Science Education Collection

Electro-encephalography (EEG)

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Abstract

EEG is a non-invasive technique that can measure brain activity. The neural activity generates electrical signals that are recorded by EEG electrodes placed on the scalp. When an individual is engaged in performing a cognitive task, brain activity changes and these changes can be recorded on the EEG graph. Therefore, it is a powerful tool for cognitive scientist aiming to better understand the neural correlates associated with different aspects of cognition, which will ultimately help them devise improved treatments for patients with cognitive deficits.

Here, JoVE presents a brief overview of EEG and its applications in cognitive research. First, we discuss where and how EEG signals are generated. Then, we explain the use of EEG in studying cognition along with a detailed step-by-step protocol to perform an EEG experiment. Lastly, the video reviews some specific cognitive experiments that use EEG in combination with other techniques such as functional Magnetic Resonance imaging (fMRI) or transcranial direct current stimulation (tDCS).

Transcript

Electroencephalography, or EEG, is an electrophysiological technique commonly used by researchers studying cognition. The brain constantly generates electrical activity, which can occur spontaneously, or when induced by stimulation. EEG is a noninvasive, portable and inexpensive technique that can detect and quantify changes in the brain's activity, making it particularly useful for cognitive studies. In this video, we will briefly explain how EEG signals are generated, how EEG is applied to cognitive research, the standard method of EEG recording, and some specific applications.

To begin, let's look at where and how the EEG signals are generated.

The EEG signal is an electrical activity recorded from the surface of the brain using electrodes placed on the scalp. It's generated primarily in the outermost layer-the cerebral cortex-by activated pyramidal neurons, which are the principal output neurons of the cortex. These neurons receive and integrate synaptic inputs from other parts of the brain, and their collective activity reflects the processing of information.

Notably, excitation moves positively-charged ions through the membrane and into the neuron, creating a current "sink" in the dendritic region, which is neutralized by the outward movement of charge around the soma-the current "source." This brings the neuron to a "dipole" state, generating an electric potential, and creating current flows between apical dendrite and soma. Electrodes capture the sum total of potentials produced by large numbers of these "neural dipoles" acting synchronously.

Now that you're familiar with the physiology behind EEG signals, let's discuss what they tell us about cognitive functions.

Normal EEG exhibits spontaneous oscillations. This rhythmic activity consists of several overlapping sub-rhythms that can be unmasked by mathematical transformations, such as the Fourier transform. Using this technique, EEG time series is decomposed into its component sub-rhythms and plotted as a "power spectrum." Each sub-rhythm, based on its frequency, is plotted according to its "concentration" or signal power in the total EEG record.

The frequencies for the brain rhythms are: Delta wave, which is the slowest at less than 4 Hz; Theta wave, at 4-7 Hz; Alpha wave, at 8-12 Hz; Beta wave at 13-30 Hz; and Gamma wave, the fastest at greater than 30 Hz. Each rhythm is also correlated with a behavioral state: Delta and Theta waves are observed in the sleeping state, Alpha waves occur in the awake and relaxed state, and Beta and Gamma waves occur during active cognition.

Change in EEG activity is used to investigate the brain's response to stimulation during cognitive tasks. For example, during a cognitive experiment, a subject may be asked to view faces on a computer screen, and discriminate between them. The test is repeated a number of times. Subsequent EEG responses are time-locked to the onset of the visual stimulus and averaged; this raises the signal level above the background noise. Mean EEG activity evoked by a specific stimulus is known as the event-related potential. or ERP.

The peaks in the ERP graph correspond to coordinated neural activity. Here, an earlier peak relates to the direct response of the visual system. Then, a later peak of synchronized neural activity relates to cognitive processing of the stimulus.

Now that you've learned how EEG is used to study cognition, let's look at how an EEG experiment is conducted.

EEG experiments require that only meaningful signals are collected, because actual cortical potentials are very small. To capture those signals, EEG electrodes are made of highly conductive materials, such as silver and silver chloride, which are arranged in a cap according to the standardized 10-20 placement system. This system ensures consistent positioning of electrodes so experiments are reproducible across time and subjects. Electrodes are designated according to identified cortical areas and hemisphere location, and are systematically separated to within 10% or 20% of the total front-to-back or right-to-left distance of the skull.

Electrolyte gel is used with electrodes to increase conductivity. Active signals are amplified relative to a reference electrode, and the system is grounded to reduce noise. Furthermore, signals are filtered to collect only those that fall within the EEG frequency range. Artifacts from bodily movements, such as eye-blinking, are typically monitored and subtracted from the data.

Before the experiment, procedures are explained to the participant and a written consent is obtained. The subject's head circumference is measured, and an appropriate electrode cap size is selected. Landmarks for placing the cap are marked and followed according to the 10-20 placement system. Next, conductive gel is injected inside each electrode holder, making a stack of gel against the scalp, just enough to avoid interference between neighboring electrodes. Active electrodes are then fixed into the holders. The subject is now positioned for the experiment, and is reminded to minimize unnecessary movements. Finally, the EEG display is checked to make sure that everything is running properly.

Now that you've learned the basics of running an EEG experiment, let's examine some specific applications of this technique in cognitive research.

EEG is used to study social cognition in adults and infants. Here, the experiment involves a face-to-face puppet demonstration with an infant as subject to test immediate recall and imitation. Data collected from the entire scalp show differences in EEG activity at various experimental time-points.

Functional magnetic resonance imaging, or fMRI, is another noninvasive technique that measures brain activity. The sensitivity of fMRI to the location of activation can be combined with the sensitivity of EEG to the timing of activation. Together, these techniques enable functional mapping at a higher level to understand such cognitive processes as sleep, consciousness, emotion, learning, and memory.

Finally, EEG can be combined with transcranial direct current stimulation, or tDCS, a technique that enables brain stimulation to modulate neuron excitability. tDCS holds potential for treating neurological disorders that affect cognitive abilities, and EEG is used to monitor and optimize the effects of direct stimulation. Software programs running automatic fast Fourier transforms are used to observe changes in the EEG power spectrum in real time.

You've just watched JoVE's video on EEG. This video discussed how EEG signals are generated, how this technique is used to understand cognition, the basics of conducting an EEG experiment, and finally, some specific applications in cognitive studies. As always, thanks for watching!