

## Generator Sources of EEG Large Waves Elicited by Mental Stress of Memory Recall or Mental Calculation

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**Abstract:** Preceding mental sweating response (MSR) during mental stress, small wavelets and large waves are observed on EEG. In the present study, locations of current sources of the large waves were estimated. The results revealed

that the current dipole was estimated around the orbits, reflecting activity of the eyelid or eye muscles. [Japanese Journal of Physiology, 51, 621–624, 2001]

**Key words:** generator sources, EEG large waves, mental stress.

When mental stress such as memory recall or mental calculation is given to a human subject, sweating appears on the glabrous skin; this is termed the mental sweating response (MSR). In relation to MSR, small wavelets appeared approximately 4 s before MSR, and large waves as well, when subjects were engaged in a recall of declarative memory or mental calculation [1].

Source generators of both waves on EEG could be estimated with the dipole tracing method (SSB/DT method [2]). The location of current sources of the MSR wavelets was previously estimated in the limbic system [1, 3]. Meanwhile, the location of the current dipole of especially large EEG waves (termed here as large particular waves) remains to be determined. The amplitude of large particular waves is so large compared with those of MSR wavelets that it is possible to estimate the current source even for an individual large particular wave. In the present study, we first differentiated large particular waves from the MSR wavelets, then determined the current sources of the former. The results showed that these current sources originated from activity of the eyelid or eye muscles.

Subjects were three right-handed healthy male students (DK, TH, and KH, 22–24 years old). They gave informed consent to participate in the experiments. Wavelets relating to a mental sweating response (MSR

wavelets [3]) and large particular waves were recorded with 21 electrodes on the scalp from the onset of mental stress application to the appearance of MSR.

The subject was asked to reply to a questionnaire consisting of 10 questions for episodic memory recall and 10 questions for mental calculation: e.g., “What was the name of the school principal at your primary school?” for memory recall; “ $93 - 25 = ?$ ” for mental calculation. These questions were presented to the subject in random order. The interval for each question was about 10 s. In reply to questions, a transient MSR was evoked on the index finger with an apparatus of Perspiro (Suzuken, Nagoya; cf. also Sakaguchi *et al.* [4]). Small waves on EEG (indicated by arrows at P3 electrode in the left column of Fig. 1) could be recognized about 4–5 s before MSR (MSR wavelet). Besides MSR wavelets, large particular waves appeared randomly on EEG, as shown on Fpz in the left column of Fig. 1; e.g., three negative (downward) waves with a relatively similar shape and one positive (upward) wave (as shown with numbers 1 to 3 at Fpz electrode). One negative wave was numbered as 1, another large negative wave was numbered as 2, and the large positive wave was numbered as 3. All these large negative or positive waves were predominantly larger than MSR wavelets, and it was very easy to differentiate between both kinds of waves. Therefore current

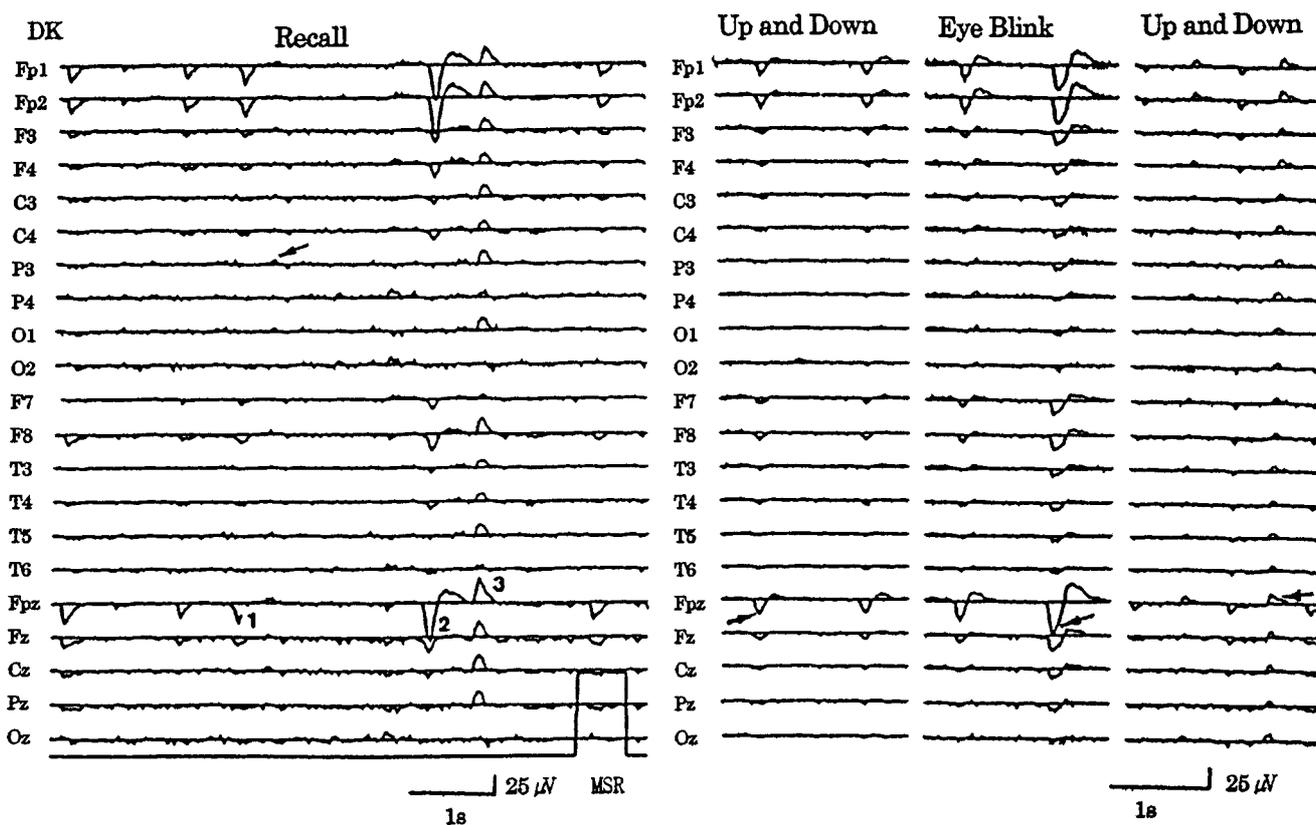
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sources of these large particular waves could be determined by the SSB/DT method even for a single wave, without averaging, as with the MSR wavelet.

In the first step, the SSB/DT method was used to approximate one dipole for the currently interested wave in the brain [2, 5–7]. Then the potentials produced for 21 electrodes on the scalp from the approximated dipole were calculated. These potentials were termed as calculated potentials ( $\Phi_{\text{cal}}$ : vector expression). The difference ( $d$ ) between the square of the measured potentials ( $\Phi_{\text{meas}}$ ) and  $\Phi_{\text{cal}}$  was then calculated. The minimum ( $d$ ) was calculated by changing the approximated location of the dipole. When the minimum was obtained, the location thus determined was regarded as a “real” location of the current dipole to produce the measured potentials [2, 5–7]. Even though the minimum was thus obtained, error from residue was still a possibility. The percentile value of the residue to  $\Phi_{\text{meas}}$  was calculated, the value of which was defined as dipolarity. If the dipolarity thus calculated for the estimated location was larger than 98%, we regarded the estimation for the location to be

“real” [2]. A two-dipole model enabled calculation of the two dipoles in the brain. The  $\Phi_{\text{cal}}$  produced on the scalp from two dipoles was calculated for 21 electrode positions. The minimum difference between  $\Phi_{\text{meas}}$  and  $\Phi_{\text{cal}}$  was then calculated. The locations of the two dipoles estimated as such were regarded as true locations of the current sources when the dipolarity was larger than 98%. Another concern was the influence of conductivity of the scalp, skull, and brain, particularly that of the skull, for the precise estimation of the location of current dipole. Accordingly, the shape, thickness, and surface area of the scalp (skin) and the skull, including its basilar portion, were calculated by using the head model constructed for each subject from the X-ray CT photograph taken previously with a 5 mm slice interval. The three-dimensional shape of the brain and its surface was also calculated [2]. Then the standard conductivity values of 0.33 (skin), 0.0041 (skull), and 0.33 S/m (brain) were used in the calculation of  $\Phi_{\text{cal}}$  with the dipole tracing method (SSB/DT method). With this method we could determine the location of the current dipole of large particular waves.



**Fig. 1. Large particular waves on EEG (subject DK).** **Left:** specimen record of MSR wavelet (downward arrow) and large particular waves; that is, negative (numbered 1 and 2) and positive (numbered 3) large waves. At the bottom, rectangular pulse is shown, which was triggered at the rising phase of MSR. **Right:** large waves elicited by voluntary up-and-down eye movements or eye blink. The left col-

umn shows an example of negative large waves (indicated by an arrow) related to voluntary up-and-down eye movements. The middle column shows negative large waves elicited in conjunction with eye blink. The right column shows an example of a positive large wave elicited in conjunction with up-and-down movement.

The left column of Fig. 1 shows an example of MSR wavelets and large particular waves on EEG in relation to the mental sweating response (MSR) in subject DK. Twenty-one EEG traces are shown. The time of zero was defined at the start of the rectangular pulse generated from the transient MSR by using a Schmidt trigger circuit. A spikelike small wave (MSR wavelet) is indicated by an arrow at the P3 electrode. MSR appeared 4 s after the MSR wavelets (see Homma *et al.* [3]).

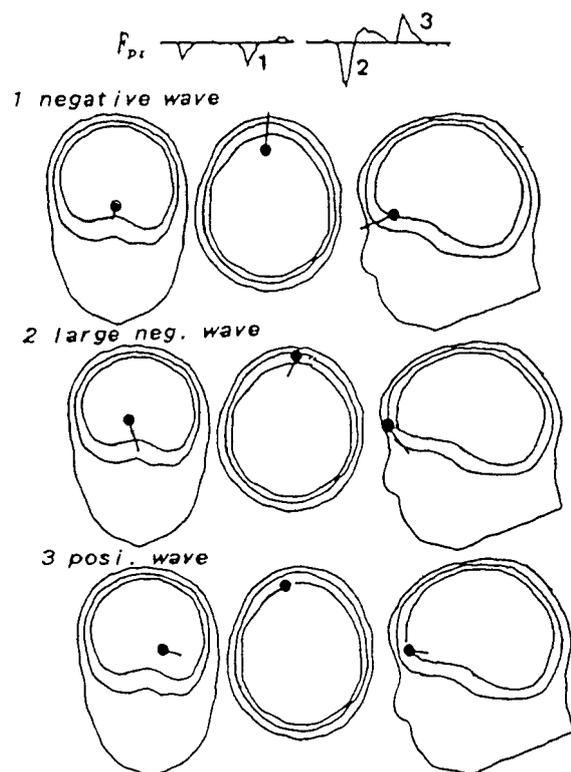
Large particular EEG waves were observed during mental stress, as shown in the left column of Fig. 1. They were numbered from 1 to 3 in the recording from the Fpz electrode. This kind of wave cannot be observed in normal EEG waves at rest, but they appeared with an exceptionally large amplitude when mental stress was applied to the subject. Here we term these large particular waves. As was mentioned, MSR wavelets appeared about 4 s before MSR, but large particular waves appeared at random. We tried to estimate the location of the current sources of these large particular waves in this study.

Figure 2 shows the results of estimated locations for three different large particular waves. The current source of the negative waves (numbered 1) was situated in the location corresponding to the lower part of the orbit, probably reflecting the activity of eye muscles. The location of the current source of very large negative waves (numbered 2) was estimated also at places around the eyelids corresponding to the upper part of the orbit. The current source of the large positive waves (numbered 3) was found to locate in the area corresponding to the upper part of the orbit, also likely reflecting activity of eye or eyelid muscles.

The results of Fig. 2 were summarized as follows: negative large waves originated from activity of the eye muscles (probably the inferior rectus muscle), very large negative waves reflected activity of the left eyelid muscles (the palpebral muscles), and positive waves originated from eye or eyelid muscles slightly cranial to those of the negative large waves (probably the superior rectus muscles). Therefore large particular waves were thought to be of eyelid or eye muscle origin.

To confirm this inference, we asked the subjects to voluntarily blink or make eye movements every 2 s. The large waves thus evoked on EEG during voluntary eye blink or eye movements are shown in the right column of Fig. 1. The results of estimated locations for large waves related to up-and-down eye movement (top), eye blink (middle), and up-and-down movement (bottom), are shown in Fig. 3.

The estimated locations of respective waves are il-

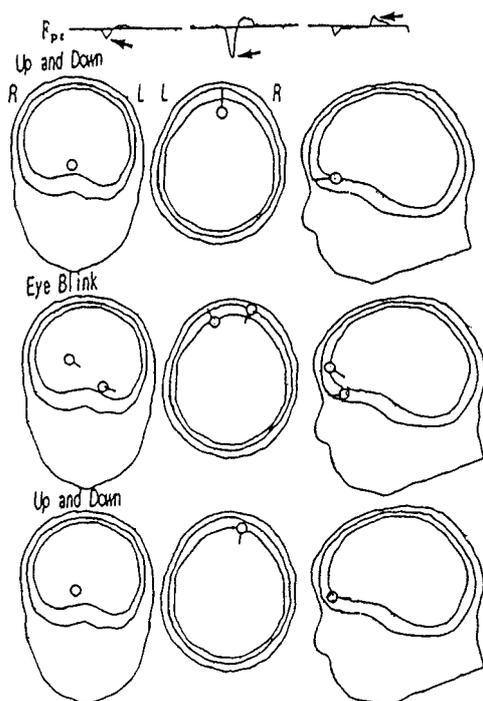


**Fig. 2. Estimated locations of large particular waves during mental stress on three different planes (frontal, horizontal, and sagittal planes from left to right).** The **upper** raw data show the estimated location of the negative large particular wave (numbered 1 on the top illustration). The **middle** trace, the estimated location of the negative large particular wave (numbered 2 in the top illustration). The **lower** trace, the estimated location of the positive large particular wave (numbered 3 in the top illustration).

lustrated in three-dimensional planes (Fig. 3). The location of the current dipole of negative waves related to up-and-down eye movements was estimated near the midline at the level of the lower margin of the orbit. This reflected the activity of lower eye muscles (upper frame of Fig. 3). This location nearly corresponded to that estimated for large waves (numbered 1) in the left column of Fig. 1. Even the directions of both vectors were the same (cf. Fig. 2, top). The origin of this dipole could be attributed to the activity of the inferior rectus muscles.

The locations of the negative large waves related to eye blink were estimated in two loci, by the two-dipole model, probably reflecting the activity of the palpebrae and the inferior rectus muscles on both sides. It means that responses of eye blink and up-and-down eye movement were simultaneously elicited by the voluntary eye blink. The area of the palpebral muscles coincided with those observed for negative large waves (numbered 2) in Fig. 1.

The location of the dipole of the positive large



**Fig. 3. Estimated locations of large waves elicited by voluntary up-and-down movements or eye blink.** Specimen records of each wave on Fpz are illustrated at the top of the figure. The **upper** raw data shows the estimated location of the current dipole of the negative large particular wave elicited in relation to up-and-down eye movements. The **middle** frame is that of eye blink, and the **lower** frame is that of positive large particular wave in relation to up-and-down eye movement.

waves synchronous with up-and-down eye movements was situated in the area corresponding to the upper part of the orbit (lower frame in Fig. 3). It coincided with that estimated for large positive waves (numbered 3) in Fig. 1. The muscle attributable to form the large positive waves was thought to be eye or eyelid muscles.

In the present study, the SSB/DT method successfully estimated the location of current dipole of negative or positive large particular waves. Hari *et al.* [8] previously demonstrated strong magnetic signals close to both orbits during blinking, with the magnetic flux emerging from the scalp over the right side to the left side. The present results are consistent with that study. The present study demonstrated that the origin of large particular waves during blinking is attributed to

activity of eye or eyelid muscles [9]. However, there is another report that Bell's phenomenon is not observed during blinking [10]. Thus, the estimated dipole source during blinking in the present study was more closely related to the activity of eyelid muscles than oculomotor muscles. It is also important to note from the present study that the SSB/DT method could determine the current dipole even outside the skull.

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