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Correlates of eye blinking as determined by synthetic aperture magnetometry

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Abstract

Objective: To evaluate the spatiotemporal characteristics of ocular and cerebral current sources during voluntary eyeblinking.

Methods: Whole-head magnetoencephalographic (MEG) recordings were acquired during voluntary blinking in eight healthy adults and analysed using synthetic aperture magnetometry (SAM).

Results: Fronto-temporal MEG sensors showed a large slow wave lasting approximately 400 ms and a small burst of activity with frequencies above 30 Hz at the initiation of the blink. Group maps of blink-related oscillatory activity at frequencies between 1–18 Hz and 32–64 Hz showed increased activity in and around the orbits during the 400 ms following blink onset. Increased oscillatory activity occurred in occipital regions 200 ms after blink onset at frequencies between 18 and 64 Hz.

Conclusions: Blink-related MEG signals are recorded in the regions of the eyes and in the occipital cortex. The anterior activation is likely a combination of muscle contraction and eyelid currents. Occipital activation likely represents neural processes concerned with re-establishing the visual image after transient ocular occlusion.

Significance: The possibility of eyeblink-related fields should be considered when interpreting frontal and occipital source activities during SAM analyses.

Keywords: Eyeblink; Artefact; Oscillatory activity; Magnetoencephalography; Synthetic aperture magnetometry

1. Introduction

Fronto-temporal magnetoencephalographic (MEG) fields measured during an eyeblink are an order of magnitude larger than the magnetic fields of ongoing brain activity and up to two orders larger than event-related fields (Antervo et al., 1985). When eyeblinks occur at the same time as observed neural events, it may become difficult to separate the activities generated in the brain and in the eyes. Eyeblink artefacts are generated by current flow between the eye and scalp, with the eyelid acting as a sliding electrode (Lins et al., 1993a; Matsuo et al., 1975). Although the eyes rotate upward during closure of the eyes, during spontaneous blinking the eyeballs rotate slightly downward and inward (Collewijn et al., 1985). This minor saccadic motion contributes partially to the recorded artefact. Normal, spontaneous blinking occurs up to 20 times per minute (Iwasaki et al., 2005).

When an eyeblink occurs, downward forces are applied on the eyelid mainly by excitation of the orbicularis oculi muscle and relaxation of the levator palpebrae superioris muscle. During the return phase, the orbicularis oculi relaxes and the eyelid rises with slower velocity than during eye closure (Aramideh et al., 1994). The eyelid reaches a closed position 100–150 ms after the blink is initiated and returns to a fully open position 180–300 ms after closure (Collewijn et al., 1985; Lins et al., 1993a). The time courses of the vertical electro-oculogram, and the artefact recorded by electroencephalography (EEG) and MEG during a spontaneous blink correspond to the eyelid motion. A forced eyeblink occurs when the eyelid is forcibly closed. During a forced blink, the eyelid remains closed for as much

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as 500 ms and the eyeball rotates upward by 5–30°. Again, the time course of the EEG correlate follows the eyelid movement with the eye movement having a minor influence (Iwasaki et al., 2005).

In addition to the currents generated in or near the eyes, parietal, frontal and occipital sources may also be activated during voluntary blinking. Berg and Davies (1988) used a regression method to remove the electro-ocular signals from EEG recordings and found a light-sensitive positive peak in occipital scalp electrodes 300 ms after the blink maximum. They suggested that this activity was an evoked response elicited by the off–on light transitions associated with the eye closure. Hari et al. (1994) found activation in the visual cortices, as well as light-sensitive activity in the posterior parietal cortex occurring 220–285 ms after the blink maximum using MEG (Hari et al., 1994). They proposed that the parietal source might represent processes ensuring that the perception of the world is not changed by occlusion during blinking. Using functional magnetic resonance imaging (fMRI), Bodis-Wollner et al. (1999) also implicated the posterior parietal cortex in maintaining perceptual continuity during voluntary blinking. fMRI studies have also revealed activation of the visual cortices, as well as the pre-central gyrus, posterior frontal gyrus, superior frontal gyrus, and orbitofrontal cortex related to motor control of blinking (Bodis-Wollner et al., 1999; Bristow et al., 2005; Kato and Miyauchi, 2003; Tsubota et al., 1999; Yoon et al., 2005). Interpretation of cerebral recordings (with EEG, MEG or fMRI) should, therefore, consider neural sources associated with eyeblinking during the task.

Synthetic aperture magnetometry (SAM) is a spatial filtering analysis technique for MEG data that results in a volumetric image of cortical activation (Robinson and Rose, 1992). SAM estimates the source signal at each location in the brain by attenuating correlated activity occurring at other sites in the brain. The resultant source signals can demonstrate evoked (phase-locked) and induced (non–phased-locked) activity and can be calculated independently for multiple sites in the brain. SAM is an adaptive technique that does not rely on an a priori hypothesis regarding the number and location of sources. This method has been widely used to look at brain sources, but the effects of blinking on SAM results are not known.

The purpose of this study was to determine the locations and waveforms of activity seen with SAM during voluntary eyeblinks. This would allow us to see what occurs in the eyes and brain during eyeblinks, and to determine how much the SAM analysis of brain activity might be contaminated by blink artefacts. We generated volumetric maps of source activity within the head using SAM during voluntary eyeblinking in light and dark conditions. We hypothesize that the current activity related to blinking would localize to the eyes in both conditions and that light-sensitive cortical activity might also occur in parieto-occipital areas.

2. Methods

Four male and four female subjects with an average age of 35 years (range 23–47 years) participated in this study. All subjects had normal or corrected vision. The Research Ethics Board of the Baycrest Centre for Geriatric Care reviewed the project. Informed consent was obtained from each subject before the experiment.

MEG data were collected using a 151-channel whole-head first-order gradiometer system (VSM-Medtech, Coquitlam, BC, Canada) at a sampling rate of 1250 Hz with a bandwidth of 0–400 Hz. In each 3–5 min collection, the subjects voluntarily blinked about once every three seconds while fixating on a point on the wall of the magnetically shielded room. They were asked to blink as naturally as they could. In the first run, the room lights were on. In the second run, the lights were turned off. When the lights were off, we ensured the subjects were unable to see anything, and asked them to maintain ocular fixation by memory.

We automatically detected the eyeblink wave in the MEG data using a template-matching algorithm. For each subject, we identified the MEG sensor with the maximal signal during the eyeblink. A single representative blink waveform from this sensor was used as a template. Signal segments from the same sensor that matched the template with a correlation coefficient greater than 0.9 were then marked as eyeblinks. The blink onset was defined as the time at which the template waveform exceeded twice the standard deviation of the ongoing background activity.

For each subject, we averaged the MEG data in the time interval from 900 ms before to 900 ms after blink onset. We determined the onset-to-peak latency and half-amplitude duration (time between the half-amplitude points prior to and following the blink peak) for the average eyeblink signal at the maximal responding sensor. For the same sensor we also calculated the short-time Fourier transform (STFT) for each eyeblink epoch and averaged the resultant STFTs across all epochs to obtain a time–frequency representation of the mean power. For each subject, the power change in each frequency bin was normalized as the logarithm of the ratio between the averaged power at each time point and the mean power in the pre-onset interval. We calculated the group mean of the normalized power change at each time–frequency bin to generate a group-averaged STFT.

For the SAM analysis of eyeblink related activity we calculated the source power difference between the active interval (0–400 ms after the blink onset) and the control interval (600–200 ms before the blink onset) in the 1–18, 18–32, and 32–64 Hz frequency bands for each 5 mm cubic volume element within the head. The frequency bands were selected according to time–frequency analysis of frontal MEG channels in order to separate the main effects. We also generated volumetric maps of power change for the traditional theta (4–7 Hz), alpha (8–13 Hz), and beta (14–25 Hz) bands. The source power difference between