using functional imaging techniques, first with single photon emission computer tomography (SPECT) and positron emission tomography (PET), and then with functional magnetic resonance imaging (fMRI). A recent review by Cabeza and Nyberg [10] summarizes 275 PET and fMRI studies on human cognition, documenting this tremendous activity. In their review the authors conclude that several brain regions are usually activated by a given cognitive task and that some brain regions are involved in several different tasks. This is in line with the notion that cognitive functions are based on large-scale neural network interactions and the role of each brain area in this network is governed by its dynamic interactions with the others [41].

The study of dynamic interactions between different brain areas poses a challenge to standard functional imaging techniques because of their low temporal resolution. New approaches such as covariance-based analysis of PET images [39] and the study of the hemodynamic response of single-trial event-related fMRI [40] solve this problem only partially: covariance-based analysis of PET data cannot give information about the direction of activation, and event-related fMRI can provide such information only if areas are activated in a strictly sequential manner without feedback loops.

At present, the only available non-invasive technique to study the temporal dynamics of brain function is the recording of the electromagnetic activity on the scalp by means of event-related electric potentials or magnetic fields recorded with the electroencephalogram (EEG) or the magnetoencephalogram (MEG). Because the temporal resolution is in the one millisecond range or faster, these techniques permit the determination of the sequence of activity of cognitive brain functions in real time. In addition, with the recent developments in electromagnetic source imaging, valuable information on the localization of these functions has become available. We here describe one such analysis method of electromagnetic recordings and its application to several different data sets.

2. Methods

2.1. Electromagnetic source imaging

Attempts to localize the electric neuronal activity in the brain that produces a certain surface electric field are faced with the so-called ‘inverse problem’ which has, by definition, no unique solution. Different intracranial generator configurations can result in the same distribution of the electromagnetic field on the scalp surface. However, if physiologically and physically valid a priori assumptions are introduced, the inverse problem can be solved and estimations of the sources become possible. Of course, the correctness of the solution depends on the correctness of the assumptions. Thus, it must always be kept in mind that the localization of sources in the brain using surface EEG and MEG is based on modeling and not on direct recording of these sources.

Most commonly, one or a few equivalent current dipoles are employed as an a priori model and iterative numerical methods are used to search for the best-fitting dipole(s) at a given time point, or for a time-varying collection of such dipolar sources [46,54]. Dipole models can be well suited for some types of data (e.g. epileptic activity [15,26,54] or early sensory and motor evoked responses [1,4,8,17]), but the fact that the number of sources has to be known in advance makes them poorly suited for cognitive event-related potentials where parallel activation of an unknown number of areas is expected. Therefore, we and other groups have developed inverse solutions which estimate the current distribution in the full three-dimensional space of the brain (for reviews see Refs. [16,19,21,23,43]). These solutions yield blurred source images in contrast to over-focalized point sources as derived by dipole methods. Distributed inverse solutions have been extensively tested in many simulations and have been repeatedly applied to the localization of epileptic foci [5,16,34,43,61], of sensorimotor [3,58,59] and visual [45,47,60] areas, as well as to studies on higher cognitive functions such as language [28,30,32] memory [33], attention [2,7,29], and face recognition [51]. There is no doubt that electromagnetic source imaging can provide valuable spatial information, with a spatial resolution comparable to other functional imaging procedures (at least for superficial sources). Thereby, MEG and EEG are comparable in terms of the amount of information they provide about the sources as long as the same number of electrodes/sensors is used in the two techniques [37].

We used different distributed linear inverse solutions in the original publications of the studies that are presented in this review (LORETA [47] in Refs. [29,30,49,59] and ELECTRA [20] in Refs. [45,57]). Spherical head models were used in all cases. We reanalyzed the data for this review using a local auto-regressive average (LAURA) solution based on interpolation formulas as described in Refs. [21,22]. In addition, a realistic model of the head is constructed on the basis of an average brain of 152 MRIs provided by the Statistical Parametric Mapping (SPM, Welcome Department UK) software. It is important to note that this new source reconstruction did not change the principal findings reported in the original articles, but did provide more possibilities for anatomical interpretation of the results.

2.2. Functional microstates of the brain

A pre-requisite for electromagnetic source imaging is the identification of the relevant time points or time periods in the event-related potentials (ERP). The traditional determination of peaks and troughs in ERP waveforms at certain channels becomes difficult with