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The Body's Electrical Language

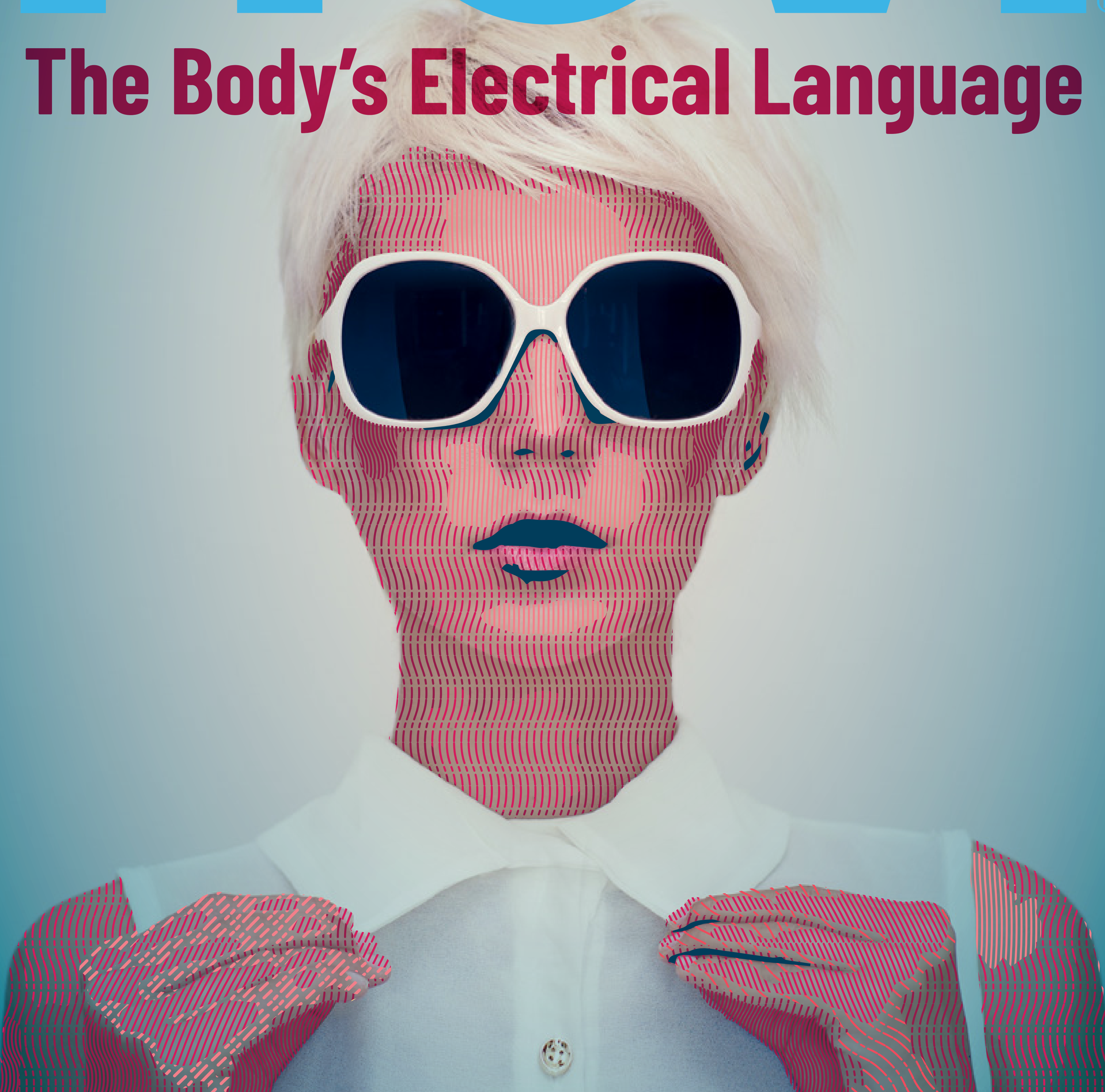
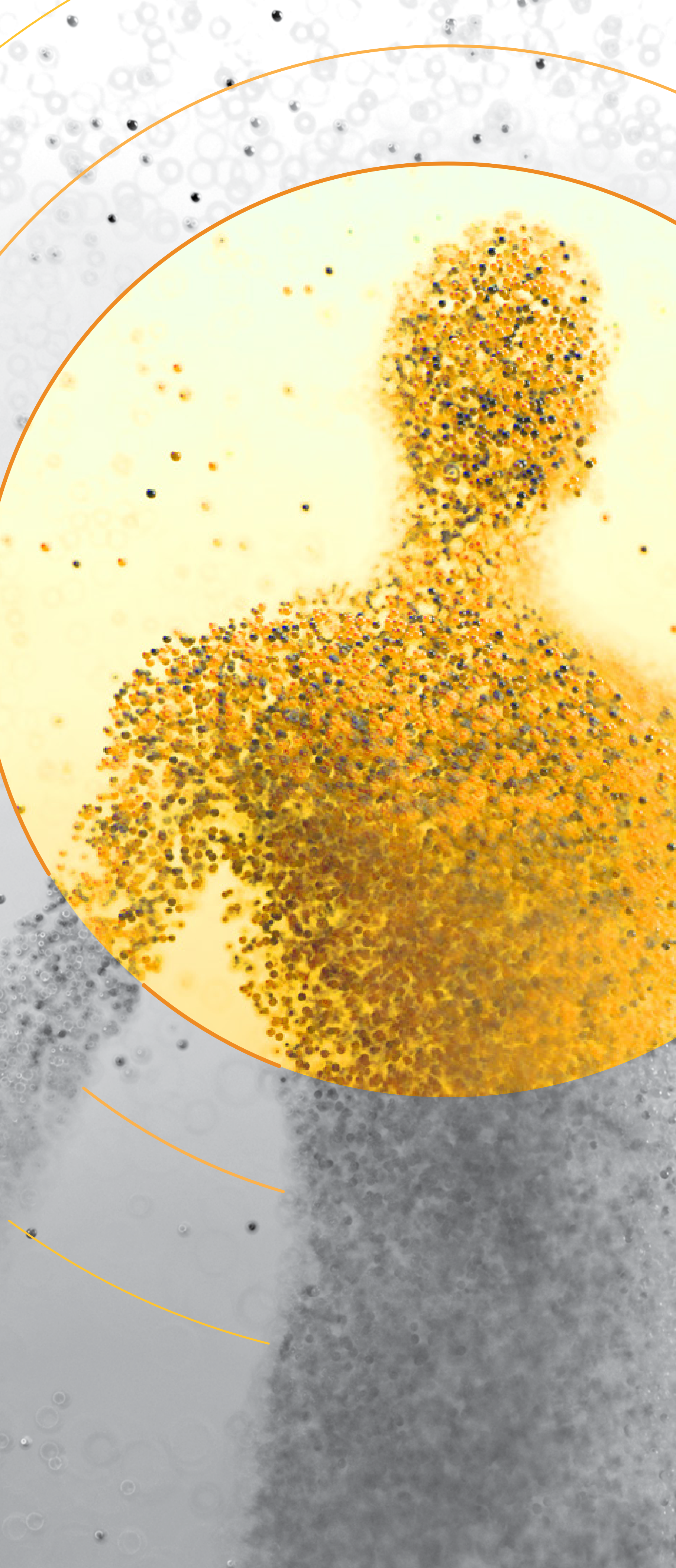


Table of Contents



HOW YOUR BODY GENERATES ELECTRICITY

We are used to thinking of electricity as a purely modern phenomenon, when in truth, electricity has always been around, in the sky, in the earth, and in ourselves. All electricity really is is energy—energy flowing from one point to another. And long before man gave this moving energy a name and harnessed it for his own inventions, it was working inside him.

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The Original Source

We start at the dinner table. Let's say you had a hamburger and fries.

All your taste buds care about is that the patty is juicy and the fries are salty—but your stomach cares about what that hamburger is made of: pieces that can be used to generate energy.

Your digestive system will dismantle your dinner, keeping the pieces that your body can use—glucose from the fries, protein from the patty, and carbohydrates from the hamburger bun—and discarding all the pieces your body can't use.

After that, your body's job is to take those useful pieces and turn them into energy. That's what calories are—potential energy from food. Your body turns that potential energy into working energy every day. Whenever you think, move, or even sleep, your body is turning calories into electrical signals and working energy.

So, as a recap, your body takes in material, usually oxygen and food, and dismantles it, through either the digestive process or cellular respiration, and that energy is then used for all kinds of conscious and unconscious bodily functions.

Some of that dismantling will result in ATP (Adenosine triphosphate) that will be used to power your muscles. But how do your muscles get the signal to move in the first place?

That requires just the right amount of electricity, in the right place, at just the right time. Such delicate electrical signals are handled by the nervous system.

Electrical Generation in The Nervous System

Your nervous system is what allows your brain to communicate with the rest of your body. Of course, that's a big responsibility! And it requires that the nervous system be able to generate and use electricity just right.

Two ingredients are crucial: sodium (not too much, mind) and potassium (Mom was right to make you eat bananas).

The cells in your nervous system take these two ingredients through several steps in order to generate electricity. And the first step is to actually keep the two ingredients *apart* from each other.

See, most of your cells have a slightly negative charge because they store negatively-charged anions and potassium on the inside of the cell and keep the positively-charged sodium outside.

There is tension, potential energy, between these positive and negative charges because they are drawn to each other but can't reach each other, due to the cell membrane that separates them. The positive and negative charges want to move, to collide, but they can't.

This is the electrical potential energy that your nervous system keeps in store for later use.

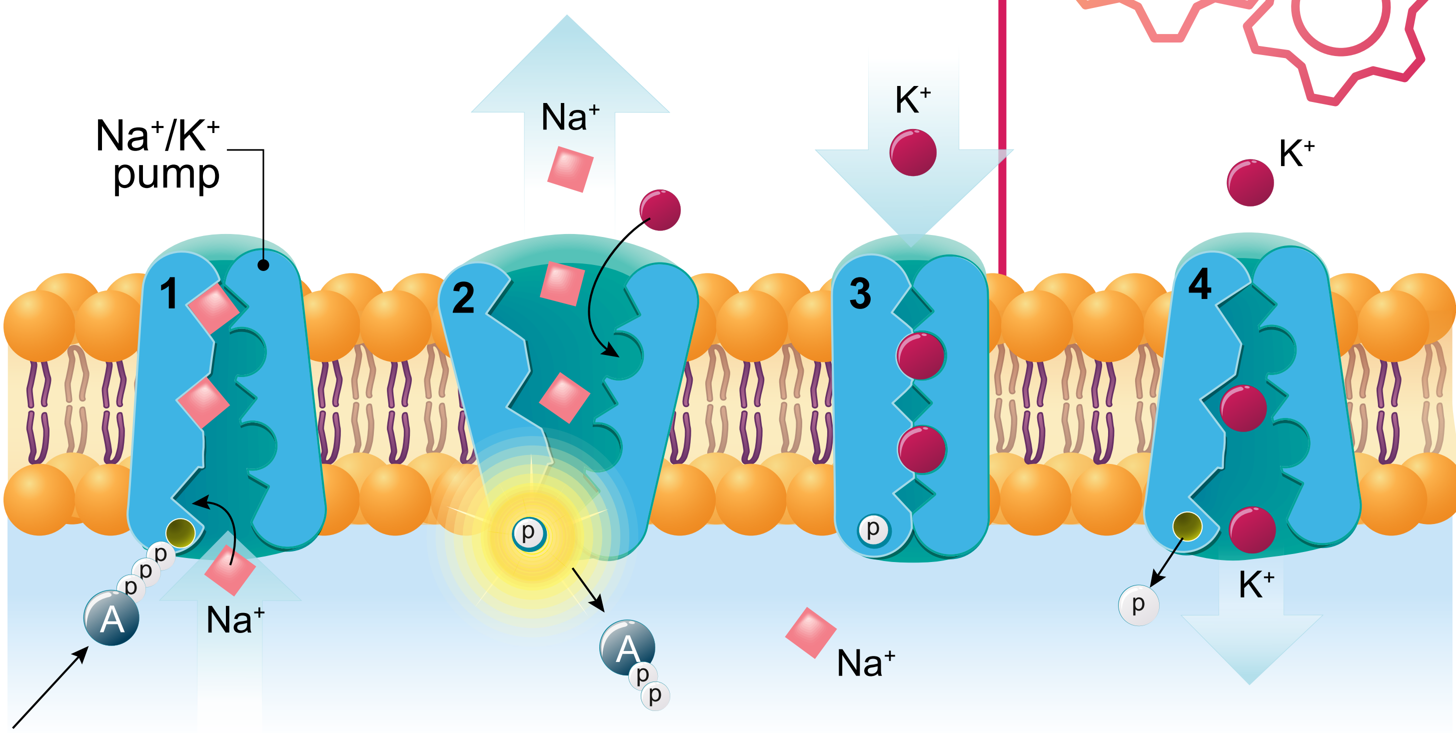
When a nervous system cell, a neuron, is activated (either by an electrical sign from another neuron or some kind of chemical interaction), the first sodium-potassium gates in the cell membrane open up.

In that moment, of course, the sodium is drawn into the cell towards the negative charge, and the potassium is drawn out of the cell toward the positive charge.

The movement of these molecules releases the tension—the electrical potential energy—in the form of an electrical pulse called an "action potential".

This action potential prompts the next sodium-potassium gates along the axon to open up as well, keeping the electrical signal going on through the neuron until it reaches the axon terminals at the end.

Sodium Potassium Gate



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How Your Body Conducts Electricity

The Nervous System is a Highway For Electrical Messages

Okay, so the electricity is there at the end of the axon terminals, born out of potential electrical energy, but where does it go from there? And how will it get there? As it reaches the end of the axon, the action potential is either carried on through an electrical synapse to another neuron, or it triggers a neurotransmitter that will carry on the message chemically, rather than electrically.

That electrical "signal" will continue from neuron to neuron, along the nervous system pathway until it reaches its destination and has done its job.

These electrical signatures are key to everything that your body does, autonomically or consciously. This is also how your body registers pain, sensory stimuli, and everything else in the world.

You might think of every "signal" working like the 1s and 0s of computer code. A certain pattern of signatures will make your eyelids blink; a more complex series of patterns will let you read, understand, and solve a math equation.

All of the nervous system "signals" that you've heard about, as well as the "firing' of synapses, is really your body generating electricity from the elements and molecules that reside inside you so that your body can function.

These electrical signals are the natural defibrillator of your body, stimulating your sinoatrial node to make your heart beat regularly—more than 100,000 times a day! Thanks, electricity!

How The Body Manages Electricity

Keep in mind that we're talking about electricity *inside* the body here.

Your skin is the shell that protects the inside of your body from the outside world. And it actually resists electrical current flow. Your palms, where the epidermis of the skin is thicker, can have up to 100,000 Ohms worth of resistance! This is meant to protect your less-resistant inner tissues from harmful amounts of external electricity.

So, your body is built to both conduct and resist electrical currents as it needs to. It's like cooking with salt (and not just because sodium helps with electrical conductivity). Your body needs just the right amount of electricity in just the right way and place. Have you ever had a dish ruined by too much or too little salt?

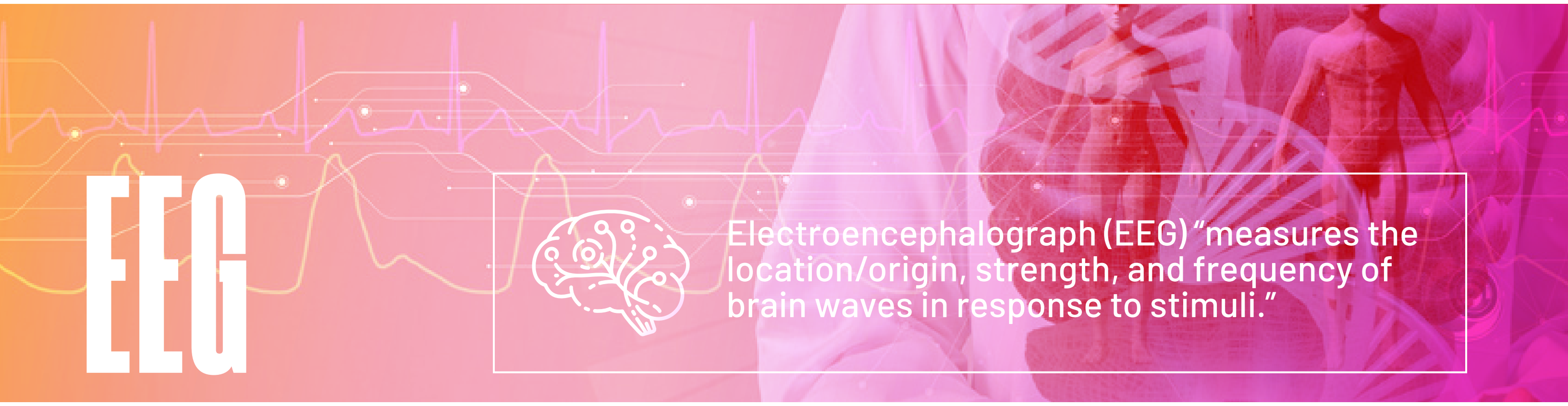
Too much or too little electricity can mean loss of motor function, being disconnected to one or more of your senses, strokes, infections, organ failures, and other unpleasant things. Thank goodness the body knows how to manage its electricity like a pro.

Electrical Biofeedback Devices

Researchers have found ways to measure the body's incredible conductance and resistance to electricity and these measurements have helped us learn more about the human body.

Modernly-used electrical biofeedback methods include:
- Electroencephalography **(EEG)**
- Electromyography **(EMG)**
- Use of the Electrocardiogram **(ECG)**
- The study of electrodermal activity **(EDA)**

We'll cover each of these in turn.



The Revolutionary Galvanometer

Back during the 18th century, a renowned scientist named Luigi Galvani realized that by applying electrical impulses to a dead frog's hindquarters, he could make those legs twitch and flex—much as they had when the frog was alive.

This resulted in a revolutionary question: Could electricity be the key to animal motion?

Frankenstein theories aside, scientists began to understand how electricity was not just something of inanimate materials—but a part of biology as well. At the time it was called "animal electricity" and before a century had passed the "galvanometer" was being used to measure electricity in living organisms.

The Discovery of Brain Waves

Hans Berger, a German psychiatrist, took his lead from the galvanometer and developed a device that could sit on the skull and measure electrical signatures from a living human brain. He called it the electroencephalograph. Berger soon found that the human brain was constantly sending off electrical impulses or—as they would soon be called—brain waves.

The human brain could now be studied like never before! Berger could measure how strong and how often these brain waves came. What's more, Berger could study the individualized brain wave changes that came when the subject was exposed to different stimuli.

His studies could be done live and non-invasively with just a few electrodes placed on the skin of the skull—quite a step up from the post-mortem studies of Galvani!

Convinced that his studies could change the world, Hans Berger kept up his experiments until he was forced to retire and banned from further research by the Nazi regime. Fortunately, his research and methods survived, going on to revolutionize neurology and neurosurgery.

EEG from the 1950s to today

By the middle of the twentieth century, scientists were using EEG (Electroencephalography) to study brain pathology, brain function, sleep, epilepsy, emotions, and more.

At first, EEG data had to be painstakingly recorded by hand and laboriously interpreted. But today, EEG is backed by over a century of research, integrated computer-EEG systems, and other technological advances, making EEG tests easier than ever to perform, record, and interpret.

EEG was eventually surpassed as the world's best brain disease diagnostic tool by computer tomography, MRI, and other advances. But it remains in use today in the study of seizures, brain tumors, and brain development in children. One 2019 study from Israel hopes to use EEG to optimize e-learning and psychometric exams for children.

Apart from conducting experiments to see how the brain's electrical signatures changed in response to various stimuli, EEG reserachers have identified several "regular" types of electrical readings, or "brain waves".

Wave Name	Approximate Wave Speed	Wave Frequency	Association
Alpha	8-13 cycles per second	8.5-12 Hz	Relaxed alertness in adults *(Not demonstrated in infants under 1 yr)*
Beta	13-40 cycles per second	12+ Hz	Active or anxious thinking Active concentration
Delta		4Hz	Very young individuals Certain encephalopathies Underlying lesions Sleep
Theta		4.5-8	Drowsiness Ages under full adulthood **Induced by:** hyperventilation, trances, meditation, deep daydreams, lucid dreaming, and light sleeping

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EMG

Electromyography (EMG) "measures muscle response or electrical activity in response to a nerve's stimulation of the muscle."

Another branch that grew out of Luigi Galvani's work was electromyography. Galvani felt sure that electricity was involved somehow in the muscle contractions of all living organisms.

Electricity and The Somatic Nervous System

Today, we know that action potentials can be generated and conducted by the neurons of the body's central and peripheral nervous systems. And as part of the peripheral nervous system, the somatic nervous system controls the sensory and motor functions of the human body.

Whenever you kick a soccer ball, play patty-cake with your baby, or even twitch your nose, you are doing it through electrical signatures traveling through your somatic nervous system.

Who Got EMG Off The Ground?

The relationship between electricity and animal muscle contraction wasn't always clear. But about half a century after Luigi Galvani had tested on frogs, another scientist took on the task of exploring exactly how muscles and electricity interact.

In 1850, Guillaume Duchenne began applying electric stimulation to live skeletal muscles instead of dead ones. He hoped to develop "electrotherapy", a practice he believed would help treat paralysis. By testing on a man "who had little feeling in his face", Guillaume mapped out the function of nearly every facial muscle. By stimulating the right muscles with electrified metal probes, Guillaume could get this man to smile, frown, or look anxious. This was a step forward in understanding, not just the functions of different muscles, but also how muscles work in the first place. Guillaume's experiments gave birth to the scientific field of neurology and he became known as the father of both electrotherapy and neuropathology.

EMG Today

Today EMG is used to measure how well a muscle is responding to or connected to the appropriate nerve. This proves useful in diagnosing or ruling out muscle disorders, carpal tunnel syndrome, Lou Gehrig's disease, myasthenia gravis, and other conditions associated with the somatic nervous system.

EMG tests are not generally quite as painless and non-invasive as EEG scans—because in this case the test isn't meant to measure an autonomic response; it is meant to trigger a normally somatic response.

EMG tests usually require a few needle injections and few small electric shocks, but the pain that comes with an EMG test isn't usually severe enough to call for pain medication.

ECG

> Electrocardiogram (ECG) "measures the electrical frequencies that correspond to individual heartbeats."

Electrocardiography is probably the electrical biofeedback method you are most familiar with.

The History of ECG

In 1842, Dr. Carlo Matteucci, a professor of physics at the University of Pisa, measured an electrical current with every heartbeat from a living frog. It seemed that Galvani's theories about animal electricity in the muscles applied to the heart as well!

Before the end of the century, Augustus Waller had published a "readout" of the heart's electricity—a graph that charted the regular rises and falls of the bioelectric current. Each peak in the graph corresponded with a single beat of the human heart.

It was crude by today's standards, but it was a definite step forward in the study of heart health.

The word "electrocardiogram" wasn't used until the early 1900s when Dr. Willem Einthoven pursued the same idea, but with a better measuring device (replacing the Waller's capillary electrometer with a string galvanometer) and interpretive math (that would account for various factors that Waller had left out).

The result was a 600-pound electrocardiograph that required five men to operate and multiple buckets of saltwater. But the electrocardiograms it produced were beyond anything that had been seen before—and won Einthoven a Nobel Prize in 1924.

Before long the electrocardiograph was made more exact and more portable and was being used to study and diagnose heart conditions.

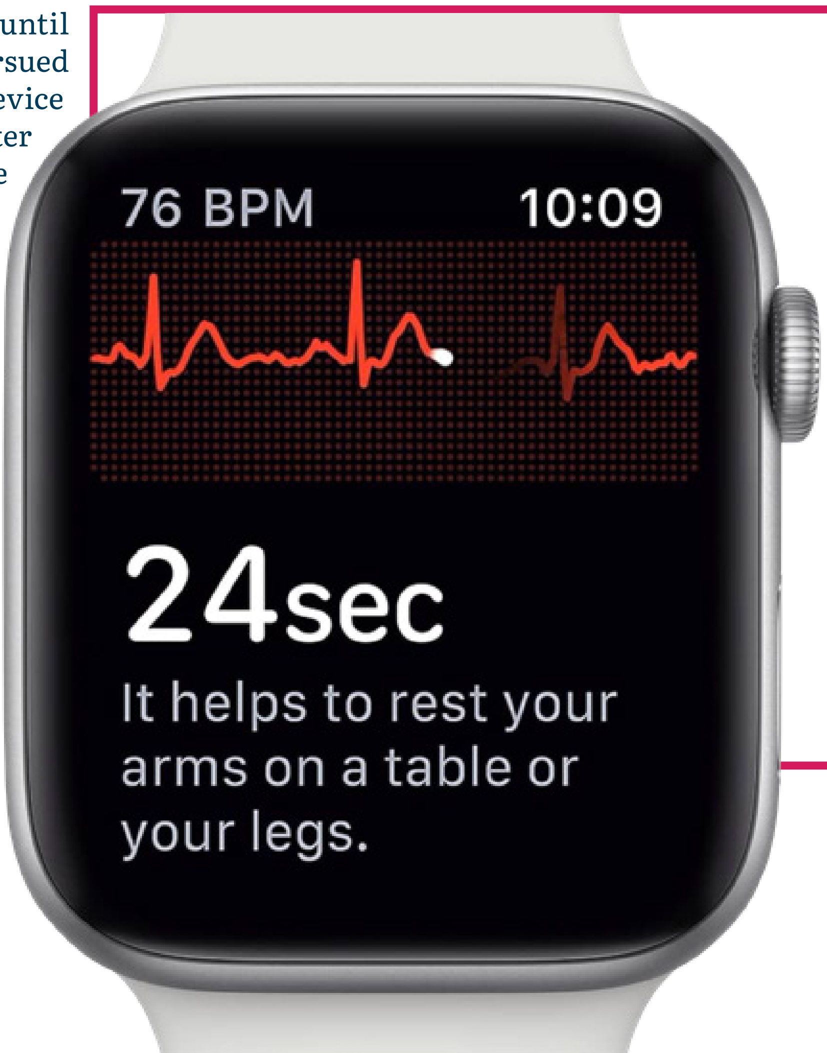
ECG Capabilities Today

Today's 12-lead electrocardiogram doesn't just measure your heart's general electrical signature, it measures the electrical waves from 12 different parts of your heart. It measures wave amplitude, rate, rhythm, and can even estimate how much blood is flowing through your heart!

With all this electro-cardio information, doctors have been able to pin down exactly what the waves should look like for a healthy heart—P waves for the upper chambers, QRS Complex for the lower chambers, and T waves for a heart returning to the resting state.

Basically, if any part of your heart is working too hard or not working as it should, a doctor trained to read your electrocardiogram will know.

The electrocardiograph is now considered indispensable for patient monitoring and diagnosing heart disease.



EDA

Electrodermal activity (EDA) "measures the changes in the electrical conductivity of skin in response to stimuli."

The History of EDA

Several scientists helped bring EDA studies into existence, but the most accredited would seem to be the French neurologist Charles Ferė. Taking his lead from Luigi Galvani, Charles Ferė studied the interactions of electricity with human skin.

He placed two electrodes on the skin of a human subject, instigated an electrical current, and then used a galvanometer to measure the strength of the current as it passed through the skin. In this way, he could measure the skin's level of resistance to the electrical current.

Instead of recording a steady current though, the galvanometer registered *changes* in the electrical current! The level of resistance in the skin was changing! Interestingly, the current and voltage seemed to increase momentarily whenever the subject was presented with some sort of significant sensory stimulant. Not only that, but the changes in current could be markedly different from subject to subject. Even when presented with the same stimulus, some test subjects manifested a stronger change in skin resistance than others.

Why was this happening? Charles Ferė's friend, Jaques-Arsene d'Arsonval, helped him understand that these changes in the skin's conductivity were happening as a result of the sweat glands being activated deep in the hypodermis.

Even if the subjects weren't breaking into dramatic, visible sweating, if they were psychologically or physiologically aroused by the stimulus put in front of them, their arousal would trigger the sweat glands in their hypodermis, briefly increasing the conductivity of their skin.

Charles Ferė leaped at the chance to study human psychology through these individualized, quantifiable reactions to stimuli.

EDA in GSR

The study of electrodermal activity using a galvanometer eventually came to be known as Galvanic Skin Response (GSR).

It might seem strange that many GSR scans are taken from the skin of the palms. After all, the skin of the palms is one of the patches of skin most resistant to electrical currents. But the palms are actually the ideal place to measure electricity in the skin because GSR is all about measuring changes in the electrical resistance of human skin. And those changes are most pronounced in areas of the skin that have lots of sweat glands, i.e. your palms, soles, and forehead.

GSR measures those changes in skin resistance and uses that data to study your conscious and autonomic reactions to different stimuli.

Want to know if you have a stronger reaction to a scary clown face or a spider? What music genre gets you pumped up the most? Does your physiological response to the stress of a calculus problem last as long as your response to the stress of an oral exam? A GSR Scan can track and compare your electrodermal responses to give you answers. Your quantifiable reactions to any stimulus can also be compared to the reactions of your friend, your neighbor, or a complete stranger.

Today GSR tests are used as research tools in psychology, psychotherapy, clinical studies, neuroscience, digital usability testing, and marketing. In the last few years, GSR scans have become a popular resource for studying education methods and mental disabilities.

Conclusion

There is still so much to learn about the human nervous system and with EGG, ECG, EMG, and EDA, scientists are getting closer every year to understanding how the body's electrical language works.

Until then, we remain grateful for pioneers like Luigi Galvani, Hans Berger, Guillaume Duchenne, and Charles Ferė for opening doors for us so we could begin to understand and read the electricity that helps run the human body.

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