleep disorders include: difficulty in falling asleep, waking up more, prolonged shallow sleep, difficulty in falling asleep after waking up, etc (Tomoyuki Kawada 2011). However, noise pollution has become one of the most important factors that interfere with people's lives, their work and leisure. It is also a major cause of human sleep disorders (Tomoyuki Kawada 2011). The negative impacts of noise include hearing impairment, communication interference, which may lead to psychological and behavioral issues. The impacts of noise on sleep also vary in different people depending on their subjective feelings, gender, age, health, etc (Griefahn B & Gros E 1986). People still receive the stimulus from the environment during sleep. The sensitive degree of stimulation is determined by many factors. These factors include various kinds of noise, its intensity, frequency, spectrum, relationships between noise and background sounds, etc. Other factors include sleepers’ age, gender, occupations, their sensitivities to noise, etc. The purpose of this experiment is to discuss the importance of sleeping in a quiet environment and how the noise impacts the quality of the sleep.

2. THE IMPACTS OF NOISE ON SLEEP

When giving sleepers a strong stimulus in any sleep period, it can result in immediate awakening. When sound stimulation is not very strong, people's response to sound stimulus is not same in different periods of sleep. In the shallow sleep period, it can

be easier to wake up when receiving an auditory stimulation. On the other hand, when sleepers get into the SWS (slow-wave sleep), a light auditory stimulus does not wake them up easily. However, it does not mean that the light noise will not impact on sleepers, as in certain cases the noise changes the sleep stage from the SWS and the REM sleep into the shallow sleep, reducing the proportion of the SWS stages and REM sleep stages. Moreover, the number of tossing and turning increases as well as changing the sleepers' heart rate (Keith Archibald 2005). The impact differs on sound pressure, level of noise, wave, duration, type and content of sleep.

2.1 The impacts of noise on the all-night sleep

According to the former researches on the all-night sleep, it can be concluded that impacts of noise on the all-night sleep are as follows.

1) Shortening of the sleep period

Total sleep time can be shortened by taking extended time to fall asleep and waking up too early. According to the report, the intermittent noise that peaks or exceedes 45 dB, increases the time to fall asleep from a few minutes to 20 minutes (Ohrstrom E 1993). In addition, mental pressure was significantly reduced after the first 5 hours of sleep. In addition to making sleepers easier to be woken up, it also takes longer time to fall back asleep in presence of noise.

2) The impact on the SWS and the REM sleep

SWS and REM sleep are important stages of sleep that are essential for a healthy sleep routine. The REM sleep is the stage when a human body accumulates energy, while the SWS is more about psychology and memory. Carter describes that the SWS of young people is reduced because of the exposure to the intermittent noise. Some studies conclude that the increase of the shallow sleep can reduce the length of the SWS and the REM stages (Carter NL 2005). Shallow sleep is an unstable process that can potentially harm human body if practiced for extensive periods of time.

3) Increase the number of awakening

When observing the wake-up threshold of noise（sleepers are asked to press the button when wake up）it was found out that, the threshold is particularly high when the sleeper is in the SWS stage and very low in shallow sleep stages. If sleepers are in the shallow sleep stage for a long time during the night, the probability of being awoken increases.

2.2 The impacts of noise on a nap

The experiment is conducted during the nap at noontime. Each one's siesta habit may be different, and people's nap habits also depend on the individual's health status, working and living environment and cultural differences. Appropriate nap can help people to alleviate fatigue and improve the state of awakening. A research of the noon sleep concluded that only when sleepers processed SWS, memory performance could be improved. Thus, the importance of the SWS stage can be seen both in the noon nap and the night sleep.

For the participants of this experiment, noisy environment of a dormitory at a noon sleep stage often causes the interference of sleep. The research is mainly focused on whether the noise can affect the noon nap, reduce the REM sleep and the SWS and increase the number of being awoken and the time to fall asleep.

3. METHOD

3.1 Introduction of sleeping monitoring instrument——Zeo

Figure 1: Zeo

The monitor of the sleep process is the key to this experiment, through which we can get information about interconnection between sleep stages.

A number of parameters that determines sleep quality can be obtained through Zeo, including shallow sleep time, SWS and REM time, awakening times, time to fall asleep, etc. On the whole, a complete process and sequence of sleep stages can be tracked using this device. The sample of the detected sleep process is demonstrated in the chart below.

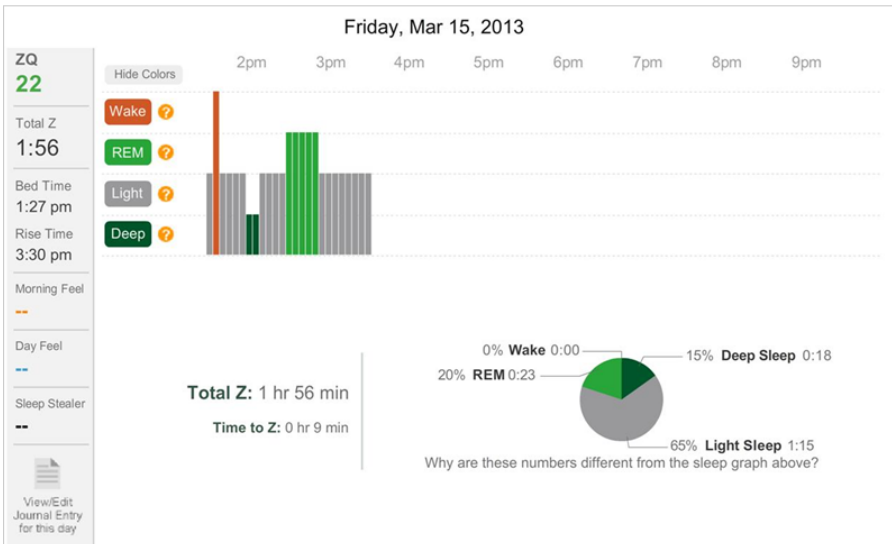

Figure 2: Detected sleep information by Zeo

3.2 Comparing experiment

For the comparing experiment, a 0dB (A) room was selected to be compared with a daily level of noise in the dormitory. Tsinghua university architecture department constructed the physical acoustics laboratory where background noise is kept below 0dB (A) with average humidity and temperature. This purposefully-built laboratory is aimed at studying psychological and physiological reactions of people in a silent environment. When supplying the air, the background noise is less than 5dB(A). Inside the room there are windows that can be opened and the indoor lighting appliances.

The test results of the background noise in the 0dB(A) lab are as follows (Table 1).

Table 1: Background noise in the 0dB(A)

Environment Condition:	Sound pressure level dB(A)
Fan, air conditioning closed	＜0
Fan, air conditioning open，Air changes 16 per hour	＜5.0
Open the window	33.0
The background noise outside the room	59.3

In addition, acoustic technology processed inside the 0dB (A) room, the materials for celling and walls are constructed using the sound-absorbing paint technology. The indoor reverberation times are measured as follows (Table 2).

Table 2: Reverberation time in 0db (A)

Frequency /Hz	125	250	500	1000	2000	4000
RT /s	0.34	0.22	0.23	0.27	0.38	0.39

A total of six participants (4 men and 2 women) took part in four to six sleep sessions during the experiment. Participants were allowed to fall asleep between 12:00-13:00 for the period of one or two hours that was followed by a voluntary or enforced wake-up. When sleeping in the dormitory with noise, relatively quiet environment should be kept. The indoor noise monitored is around 32dB (A) at minimum, peaking up to 50dB(A) with 35dB(A) on average. Participants could change clothes accordingly to their personal preferences and the temperature inside. An electric heater in the silent room was turned on to make the room temperature equal to the requirements. Other variables were set aside due to their insignificance.

3.3 Methods of the evaluation of sleep

We used two kind of methods to evaluate the quality of the sleep, that is subjective evaluation and objective evaluation. For subjective evaluation, here is the main reference of Pittsburgh sleep quality index (PSQI) (Liu Xianchen 1996). PSQI's advantages include simplicity and easy operation, high reliability and validity, and a very high correlation with the sleep EEG measuring results. Due to the nature of the PSQI for the whole night sleep and long-term duration of tests (one month), it cannot be directly applied for this experiment to evaluate the subjective sleep quality of the sleeper. Thus, the core questions of PSQI were chosen in order to compile a questionnaire for the nap experiment.

Table 3: Questionnaire of subjective evaluation for sleep quality

Subjective Evaluation for sleep quality
1. Subjective Evaluation for sleep quality: ( )
A. Excellent B. Good C. fair D. bad
2. Time to sleep: ( )
A. Soon B. For a little while C. Long time D. Can't fall asleep
3. Total sleep time: ( )
A. Long time (≧2h) B. Moderate (1h—2h) C. Short time (≦1h)
4. Efficiency: ( )
A. High B. Good C. fair D. low
5. Sleep disorders: ( )
A. Feel no obstacle B. Feel a little hard to fall asleep C. Feel pretty hard to fall asleep D. Can't fall asleep
6. Feeling after sleep: ( )
A. Excellent B. Good C. Still feel tired after sleep

According to the self-evaluation questionnaire mentioned above, sleepers can estimate quality of afternoon naps. In the subjective evaluation questionnaire, sleep quality, sleep efficiency, general condition upon waking up are positively related to the sleep quality. However, the duration of sleep and sleep disorders are negatively related to the sleep quality. In addition, moderate sleep time is considered to be an optimal choice due to disadvantages of both overly long and inadequately short nap times.

According to the theory of regression analysis based on subjective evaluation questionnaire, the subjective evaluation formula can be represented as follows.

$$y = -0.1001 \times \log^{x_1/2} + 0.3284 e^{x_2/2} - 0.0126 (x_3)^2 + 1.1152 \log(x_4 + 1)$$

The independent variables X_1, X_2, X_3, and X_4 are sleep time, sleep efficiency, sleep disorder, the feelings after sleep sequently. The dependent variable “y” is the subjective evaluation score which each sleeper receives.

However, objective evaluation implies assessing the sleep according to the actual situation of the sleep and the detected information. The information that needs to be collected include sleep time, shallow sleep time, REM sleep time, SWS time, total sleep time, awakening times. Each variable may be in a positive or a negative correlation to sleep that helps to acquire a broader view of sleep quality.

According to the theory of regression analysis based on objective evaluation questionnaire, the objective evaluation formula can be represented as follows.

$$y = 60 + 15 \times (0.9378 e^{x_1} - 5.6652 \ln^{(x_2+1)} + 1.3786 e^{x_3} - 7.1858 x_4^{\frac{1}{2}} - 1.001 \ln^{\frac{x_5}{10}})$$

The independent variables include deep sleep time, shallow sleep time, REM sleep time, awakening time, total sleep time sequently. The dependent variable “y” is the objective evaluation score which every sleeper receives.

4. RESULTS

4.1 Results of the increased proportion of REM sleep in a quiet environment

After analysing the experimental data, the rate of REM sleep time in test subjects No.2, 3, 5 and 6 has shown an increase up to 8% from 5%. There were two cases of a slight decrease of SWS sleep time, one case has not changed its value and one participant’s SWS time has increased.

4. 2 Results of the increased proportion of SWS in a quiet environment

After analysing the experimental data, the rate of SWS sleep time in test subjects No.2, 3, 5 and 6 has shown an increase up to 2% from 1%. Only No.2 participant’s REM time has maintained the growth while a slight decrease was shown amongst other test subjects.

4.3 Results of the decreased proportion of sleep time in a quiet environment

The experiment reveals that participants’ sleep time is influenced by their state of mind prior to falling asleep. It is said by participant No.5 that it was difficult to sleep in 0dB(A) room because of random thoughts. For the participants No.4 and No.6 time to sleep between two environments did not make any difference. However, a reduction of sleep time for participants No.1 and No.3 was reported.

4.4 Results of the decreased times of awakening in quiet environment

All the times that volunteers were awakened during sleep are limited in relatively quiet environment, and times of being awakened grow remarkably when it comes to noisy days. When volunteers slept in the 0db (A) room, their awokened times did not appear to occur.

4.5 Analysis of a good noon-nap mode

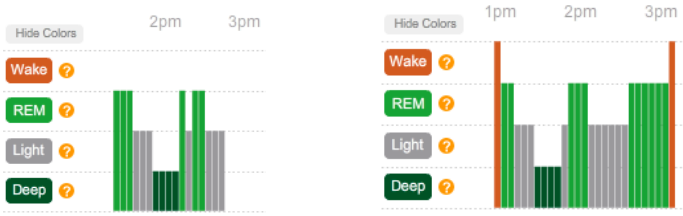

Figure3: Good sleep progresser with high scores

The graphs in Fig.3 show that participants experienced REM sleep followed by shallow sleep changing to SWS in the end. The whole process is not repeated to enter into the shallow sleep time after time, and this process means that participants' mental and physical strengths are restored.

It can be called as a highly efficient nap compared to other sleep process.

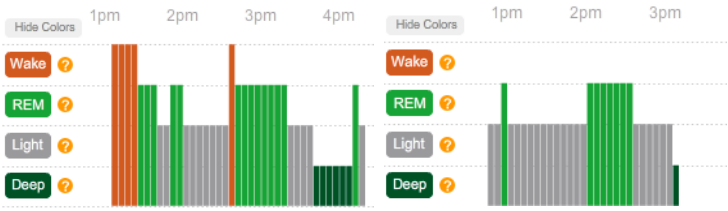

Figure4: Inefficient sleep progresser with low scores

In the process of two sleep sessions, REM sleep alternates with shallow sleep for multiple times making participants to spend a long time to enter into the SWS stage. It is belived that a big proportion of shallow sleep aggravated by noise leads to inefficient sleep patterns and sleep disorders.

From these two kind of sleep mode, we assume that when the processes of a sleep match with a good nap sleep mode mentioned earlier, people can make their sleep more efficient and less time-consuming as well as being able to recover physical and mental state in order to improve their work efficiency upon waking up.

5. DISCUSSION

In experimental results it can be seen that the quality of sleep in a quiet environment is more efficient than in the presence of noise. The results are mainly embodied in the increase of REM sleep and SWS sleep, decrease of the shallow sleep, more processes according with the good sleep mode, and a higher subjective self-evaluation of volunteers in the quiet environment. Among 27 recorded results, 14 times are in the quiet environment and 13 times are in the noisy environment. The times that subjective evaluation score is higher than or equal to 3 (⩾3) are 8 in quiet environment, while the times that subjective evaluation score is higher than or equal to 3 (⩾3) are only 3. The subjective evaluation of sleep rise around 40% at an

average level, each one's result of subjective evaluation and the rate of growth are in the following table.

Table 4: Results of subjective evaluation for sleep quality

Number	The average score in noise environment	The average score in quiet environment	The rate of growth
1	1.5	3.5	133%
2	2	2.8	41%
3	2	3.25	62.5%
4	3	3.8	27%
5	2	1.75	-12.5%
6	2	2.5	25%

This shows that most participants prefer to sleep in a quiet environment.

From the objective data analysis, the times that score is higher than or equal to 60 (⩾60) are 10 in quiet environment. The times that score is higher than or equal to 60 (⩾60) are 6 in noisy environment. Each one's objective evaluation of sleep rises 10% at an average level. The objective evaluation scores and the rate of growth are in the following table.

Table 5: Results of objective evaluation for sleep quality

Number	The average score in noise environment	The average score in quiet environment	The rate of growth
1	54	80	46%
2	62	63	1%
3	72	87	20%
4	69	74	5%
5	47	55	17%
6	45	36	26%

This shows that most participants have a better sleep in a quiet environment by objective data.

The good sleep modes appearing in a quiet room are found more often than that in the noise environment, however, it does not mean that there are no good sleep modes appearing in the noise environment. The reason is the different sensitive degrees of sound with less quantity. According to sound pressure measured in these good-sleep days in the noise environment, it is maintained around 32dB(A) without high peak noise so that these environments still can be considered as relatively quiet environment.

6. CONCLUSION

From the results we can see that the objective evaluation data and the subjective data both support a potential opportunity for a person to be able to have a good sleep in the quiet environment. It also shows that it is more potential to have a sleep which matches with good nap sleep mode in the quiet environment. From the all of these informations, it can be concluded that a quiet environment plays a very positive role for sleep.

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