Engineering 3

[00:00:02.53] In this portion of the lecture we're going to review tools for recording from the brain and body and how they're used in neural engineering. In many fields of neuroscience we use single unit recordings, which record the activity of individual neurons. The setup looks like part A of this figure where you have an electrode that records the electrical activity of just one cell. And that electrical activity might look something like the trace in B, what is happening to the electrical properties of just one neuron over time.

[00:00:37.57] If the neuron fires an action potential multiple times, then as you see in part C, you can identify individual spikes of that neuron. And then if you take many neuron's individual spiking patterns and add them up, then you get a stimulation pattern like you see in part D. Where the group of neurons together becomes more active in response to a stimulus.

[00:01:02.35] In neural engineering, we more commonly want to use signals like we see in part D, the aggregate activity of many neurons working together to form a complex signal. And this is for many reasons. Partly because it's not easy to get a dependable signal from only one neuron.

[00:01:21.16] Having the recording from just a single neuron reduces the potential complexity of that signal because it's just on or off and it doesn't have the sort of gradation that a group of neurons added together can form like you see in part D. And the equipment that's used to record from single neurons is far more invasive and fragile than it is for recording groups of neurons.

[00:01:49.72] When we record from groups of neurons, we get signals that look something like this. This is the sum of hundreds or hundreds of thousands of individual neuron's spikes that are added together. And we can extract complex features that correspond to the combined activity of these thousands of cells.

[00:02:10.72] And the general properties and specific activity of groups of neurons varies across the brain, depending on what the person is doing and on the job of that specific area of the brain. We can use these complex electrical signals to control neural engineering devices. We can also study what these signals look like in order to replicate them. For example, to deliver a simulation that replicates what a person might feel when they are touching something with their hand.

[00:02:46.03] Electroencephalogram or EEG is one of the most common technologies for first line experiments or clinical investigation. It's cheap, easy, noninvasive, and it's easy to get. So it's in very wide use. But it has low resolution both in space and in frequency. So you can't tell the difference between different frequency patterns in the brain very easily.

[00:03:12.01] And the signal is smeared in space. It's sort of like listening to music through a wall. You can only hear part of the signal, you can't hear the whole song very well. And you can't tell very easily where in the room next door the speaker might be.

[00:03:26.11] There's also very high noise. The signal has to travel through muscle, skull, and scalp in order to reach the electrode. And that introduces a lot of additional signal that doesn't actually come from the brain. EEG also only works if the person is sitting still. And the signal can be degraded by the person's hair and if it's wet.

[00:03:46.27] And there's low consistency in day to day electrode placement if the person is being experimented on for multiple days. So it's not very viable for long term everyday use where a person would need these EEG electrodes to be placed every day for the rest of their life.

[00:04:02.03] There is a subdermal variant of EEG, subdermal meaning below the skin. Where electrodes are temporarily or permanently implanted under the skin of the scalp. And this is a little better, because you don't have to worry about the electrodes being in the same place every day. And it avoids some of the degradation of the signal by getting under the scalp and under some of the muscle tissue. But it's not widely used experimentally, so there's not a whole lot of data to say right now.

[00:04:33.04] Electrocorticography or ECoG works much the same as EEG, except that the electrodes are placed directly on the surface of the brain inside of the skull. So the pros of using ECoG are that the noise levels are very low because you don't have the skull and the scalp generating extra signal that gets in the way of the brain signal. It has much better resolution that you don't have this smearing in space of the signal. What each electrode is placed over is all that it records.

[00:05:02.74] It's easy to interpret the data, relatively speaking. And it can be placed for many days. Most of the time it's placed for seven days at a time.

[00:05:10.78] It's also already used, not for brain computer interfaces in clinical settings, but it's used for the treatment of epilepsy in order to identify where seizures are coming from. So there are subjects available who can participate in research who don't need to volunteer to have electrodes placed just for the purposes of research. They're already having them placed anyway.

[00:05:31.24] It comes in two sizes that are the most common available that are one centimeter or a little under 1/2 an inch apart or two millimeters apart. But the resolution, even in the micro version, even in the two millimeter spacing is too low for a lot of clinical applications. And it's invasive and it's expensive.

[00:05:55.75] Many of the experimental brain computer interfaces where the volunteers have been paralyzed and are volunteering specifically to receive implants that are treating paralysis use penetrating microelectrodes. And these penetrating microelectrodes have extremely high spatial resolution and they provide the best brain computer interface control in existing trials.

[00:06:17.63] So the woman in the red shirt that I showed you in the previous segment of this lecture who was controlling the robotic arm, this is what she has. And it has only been used in less than 10 patients for the purposes of treating paralysis. It's used more often in animals, but it's currently rarely used in humans.

[00:06:36.25] On the downside, it has very low spatial coverage. This entire unit is about two millimeters on each side. And it's highly invasive.

[00:06:45.58] So electrocorticography is considered minimally invasive technology. Which I know sounds strange that it's minimally invasive because it requires brain surgery. But the placement of the electrodes does not do any damage to the neural tissue. Whereas penetrating microelectrodes actually press into the surface of the tissue and it does cause a little bit of damage.

[00:07:06.25] It's expensive and it's difficult to place, because you have to get the placement of it exactly right, because it records over such a small area. And because it causes tissue damage, it can also cause significantly more scarring than surface electrodes do.

[00:07:19.81] Remember when we talked about glia that we talked about how glia protect the brain from foreign invaders. And the brain sees these penetrating microelectrodes as foreign invaders. But despite these drawbacks, penetrating microelectrodes are probably the most likely to be used for clinical applications of brain computer interfaces as the technology gets better.

[00:07:43.22] MRI is also one of the most common technologies used in neuroscience. It's easy to access. Pretty much every hospital has at least one. It gives very high spatial resolution pictures of the brain on a one millimeter scale, so very small. Smaller even than the penetrating electrodes.

[00:08:01.03] And it provides access to deep structures of the brain like the basal ganglia and the thalamus that we currently can't reach very easily with any other recording technology available for use in humans. It's also noninvasive. It doesn't require any surgery, so you can do this on anybody. And it's really good for research on the correspondence between anatomy and function, what parts of the brain are associated with what functions.

[00:08:25.27] But MRI cannot be used for practical brain computer interfaces. It just isn't feasible to expect a person to lay in a three ton magnet that cost several million dollars every single day for the rest of their life in order to operate their brain computer interface.

[00:08:40.60] Also, an MRI is very slow. Neurons can fire up to approximately 200 times per second. And an MRI takes a snapshot of brain activity approximately once a second. So this just isn't a fast enough signal for any kind of practical use.

[00:08:56.56] MRIs also measure brain activity indirectly. They're not actually measuring what neurons are doing, they're measuring the blood flow in the brain. So MRIs are mostly used for establishing the anatomy of an individual. And they're especially useful for diagnosis of atypical anatomical features in the brain.

[00:09:14.98] Finally, nerve cuffs can be used for peripheral recording and stimulation of the nervous system. There are minimally invasive. They don't require brain surgery, though They do require surgery to place.

[00:09:26.26] And they're highly specific. They only record from or stimulate the nerves that they are wrapped around. They're also relatively inexpensive compared to a lot of other of the technologies that we've talked about here. And they can be used to both stimulate and record from the nervous system.

[00:09:41.23] But they won't work if the nerves or limb is too damaged. And they won't work if their is spinal cord damage. So the person has to have some healthy surviving nerves in order to record from and if desired, stimulate to. And they have to be receiving and sending signals. So if there's a spinal cord injury then this isn't a viable solution.

[00:10:03.01] And you can only control one target per nerve cuff. So if you want to control all 27 joints and degrees of freedom in the hand, all of the different ways that you can move individual finger joints and in the multiple directions that some joints can move, you would have to have 27 nerve cuffs to control all those individual pieces. So this can add up and take up a lot of space and processing power very quickly.

[00:10:29.41] So this has been a review of commonly used technology in neural engineering, especially as it is used in humans or could be used in humans. As we continue onto the sensory and motor system lectures in this course and discuss some of the features of the nervous system that we might want to manipulate in neural engineering, remember these technologies and their uses and limits.