Neural Recording:

In neuroscience, **single-unit recordings** (also, single-neuron recordings) provide a method of measuring the electro-physiological responses of a single neuron using a microelectrode system. When a neuron generates an action potential, the signal propagates down the neuron as a current which flows in and out of the cell through excitable membrane regions in the soma and axon. A microelectrode is inserted into the brain, where it can record the rate of change in voltage with respect to time. These microelectrodes must be fine-tipped, impedance matching; they are primarily glass micro-pipettes, metal microelectrodes made of platinum, tungsten, iridium or even iridium oxide. Microelectrodes can be carefully placed close to the cell membrane, allowing the ability to record extracellularly.

Single-unit recordings are widely used in cognitive science, where it permits the analysis of human cognition and cortical mapping. This information can then be applied to brain–machine interface (BMI) technologies for brain control of external devices.

There are many techniques available to record brain activity—including electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI)—but these do not allow for single-neuron resolution. Neurons are the basic functional units in the brain; they transmit information through the body using electrical signals called action potentials. Currently, single-unit recordings provide the most precise recordings from a single neuron. A single unit is defined as a single, firing neuron whose spike potentials are distinctly isolated by a recording microelectrode.

The ability to record signals from neurons is centered around the electric current flow through the neuron. As an action potential propagates through the cell, the electric current flows in and out of the soma and axons at excitable membrane regions. This current creates a measurable, changing voltage potential within (and outside) the cell. This allows for two basic types of single-unit recordings. Intracellular single-unit recordings occur within the neuron and measure the voltage change (with respect to time) across the membrane during action potentials. This outputs as a trace with information on membrane resting potential, postsynaptic potentials and spikes through the soma (or axon). Alternatively, when the microelectrode is close to the cell surface extracellular recordings measure the voltage change (with respect to time) outside the cell, giving only spike information. Different types of microelectrodes can be used for single-unit recordings; they are typically high-impedance, fine-tipped and conductive. Fine tips allow for easy penetration without extensive damage to the cell, but they also correlate with high impedance. Additionally, electrical and/or ionic conductivity allow for recordings from both non-polarizable and polarizable electrodes. The two primary classes of electrodes are glass micropipettes and metal electrodes. Electrolyte-filled glass micropipettes are mainly used for intracellular single-unit recordings; metal electrodes (commonly made of stainless steel, platinum, tungsten or iridium) and used for both types of recordings.

Single-unit recordings have provided tools to explore the brain and apply this knowledge to current technologies. Cognitive scientists have used single-unit recordings in the brains of animals and humans to study behaviors and functions. Electrodes can also be inserted into the brain of epileptic patients to determine the position of epileptic foci. More recently, single-unit recordings have been used in brain machine interfaces (BMI). BMIs record brain signals and decode an intended response, which then controls the movement of an external device (such as a computer cursor or prosthetic limb).

Electrophysiology

The basis of single-unit recordings relies on the ability to record electrical signals from neurons.

Neuronal potentials and electrodes

When a microelectrode is inserted into an aqueous ionic solution, there is a tendency for cations and anions to react with the electrode creating an electrode-electrolyte interface. The forming of this layer has been termed the Helmholtz layer. A charge distribution occurs across the electrode, which creates a potential which can be measured against a reference electrode. The method of neuronal potential recording is dependent on the type of electrode used. Non-polarizable electrodes are reversible (ions in the solution are charged and discharged). This creates a current flowing through the electrode, allowing for voltage measurement through the electrode with respect to time. Typically, non-polarizable electrodes are glass micropipettes filled with an ionic solution or metal. Alternatively, ideal polarized electrodes do not have the transformation of ions; these are typically metal electrodes. Instead, the ions and electrons at the surface of the metal become polarized with respect to the potential of the solution. The charges orient at the interface to create an electric double layer; the metal then acts like a capacitor. The change in capacitance with respect to time can be measured and converted to voltage using a bridge circuit. Using this technique, when neurons fire an action potential they create changes in potential fields that can be recorded using microelectrodes. Single unit recordings from the cortical regions of rodent models have been shown to dependent on the depth at which the microelectrode sites were located.

Intracellularly, the electrodes directly record the firing of action, resting and postsynaptic potentials. When a neuron fires, current flows in and out through excitable regions in the axons and cell body of the neuron. This creates potential fields around the neuron. An electrode near a neuron can detect these extracellular potential fields, creating a spike.

Experimental setup

The basic equipment needed to record single units is microelectrodes, amplifiers, micromanipulators and recording devices. The type of microelectrode used will depend on the application. The high resistance of these electrodes creates a problem during signal amplification. If it were connected to a conventional amplifier with low input resistance, there would be a large potential drop across the microelectrode and the amplifier would only measure a small portion of the true potential. To solve this problem, a cathode follower amplifier must be used as an impedance matching device to collect the voltage and feed it to a conventional amplifier. To record from a single neuron, micromanipulators must be used to precisely insert an electrode into the brain. This is especially important for intracellular single-unit recording.

Finally, the signals must be exported to a recording device. After amplification, signals are filtered with various techniques. They can be recorded by an oscilloscope and camera, but more modern techniques convert the signal with an analog-to-digital converter and output to a computer to be saved. Data-processing techniques can allow for separation and analysis of single units.

Types of microelectrodes

There are two main types of microelectrodes used for single-unit recordings: glass micropipettes and metal electrodes. Both are high-impedance electrodes, but glass micropipettes are highly resistive and metal electrodes have frequency-dependent impedance. Glass micropipettes are ideal for resting- and action-potential measurement, while metal electrodes are best used for extracellular spike measurements. Each type has different properties and limitations, which can be beneficial in specific applications.

Glass micropipettes

Glass micropipettes are filled with an ionic solution to make them conductive; a silver-silver chloride (Ag-AgCl) electrode is dipped into the filling solution as an electrical terminal. Ideally, the ionic solutions should have ions similar to ionic species around the electrode; the concentration inside the electrode and surrounding fluid should be the same. Additionally, the diffusive characteristics of the different ions within the electrode should be similar. The ion must also be able to "provide current carrying capacity adequate for the needs of the experiment". And importantly, it must not cause biological changes in the cell it is recording from. Ag-AgCl electrodes are primarily used with a potassium chloride (KCl) solution. With Ag-AgCl electrodes, ions react with it to produce electrical gradients at the interface, creating a voltage change with respect to time. Electrically, glass microelectrode tips have high resistance and high capacitance. They have a tip size of approximately 0.5-1.5 µm with a resistance of about 10-50 MΩ. The small tips make it easy to penetrate the cell membrane with minimal damage for intracellular recordings. Micropipettes are ideal for measurement of resting membrane potentials and with some adjustments can record action potentials. There are some issues to consider when using glass micropipettes. To offset high resistance in glass micropipettes, a cathode follower must be used as the first-stage amplifier. Additionally, high capacitance develops across the glass and conducting solution which can attenuate high-frequency responses. There is also electrical interference inherent in these electrodes and amplifiers.

Metal electrodes

Metal electrodes are made of various types of metals, typically silicon, platinum, and tungsten. They "resemble a leaky electrolytic capacitor, having a very high low-frequency impedance and low high-frequency impedance". They are more suitable for measurement of extracellular action potentials, although glass micropipettes can also be used. Metal electrodes are beneficial in some cases because they have high signal-to-noise due to lower impedance for the frequency range of spike signals. They also have better mechanical stiffness for puncturing through brain tissue. Lastly, they are more easily fabricated into different tip shapes and sizes at large quantities. Platinum electrodes are platinum black plated and insulated with glass. "They normally give stable recordings, a high signal-to-noise ratio, good isolation, and they are quite rugged in the usual tip sizes". The only limitation is that the tips are very fine and fragile. Silicon electrodes are alloy electrodes doped with silicon and an insulating glass cover layer. Silicon technology provides better mechanical stiffness and is a good supporting carrier to allow for multiple recording sites on a single electrode. Tungsten electrodes are very rugged and provide very stable recordings. This allows manufacturing of tungsten electrodes with very small tips to isolate high-frequencies. Tungsten, however, is very noisy at low frequencies. In mammalian nervous system where there are fast signals, noise can be removed with a high-pass filter. Slow signals are lost if filtered so tungsten is not a good choice for recording these signals.

Applications

Single-unit recordings have allowed the ability to monitor single-neuron activity. This has allowed researchers to discover the role of different parts of the brain in function and behavior. More recently, recording from single neurons can be used to engineer "mind-controlled" devices.

Cognitive science

Noninvasive tools to study the CNS have been developed to provide structural and functional information, but they do not provide very high resolution. To offset this problem invasive recording methods have been used. Single unit recording methods give high spatial and temporal resolution to allow for information assessing the relationship between brain structure, function, and behavior. By looking at brain activity at the neuron level, researchers can link brain activity to behavior and create neuronal maps describing flow of information through the brain. For example, Boraud et al. report the use of single unit recordings to determine the structural organization of the basal ganglia in patients with Parkinson's disease. Evoked potentials provide a method to couple behavior to brain function. By stimulating different responses, one can visualize what portion of the brain is activated. This method has been used to explore cognitive functions such as perception, memory, language, emotions, and motor control.

Brain–machine interfaces

Brain–machine interfaces (BMIs) have been developed within the last 20 years. By recording single unit potentials, these devices can decode signals through a computer and output this signal for control of an external device such as a computer cursor or prosthetic limb. BMIs have the potential to restore function in patients with paralysis or neurological disease. This technology has potential to reach a wide variety of patients but is not yet available clinically due to lack of reliability in recording signals over time.