LED and Binaural Beats Sleeping Mask as Sleep-Wake Cycle Regulations Based on Brain Wave Stimulation

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Abstract

Depression rate has reached 17-27% in Indonesia, while about 5-10% of world population have sleep disorder. Unsurprisingly, one of the symptoms of depression is sleep disorder. Sleeping disorder could be treated by sleeping mask. The material of sleeping Mask is PLA (polylactic acid) in 3D printing. There is Arduino Uno as microcontroller to control alarm for sleep-wake cycle. Device works until the first 30 minutes for blue LED and delta binaural beats and the last 30 minutes for yellow LED and gamma binaural beats.. Blue LED and delta wave of binaural beats can stimulate the delta brainwave which related with deep sleep. While yellow LED and gamma binaural beats could stimulate the gamma brain waves and trigger awakening. This research employs causal quantitative method with experimental primary data collection. Additionally, there are two tests in this research, namely sleep and awakening test. A delta wave stimulation is shown in lead C3-C4 during the sleep test. Stimulated delta wave records 23.42 times higher rate than without stimulation. Thus, the system can actually trigger a deep sleep faster. During the awakening test, the stimulation using gamma binaural beats and yellow light shows that delta brainwave amplitude in lead C3-C4 is lower; while alpha brainwave amplitude in lead O1-O2 is higher. Thus, this system is able to stimulate alpha wave faster than without stimulation. The mask could regulate sleep-wake cycle for alarm device and enhance sleep quality.

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Introduction

Depression is a fairly serious health problem in the society. The depression rate in Indonesia ranges between 17 and 27 percent, while the worldwide rate is around 5 to 10 percent. World Health Organization (WHO) even stated that depression will be the second endemic global disease after ischemic heart disease.[1] One of the symptoms of depression is sleep disorder. The etiology of depression which supports its relationship with sleep disorder is the disruption of neurotransmitter serotonin and Cortical – Hypothalmic – Pituitary - Adrenal Corticol Axis (CHPA) hormone regulation.[2,3,4] This is certainly related to the lack of balance between sleep quality and daylong activities.

However, for several cases, professionals with more hectic activities are forced to sleep for a shorter duration, but they have to be fresh in the following day. Entrepreneurs, doctors, technicians, or other officers sleep for averagely four hours a day. The loud ring of mobile phone alarm or other alarm clocks may shock their bodies and causes forced and sudden awakening to the body prior to its time to wake. It is the main reason why some people do not feel refreshed when they wake up. Several portable devices are available, or being developed, the subjects are more convenience of being monitored at home.[5] Based on the case above, an idea to offer a solution to improve the sleep quality and freshen somebody's awakening process from the short sleep duration was generated. This instrument is called 'LED and

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Binaural Beats Sleeping Mask', which utilized the visible light radiation of particular wavelength and binaural beats concept using sound frequency difference. Delta wave as the sleep quality manager and gamma wave as the sleep duration manager (alarm) were the waves which became the focus in the brain wave stimulation method.

This research intends to produce LED and Binaural Beats Sleeping Mask as an alarm instrument to improve somebody's sleep quality. Therefore, this instrument is expected to be an alternative solution in managing sleep duration and quality for poor sleep quality, sleep disorder, or even depression. Moreover, it is also expectedto support a government program titled *Indonesia Sehat 2025* (Healthy Indonesia 2025) by improving Indonesian's sleep quality and managing their sleep duration.

Materials and methods

The research method was quantitative causal experimental method with primary and secondary data collection. This research took five months in Medical Instrumentation Laboratory at the Faculty of Science and Technology of Airlangga University, ITD (Institute of Tropical Disease), and RSUD Dr. Soetomo Surabaya. The research procedures are presented in Figure 1. Meanwhile, the block diagram of LED and Binaural Beats Sleeping Mask'instrument is presented in Figure 2.

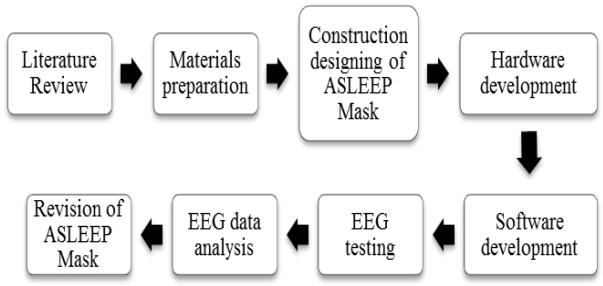

Figure 1. The flow chart of research procedures.

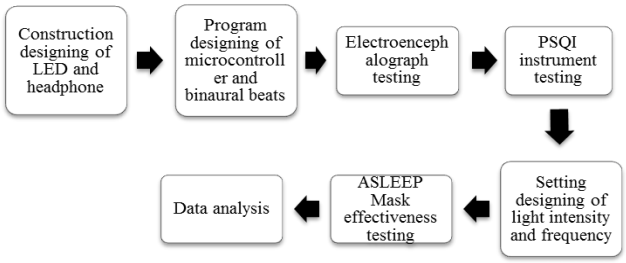

Figure 2. Block diagram of LETD and Binaural Beats instrument.LEEP Mask instruments.

Results

Visible Light Wave

Visible light wavelength is related to light frequency and energy.[6] The higher the frequency, the shorter the wavelength and the bigger the radiated energy shall be. If the wavelength of a light wave is shorter, that means that the frequency will be higher because one cycle can pass in a shorter amount of time. This means that more cycles can pass by the set point in 1 second. Likewise, a light wave that has a longer wavelength will have a lower frequency because each cycle takes a longer time to complete.[7]

Visible light consists of red, orange, yellow, green, blue, and violet spectrums. In this research, the visible light utilized in LED and Binaural Beats Sleeping Mask is blue light with wavelength of 450-500 nm and yellow light with wavelength of 570-590 nm. Some previous studies stated that stimuli in the form of certain light can stimulate human's brainwave.[8]

Binaural Beats

Binaural beats based on auditory brainstem responses which originate in the superior olivary nucleus of each hemisphere. They result from the interaction of two different auditory impulses, originating in opposite ears, be low 1000 Hz and which differ in frequency between one and 30 Hz. Binaural beats did yield an increase in the occurrence of alpha however, another group which heard artificially produced surf sounds also showed a comparable increase in alpha. [9]

Brainware

The consciousness phase of human is closely related to brain activity.[10] This activity can be measured using EEG to see the produced brainwave frequency.[11] Based on the frequency, brainwave is classified into delta, theta, alpha, beta, and gamma.[12]

The wave with the lowest frequency is delta wave at 0.5-4 Hz. This brainwave is produced when somebody experiences a deep sleep. Meanwhile, the highest frequency is gamma wave. Gamma wave occurs when somebody experiences quite high brain activity,[13] see Figure 3.

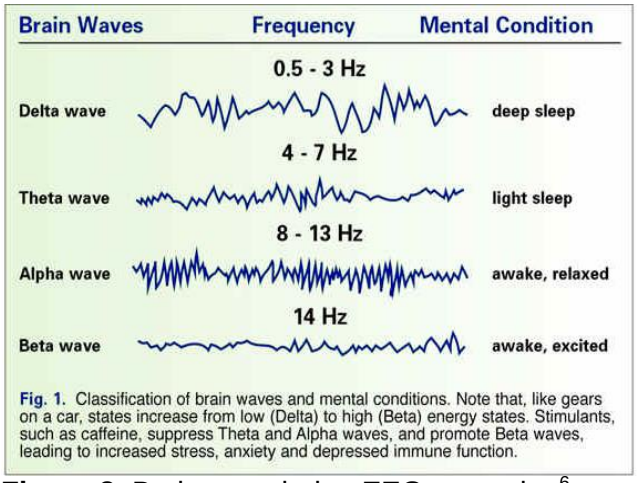

Fig. 1. Classification of brain waves and mental conditions. Note that, like gears on a car, states increase from low (Delta) to high (Beta) energy states. Stimulants, such as caffeine, suppress Theta and Alpha waves, and promote Beta waves, leading to increased stress, anxiety and depressed immune function.

Figure 3. Brainware during EEG screening[6]

Sleep Cycle

Sleep is an unconscious condition which is relatively more responsive to internal stimuli, see Table 1. The difference between sleep and other unconscious conditions is that the sleep cycle is predictable and the person who sleeps is less responsive to external stimuli. Sleep function is to restore body organs (restorative).[14]

According to Rechtschaffen and Kales,[15] the stages of sleep are divided into Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM). Based on EEG (electroencephalogram), EOG (electrooculogram), and EMG (electromyogram) screenings, five sleep pattern stages were found; four of which are in NREM stages (deep sleep) and the rest is in REM (shallow sleep).

Stage	Frequency (Hz)	Amplitude (micro Volts)	Waveform type
awake	15-50	<50	
pre-sleep	8-12	50	alpha rhthym
1	4-8	50-100	Theta
2	4-15	50-150	spindle waves
3	2-4	100-150	spindle waves and slow waves
4	0.5-2	100-200	slow waves and delta waves
REM	15-30	<50	

Table 1. The frequency and amplitude of sleep wave.

Electroencephalograph (EEG)

EEG is a non-invasive measuring method which represents electrical signal of brain activity gained by placing a number of electrodes on brain's scalp area. Thus,brain electrical signal is obtained to be processed and analyzed. EEG is an important instrument for clinical practitioners to diagnose, monitor, and overcome nerve disorders or diseases.

Currently, portable EEGs using some required channels are available, one of which is EEG SMT. EEG SMT is an EEG device produced by OLIMEX Ltd., which has two channels called CH1+, CH1-, CH2+, and CH2- and one ground. In EEG SMT, each epoch produces 256 data per second, so the number is bigger and more precise.[16]

LED and Binaural Beats Sleeping Mask Prototype

The 'LED and Binaural Beats Sleeping Mask' prototype consisted of several designs. First, the hardware assembly, which included LED lamps and headphones fitting on the mask. LED light exposure over the user's eyes used yellow light as the gamma wave stimulator and blue light as the delta wave stimulator. Second, a program using Arduino Uno, which integrated LED light with binaural beats delta and gamma.

Both designs were then tested using EEG to obtain brainwave after they were completed. The last stage was to put them into a packaging using two layers of cotton. The second layer reduced the intensity of LEDs. 'LED and Binaural Beats Sleeping Mask' prototype is presented in Figure 4.

Figure 4. LED and Binaural Beats Mask prototype.

Signal Data Collection

The data of brainwave signal were obtained using EEG SMT. The electrodes placement was based on 10-20 electrode placement rule. In this study, it was recommended for the research subjects to be bald in order to reduce noise. The electrodes are then placed on C3-C4 lead (central) and O1-O2 lead (occipital). They could obtain sleep-wake brainwave and sleep stages.[17]

Discussion

LED and Binaural Beats Sleeping Mask Testing Method

Signal analysis

'LED and Binaural Beats Sleeping Mask' test was conducted in several stages, as presented in Figure 5. The output signal from EEG was read using Open Vibe software in time domain. It had to be converted into frequency domain to analyze the brainwave frequency using Matlab 7.6, as presented in Figure 6.

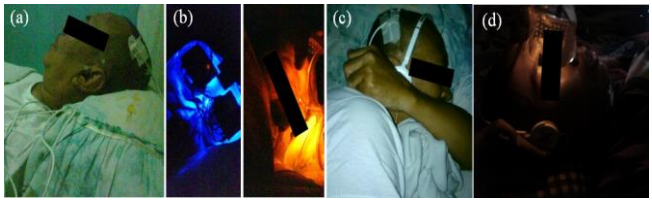

Figure 5. Testing on the user. (a) control condition; (b) using LED; (c) using binaural beats; and (d) using both LED and binaural-beat.

Testing using The Pittsburgh Sleep Quality Index (PSQI)

The sleep quality was tested using The Pittsburgh Sleep Quality Index (PSQI) and displayed in Table 2. EEG signal was tested to prove that'LED and Binaural Beats Sleeping Mask ' could lull and wake user up. The dominant frequency of the brainwave when the user was asleep was observed. The sleep indicator could be observed from the dominant frequency between 0 and 4 Hz, known as delta brainwave. Therefore, the focus of the observation was the amplitude of the delta wave in C3-C4 lead (Channel 1) and O1-O2 lead (Channel 2). Results of EEG recording are displayed in Table 3 and Table 4.

Data Analysis of LED and Binaural Beats Sleeping Mask Testing

Testing using PSQI

PSQI was indicated by seven components. The first indicator showed subjective sleep quality. The second indicator showed period of time someone takes to fall asleep (sleep latency), while the third and the fourth indicators showed sleep duration and habitual sleep efficiency. Additionally, the fifth indicator showed sleep disorders (sleep disturbance), the sixth indicator showed the medications to sleep (use of sleeping medication), and the seventh indicator showed activities disruption during daytime (daytime dysfunction). It was found that the subjects had Global PSQI scores of 6 and 8, which means they were experiencing sleep disorders.

Brain signal testing using *Electroencephalograph* (EEG)

The testing on C3-C4 lead was conducted to analyze delta wave during sleep.[18] As a result, it showed that the higher the occurring amplitude is, the deeper the person slept. Meanwhile, the testing on O1-O2 lead was conducted to see the occurrence of delta wave too, but it was different from the C3-C4 lead. O1-O2 lead could show alpha wave (initiate awareness), so deep sleep stage shows that delta wave amplitude decreases and vice versa.

The results showed that for people who sleep without any treatment (normal), the brain wave was dominated by delta and alpha waves (sleepiness).[19] Meanwhile, for those given a treatment in the form of blue LED (stimulus delta brain waves) on Channel 1 (C3-C4), the amplitude of the brainwave increased; while on Channel 2 (O1-O2), the amplitude decreased which means they slept deeper. When two stimuli were given to the subject at the same time, the amplitude of brain's delta wave on C3-C4 lead increased (nearly twice higher) and decreased on O1-O2. It showed that deep sleep might happen using two stimulations in the form of blue light and the sound of binaural beats. More details can be seen in Figure 7 and Figure 8 below.

For the awakening test results, it could be seen on Channel 1 (C3-C4) that without any treatment, the amplitude of delta wave was quite high; while Channel 2's (O1-O2) was still fairly small.

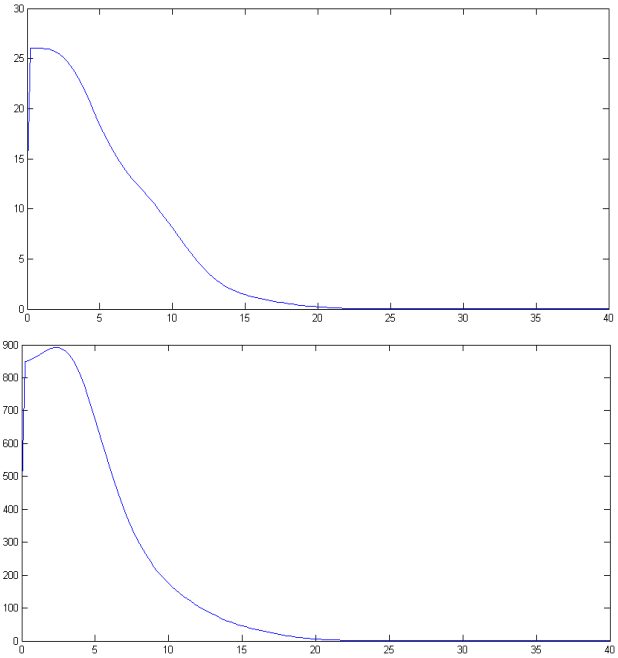

Figure. 6. EEG signal in frequency domain: (a) Channel 1 (C3-C4 lead) and (b) Channel 2 (O1-O2 lead).

No	Criteria	Subject 1		Subject 2	
		Score	Note	Score	Note
1.	Subjective sleep quality	0	very good	1	fairly good
2.	The duration required for sleeping	2	31-60minutes	0	< 15 minutes
3.	Sleep duration	2	5-6 hours	3	< 5 hours
4.	The efficiency of sleeping habits	0	very efficient	0	Very efficient
5.	Sleep disorders	1	<once a week	2	1-2 times a week
6.	Medication of sleep	0	Never	1	<once a week
7.	Activity disruptions in the daytime	1	rarely happens	1	rarely happens
PSQI global score		6	**Sleep disorder occurred**	8	**Sleep disorder occurred**

Table 2. The results of PSQI test.

No	Treatments	Results			
		Channel 1 (C3-C4)		Channel 2 (O1-O2)	
		Dominant waves	Amplitude (μV)	Dominant waves	Amplitude (μV)
1.	No treatment	Delta & Alpha	38	Delta	120
2.	Blue LED	Delta	450	Delta	56
3.	Blue LED + Binaural beats Delta	Delta	890	Delta	26,5

Table 3. The results of lulling test.

These results suggested that while the person was still in deep sleep stage, treatment stimulus using binaural beats alone could reduce the amplitude of the delta wave on Channel 1 and increase the amplitude on Channel 2. It means that the sleeping conditions were getting closer to the waking-up state. While using two stimulations of yellow LED and binaural beats gamma, we obtained the amplitude of lower frequency delta waves on Channel 1 and higher waves on Channel 2. It suggests that a person starts waking up.[20]

No	Treatments	Results			
		Channel 1 (C3-C4)		*Channel* 2 (O1-O2)	
		Dominant waves	Amplitude (μV)	Dominant waves	Amplitude (μV)
1.	Without Treatment	Delta	405	delta	54
2.	Binaural beats Gamma	Delta	108	delta	98
3.	Yellow LED+ Binaural beats Gamma	Delta	26,5	delta	155

Table 4. The results of awekening test.

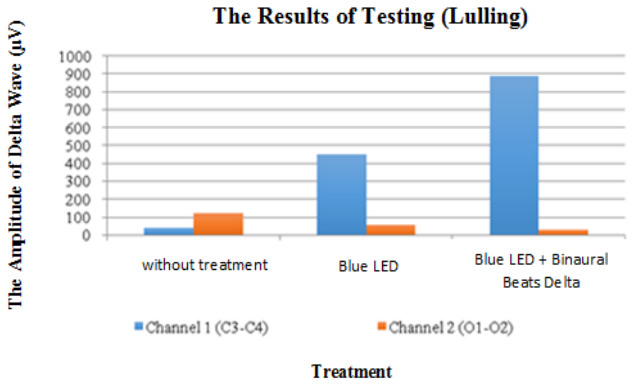

Figure 7. The results of delta wave amplitude during lulling.

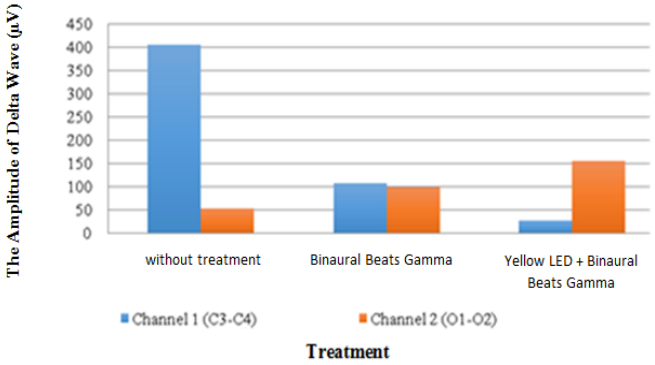

Figure 8. The results of delta wave amplitude during lulling awakening.

Conclusions

'LED and Binaural Beats Sleeping Mask' is an instrument which functions as an alarm based on high amplitude generated in the process of sleeping and awakening. 'LED and Binaural Beats Sleeping Mask' also improves sleep quality with irregular waves which pass through the delta-theta-alpha-beta-gamma phase, and vice versa.

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