

Neuroimaging

– Some Key Questions –

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1 Describe two methods for studying brain function. How can each of these methods be used to obtain insights into how the brain supports particular cognitive functions?

Functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) are both non-invasive techniques that allow observation of physiological changes in the brain while a subject is, e.g., engaged in a cognitive task.

fMRI employs magnetic fields to measure hemodynamic changes in the brain; it exploits the differential magnetic properties of oxygenated vs. deoxygenated blood (how long it takes protons to realign with the original magnetic field after being hit by a perpendicular one) to obtain the blood oxygen level dependent (BOLD) signal. The hemodynamic response is assumed to be modulated by neural activity *via* neurovascular coupling – a process not yet fully understood (Arthurs & Boniface, 2002) and likely affected by disease and/or aging (D'Esposito, Deouell & Gazzaley, 2003).

The BOLD signal reflects aggregate activity across periods of time; a signal increase indicates stronger or longer-lasting neural activity (Heeger & Rees, 2002). Rather than its spiking output, the BOLD signal reflects “the input and intracortical processing of a given area” (Logothetis *et al.*, 2001). This highlights that a stronger BOLD signal does not necessarily justify the conclusion to more involvement of a particular area as the signal increase may well be due to inhibitory neural activity.

The magnetic resonance measure and the intrinsic delay of hemodynamic changes constrain the temporal resolution of fMRI to seconds while neural activity operates on a

millisecond scale. On the upside, fMRI provides a good spatial resolution: depending on the magnet's strength, the brain can be decomposed into spatial units (voxels) of only a few mm^3 in size. However, the secondary nature of the target variable constrains the spatial resolution: we do not observe changes in local field potentials but the vascular changes that follow – but these may affect different locations.

EEG employs electrodes mounted to the subject's scalp to directly measure electrical potentials arising from brain activity. The signal has a very high temporal resolution, and is sensitive to both duration and strength of neural activity. Its spatial resolution is rather crude; for even, say, 512 electrodes will not allow inferences as to which of the billions of neurons in a brain generated the EEG signal (*inverse problem*). Source localisation is further complicated by the signal's distortion as it passes through different tissues.

EEG data can be analysed in two principal ways. (i) Event-related fields/potentials (ERFs/ERPs) are average responses time-locked to stimulus onset. Amplitude changes indicate a quantitative differences in neural processing, identical scalp distributions indicate functional equivalence, and alternations in the time course of ERPs/ERFs indicate alternations in the time course of cognitive processing (Luck, 2004). (ii) Analysis in the frequency rather than temporal domain allows the detection of oscillation patterns possibly indicating information integration due to synchronous activity of multiple areas (Buzsáki & Draguhn, 2004; Tallon-Baudry, & Bertrand, 1999).

Typically, EEG will be used to study the temporal dynamics of brain and cognitive function and/or the coherence of neural activity. It can, e.g., be employed to investigate differential pre-stimulus activity for remembered and forgotten items (Gruber *et al.*, 2004). fMRI, on the other hand, will be employed for questions of localisation. Activity in a low-level condition (reading random letter sequences) is often *subtracted* from that in a high-level condition (reading and categorising words) to study higher-level (semantic) processing. fMRI can be useful for verifying task-location mappings obtained from lesion studies.

Both methods are merely correlational techniques. They allow identification of differences in neural processing based on observed differences in the measured signal where the nature of the difference remains unknown. Identical observed patterns, however, do not guarantee identical processing.

2 In one experiment, 90% of participants showed EEG data with artefacts. Discuss the possible causes.

Artefacts in EEG data are signals not induced by the experiment. If the 90% of participants showed data with systematically similar artefacts, the perhaps best way to identify their cause is comparing the experimental procedures they underwent with that of the remaining 10%. Has a different piece of equipment been used, or a different montage? Did subjects participate in a different experimental condition, did another experimenter conduct the experiment doing something differently than his colleagues, or did the subjects show a clearly different pattern of performance? If the artefacts observed do not show any sort of resemblance across subjects, they could be caused by individual subject factors, such as movement, eye-blinks or stem from various different sources.

An indication for an artefact's source may be provided by what it looks like: e.g., electrode-movements and eye-blinks tend to induce greater deviations from baseline in a lower frequency range than contaminated connections. In the absence of such information, I will consider sources of artefact more generally.

Eye-blinks and eye-movements are electrooculographic (EOG) artefacts likely to occur in any subject. Blinking is a natural reflex not too easy to suppress; problematically, trials with eye-blinks may be systematically different from trials without (Simons, Russo & Hoffman, 1988). Saccades can be triggered, e.g., when a task involves watching stimuli on a screen, if a peripheral item attracts attention, or even if the participant just wants to check the position of her fingers on the response box.

Electrodes near the eyes should be used to monitor EOG artefacts (Picton *et al.*, 2000). One way to eliminate these in subsequent analysis is to use a source component analysis to estimate characteristic signals associated with different types of eye-activity in a subject that can be subtracted from the EEG signal.

Muscle activity directly on the scalp, **clenching teeth, jaw and tongue movements**, and even distant **joint movement**, induce bioelectric activity and may cause saturation errors after analogue-to-digital (A/D) conversion (Usakli, 2010).

Other than ocular and tongue activity, potentials from scalp skin and muscles can often adequately be monitored using the same channels used for ERP recordings (Picton *et al.*, 2000). To correct for tongue artefacts (which may be unavoidable if the experiment requires subjects to speak), similar procedures as for EOG artefacts are available; electrodes on the cheek will monitor the relevant activity but also pick up ocular artefacts.

Perspiration changes skin conductivity causing very slow potentials enduring several seconds (Usakli, 2010). As a result, the baseline may be instable and/or electrode impedances generally reduced.

Drift is electrode movement, e.g. resulting from perspiration; it causes signal fluctuations and spikes (Uskali, 2010). Changes to electrode placement (or high coverage in general) may induce *cross-talk* between channels.

Imperfect electrode contact may affect impedances; less than $1\text{k}\Omega$ yields shortcuts whereas more than $10\text{k}\Omega$ make recording impossible (Uskali, 2010). Picton *et al.* (2000) suggest keeping impedances below $2\text{k}\Omega$.

Contamination of contact between electrode and clip and/or input plug and socket may also cause high-frequency fluctuations.

A/D saturation can be caused by limited dynamic ranges in the amplifier and/or A/D converter; if the limit is exceeded, signals are distorted, non-linearities induced, and the analogue signal may be lost. Enlarging the dynamic range worsens the signal-to-noise ratio (Schlögl *et al.*, 1999).

Electromagnetic background noise can be caused by electronic devices (e.g. screens), and fluorescent lamps (Uskali, 2010). Magnetic fields to the subject's head and body cause voltage drop across electrodes; on electrode cables, they induce noise as does improper grounding of the subject.

Finally, **stimuli** themselves may cause artefacts, e.g. if they trigger additional cognitive processing (an air-puff “touches” but also “makes sound”).

3 What is an ERP ‘component’? How can ERP components be used to understand mind-brain relationships?

Event-related potentials/fields (ERPs/ERFs) represent and aggregate of effects over space and time. For their interpretation, decomposition into *components* associated with specific cognitive processes can be used. An ERP component is “scalp-recorded electrical activity that is generated in a given neuroanatomical module when a specific computational operation is performed.” (Luck 2004, p. 22) That is to say, ERP components are parts of a waveform with circumscribed scalp distributions and relationships to experimental variables; they may originate from certain neural configurations thought to subserve the cognitive function being investigated.

Electrodes record a series of overlapping *latent* components. The observed waveform thus could have arisen from a range of possible combinations of latent components where their morphology is not necessarily obvious from the observed waveform (see Figure 1). Similarly, it is sometimes difficult (or impossible) to identify and/or distinguish different ERP components (Luck, 2004).

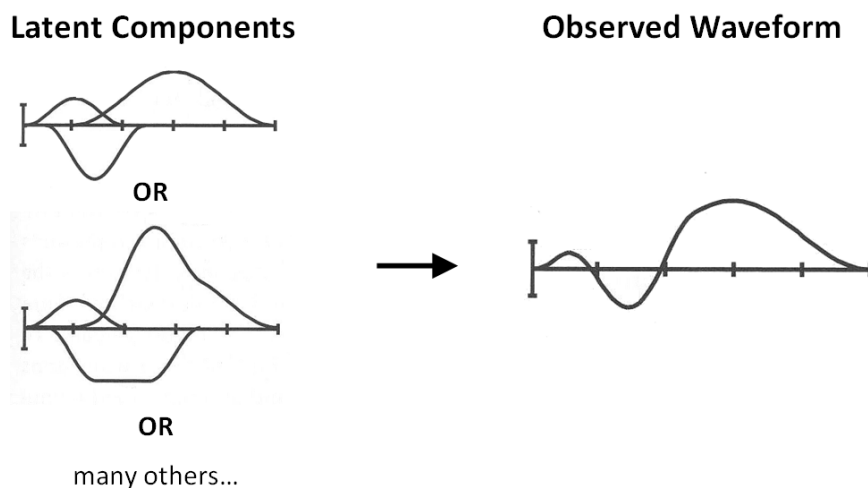


Figure 1: Adopted from Gruber and Abreu (2009).

While many component labels are based on the component’s amplitude and polarity – for instance, a P300 is a positive deflection 300ms after stimulus onset (typically if an expectation is not met – (Sutton *et al.*, 1965), some labels indicate functionality – a

mismatch negativity (MMN) (Näätänen, Gaillard & Mäntysalo, 1978) is associated with a deviant sensory stimulus within an otherwise homogeneous sequence (such as an “s” among a train of “b”s). It remains unclear whether a single component indicates the same functionality when occurring in different cognitive processes, (e.g. language and memory). The exact functional significance of a component is seldom fully understood. Labeling thus often is more a matter of establishing a *common ground* among researchers than actually adding meaning.

Assuming psychological phenomena are essentially based on electrophysiology, ERPs can be used to study brain processes underlying cognitive functions. They can be used as physiological markers indicating specific mental processes and be employed to interpret observed EEG effects. For instance, ELAN (Friederici, Pfeifer & Hahne, 1993), N400 (Kutas & Hillyard, 1984), and P600 (Osterhout & Holcomb, 1992) are well-defined components in language processing associated with syntactic (ELAN, P600) and semantic (N400, P600) processes. EEG data analysis from psycholinguistic studies in terms of these components allows research to be integrated. For instance, Friederici (2002) developed a neural model of auditory language processing based (in part) on various EEG studies.

Reference to ERP components may further be consulted to aid interpretation of experimental data: known components can be “subtracted” from the observed signal to reveal a different, formerly invisible, effect.

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