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Regular Article

Source localization of posterior slow waves of youth using dipole modeling

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Aim: Posterior slow waves of youth have a well-known electroencephalographic pattern that peaks in adolescence and usually disappears in adulthood. In general, posterior slow waves of youth are regarded as normal, but some reports have suggested that their presence is related to immature personalities or inappropriate social behavior. The physiological significance of this electroencephalographic pattern, however, remains unclear. The purpose of this study was to investigate the neural origins of posterior slow waves of youth using dipole source modeling.

Methods: Electroencephalographic epochs, including clear posterior slow waves of youth, were visually selected from electroencephalograms obtained from six normal adolescents using 25 scalp electrodes. The selected epochs were then averaged by arranging the negative peak of the slow waves at the occipital area of each epoch on the time axis. The averaged waveforms consisting of six right and one left posterior slow waves of youth were used for dipole source analysis. A single equivalent current dipole was estimated for the averaged waveforms.

Results: The best equivalent current dipoles were estimated to be located in or around the fusiform and middle occipital gyrus ipsilateral to the posterior slow waves of youth.

Conclusions: The location of the estimated dipoles of posterior slow waves of youth was on the so-called ventral visual pathway. Further research is required to clarify the physiological significance of posterior slow waves of youth with respect to their origin.

Key words: adolescent, dipole, electroencephalogram, slow waves, source localization.

POSTERIOR SLOW WAVES of youth (PSWy) in electroencephalography (EEG) were first described by Aird and Gastaut in 1959 as transient sporadic delta waves that were superimposed on or fused with the dominant alpha rhythm in the occipital area.[1] PSWy show a well-known EEG pattern that is regarded as normal in children. They are most prevalent between the ages of 9 and 14 (younger adolescence) and progressively decrease towards the age of 20.[2] PSWy have not received much attention; therefore, their physiological significance remains unclear.

Dipole source modeling is a non-invasive method for localizing the generators of cerebral activity. Several studies have used this method to clarify the origin of distinctive delta waves.[3–6] In this study, we

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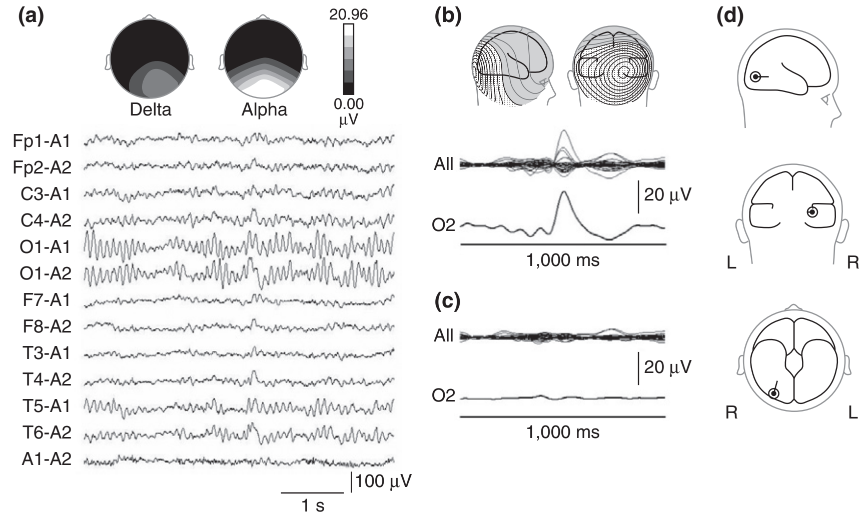

Figure 1. Single-dipole source analysis of posterior slow waves of youth (PSWy) in a representative case. (a) Example of PSWy and scalp topographies of the spectral power for delta (1–3.5 Hz) and alpha (8–11.5 Hz) bands. (b) Averaged waveforms of PSWy and isocontour maps at peak latency. The lines in the isocontour map are separated by 2 μV. Black lines and dark dotted areas, negative voltages; gray lines and lightly shaded areas, positive voltages. (c) Residual waveforms that cannot be explained by the dipole model. (d) Schematic drawing of the location and orientation of the estimated dipole source.

investigated the neural origin of PSWy using dipole source modeling.

METHODS

Subjects

Six right-handed junior high school students (four girls, two boys; mean age, 13.5 ± 0.7 years) without any history of neurological or psychiatric problems participated in the study. We selected EEG epochs including PSWy for the six subjects. All subjects underwent brain magnetic resonance imaging (MRI), and MRI findings of all subjects were normal. The study was approved prior to initiation by the Ethics Committee of Mie University Graduate School of Medicine. All children and their parents were instructed about the study and written informed consent was obtained from both.

EEG recordings and procedures

The subjects were awake and resting with eye closed throughout the recording in a shield room. EEG were recorded from the standard 19 electrodes of the 10–20 system placed on Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz, and an additional six inferior temporal electrodes (F9, F10, T9, T10, P9, and P10 according to the 10-10 system) were used to improve the estimations for dipole source localization.[7] The impedance of the electrodes was kept below 5 kΩ. The EEG signals were recorded using a bandpass filter of 0.5–35 Hz at a sampling rate of 500 Hz.

According to the description of Aird and Gastaut,[1] PSWy were defined as sporadic delta waves (approximately 3 Hz) at the occipital electrodes (O1 or O2). These waves were superimposed or fused with the dominant alpha rhythm. In each subject, we visually detected PSWy referenced to the earlobes (A1 or A2) without remarkable artifacts caused by body or eye movements. A typical example of PSWy is shown in Fig. 1(a). The scalp topography for the spectrum power of the delta band differed from that of the alpha band (Fig. 1a). We used an averaged waveform to reduce the influence of superimposing activities because the background activities were considered to affect equivalent current dipole (ECD) estimation. PSWy are not always symmetrical between the left and right occipital electrodes.[2] Because we considered the left and right PSWy to be independently generated, the EEG epochs including PSWy on both sides were excluded from subsequent dipole source analysis. The selected EEG epochs (10–31 per subject) were then averaged by arranging the negative peak of the slow waves at the occipital area (O1 or O2) of each epoch on the time axis. The averaged waveform in each subject was used for source analysis. The window of analysis was 1000 ms (500 ms before and after the peak of the delta wave). A 200-ms period (from 500 ms to 300 ms before the peak of the delta wave) was used as the baseline. We estimated a single ECD for PSWy using the Brain Electrical Source Analysis software package (MEGIS Software, Graefelf-

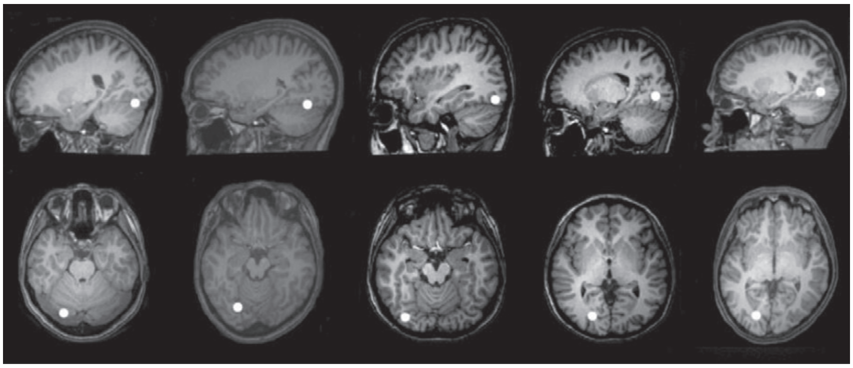

Figure 2. Location of the source of the right posterior slow waves of youth superimposed on the subjects' own axial and sagittal magnetic resonance imaging.

ing, Germany), which uses a spherical four-shell model (brain, cerebrospinal fluid, bone, and skin). An averaged reference was used for dipole source analysis. ECD at the averaged peak point was determined automatically by repeated least-squares fit. The goodness of fit (GOF) indicated the percentage of the data that could be explained by the model. The GOF during a 20-ms period (10 ms before and after the peak of the delta wave) was calculated, and the ECD with the best GOF was selected. The dipole source location was expressed in Talairach coordinates.[8]

This location for each subject was superimposed on MRI using Brain Voyager (Brain Innovation, Maastricht, Netherlands). T1-weighted axial image slices obtained every 1 mm were used, and registration of the electrodes with the volumetric model was performed using the nasion and preauricular points as fiducial points.

RESULTS

We used the averaged waveforms of six right PSWy from all subjects and a left PSWy from one subject for dipole source analysis. Figure 1 shows the single-dipole analysis procedure and results for a representative subject. The background activities superimposed on the averaged waveforms were not noticeable, and the averaged waveforms showed a clear distribution of a dipolar pattern (Fig. 1b). The best ECD was estimated to be located in the lateral ventral region from the primary visual cortex, ipsilateral to the slow waves (Fig. 1d). After fitting the best ECD for this wave, the residual waveforms obtained by subtraction of the theoretical waveforms of the estimated dipole from the original waveform showed no clear activities (Fig. 1c). When the period of analysis was expanded to 20 ms (10 ms before and after the peak of the delta wave), GOF was 95%.

In the remaining five subjects, similar procedures were applied to the PSWy. The ECD of the PSWy were estimated to be located in a similar region in all subjects with GOF >90% (90–95%) in the time window of 20 ms around the delta peak. The mean Talairach coordinates of ECD of the right PSWy across subjects (26.8 ± 6.0, −82.7 ± 3.0, 4.4 ± 7.5) corresponded to the middle occipital gyrus. The ECD of the left PSWy were estimated to be located in the lingual gyrus (−9.6, −72.6, and 4.5 in Talairach coordinates).

The ECD of the right PSWy were superimposed on the subjects' own MRI and located in a region lateral and ventral to the primary visual cortex, which corresponded to the fusiform, lingual, or middle occipital gyrus (Fig. 2).

DISCUSSION

The present study investigated the neural origin of PSWy by dipole source modeling. It was found that PSWy originated from a cortical region around the fusiform, lingual, or middle occipital gyrus, ipsilateral to the PSWy (Fig. 2).

The location of the estimated dipoles of the PSWy was on the so-called ventral visual pathway, extending from the primary visual cortex to the more anterior temporal regions; this pathway is involved in object perception.[9] The fusiform gyrus and the middle occipital gyrus are particularly related to face perception.[10,11] The capacity of children to evaluate and correctly interpret facial emotions follows a very slow developmental course that continues through adolescence.[12] In this study, the right PSWy were more frequently observed than the left PSWy, which is in accordance with the finding of a previous study.[1] Right hemisphere dominance is also reported in face perception.[13] The prevalence of PSWy peaks in younger adolescents and gradually decreases with age.[2] Anatomically, considering brain development, the cortical gray matter volume increases during growth, peaks around the age of 14–16 years, and then decreases gradually. Thickening and thinning of the gray matter are believed to reflect changes in the size and complexity of neurons.[14] Reductions in the gray matter volume resulting from synaptic pruning over adolescence should result in reductions in the EEG power over the same period.[15] PSWy may be associated with brain maturation with respect to face recognition and brain structural changes in adolescents.

PSWy are regarded as normal, but some reports have suggested that their presence is related to immature personalities or inappropriate social behavior.[16] It would be important and interesting to assess whether there is a relationship between the presence of PSWy and intelligence or cognitive ability in older children or adolescents. To clarify the clinical significance of PSWy, psychological or cognitive function tests should be performed in future studies. Assessment of visual event-related potentials would allow testing of cognitive function.

Conclusion

This was a preliminary study to estimate the origin of PSWy using dipole source analysis. To clarify the physiological significance of PSWy, further studies should be conducted in combination with psychological or brain function tests using a larger number of subjects from various age groups. The present source estimation results should be confirmed with standardized low-resolution brain electromagnetic tomography, which is another source localization method for EEG waveforms with high reliability.[17]

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