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Psychophysiological Methods in Neuroscience

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Abstract

Psychophysiology is a relatively new discipline. In the mid-1950s, a group of physiological psychologists began referring to themselves as psych physiologists. However, the subject matter of psychophysiology — the interaction of mind and body — has been studied for centuries by people trained as philosophers, physicists, physicians, physiologists, and, most recently, psychologists. John Stern (1964) defined the work of psychophysiology as "any research in which the dependent variable (the subject's response) is a physiological measure and the independent variable (the factor manipulated by the experimenter) a behavioural one". Stern's definition of psychophysiology is not incorrect, but with the passage of time it has become too limiting.

Introduction

As a generally non-invasive subset of neuroscience methods, psychophysiological methods are used across a variety of disciplines in order to answer diverse questions about psychology, both mental events and behaviour. Many different techniques are classified as psychophysiological [1]. Each technique has its strengths and weaknesses, and knowing them allows researchers to decide what each offers for a particular question. Additionally, this knowledge allows research consumers to evaluate the meaning of the results in a particular experiment [2].

It is important to consider the root cause of the symptoms. Did stress cause a headache or is the patient stressed because of a headache? Somatoform illnesses have physical symptoms without a physical cause. These symptoms could include stomach pain, tiredness, and nausea, among others [3]. If a person feels dread and panic, they might also experience a racing heart, an increase in body temperature, and shortness of breath. These are physical symptoms caused by the psychological illness—in this case, a panic attack. A panic attack can also set off an asthma attack; this makes the overall symptoms and illness worse [4].

Physical illnesses can be intensified by psychological factors. If a person has coronary heart disease, they might develop anxiety about future heart attacks and their future quality of life. This anxiety can intensify their heart disease [5].

Psychophysiology refers to a top-down approach in neurosciences, with a focus on how psychological, social, and behavioural phenomena are related to and revealed through physiological events and principles. In other words, when we measure respondents' skin conductance responses, or any physiological response for that matter, our focus is not on isolated components of the body, but rather on the interaction between the person and the environment, assuming that this information can shed some light on the human mind [6].

Psychophysiology views the mind as having a physical substrate, and as it offers tools for mining information about nonconscious and non-reportable processes, it can substantially contribute to our understanding of cognition, emotions and behaviour (ibid) [7]. An interesting demonstration of physical substrates of emotion are related to the topic of affective blind sight, where patients with damage to the primary visual cortex are unable to report any visual stimuli, but react reliably to their emotional valence (as measured with fMRI and EEG) and even mimic the facial expressions that they are exposed to [8].

The mammalian brain is layered over the reptilian brain and consists primarily of a system of brain areas referred to as the limbic system. It evolved to respond to mammalian evolutionary pressures, and as described by J. Panksepp, includes various emotional systems, each with a distinct 'wiring diagram'. The four fundamental emotion systems that appear shortly after birth in all mammals include seeking, fear, rage, and panic, and as the mammal develops, also lust, care, and play systems come online. In line with the evolutionary conditioning, the limbic system would rather be 'safe than sorry', which explains why fear-relevant or otherwise salient stimuli capture immediate attention and trigger automatic bodily responses [9,10].

The primate brain, also called the neocortex, developed most recently in our evolutionary history. Not only does it control expressions of emotions that originate in the limbic system, but it also allows us to adapt to dynamic environments and socialize using a more nuanced emotional repertoire. Our complex cognitive, linguistic, motor, sensory, and social abilities all originate from the processes of this outer layer of the cerebrum , yet these higher level processes are still influenced by underlying emotional systems and bodily processes [11].

The premise that both explicit and implicit knowledge can impact higher level processes indicates that we do not have conscious access to everything that is going on in our mind. In fact, almost all cognitive tasks, as well as vision and working memory have both conscious and nonconscious, or reportable and non-reportable components [12]. The concept of consciousness is closely linked to controlled and automatic processes, where the former can be described as serial and effortful and the latter as parallel and effortless

In the mid-19th century, a railroad worker named Phineas Gage was in charge of setting explosive charges for blasting through rock in order to prepare a path for railroad tracks. He would lay the charge in a hole drilled into the rock, place a fuse and sand on top of the charge, and pack it all down using a tamping iron (a solid iron rod

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approximately one yard long and a little over an inch in diameter) On a September afternoon when Gage was performing this task, his tamping iron caused a spark that set off the explosive prematurely, sending the tamping iron flying through the air [13].

Unfortunately for Gage, his head was above the hole and the tamping iron entered the side of his face, passed behind his left eye, and exited out of the top of his head, eventually landing 80 feet away. Gage lost a portion of his left frontal lobe in the accident, but survived and lived for another 12 years. What is most interesting from a psychological perspective is that Gage's personality changed as a result of this accident. He became more impulsive, he had trouble carrying out plans, and, at times, he engaged in vulgar profanity, which was out of character [14]. This case study leads one to believe that there are specific areas of the brain that are associated with certain psychological phenomena. When studying psychology, the brain is indeed an interesting source of information. Although it would be impossible to replicate the type of damage done to Gage in the name of research, methods have developed over the years that are able to safely measure different aspects of nervous system activity in order to help researchers better understand psychology as well as the relationship between psychology and biology [15].

Psychophysiology is defined as any research in which the dependent variable (what the researcher measures) is a physiological measure, and the independent variable (what the researcher manipulates) is behavioral or mental. In most cases the work is done noninvasively with awake human participants. Physiological measures take many forms and range from blood flow or neural activity in the brain to heart rate variability and eye movements [16]. These measures can provide information about processes including emotion, cognition, and the interactions between them. In these ways, physiological measures offer a very flexible set of tools for researchers to answer questions about behaviour, cognition, and health [17].

Psychophysiological methods are a subset of the very large domain of neuroscience methods. Many neuroscience methods are invasive, such as involving lesions of neural tissue, injection of neutrally active chemicals, or manipulation of neural activity via electrical stimulation. The present survey emphasizes non-invasive methods widely used with human subjects [18].

Crucially, in examining the relationship between physiology and overt behaviour or mental events, psychophysiology does not attempt to replace the latter with the former. As an example, happiness is a state of pleasurable contentment and is associated with various physiological measures, but one would not say that those physiological measures are happiness. We can make inferences about someone's cognitive or emotional state based on his or her self-report, physiology, or overt behaviour. Sometimes our interest is primarily in inferences about internal events and sometimes primarily in the physiology itself. Psychophysiology addresses both kinds of goals [19].

This module provides an overview of several popular psychophysiological methods, though it is far from exhaustive. Each method can draw from a broad range of data-analysis strategies to provide an even more expansive set of tools. The psychophysiological methods discussed below focus on the central nervous system. Structural magnetic resonance imaging (sMRI) is a non-invasive technique that allows researchers and clinicians to view anatomical structures within a human. The participant is placed in a magnetic field that may be 66,000 times greater than the Earth's magnetic field, which causes a small portion of the atoms in his or her body to line up in the same direction. The body is then pulsed with low-energy radio frequencies that are absorbed by the atoms in the body, causing them to tip over. As these atoms return to their aligned state, they give off energy in the form of harmless electromagnetic radiation, which is measured by the machine. The machine then transforms the measured energy into a three-dimensional picture of the tissue within the body. In psychophysiology research, this image may be used to compare the size of structures in different groups of people (e.g., are areas associated with pleasure smaller in individuals with depression?) or to increase the accuracy of spatial locations as measured with functional magnetic resonance imaging (fMRI).

Functional magnetic resonance imaging (fMRI) is a method that is used to assess changes in activity of tissue, such as measuring changes in neural activity in different areas of the brain during thought. This technique builds on the principles of sMRI and also uses the property that, when neurons fire, they use energy, which must be replenished. Glucose and oxygen, two key components for energy production, are supplied to the brain from the blood stream as needed. Oxygen is transported through the blood using haemoglobin, which contains binding sites for oxygen [20]. When these sites are saturated with oxygen, it is referred to as oxygenated haemoglobin. When the oxygen molecules have all been released from a haemoglobin molecule, it is known as deoxygenated haemoglobin. As a set of neurons begin firing, oxygen in the blood surrounding those neurons is consumed, leading to a reduction in oxygenated haemoglobin. The body then compensates and provides an abundance of oxygenated haemoglobin in the blood surrounding that activated neural tissue. When activity in that neural tissue declines, the level of oxygenated haemoglobin slowly returns to its original level, which typically takes several seconds [21].

Positron emission tomography (PET) is a medical imaging technique that is used to measure processes in the body, including the brain. This method relies on a positron-emitting tracer atom that is introduced into the blood stream in a biologically active molecule, such as glucose, water, or ammonia. A positron is a particle much like an electron but with a positive charge. One example of a biologically active molecule is fludeoxyglucose, which acts similarly to glucose in the body. Fludeoxyglucose will concentrate in areas where glucose is needed—commonly areas with higher metabolic needs. Over time, this tracer molecule emits positrons, which are detected by a sensor. The spatial location of the tracer molecule in the brain can be determined based on the emitted positrons [22]. This allows researchers to construct a three-dimensional image of the areas of the brain that have the highest metabolic needs, typically those that are most active. Images resulting from PET usually represent neural activity that has occurred over tens of minutes, which is very poor temporal resolution for some purposes. PET images are often combined with computed tomography (CT) images to improve spatial resolution, as fine as several millimeters. Tracers can also be incorporated into molecules that bind to neurotransmitter receptors, which allow researchers to answer some unique questions about the action of neurotransmitters. Unfortunately, very few research centers have the equipment required to obtain the images or the special equipment needed to create the positron-emitting tracer molecules, which typically need to be produced on site [23].

Discussion

The psychophysiological methods discussed above focus on the central nervous system. Considerable research has also focused on the peripheral nervous system. These methods include skin conductance, cardiovascular responses, muscle activity, pupil diameter, eye blinks, and eye movements. Skin conductance, for example, measures the electrical conductance (the inverse of resistance) between two points on the skin, which varies with the level of moisture. Sweat glands are responsible for this moisture and are controlled by the sympathetic nervous system (SNS). Increases in skin conductance can be associated with changes in psychological activity. For example, studying skin conductance allows a researcher to investigate whether psychopaths react to fearful pictures in a normal way. Skin conductance provides relatively poor temporal resolution, with the entire response typically taking several seconds to emerge and resolve. However, it is an easy way to measure SNS response to a variety of stimuli [24].

Just as there are many symptoms of different physical disorders, there are many symptoms of psychophysiological disorders. Consider a stress induced migraine. The symptoms would include pain in the head, sensitivity to light and sound, and nausea. Anxiety can cause an increased heart rate, jitters, and feeling warm. Depression can cause sleep difficulties, food cravings, and heart problems. Fear can cause tightened muscles, pain, and joint problems.

The symptoms vary for each individual. For example, one person with high stress may develop a headache and sensitivities, while another person might develop digestive and urinary tract problems. If the body remains in this state for a long time, it can lead to long-term or chronic disorders, including fibromyalgia and chronic fatigue.

The psychophysiology of disease is a vigorous and exciting area of research. It involves the integration of several disciplines including neuroscience, pathophysiology, and health psychology, and in each of these areas new discoveries are constantly changing our levels of understanding. The complexity of links between the brain, peripheral physiological function, and disease risk is formidable, and linear models are of limited value.

Conclusion

The broad processes linking psychophysiological factors with disease risk are now understood, although many of the biological mediators remain tantalizingly elusive. Important challenges for future research include delineation of the processes through which psychosocial factors such as social inequality and social isolation affect disease, understanding how emotional and behavioral coping responses can modify physiological reaction patterns and contribute to resistance and vulnerability, and defining the ways in which psychophysiological knowledge can be harnessed for prevention and disease management. Techniques such as brain imaging, genetic analysis, molecular biological approaches to gene expression, and assays of the microbiome will become more prominent in the field. We are also likely to see greater integration of behavioral medicine work on physical diseases with studies of behavioral and psychiatric problems. Psychophysiology is one of the cornerstones of clinical health psychology and is of prime importance in understanding how psychological and social experience can influence health and disease.

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Conflict of Interest

There is no Conflict of Interest.

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