Human sleep in silent environment: experiment and results

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Summary

It's commonly believed that noise has certain influences on human sleep. Many researches have studied the influence of noise on sleep by adding certain noise to volunteer subjects' sleeping environments. In this experiment, this influence was studied by comparing people's sleeping qualities in a quiet space which has a background noise under 5dB(A) with common bedrooms which have background noises between 22-48dB(A). 35 volunteer subjects were wearing sleep evaluation head band when sleeping in the silent room and at their homes with measured background noise. From the results there can be found that there is an overall improvement of people's sleeping qualities in the silent room compared with common bedrooms: the length of total sleep, deep sleep, and REM sleep have averagely increased by 11.4%, 9.3%, and 12.2% respectively. The proportion of REM sleep length in total sleep length has averagely increased by 0.8%.

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1. Introduction

1.1. Human Sleep

Sleep is a necessary biological activity for human beings and all mammals. Many researches have studied the mechanism and functions of sleep through experiments, but because of the complexity of sleep, people still haven't figure out the exact function of sleep for animals. Different hypotheses including brain detoxification and cooling [1-4]; energy conservation and allocation [5-7]; and tissue restoration [8-9] have been proposed. Experiments found that sleep deprivation would affect people's moods and functions [10], and in a long term may increase the risk of corpulence and diabetes [11].

Human sleep consists of 2 states: REM (rapid-eye-movement) sleep and NREM (non-rapid-eye-movement) sleep [12]. NREM sleep can be further divided into 4 stages from stage 1 to stage 4, of which stage 3 and stage 4 fall into the concept of slow wave sleep, also known as deep sleep. People deprived of deep sleep tend to suffer from depression while lacking REM sleep results in higher irritability [13]. REM sleep is also believed to be related to memory consolidation and emotion regulation [14-15].

1.2. Noise and Sleep

Noise is a big threat to people's sleeping qualities, especially in big cities. The background noise of normal residence consists mainly of traffic noise, industrial noise and noise inside the buildings (e.g. neighborhood noise, mechanical noise) [16]. The short-term effects of noise to sleep found in experiments include the effects on sleeping qualities (e.g. more awakening, shorter sleep length, fragmental sleep cycles) and on daytime performances (e.g. annoyance, sleepiness, less focus)[16-18]. Experiments also indicate that noise disturbances during sleep in the long term

may raise health issues (e.g. higher risks of hypertension, cardiovascular disease, obesity, type 2 diabetes) [16-19]. In most existing experiments, this influence is studied by analyzing existing noise and sleep or adding specific noise to normal sleep environment. Because in our daily life, background noise is everywhere, it was considered as a negligible constant in these experiments. In 2000, WHO recommended a maximal noise level (L_{Amax}) of 45 dB inside nighttime bedrooms, and an average level (L_{night}) of 30 dB [20]. Little research has been found to study whether environments with background noises under 30dB have influence on human sleep, and that's the blank this experiment tries to fill in.

1.3. Silent Room

The silent room used in this experiment was built by Tsinghua University in 2012. It was built with the treatments in anechoic chambers and isolation rooms for acoustic researches, but compared to these laboratory rooms which are usually air-tight with unaesthetic absorptive materials that might make people uncomfortable, the silent room was built to look just as a normal bedroom. The glass window, electrical equipment, furniture, bathroom, and the style of interior design are all similar to a common bedroom.

The room has a hexagonal plan of 20 m^2 big and 3m high, built with a "box in box" structure. The inner layer was completely isolated on springs. The air gap between the boxes also serves as plenum chamber to silence the air conditioner. Fresh air comes through a filtration unit, a thermoregulation unit, and a dehumidification unit before entering the air gap. When the air conditioner is turned on, the background noise inside the room stays below 5 dB(A) [21-22].

1.4. Procedure

35 volunteer subjects, 16 females and 19 males, with ages evenly scattering from 20 to 60, slept for one night in the silent room, and the second at their homes successively. They were asked to go to sleep and wake up at their normal pace without arousing.

The sleep monitor and evaluation devise used in this experiment was Zeo Sleep Manager Pro by Gibson Research Corporation. Zeo can automatically define sleep stages by tracking EEG [23]. Compared with PSG, the official equipment used for medical researches, it has been proven precise enough for scientific research [21, 24]. It's in the form of head band, so compared with PSG, it's more comfortable and thus less influential to subjects' sleep.

To minimize the influence of the equipment on subjects' sleep, the night before the experiment, each subject was asked to wear the band for one sleep at home as preparation. Only if the subject considered the influence negligible would he continue the experiment.

1.5. First Night Effect

Based on precedent study [25], when people change their sleep environment, they tend to experience more awakening periods and more light sleep, less REM sleep, delays on the onset of deep sleep and REM sleep, and more fragmental sleep cycles. The First Night Effect will be largely alleviated from the second night. But in this experiment, the subjects only have one night to sleep in the silent room, so it was their first night. Therefore, the First Night Effect may have negative influences to the subjects' sleep quality results in the silent room.

If the subjects stay for more than one night in the silent room, it is safe to presume that after they are more adapted to the environment, their sleep quality may improve.

1.6. Calculation

Sleep is a very complex process influenced by many factors. Noise may be a relatively small factor compared with clinical disorders like sleep apnea [26]. Internal factors of each subject, including his previous activities and health conditions, may have more significant influence on his sleep qualities than external factors, including sound, light, heat and body contact. The internal factors are not controllable. However, due to the randomness of the internal factors, the mean value should remain stable [27]. The main variation of external factors is the background noise, so after average calculation, the influence of noise will show.

Also, to eliminate the weight influence of long and short sleepers, the ratio of value is used. For each index A, the following equation is used for calculation:

$$\mathrm{A} = \sqrt[35]{\frac{A_{s1}}{A_{h1}} * \frac{A_{s2}}{A_{h2}} * \dots\dots * \frac{A_{h35}}{A_{h35}}}, \qquad (1)$$

whereas $\boldsymbol{A_{si}}$ stands for the value of subject no.i in the silent room and $\boldsymbol{A_{hi}}$ stands for the value of subject no.i at home.

If A>1, this index is higher in the silent room; if A<1, this index is higher in normal bedrooms; and if A≈1, this index is almost the same in these 2 environments.

Deep sleep usually only appears at the early cycles in a whole night's sleep and REM sleep spreads across the night[12,28]. Therefore, for deep sleep, only the length is calculated, as it's not affected much by the total length of sleep. But for REM sleep, both the length and the proportion is calculated.

2. Results and Analysis

2.1. Results Value

The results of total sleep length, deep sleep length and REM sleep length (in minutes) of each subject is listed below, in the ascending order of background noise level at their homes.

Table I. Detailed results

No.	Backgro-und noise dB(A)	Total sleep length (min)		Deep sleep length (min)		REM sleep length (min)	
		S	H	S	H	S	H
1	22.2	309	216	52	24	48	21
2	23.3	435	339	68	73	126	92
3	24.4	398	420	47	57	91	96
4	24.6	506	401	41	27	167	183
5	24.7	476	273	36	24	128	49
6	24.9	452	456	20	23	100	105
7	25.8	561	542	22	19	163	186
8	28.7	273	500	35	52	91	187
9	28.8	554	554	70	39	256	199
10	29.3	414	331	122	127	67	71
11	29.5	457	362	78	68	197	122
12	30.6	390	432	43	38	108	148
13	30.9	312	280	27	62	76	70
14	32.5	433	384	49	41	79	82
15	34.5	476	401	28	32	129	91
16	35.8	399	369	52	69	107	69
17	35.9	494	273	62	65	151	83
18	36.0	214	218	59	54	9	12
19	36.0	406	411	62	91	127	174
20	37.6	368	330	35	56	123	106
21	39.2	495	466	51	55	159	171
22	39.3	240	304	75	29	22	56
23	40.1	335	353	101	91	99	136
24	40.2	357	374	61	63	95	108
25	40.2	399	375	69	50	98	85
26	40.9	476	277	38	23	147	143
27	41.2	490	435	49	35	180	120
28	41.5	410	339	40	36	149	68
29	42.5	397	451	21	45	85	100
30	42.7	425	467	69	55	101	110
31	42.8	385	400	70	57	105	134
32	44.2	561	365	43	26	88	24
33	44.4	591	405	65	45	178	76
34	45.0	321	284	52	55	103	92
35	48.0	377	312	42	24	107	111

(S – Silent room; H – Home)

2.2. Average Calculation

Using the calculation method stated in 1.6, the following results can be calculated:

Table I. Calculated average (silent room vs. common bedrooms)

	Total sleep length	Deep sleep length	REM sleep length	REM sleep proportion
Total average	+11.4%	+9.3%	+12.2%	+0.8%
Increase count	23	20	17	16
Increase average	+25.1%	+42.2%	+60.8%	+31.1%
Decrease count	12	15	18	19
Decrease average	-11.0%	-23.0%	-20.1%	-19.3%

The Total average is the average change of the index of all 35 subjects, positive number means there's an increase in the silent room than common bedrooms, and negative number means a decrease; the Increase count is the number of subjects that has a higher index in the silent room and the Increase average is the average of the index of these subjects; while the Decrease count is the number of subjects that has a higher index in at their homes and the Decrease average is the average of the index of these subjects.

From the table we can see that the lengths of total sleep, deep sleep and REM sleep have all increased in the silent room, while the proportion of REM sleep has no obvious change. More people have an increase in the length of total sleep and deep sleep with a higher average increase value than the average decrease. More people have a decrease in the length of REM sleep and the

proportion of REM sleep, but with a lower average decrease value than the average increase.

3. Conclusions

From this experiment, it can be seen that the subjects have better sleep qualities in the silent room than at their homes in terms of total sleep length and deep sleep length.

More people have longer total sleep length and deep sleep length in the silent room than at their homes. 35 subjects averagely have 11.4% increase in total sleep length and 9.3% increase in deep sleep length.

The length of REM sleep increased according to the total sleep length, but the proportion of REM sleep didn't have significant changes.

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