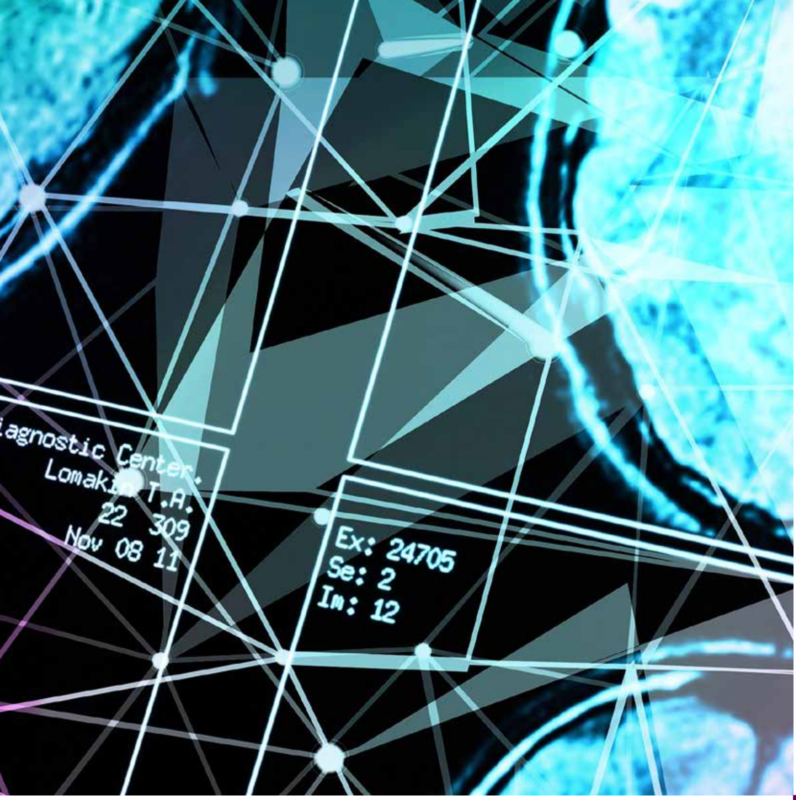

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Karina Maciejewska, PhD, Associate Professor is the head of a research group at the Institute of Biomedical Engineering of the University of Silesia that deals with the processing and analysis of biomedical signals in order to better understand the psychophysiological activity of the human nervous system and its reactions to the environment. The researchers focus on studying the electrical activity of the brain and other biomedical signals. The application of the latest achievements in the field of biomedical engineering, i.e. virtual reality and mobile brain and body imaging, allows researchers to contribute to the development of cognitive neuroscience, thanks to which we can better understand how human cognitive processes work in the natural environment, as well as improve specialised tools for the analysis of biomedical signals.

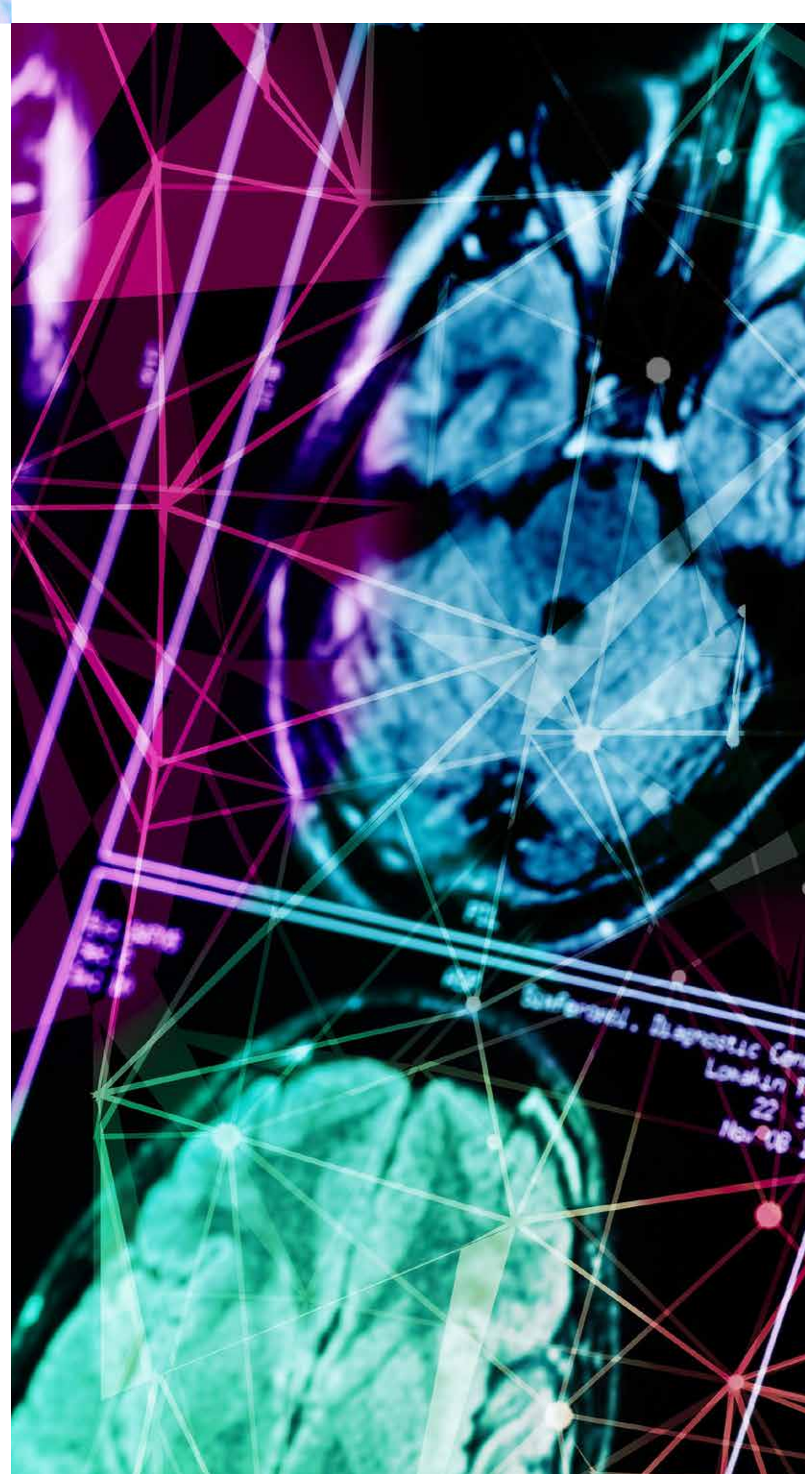
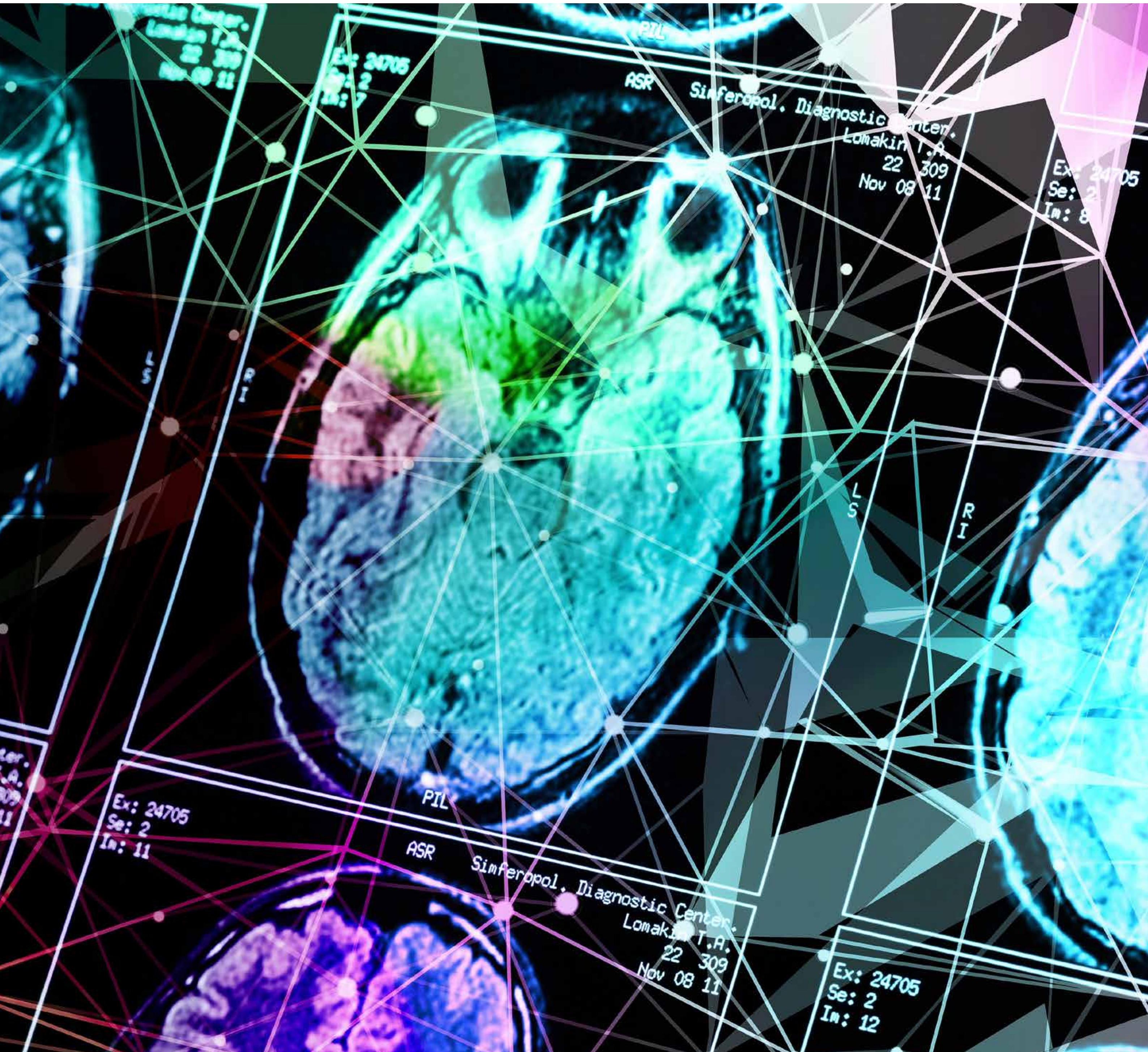


Photo: Freepik

HOW **BRAIN RESEARCH** WILL CHANGE THE FUTURE OF HUMANITY



NEUROSCIENCE AND BIOMEDICAL ENGINEERING

It is a broad interdisciplinary scientific field that studies the nervous system with a particular focus on the brain. It combines many scientific disciplines – from biology, neuroscience, chemistry, physics, biomedical engineering, to computer science and even psychology, humanities, philosophy and linguistics. Neuroscientists analyse the processes responsible for thinking, memory, interactions with other people, emotions, and decision-making. Another important area of research is the search for causes and treatments for neurological diseases. The nervous system can be observed and analysed using various technological solutions, e.g. magnetic resonance imaging (MRI) and electroencephalography (EEG). Neuroscientists study the nervous system on many levels: individual ion channels (proteins that are located inside cell membranes), neurons (nerve cells), tissues, organs and on a systemic level, i.e. the whole organism; social neuroscience deals with interactions with other people.

Scientists are trying to find out how various cognitive processes work in a healthy organism, e.g. short-term and long-term memory and the attention process, which are crucial for human survival and adaptation to the environment.

'In the attention process, the human brain is able to choose, i.e. to select and isolate specific information from among all the others that reach it. These include billions of stimuli related to, among other things, language processing, language comprehension, spatial orientation, perception, etc. Cognitive processes can be studied using behavioural measures – an experiment is set up in which a volunteer answers questions, and scientists study the answers or the speed of response to the questions and then interpret the results. We, on the other hand, try to explore the topic of cognitive processes of the human brain using biomedical signals, which are objective and more sensitive because they directly measure the activity of the brain, muscles, heart, or eyes', explains the researcher.

BIOMEDICAL SIGNALS

Biomedical signals are measurable physiological signals from the human or animal body that reflect the functioning of biological systems. They can be electrical, mechanical, chemical, and thermal and are used in diagnostics, health monitoring, and scientific research.

One of the most basic and frequently studied biomedical signals is the measurement of the functioning of the central nervous system by analysing the electrical activity of the brain (EEG).

EEG and VR system tested by a team member
Photo: Agnieszka Sikora

'This is the main method we use, along with peripheral signals, which measure the activity of other organs controlled by the nervous system. It allows us to learn more about how the brain, nervous system and the entire body function in a specific situation or in response to a certain stimulus,' explains the researcher.

Another biomedical signal studied is electrocardiography (ECG). This type of research involves recording and analysing the electrical activity of the heart. The ECG measures the changes in electric potential generated during the contraction and relaxation of the heart muscle. Keep in mind that the heart does not actually beat. It is a mechanical process during which the heart muscle contracts and pumps blood into the blood vessels, but it is closely related to electrical activity, since it is electrical impulses that initiate and coordinate the contractile movements of the atria and ventricles, i.e. they initiate the depolarisation and repolarisation of the heart muscle.

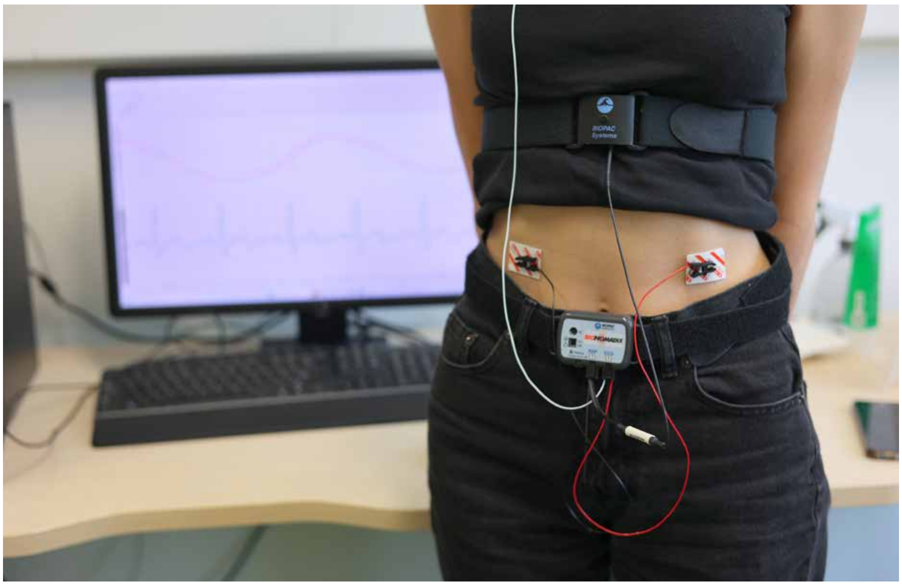
Another biomedical signal that scientists use is the respiratory signal. This involves recording and analysing such breathing parameters as frequency, depth, and regularity. A special belt is placed on the chest to record its movements during inhalation and exhalation. This allows scientists to track the subject's breathing patterns.

Another important signal is electromyography (EMG), a test that records the electrical activity of muscles, which makes it possible to analyse neuromuscular connections and diagnose certain diseases, such as neuropathies. EMG is often associated with rehabilitation procedures and sports examinations, but it is also used in facial muscle testing. We know that facial expressions are linked to a person's psychophysiological and emotional state. By observing the face, we can recognise which muscles are activated and thus contribute to a specific facial expression and the emotions behind it. This allows us to recognise certain illnesses or states of agitation. Artificial intelligence is increasingly being used for this type of analysis, as it can recognise human facial expressions and classify grimaces. However, many changes cannot be seen with the naked eye, which is why biomedical signals have the advantage of detecting even very small activations.

Electrodermal activity (EDA) is particularly interesting. It measures changes in the electrical conductivity of the skin, which are triggered by sweating. Sweat gland activity is controlled by the sympathetic nervous system and is, therefore, closely linked to emotional reactions, stress, and arousal. Of course, sweating is also dependent on external conditions, but these are controlled during testing. The electrodermal reaction is used in so-called polygraphs, or lie detectors. However, this type of research should be approached with a great deal of distrust so that we can avoid drawing too far-reaching conclusions. Therefore, when using EDA measurements, other biomedical signals are often used as well, e.g. eye movement tracking – the so-called electrooculography (EOG). This allows for a more comprehensive analysis of physiological and cognitive responses, especially with regard to emotions, attention, and information processing.

Another very important neuroscience test is functional magnetic resonance imaging (fMRI) – a technique that allows to identify brain areas that activate during the test. It uses blood flow changes in the brain as an indicator of neuronal activity.

Positron emission tomography (PET) is also used in neuroscience. This imaging technique allows the evaluation of metabolic and functional processes in the body using radiation emitted by radioactive substances (markers) that are introduced into the human body. However, these last two methods are characterised by a poor temporal resolution. It means that the measured signal only appears sometime after the stimulus, and since we are interested in studying the dynamics of the brain's information processing, biomedical signals, such as EEG, have a huge advantage here. Not only do they allow biopotentials to be measured in milliseconds (i.e. thousandths of a second), but the greater availability, no need for a massive infrastructure, and the rapid development of technology enabling their miniaturisation and portability allow us to explore the secrets of the human brain in a more natural environment.


Wireless biomedical signal measurement system tested by a team member | Photo: Agnieszka Sikora

MOBILE BRAIN AND BODY IMAGING (MOBI)

In standard examinations, the person has to be examined in a stationary position. They sit in front of a monitor, have to look at the centre of the screen without moving their eyes, which can cause artefacts, not move their arms and legs, breathe freely but not too deeply, not move their tongue, and not clench their jaw and neck muscles. Then they react by pressing a button when they see a certain group of stimuli. All of this introduces a number of limitations.

Mobile brain and body imaging makes it possible to study neurophysiological processes in a more natural, everyday settings, even outside the laboratory or hospital. Its main purpose is to monitor brain, muscle, heart, and other bodily functions, as well as to track eye and body movements in a dynamic environment, e.g. during movement, work, exercise, sleep, and interaction with the environment, objects, and people. Lightweight, portable sensors are used instead of large, stationary devices. They can be worn as belts, armbands, caps, vests, and other small devices attached to the skin. Data is collected in real time and transmitted wirelessly to an analysis device (e.g. a phone, tablet, or computer).

In the future, thanks to developments in biomedical engineering, brain and nervous system research will certainly push towards an increasingly accurate understanding of brain mechanisms, disease diagnosis, and the development of modern treatment options. Noteworthy among the key areas of development is the intensification of work on brain-computer interfaces (BCI). It is a dynamically developing field of neuroscience and biomedical engineering that enables direct communication between the brain and external (electronic) devices. They already help people with disabilities to communicate with their environment (as in the case of the famous physicist Stephen Hawking) or to regain some motor functions. Brain signals can be used to control the movements of prostheses, virtual cursors, wheelchairs, robots, and computer applications. It is safe to assume that Neuralink technologies will also continue to develop, i.e. implants that enable their users to communicate with a computer or to control devices with thoughts. In the future, interfaces may allow us to ‘expand’ our memory and improve other cognitive abilities.