from the perspective of electrical stimulation mapping. *Behavioral and Brain Sciences* 6.189–230.

Perani, Daniela, et al. 1987. Aphasia and neglect after subcortical stroke: A clinical/cerebral perfusion correlation study. *Brain* 110.1211–1230.

Pinker, Steven. 1999. *Words and rules: The ingredients of language*. New York: HarperCollins.

DAVID CAPLAN

Functional Brain Imaging

The most widely used functional imaging techniques are based either on the electrical or magnetic components of neural activity (EEG/MEG), or on the effects of local changes in brain activity on local blood flow (fMRI, PET).

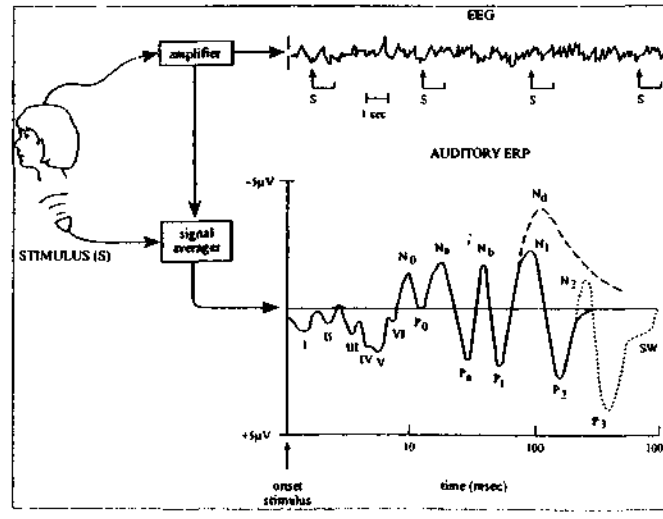
1. EGG/ERP. The so-called event-related potential (ERP) is an electrical change, recorded from electrodes placed on the scalp, that occurs as the brain reacts to an event, either in the external world or within the brain itself (see Figure 1). ERPs primarily reflect postsynaptic currents in regions where (i) the distribution of current sources and sinks within the neurons is not radially symmetric (has an "open field structure"); (ii) the neurons are aligned—that is, non-randomly oriented toward one another; and (iii) the neurons are activated in local synchrony. In particular, the apical dendrites of the pyramidal cells satisfy these requirements. About 70% of the cells in the neocortex are pyramidal cells with apical dendrites extending from the soma toward the surface of the cortex. The extracellular currents recorded via scalp electrodes require the synchronous activity of a few hundred thousand pyramidal neurons.

The electroencephalogram (EEG) represents the spontaneous rhythmic electrical activity of the brain. Within the EEG one can distinguish different frequency bands. Event-related synchronizations in the alpha (8–12 Hz) and lower beta (18–30 Hz) frequency bands are the electrophysiological correlates of resting or idling cortical areas. Measurements of transient periods of desynchronization or synchronization of EEG, especially in the gamma frequency range (around 40 Hz), in relation to different aspects of information processing by the brain, are used for making inferences about the neural organization of perception and cognition.

One of the strengths of electric and magnetic recordings is their high temporal resolution, in the order of tenths of milliseconds. To know *when* certain cognitive operations take place, EEG/ERP and magnetoencephalography (MEG) recordings are far better than the hemodynamic measures provided by positron emission tomography (PET) and functional magnetic resonance imaging (fMRI).

While the spatial resolution of electric and magnetic recordings is relatively poor, new mathematical tools for inverse modeling have opened up ways to determine the location of the neural sources that generate the surface potentials. The potential of integrated experimentation with fMRI will make it easier to determine the location of the neural generators of the scalp-recorded ERP/EEG

FIGURE 1 *ERP Components that Become Visible after Averaging the EEG to Repeated Stimulus Presentation*



In W. J. Frawley (Ed.)
International Encyclopedia of Linguistics
(2 ed., pp. 142-145).
New York: Oxford University Press
(2003)

signals. This will allow tracing not only of the sources of very early (perceptual) ERP components, but also of later (more cognitive) components.

A prerequisite for functional localization of electrical brain responses is a high-density EEG recording. Until recently, EEG recordings have been based on the 10–20 system of electrode placement, with inter-electrode distances of about 7 cm. This is not sufficient in relation to the distance between adjacent gyri (approximately 1 cm). The international standard has therefore moved in the direction of recording from 64 or even 128 leads. EEG/ERP is the least complicated and the least expensive among brain imaging methods; also, it is the only one that does *not* require head immobilization, giving it considerable advantages in studies with subjects less tolerant of head restraint (children, elderly subjects, aphasic patients).

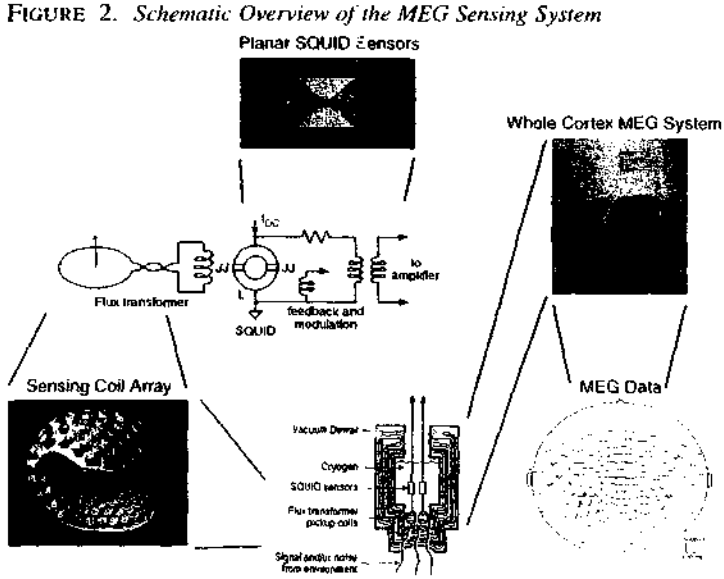
2. Magneto-encephalography (MEG). MEG provides a complementary picture of neural activity. Local current flow generates a magnetic field encircling the flow. The summation of the magnetic fields generated by all active areas creates a field that is detected outside the head by the MEG scanner. Neuromagnetic signals are typically in the order of 50–500 femtoTesla, which is between 10^{-8} and 10^{-9} of the earth's magnetic field.

The MEG method is based on a sensitive detector of magnetic flux, the superconducting quantum interference device (SQUID). Whole-head MEG systems contain 100 to 300 SQUIDs connected to sensor coils that lie in a configuration roughly following the curvature of the head (see Figure 2). Since the environmental magnetic noise level from traffic, elevators, and so on is several orders of magnitude higher than the neuromagnetic signals, the MEG scanner must be placed in a magnetically shielded room.

The major advantage of MEG is that, in contrast to EEG, the magnetic fields are largely unaffected by inhomogeneities in the skull and scalp. Another important difference between MEG and EEG is that MEG is insensitive to current flows oriented perpendicularly to the scalp: only the tangential component of a current flow will produce a measurable field, while EEG measures the combination of radial and tangential sources. In practice, this implies that MEG is most sensitive to activity on the banks of sulci and less sensitive to activity generated at the crowns of gyri. This constraint on the orientation of the underlying sources makes source localization more tractable in MEG than in EEG. Co-registration of EEG and MEG might be helpful in separating tangential and radial sources.

3. Functional magnetic resonance imaging (fMRI). fMRI, in contrast to EEG and MEG, does not provide a direct measure of neural activity; instead, it records local blood flow change, which increases in areas with increased neural activity. The major differences between hemodynamic and electromagnetic signals are that the hemodynamic signal (i) does not require that neural activity be synchronous, (ii) does not require a particular geometrical orientation of the neurons (so is not restricted to measuring the activity of pyramidal cells), (iii) mea-

FIGURE 2. *Schematic Overview of the MEG Sensing System*



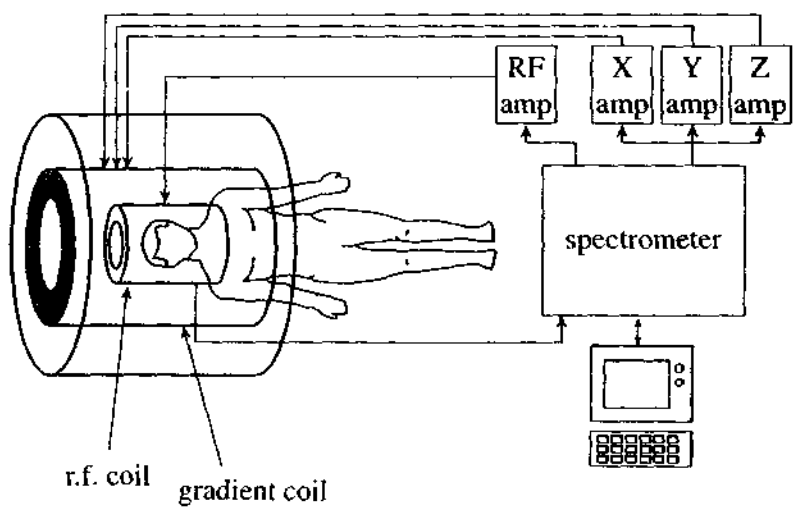
sures the consequences for the local blood flow over a certain time range, rather than the instantaneous activity changes of groups of neurons, and (iv) records changes in neural activity only insofar as this activity changes the net metabolic demands of the cells. Blood volume, blood flow, blood vessel geometry, and oxygen consumption are all jointly responsible for the so-called BOLD (Blood Oxygen Level Dependent) signal change.

A major advantage of fMRI over other neuroimaging techniques is the high spatial resolution (on the order of 2 mm) in identifying active cortical areas. However, the temporal resolution is on the order of seconds, much poorer than EEG/MEG. fMRI thus allows accurate inferences about *where* in the brain a particular cognitive process is instantiated, but not *when*; for inferences about the temporal cascade of activation processes, EEG/MEG recordings are required. Only through combined experimentation can the full neural dynamics underlying cognitive processes be characterized.

The fMRI signal is a variant of the MRI signal. Recording MRI signals involves the participant's being subjected to a large static magnetic field, produced by a superconducting whole-body magnet (see Figure 3). As a result, some of the protons of brain tissue align their magnetic axes parallel to the static field. After excitation with a radiofrequency (RF) pulse, the alignment of the proton magnetic moments changes; when the pulse stops, the protons recover their parallel alignment in tenths of seconds to seconds. During this process, the protons emit a radio signal, whose frequency depends upon their location, so their position can be reconstructed by analyzing the signal's frequencies. Depending on the type of tissue (gray matter, white matter, cerebrospinal fluid), the recovery of parallel alignment (T1-relaxation) takes more or less time, leading to local differences in signal intensities, which are translated into image contrasts. A second source of local decay of signal intensity lies in the dephasing of proton spins (T2-relaxation), such as that due to magnetic field inhomogeneities.

The BOLD methods in fMRI depend on the paramagnetic properties of deoxyhemoglobin. Owing to enhanced T2-relaxation, there is an inverse relation between the concentration of deoxyhemoglobin and the signal strength. An increase of neural activity causes an increase

FIGURE 3. *Schematic Overview of MRI-Scanning.*



in local oxygen demand, resulting in a short initial increase in deoxyhemoglobin concentration. This is immediately followed by an increase in regional cerebral blood flow (rCBF), which, for reasons that are not completely understood, overcompensates the increased oxygen demand. This overcompensation leads to a higher oxygenation (decrease in deoxyhemoglobin concentration) of the local capillary and venule beds, and a concomitant signal increase, which forms the main source of the BOLD fMRI signal.

Today, many MRI scanners have a magnetic field strength of 1.5 Tesla. Higher magnetic fields promise to improve signal-to-noise ratios, which potentially will allow higher resolution BOLD images, since the contributions from the smaller cortical vessels can be enhanced. These are closer to the sites of neuronal activity than the draining veins, which can be centimeters away from the site of activation. It is generally assumed that the increased microvascular sensitivity available with the higher field scanners will be necessary to map at the level of cortical columns of neurons with similar properties. Improved signal-to-noise ratios will also be required for utilizing the recently introduced fMRI modality of single-trial paradigms.

4. Positron Emission Tomography (PET). Brain activity is also measured through its effects on blood flow in PET scans, but in contrast to the other brain imaging techniques, PET is invasive. Just before performing a cognitive task, the participant is injected with a radioactive tracer, usually an ^{15}O-labeled molecule, such as water or butanol. ^{15}O has a half-life of two minutes; when it decays, a positron is emitted. Upon collision of this positron with a nearby electron, both are annihilated, resulting in two high-energy photons that travel in opposite directions. They are detected simultaneously, and the direction of their origin is reconstructed. The number of decay events (count rate) varies monotonically with the regional cerebral blood flow, allowing for absolute rCBF quantification. The spatial resolution of a PET scan is about 5 to 10 mm. Since the coincidence detections must be sampled over a period of 40 seconds, the temporal resolution of PET is not as good as that of fMRI. Also, experimentation requires designs in which items of a particular condition must be presented as a block, not in a random order.

[*See also* Aphasia *and* Psycholinguistics.]

PETER HAGOORT

NEUTRALIZATION. *See* Markedness.

NEW CALEDONIAN LANGUAGES. A group spoken in New Caledonia, constituting a branch of REMOTE OCEANIC.

LANGUAGE LIST

Ajië: also called Houailou, Wailu, Wai, Anjie, A'jie. 7,000 speakers in Houailou: east coast Monéo to Kouaoua and inland valleys. Language of wider communication.

Arhâ: also called Ara. 250 speakers in upper valleys of Poya. Different from Arhö Bilingualism reported in Ajië.

Arhö: also called Aro. 50 speakers in Poya, Cradji and Nékliai villages. Bilingualism in Ajië.

Bwatoo: 300 speakers in Voh-Kone: Baco, Gatope, Oundjo; Poya: Népou. Treated as a dialect of Voh-Kone. May be a dialect of Haveke.

Caac: also called Moenebeng. 750 speakers in Pouébo, northeastern coast. Dialects are Pouébo (Pwebo), La Conception (St. Louis).

Cemuhî: also called Camuhi, Camuki, Tyamuhi, Wagap. 3,000 speakers in Touho: eastern coast from Congouma to Wagap and inland valleys.

Dumbea: also called Ndumbea, Naa Dubea, Dubea, Drubea. 1,400 speakers in Paita on the western coast, Ounia on the eastern coast.

Fwâi: also called Poai, Yengen, Yehen. 1,000 speakers in Hiènghène on the eastern coast; Ouenguip to Pindache and lower valleys.

Haeke: also called Aeke, 'Aeke, Haeake. 100 speakers in Voh-Kone, in Baco. Speakers are reported to be bilingual in a neighboring dialect.

Haveke: also called Aveke, 'Aveke. 300 speakers in Voh-Kone, in Gatope, Oundjo, Tiéta. Bwatoo may be a dialect.

Hmwaveke: also called 'Moaveke, Ceta, Faa Ceta. 300 speakers in Voh, in Tiéta.

Jawe: also called Njawe, Diahoue, Oubatch, Ubach. 900 speakers on the northeastern coast from Tchamboenne to Tao and upper valleys.

Kumak: also called Koumac, Fwa-Goumak. 900 speakers on northwestern coast of Koumac (Kumak dialect) and Poum (Nenema dialect). Dialects are Kumak, Nenema (Nelema).

Mea: also called Ha Mea, Hameha. 300 speakers in upper valleys of La Foa. Some influences from Tiri. Treated as a dialect of Tiri.

Neku: 200 speakers in Bourail, lower valley.

Nemi: 325 speakers on eastern coast, upper valleys north of Hiènghène, and west coast at Voh, Ouélis and upper valley.

Numee: also called Naa Numee, Kapone, Touaouru, Ouen, Kwenyii, Kunie, Tuauru, Duauru, Uen, Wen, Naa-We... 1,800 speakers in Yate, Touaouru, and Goro on main island southern coast (Numee dialect), Isle Ouen (Ouen dialect), and Isle of Pines (Kwenyii). Dialects are Numee (Touaouru), Ouen, Kwenyii (Kunie).