Original Research

Brain Rhythm Waves Pattern before Waking Up in Children: A Single-Center Study

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Abstract

Background and Objective: After going through the alpha wave before waking, a person usually enters the conscious phase physiologically by opening the eyes and communicating with the environment. We conducted the present study to investigate the brain rhythm wave pattern before waking up among the children admitted to the sleep clinic at Ghods Children's Hospital, Qazvin, Iran.
Materials and Methods: In this cross-sectional study, we investigated 42 children without physical or acute respiratory diseases for brain rhythm wave patterns, 15 seconds before waking up. Data were analyzed manually from the polysomnography (PSG) recorded during sleep. Then, we divided the children into two groups based on the results of the apnea-hypopnea index (AHI), i.e., mild to moderate and severe AHI. The frequency of brain waves before waking up on epochs 30s, 10s, and 1s were checked between the two groups statistically.
Results: Alpha waves appeared before waking up as the principal brain waves. The frequency of alpha waves went through a decreasing rate until they reached 10 Hz, and then the child woke up. We observed three repetitions of 10 Hz frequencies before waking up for both groups of low-moderate and high AHI.
Conclusion: Awakening happens with a specific trigger of alpha waves in the occipital lobe in the N2 phase at a 10 Hz frequency.

Keywords: Brain waves; Sleep; Awakening; Electroencephalography

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Introduction

Sleep and wakefulness in humans comprise a variety of phases including N1, N2, N3, rapid eye movement (REM), and wake (light, deep sleep, dream, and awakening). Alpha (8-13 Hz), beta (13-30 Hz), theta (4-8 Hz), and delta (1-4 Hz), waves appear in every sleep and wake phase (1). After going through the above phases, a person usually enters the conscious phase physiologically after at least six hours of adequate sleep by opening the eyelid and communicating with the environment. Beta waves are active in the waking phase. We see alpha waves in the occipital region by closing our eyes during sleep (2). Delta (δ) waves occur during deep sleep. There is low voltage mixed frequency (LVMF) brain waves during the dream (2).

A sleep cycle includes different stages of sleep from non-REM (NREM) to REM sleep. Sleep cycle duration is between 90 to 120 minutes, ac-

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cording to children's age groups. Sleep cycles repeat between 4 to 5 times during a night of normal sleep (3). The essential waves for scoring stages N1, N2, and N3 are vertex, K complexes - spindle, and delta waves, respectively. There is also a sawtooth wave during the REM phase (3).

The appearance of alpha waves in polysomnography (PSG) shows the physiological and brief states of wakefulness that appear between waking and sleeping (4). Before the onset of sleep, patients with insomnia show decreased alpha variability compared to normal people (5). Alpha waves bridge the gap between conscious thinking and the subconscious mind (6). Alpha waves create a feeling of calm (7).

It has been shown that repeated changes in alpha activity, even without visual stimulation or retinal entry, could show activation of the visual cortex, which may include a pre-awakening process (7). The strength of occipital alpha waves increases as the eyes close (8).

Alpha waves occur in the central regions and migrate to the posterior places during REM sleep (9). Since the activity of the cerebral cortex is higher in the REM phase, more activation at higher frequencies may be associated with sleep fragmentation (10). Previous studies suggested that sensorimotor and sensory areas in patients with insomnia might still be relatively active, even during deep sleep (7).

Armitage showed that prolonged waking led to a progressive increase in sleep pressure, which was reflected in the electroencephalography (EEG) by slowing down the brain frequency of 13 Hz to slower waves (0.5-4.5 Hz) indicating a transition from consciousness to rest. Further investigation revealed that there was not a clear difference in the sleep EEG between men and women (11). The relationship between alpha waves and drowsiness has been the subject of previous studies (12). However, to the best knowledge of the authors, the frequencies of alpha waves before waking up in the morning have not yet been explored.

PSG is the gold standard diagnostic test for evaluating sleep and waking patterns. Classification of the wake and sleep phases, brain waves frequency, and type of them are detectable objectively by a PSG (13).

Human wakes up spontaneously at any phase of sleep. This can be recorded through PSG, but the type of the pattern of brainwave, the frequency, and whether the wave pattern is constant among children are not clear.

Hemispheric asymmetry and sensory neural region are considered constant characteristics of the transition from waking to sleep (14). In addition, detecting specific alpha frequency rhythms may be necessary for predicting patients in a coma (15), treating insomnia (5), and when investigating operators whose jobs require alertness and consciousness (e.g., drivers) (12). So far, only a few studies have considered the awakening mechanisms. Hence, we investigated the rhythm of brain waves before waking up in children. The main hypothesis in the present study is that the alpha wave is the prominent wave before waking up. We also considered the pattern of these waves in terms of frequencies and rhythm.

Materials and Methods

This research was a cross-sectional study of children admitted to the sleep center at sleep clinic of Ghods Hospital, Qazvin, Iran. We got the patients to sleep in standard sleep rooms to collect their sleep profiles. Data used in this study have been collected for three years.

Out of 200 patients admitted during 3 years, we selected patients who did not have physical, respiratory, and metabolic diseases and syndromes and awakened spontaneously during the PSG test (n = 42). We got data from the PSG test results, including complete records of limb and respiration. Participants were between 1 to 16 years old. The age, height, and weight of the children were based on their medical file information that was provided in the time the patients were admitted to the hospital. The body mass index (BMI) measures were estimated based on the PSG software.

The study design included the following steps:

1. Watching the video captured from the bedroom and detecting the moment the child woke up in the morning
2. Matching the video and the moment of awakening in PSG records
3. Observing the moment of spontaneous awakening to remove from the study the patients who were awakened by a nurse
4. Checking the frequency of waves backward (every second until waking up during 15 seconds before waking up).

We investigated these patients after PSG examination with apnea-hypopnea index (AHI) between mild to moderate (AHI < 10) and severe (> 10) according to the American Academy of

Sleep Medicine (AASM) manual published in AASM 2018. We excluded the severe patients to reduce the bias. Then, we analyzed the frequency of brain waves before waking up based on the standards of 30s, 10s, and 1s. We used SPSS software (version 23.0, IBM Corporation, Armonk, NY, USA) and AASM 2018 (electrode placement F4-M1, C4-M1, O2-M1) to conduct the analysis. Another aim was to compare the brain wave frequency between the children with severe (AHI > 10) and mild to moderate AHI (AHI < 10) using t-test statistics. We also investigated the alpha wave frequency and rhythm at which the children woke up.

Results

The mean age of the patients was 7.50 ± 4.23 years old. The mean height was 110.7 ± 28.9 cm. The mean weight was 25.62 ± 18.58 kg, and the mean BMI was 18.6 ± 5.9 kg/m^2. The sample included 30 (71.4%) boys and 12 (28.6%) girls (Table 1). Patients had normal sleep architecture and structure, during at least 6 hours of total sleep time.

Table 1. Sample characteristics

Variable	Value
Gender [n (%)]	
Boy	30 (71.4)
Girl	12 (28.6)
Age (year) (mean ± SD)	7.50 ± 4.23
Weight (kg) (mean ± SD)	25.60 ± 18.50
Hight (cm) (mean ± SD)	110.70 ± 28.90
BMI (kg/m^2) (mean ± SD)	18.60 ± 5.90

BMI: Body mass index; SD: Standard deviation

Out of 42 cases, 2 (4.8%), 29 (69.0%), 5 (11.9%), and 6 (14.3%) patients woke up in phases N1, N2, N3, and REM, respectively (Figure 1). As shown, the most and the least cases woke up at N2 and N1 phases, respectively. The average frequency of the N1 phase wave was 9.1 ± 7.9 Hz. The average frequency for the N2, N3, and REM phases was 50.3 ± 17.5 Hz, 20.5 ± 11.6 Hz, and 19.1 ± 16.1 Hz, respectively.

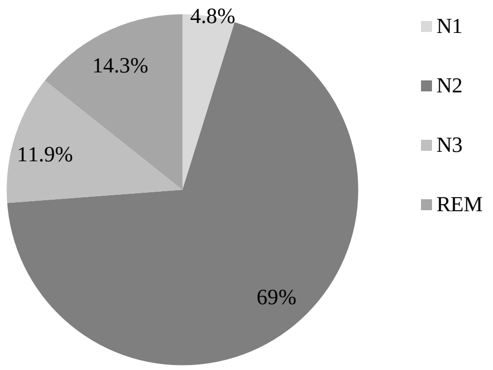

Figure 1. The frequency of patients waking up in different sleep phases

The average frequency of the whole group (consisting of 42 children) from 15 seconds before waking up (at a one-second pace) showed that the frequency started to decrease to a threshold of 10 Hz. This 10 Hz frequency was observed for about three waves remaining up to wake-up (Figure 2).

Similar to the average frequency, the median frequency was also found to decrease from 15 Hz to 10 Hz. We also observed three repetitions of waves with a median of 10 Hz before waking up (Table 2).

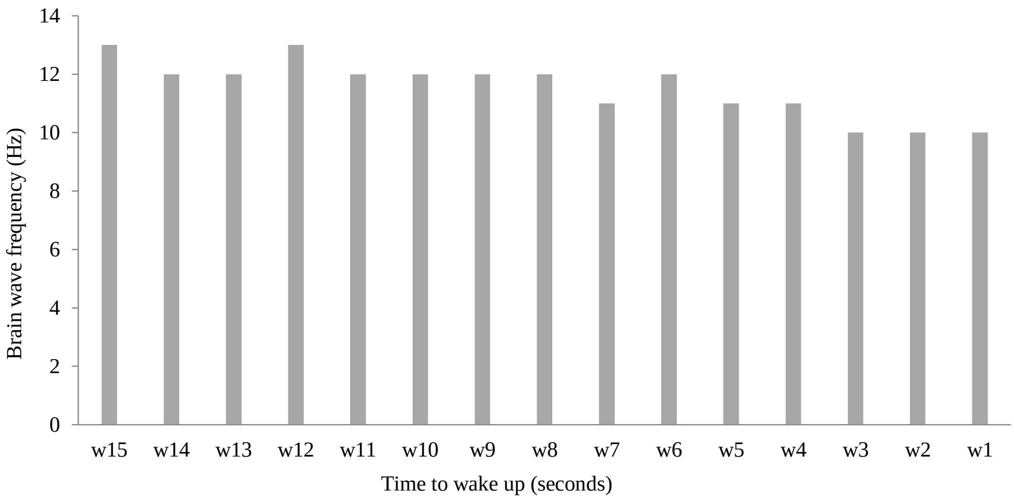

Figure 2. The average frequency of brain waves for 42 patients from 15 seconds before waking up

Table 2. The median of the decreasing brain wave pattern

Time to wake-up (second)	Median frequency (Hz) (25%-75% percentile)
W1	10 (10-11)
W2	10 (10-11)
W3	10 (10-11)
W4	10 (9-13)
W5	9 (10-14)
W6	12 (10-14)
W7	11 (10-13)
W7	10 (10-14)
W8	10 (10-14)
W9	9 (10-14)
W10	11 (9-14)
W11	9 (10-15)
W12	14 (10-14)
W13	12 (10-14)
W14	14 (10-14)
W15	15 (11-14)

We found no evidence that the difference in brain wave patterns between the two groups of patients with mild and moderate AHI and severe AHI was statistically significant (P < 0.001) (Table 3). For the two groups, analysis showed the same decreasing pattern in the alpha wave frequencies before waking up (Figure 3). We also observed three repetitions of 10 Hz frequencies before waking up for both groups.

In figure 3, the blue line represents the mild-to-moderate AHI with decreasing frequencies starting from 13 Hz and declining with some fluctuations to 10 Hz (with three repetitions). The green line also represents the severe AHI group showing a decrease in brain frequency before waking up. The figure confirms the hypothesis of decreasing the frequency of alpha waves before waking up to 10 Hz. The alpha waves originated from the occipital regions.

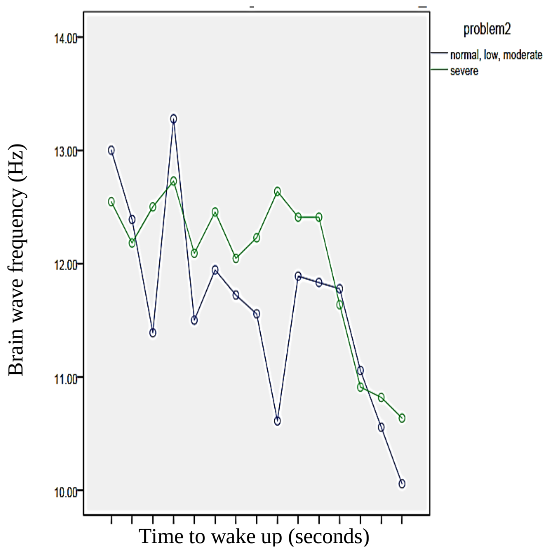

Figure 3. Average of brain wave frequencies from 15 seconds before waking up in two groups of patients with mild and moderate apnea-hypopnea index (AHI) and severe AHI

Discussion

The appearance of alpha waves in sleep EEG shows the physiological and brief states of wakefulness that lie between waking and sleeping (5). The mechanism of awaking is still unknown, and we do not have strong evidence about it (16).

Although alpha waves have been discovered to be a major wave when waking up, previous studies have not yet investigated the brain wave frequencies and wave rhythms before waking up (10).

Table 3. Comparison of brain wave patterns between the two groups of patients with mild and moderate apnea-hypopnea index (AHI) and severe AHI using t-test statistics

Time to wake-up (second)	Normal, low, moderate AHI	Severe AHI	t-value	P-value (2-tailed)
	Mean ± SD	Mean ± SD		
W1	10.05 ± 1.05	10.63 ± 1.49	-1.386	0.174
W2	10.55 ± 2.14	10.81 ± 1.91	-0.408	0.685
W3	11.05 ± 2.28	10.90 ± 2.11	0.210	0.835
W4	11.77 ± 2.81	11.63 ± 2.73	0.160	0.873
W5	11.83 ± 2.85	12.40 ± 2.95	-0.623	0.537
W6	11.88 ± 1.96	12.40 ± 3.30	-0.617	0.541
W7	10.61 ± 1.91	12.63 ± 3.56	-2.291	0.028
W8	11.55 ± 2.35	12.22 ± 2.13	-0.944	0.351
W9	11.72 ± 2.27	12.04 ± 3.72	-0.338	0.738
W10	11.94 ± 2.36	12.45 ± 3.46	-0.532	0.598
W11	11.50 ± 3.45	12.09 ± 2.74	-0.604	0.550
W12	13.27 ± 2.84	12.72 ± 3.19	0.569	0.573
W13	11.38 ± 3.03	12.50 ± 3.82	-1.001	0.323
W14	12.38 ± 3.08	12.18 ± 3.20	0.207	0.837
W15	13.00 ± 2.49	12.54 ± 2.78	0.537	0.594

AHI: Apnea-hypopnea index; SD: Standard deviation

Therefore, the present study is unique in carefully examining the frequency of alpha waves before waking up.

The present study investigates the electrical frequency of brain waves in 15 seconds before waking up to find a specific rhythm in the human waking process. We reached a certain rhythm of the brain as a trigger to waking up and discovered the stages before waking up. Few studies explained the existence of alpha waves in different sleep disorders.

The first definitive EEG phenomenon was described as a frequency of alpha rhythm of 8 to 13 Hz, which was more prominent in the occipital area when the eyes were closed, and usually stopped when the eyes opened (3, 8).

Although in one study the authors expressed the alpha rhythm from different brain regions (17), the alpha waves of 10 Hz frequency have been observed in the present study to be more prominent in the occipital region for almost 15 seconds before waking up.

Normal sleep cycles and spontaneous waking up provide enough energy, alertness, concentration, and efficiency leading to a new brain system working (17). In previous research, brain alpha waves frequency of 10 Hz is the basic frequency in which the brain has better memory function and activity. For example, in a study of patients with Parkinson's disease, alpha waves were associated with the slowness of movement. In these patients, alpha waves with a frequency of fewer than 10 Hz are associated with decreased individual performance (17). Similarly, we found that alpha waves of 10 Hz frequency were prominent during the pre-waking state and before starting the morning activities.

As the alpha waves are an indicator of the individual's sleepiness, in 2022 and for research purposes, for jobs requiring high alertness (such as drivers), a device was used to wake up the operators (12). In this device, an alarm was activated when alpha waves started to appear. Using this system to help patients with disabilities and improve their quality of life can help map their brain activities. In these applications, the frequency of brain waves with the brain-computer interface (BCI) can be effective in treating patients (18, 19).

In the present study, we found a decreasing trend in the frequency of brain waves before waking up to the waking stage. A statistical model confirmed this decreasing trend and seemed to follow a regular decreasing repeated rhythm with 10 Hz frequency. Therefore, the children's brain awakens with a specific alpha rhythm pattern in the N2 phase. A more detailed examination of the waves before awakening revealed three repetitions of alpha waves at a frequency of around 10 Hz.

Finally, we did not find any evidence showing that alpha brain frequencies were significantly different between the two groups of AHI greater and less than 10. Therefore, the severity of AHI is not effective in alpha wave frequency before waking up.

Limitations: The study was limited in the selection of patients for being entered into the analysis. Out of 200 children, only 42 children woke up spontaneously with no medical, metabolic, or respiratory diseases. According to the PSG result, most children had mild to severe AHI.

Conclusion

This study investigated the brain rhythm wave pattern before waking up among children. The study revealed that awakening happened with a specific trigger of three 10 Hz frequency alpha waves in the occipital lobe in the N2 phase. The study can be duplicated using a larger group of healthy children.

Conflict of Interests

Authors have no conflict of interests.

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