



Utilization of MRI Information in EEG Studies

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Abstract. This article introduces various methods to combine MR images and EEG signals. The methods are presented in historical order, beginning from so-called "brain mapping" in 1980's and ending up with potential applications in the future. The motivation for this kind of review is in the conviction that the combination of these two modalities is strongly increasing today, due to important steps in the development of both methods.

1. Introduction

The advances in the clinical application of the electroencephalography (EEG) have always been connected with technical innovations, such as the string galvanometer, transistor and integrated circuit (IC) technology. These have enabled sufficient signal to noise ratio as well as small size and low price of the multi-channel electronics. In the beginning of 1980's it was understood that the development of the computer technology would create a new jump in the technology of EEG, which was realized by the fast breakthrough of digital EEG during this decade. The next decade may provide us with a new imaging technology, EEG.

Since about 1980 it has been possible to record EEG digitally. From the very beginning this was applied to the approximation of topographic maps of scalp potentials [1]. In many respects, however, the technological circumstances did not meet the requirements of the users. The first devices consisted of 16 channels, screen and printer resolution of about 200 lines, and produced samples of only eight bits. Additionally, the quality of the raw signal was often worse than that produced by the conventional devices. The consequence was that the topographic maps resulting from the first digital EEG devices did not convince the EEG experts. This period may have influenced the slow progress in application of the local information as a part of EEG diagnostics.

In 1990's digital EEG devices followed the EEG mapping computers. These provide the users typically with 32 channels and 16 bits, ensuring that nothing is lost from the original analogue information. Despite of the remarkable changes in EEG interpretation practice, the neurophysiologists have adapted the new paperless methods. Although there is some reluctance to the digital EEG protocols, there are no EEG laboratories in USA anymore who are going to purchase paper EEG devices [2].

The rapid digitalization of EEG laboratories gives various options for the users to process the data. One of these is the combination of the data with MRI information. This is a relevant option today, because many neurological patients undergo diagnostic MRI examinations. The combination of these two modalities can be performed in various ways, as will be shown in the next chapter. Some of these methods can be found in commercial devices, some are under development in research laboratories, whereas some are still hypothetical.

2. Methods for combining MRI and EEG information

There are several levels for the utilization of MRI information in EEG studies. By increasing the complexity level more specific information is obtained. The complexity involves processing of both the EEG and MRI data. Various processing methods are described in Figure 1, as well as the resulting combinations.

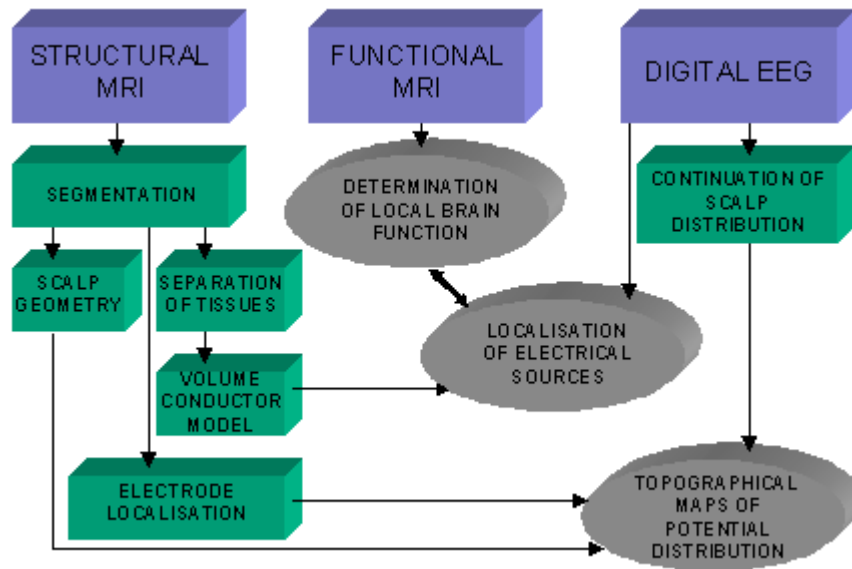


Figure 1. Procedures for combining the information from EEG signals and MR images.

2.1 Illustration of scalp EEG maps

Topographical map is one way to present EEG information, an alternative for the EEG curves. The potentials at a certain moment or period of time are coded as colors at the corresponding electrode locations. The electrical potential values on spaces between the electrode points are approximated by using, for example, interpolation or spline fitting methods. For this purpose, the scalp must somehow be shown as a 3D image on the screen or as a printout.

1. The simplest way to present the scalp is a general sketch (spherical or elliptical) of the head as a cranial projection. In some mapping realizations there are also anterior, posterior and lateral views. To enable more realistic illustration, these views can be obtained from optical or MRI images of a typical human subject. This is probably the simplest way to combine EEG and MRI data. >
2. A more sophisticated method is based on individual anatomy of the scalp, which is obtainable from segmented MRI data [3, 4, 5]. If the EEG lead system is based on anatomical landmarks (as is the case in standard 10-20 and 10-10 systems), the EEG electrode locations may be approximated from the MRI images. This can be done by searching the anatomical landmarks (for instance ears, nasion and inion) from the image and using the geometrical rules of the lead system for calculating the theoretical positions of the electrodes [6]

3. As the MRI image is available, the real locations of EEG electrodes are often desired. Numerous methods have been used for this purpose. The electrodes can be marked for instance by touching the electrode locations by a 3D scanner, which operates in a magnetic field. These kind of methods produce an optical image of the head, which must be matched with the MRI image [3]. The matching can be avoided if MRI positive markers are placed at the electrode locations after the EEG study. This method involves that the MRI imaging can be performed quite soon after the EEG recording [7]. Figure 2 shows a typical result of this kind of map.

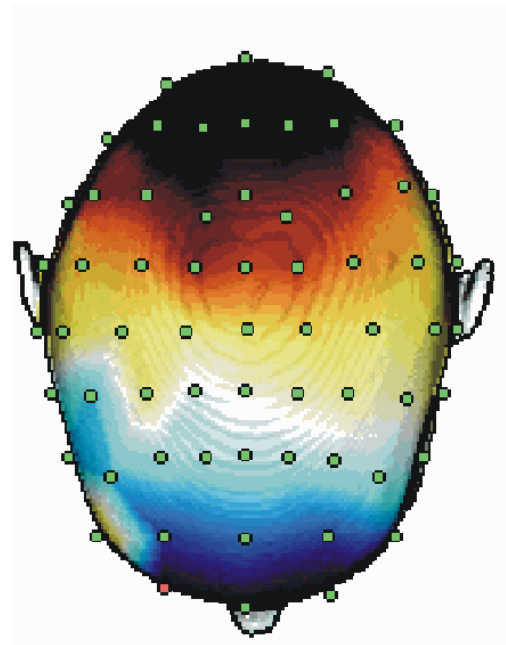


Figure 2. A topographical map presentation of the EEG potentials. The anatomy and the markers for the electrode locations of the subject are segmented from a T1 MRI slice set.

The potential distribution on the scalp can be processed in many ways. A continuation procedure is always necessary to transform the discrete voltage values into a continuous potential distribution. Interpolation of the values gives a rough estimate, resulting in piecewise linear areas. More realistic estimates constitute of fits to continuous two-dimensional distributions, such as 2D splines.

The original potential values can also be altered in order to increase the spatial information. One of the most promising methods is the surface Laplacian algorithm [9]. It produces an estimate of the radial current at each electrode point. This estimate is based on a comparison of the potential value to those of the nearest neighboring electrodes or, in optimal case, of all other electrodes. The accuracy depends also on the model for the head shape [4].

These advanced methods for the evaluation of the scalp EEG maps can quite effectively make use of the anatomical information obtained from MRI scanning. They also show that more spatial information may be obtained from EEG by increasing the number of electrodes from the standard 10-20 system. Figure 3 shows the effect of increase of recording points from 21 to 64. The amount of details in EEG maps still increases as 128 electrodes are used [10]. This corresponds to decreasing the inter-electrode distance from about 7 cm to 3 cm. An essential observation is that the ordinary potential maps do not change dramatically. However, by applying the Laplacian maps the spatial information increases with the number of electrodes [4].

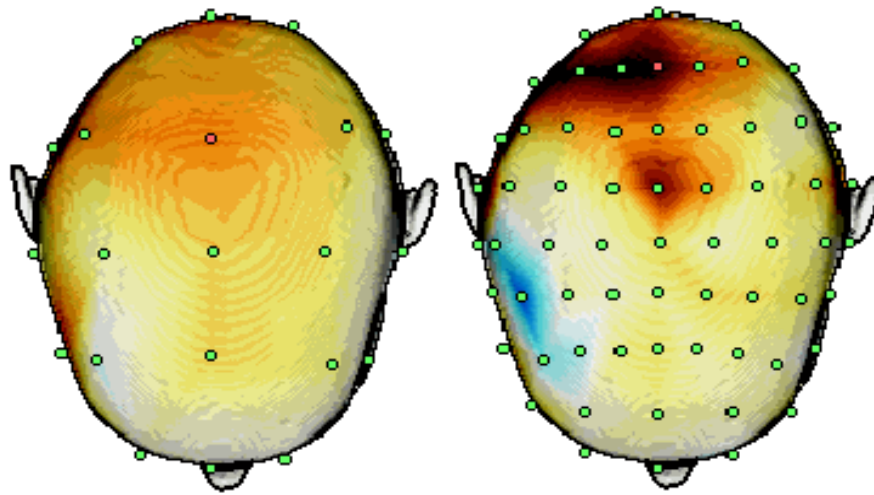


Figure 3. A topographical map presentation of EEG Laplacians during drowsiness recorded by using 21 (a) and 64 (b) channels. The anatomy of the subject and the electrode locations have been segmented from a T1 MRI slice set. Modified from Manninen et al. [11].

2.2 Reconstruction of intracranial surface maps

The scalp potential distribution reflects the distribution of intracranial electrical sources and fields. It can obviously be used for the approximation of the cortical potential distribution. Spatial deconvolution methods such as the finite element deblurring method [12] have been presented and validated by using both cortical recordings and computational models [13, 14]. The potentials are not usually evaluated on the complicated cortical surface itself, but on a more regular surface locating few millimeters apart from the cortex. Therefore the distributions are sometimes called intracranial or dural maps.

Realistic intracranial maps involve the solution of the inverse problem. This means that the maps are not unique and that the calculation of the maps takes a considerable amount of time. Unlike Laplacians and other cortical maps, the intracranial maps cannot be computed in real time. More pre-processing is also required, such as the segmentation of the scalp and skull for the potential estimation and the segmentation of the cortical surface for displaying the map in 3D. The procedure is considered in more detail in next section.

2.3 Localization of the source activity

The electrophysiology of the brain is very complicated. The EEG is roughly divided into event-related potentials and spontaneous activity. Both are distributed in a wide range of the brain, but especially some periods of event-related potentials are focused in certain locations. Also certain abnormal activity, such as epileptic spikes, may originate focally in the brain. These cases fulfill the conditions of the traditional source analysis. It is based on the assumption that the EEG can be described by one electrical point dipole source at a certain moment or period of time. More advanced methods imply multiple dipoles and distributed sources, which are in most cases more realistic models for the electrical brain activity [15]

Source analysis implies the solution of the inverse problem, which is based on several solutions of the forward problem. Not only the source has to be modeled, but also the head must be replaced by a volume conductor model /Malmivuo et al./. This model is in all practical solutions linear, resistive, piece-wise homogeneous and isotropic. In principle it would be possible to deal with even more realistic models, which have anisotropic and complex impedances. Further, the minimum size of each compartment in the model could be the dimension of the voxels obtained from the MRI scan. However, all these features demand lot of computing power and are therefore not included in present head models.

The forward models of the head can be divided into spherical [17, 18] and anatomical [19 - 23] realizations. Spherical models work fast and are thus optimal for patient studies consisting of large materials. Anatomical models are time-consuming, but give the individual geometry of the subject and suit for special cases.

Although MRI is not needed for the computation in the former case, the MRI scans are often used also in spherical modeling. The sphere can be positioned either in the center of the head or asymmetrically so as to produce an optimal source localization. [24]. Independently on the modeling method, the MRI images are often used for displaying the anatomical locations of the sources.

2.4 Evaluation of the electrical field in the brain

As the electrical sources in the brain have been estimated, it is possible to use the forward approach to solve the electrical field everywhere in the brain. However, the intracranial electrical field distribution seems not to have direct relevance in clinical or neuropsychological applications. The method has mostly been applied in visualization of simulation studies, i.e., in forward problems. In association with the inverse problem it involves heavy computation and has not been studied extensively.

On the other hand, single point dipole gives hardly a realistic representation of the whole electrical activity. For this reason special algorithms have been developed which enable the estimation of the electrical activity overall in the brain without performing the actual source localization procedure [25]. These methods are based on a priori knowledge on the spread of the activation in the neural tissues.

2.5 Temporal behavior of intracranial electrical activity

The power of EEG is mostly in its properties in temporal space. The temporal resolution itself is one or two orders of magnitude better than in the imaging methods. EEG is also basically considered as a signal, not an image, and most of the interpretation is based on the waveform analysis. Therefore it would be useful to include the temporal dimension to all analysis methods described in earlier sections.

Adding the time dimension to topographic potential maps produces a movie option, where the rate of change of the maps can be adjusted in a wide range around the real speed. This option has found to be useful in all kind of analysis of the digital EEG. In principle it is also possible to follow the movements and rotations of single or multiple dipoles in the brain. However, the speed of this procedure is reasonable only if the model is properly simplified.

2.6 Co-registration of EEG and MRI

New inventions in EEG technology have enabled the recording of EEG while the patient is positioned in the MRI magnet tube, even during the MRI recording. For this purpose several problems have been overcome. MRI imaging uses RF pulses for exciting the tissue, inducing also interference peaks in the EEG recording. On the other hand, metallic EEG electrodes and especially the wires affect the magnetic fields and blur certain parts of the image. These disturbances are attenuated when special instrumentation and methodologies are used [26].

Several methods have been suggested for applying the EEG in MRI room. Epileptic spikes in EEG may be used for triggering the functional MRI session. Also successful co-registration of EEG and MRI has been reported with acceptable quality of EEG with the exception of the period during the RF pulses.

3. Organization of a multimodal EEG protocol

There are few research laboratories that have both the MRI and EEG instrumentation. To combine these studies, co-operation with the hospitals is usually essential. Medical projects involve also close collaboration between the clinicians and the research personnel. Figure 4 shows a result of such collaboration between several departments of Tampere University Hospital, Faculty of Medicine in University of Tampere, and Ragnar Granit Institute in Tampere University of Technology. The video EEG recordings, MRI scans, spike detection and EEG interpretation, combination of EEG and MRI, 3D representation of the results, as well as the meeting for the clinical conclusions were all scheduled into one week.

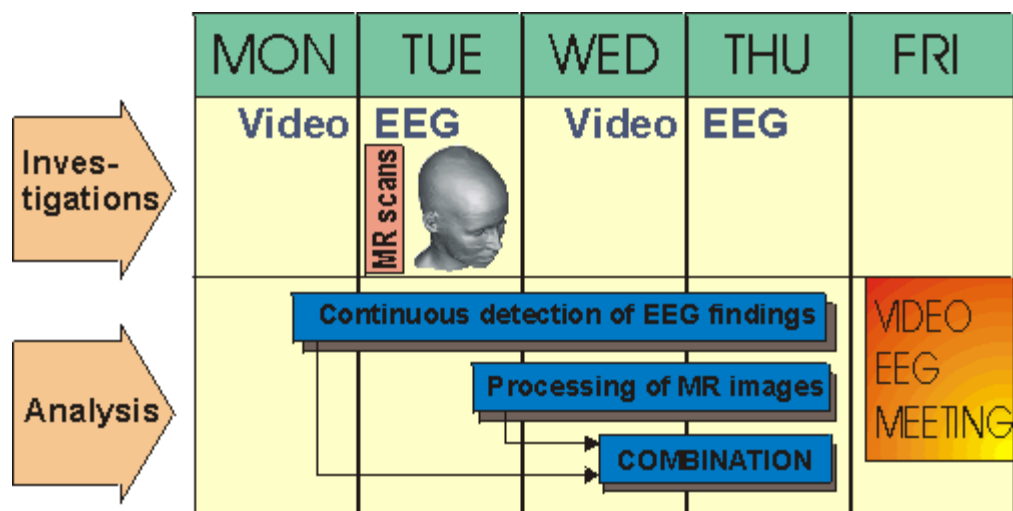


Figure 4. Weekly schedule for a selected epileptic patient, including video EEG and MRI studies and processing of the data.

Scheduling is only one part of organizing multimodal EEG+MRI studies. Several specialists are needed who all should be research orientated and motivated to the project:

- neurologists
- clinical neurophysiologists (EEG experts)
- EEG technicians
- EEG engineers or physicists
- radiologists
- radiographers
- MRI physicists
- researchers in physics/engineering
- researchers in medicine

A general conclusion from these requirements is that whenever several investigations are combined, the organizational challenges increase faster than the amount of individual examinations. This sets high requirements for the management of any project involving the combination of EEG and MRI studies.

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