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Characteristics of Vertex Wave during Light Sleep according to Age

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나이에 따른 얕은 수면에서의 정수리 파형의 특징

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Objectives: Vertex wave during sleep is a hallmark of light sleep and related to brain development. We examined voltage characteristics of vertex wave according to age. **Methods:** Electroencephalographys were selected from routine waking and sleep EEG database. The inclusion criteria were that the age of subjects was more than 4 years old; EEG showed at least 5 typical vertex waves with no abnormal findings; the neurologic examination and neuroimaging findings were normal. EEGs were classified into 7 groups according to their age. Five to 20 epochs which included the time 320 ms before and after the maximum negativity of a vertex wave from each EEG record were selected. Voltage characteristics including amplitude and topographic distribution were evaluated. Intracerebral source location of vertex wave from each age group was identified using low resolution electromagnetic tomography (LORETA). **Results:** Amplitude of vertex wave was highest in the youngest age group, decreased with age thereafter. Voltage topography showed maximum negativity over central vertex area bilaterally in all age group, which did not show any significant difference among age group. Normalized amplitude of vertex waves showed significant main effect of location (df=1.356, F=115.843, p<0.001). Interaction between age and location was also significant (df=4.088, F=3.327, p=0.016). However, age did not show any main effect on amplitude of vertex wave. Post-hoc analysis showed amplitude of group 1 (5 to 9 years), compared with other age groups, was significantly lowered only in Fz electrode. LORETA image showed maximum current density in the mid to posterior cingulate gyri, which was similar across all age groups. **Conclusions:** Our study suggests that vertex waves might be related to arousal response during sleep, although exact mechanism is still unclear. **J Korean Sleep Res Soc 2012;9:5-9**

Key Words: Vertex wave, Voltage topography, LORETA, Arousal, Sleep.

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Introduction

Vertex wave during sleep is usually diphasic, with an initial surface negative deflection followed by a low voltage surface positive phase. Vertex wave is bilaterally synchronous waves which have maximum negative amplitude at the vertex and often extend into frontal, temporal, and parietal areas.[1]

Vertex wave is a hallmark of sleep onset period.[2] Gibbs and Gibbs were the first to emphasize age-related differences in sleep onset EEG in adults and children. They identified vertex waves (calling them biparietal humps) during sleep. Vertex wave appears in well developed form at the age of 5-6 months.[3,4] It is reported that children are most likely to show parietal dominant vertex waves, while adult usually shows central maximum. However, only a few studies has been conducted to define amplitude and its topographic distribution according to brain development.

Methods

EEG was recorded from 19 scalp electrodes positioned according to the International 10-20 System referenced to Pz electrode. Then EEG signals obtained were re-referenced to a common average montage as described previously.[5] Impedance was kept below 5 kΩ, and the bandpass filter was set at 0.3-70 Hz with a sampling rate of 200 Hz.

EEGs were selected from routine waking and sleep EEG database acquired from May to September, 2007 at Korea University Medical Center, Anam hospital. Inclusion criteria were followings; 1) age of subjects was from 4 to 70 years old; 2) EEG showed at least 5 typical vertex waves with no abnormal findings; 3) the neurologic examination and neuroimaging findings were normal. EEGs were classified into 4 age groups as followings; 5 to 9 years old (group 1), 10 to 29 years old (group 2), 30 to 49 years old (group 3), and 50 to 69 years old (group 4). Vertex waves were identified as bilaterally synchronous sharp transients in the central region during light sleep.

Five to 20 epochs which included the time 320 ms before and after the maximum negativity of a vertex wave at Cz electrode from each EEG record were selected. Voltage characteristics including amplitude and topographic distribution were evaluated. Baseline to peak amplitude was measured in common average montage in the present study.

Intracerebral source location of vertex wave from each age group was identified using the low resolution electromagnetic tomography (LORETA, The KEY Institute for Brain-Mind Research, University of Zurich, Switzerland).[6] LORETA computes a unique three-dimensional electric source distribution by assuming that the smoothest of all possible inverse solutions is the most plausible, consistent with the assumption that neighbouring neurons are simultaneously and synchro-

Table 1. Number of subjects and of vertex waves at each age group

	5-9 year	10-29 year	30-49 year	50-69 year	Sum
Subject (n)	7	18	9	10	44
Vertex (n)	77	163	97	66	403

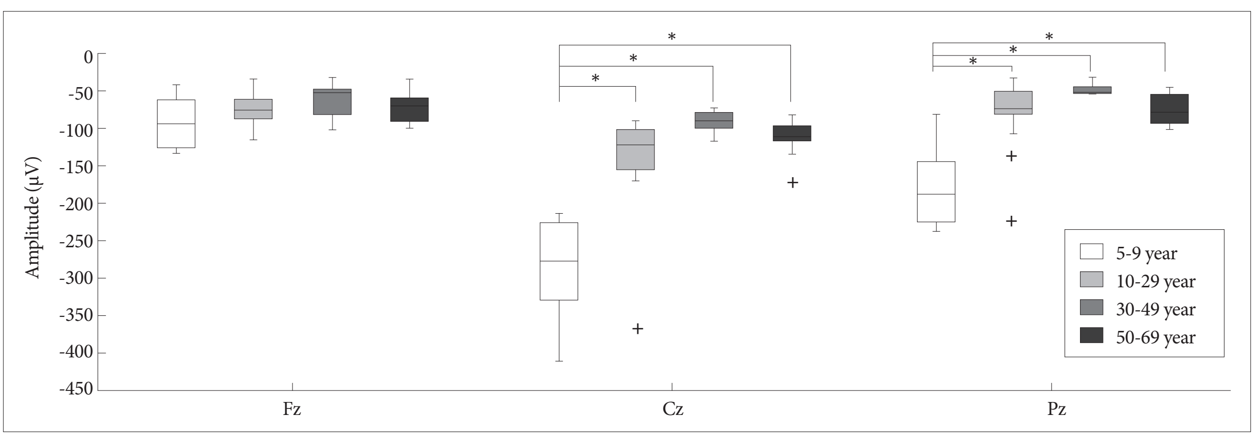

Fig. 1. Box-plot of amplitude of vertex waves within each group at the midline channels. Asterisks mean statistically significant results. The amplitude at Cz and Pz from youngest age group was significantly larger than those of the other age groups.

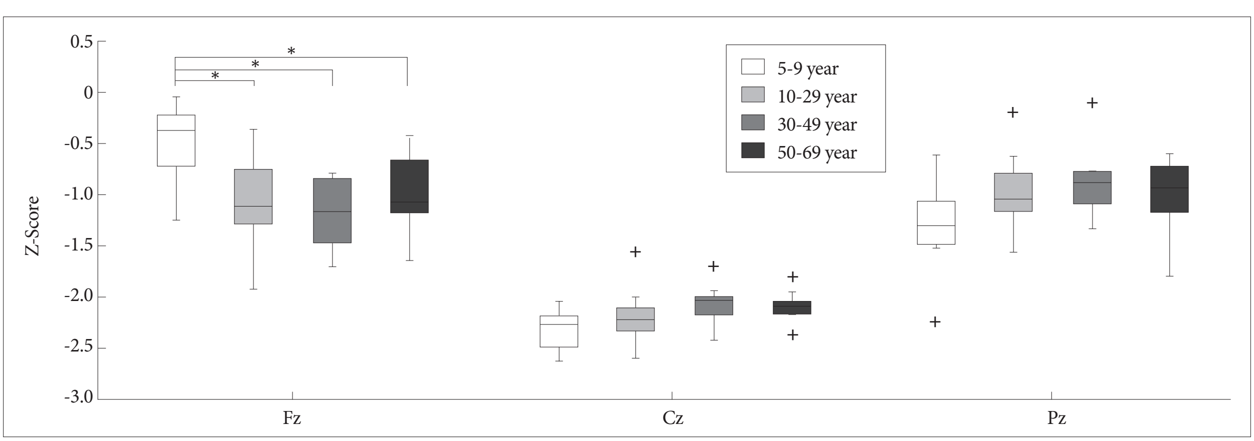

Fig. 2. Box-plot of normalized amplitude (z-score) of vertex waves within each group at the midline channels. The amplitude of youngest age group, compared with other age groups, was significantly lower only in Fz electrode. *significant level: $p<0.01$.

nously active. LORETA images represent the current density in 2394 voxels with a spatial resolution of 7 mm.

The amplitude and topographic distribution of the vertex wave was analyzed with repeated-measures analysis of variance (ANOVA). The within-subject factors was location (three levels: Fz, Cz and Pz) and between-subjects factor was age group (four levels: groups 1 to 4). The significant level of statistical tests was set to 0.05. The Greenhouse-Geisser correction was used to evaluate F ratios to control Type 1 error in repeated measure design. Bonferroni post hoc tests were

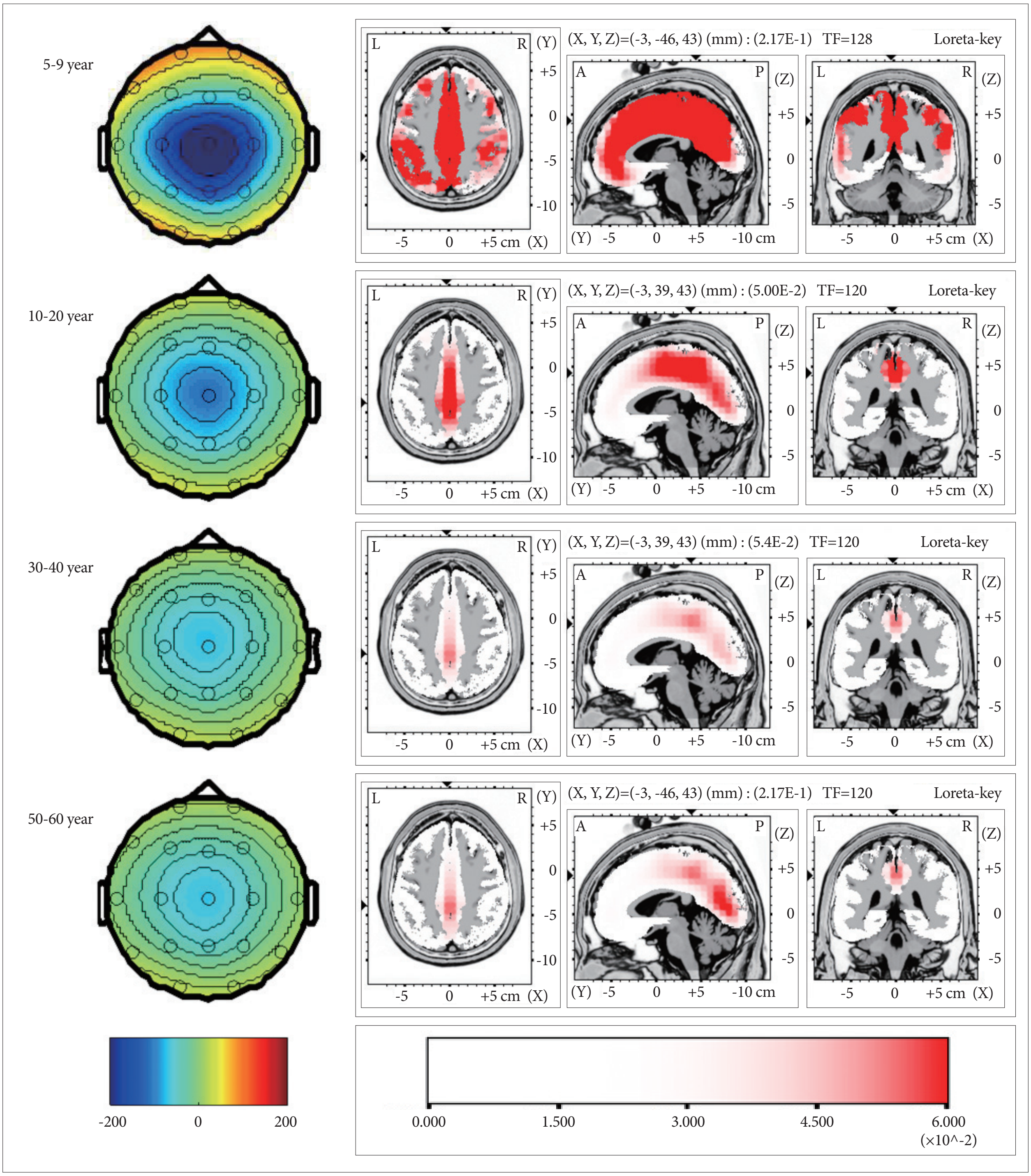

Fig. 3. Voltage topography (left panel) and low resolution electromagnetic tomography (LORETA) images (right panel) of vertex waves. Topographic distribution of vertex wave was quite similar pattern among all age groups. LORETA image shows maximum current density in the mid to posterior cingulate gyri, which was also similar across all age groups.

used to identify the sources of significant repeated measures ANOVA.

Results

The number of subject and of vertex evaluated was presented in Table 1. The amplitude of vertex wave was significantly different across locations (df=1.072, F=73.176, p<0.001). The amplitude of vertex wave was maximum over Cz electrode, followed by Pz in all age group (Fig. 1). Fz amplitude of vertex wave was the smallest in all age groups. Age showed significant main effect on the amplitude of vertex wave (df=3, F=23.872, p<0.001). The interaction between age group and electrode location was also significant (df=5.106, F=11.598, p<0.001). The amplitude at Cz and Pz from youngest age group (i.e., group 1) was significantly larger than those of the other group. However, no significant difference was observed among group 2, 3, and 4. Fz amplitude was not different between age groups.

As amplitude of vertex wave has significant correlation with age (data not shown here), we calculated z-score to normalize any difference of voltage due to age. Normalized amplitude of vertex waves showed significant main effect of location (df=1.356, F=115.843, p<0.001). Interaction between age and location was also significant (df=4.088, F=3.327, p=0.016). However, age did not show any main effect on amplitude of vertex wave. Post-hoc analysis showed amplitude of group 1 (5 to 9 years), compared with other age groups, was significantly lower only in Fz electrode (Fig. 2).

Although amplitude of vertex wave was different among age group, topographic distribution of vertex wave was quite similar among all age groups (Fig. 3). LORETA image showed maximum current density in the mid to posterior cingulate gyri, which was similar across all age groups.

Discussion

The aim of the present study was to identify amplitude and its topographic distribution of vertex waves according to subject's age. We found that amplitude of vertex wave was largest in subject whose age less than 10 years old in all midline electrodes, decreased with age thereafter. Voltage topography showed maximum negativity over central vertex area bilaterally in all age group, which did not show any significant difference among age group. However, one can argue that higher amplitude of vertex wave in younger age group may be due to thinner skull thickness.[3] To avoid this problem, amplitude was normalized with z-score in the present study. Indeed, normalized amplitude of vertex wave at Cz and Pz was not different between age groups. However, normalized amplitude at Fz electrode showed a significant tendency to increase its amplitude from younger age group to middle-year age group.

It has been suggested that vertex waves constitute EEG response to afferent stimuli arising from interoceptors and exteroceptors.[4] Either auditory stimuli or respiratory occlusion can evoke large negative component around 300-350 ms (N300 or N350) after stimulation during non-rapid eye movement sleep, which is identical to vertex waves in terms of waveform and topographic distribution.[2,7] In light of this, vertex waves are considered as one of arousal response during sleep.[8] It has been considered that arousal is a physiological phenomenon of cortical activation during sleep. In addition, it is reported that arousal index is linearly increased with age.[9] In other words, arousal threshold of sleep is higher in young children than adult.

In our study, although normalized amplitude of vertex wave from Cz and Pz was no different between age groups, normalized Fz amplitude linearly increase with age from younger children to middle-aged subjects. It has been reported that frontal lobe is closely related to cortical arousal response.[10] Therefore, lower amplitude of vertex wave of frontal region in children may suggest decreased response to arousal stimuli, hence decreased arousal response in children. To clarify the relationship between arousal response and vertex wave during light sleep, a larger study with polysomnographic data will be required to correlate vertex wave with variables pertaining to arousal responses such as arousal index, stage shifting, and cyclic alternating patterns.

In conclusion, our study suggests that vertex waves might be related to arousal response during sleep, although exact mechanism is still unclear.

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