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TITLE:

Information technology - Brain-computer Interfaces - Vocabulary

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NOTE FROM TC/SC OFFICERS:

The ISO/IEC 8663 document is ready for CDV, please help proceed the further process.

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INFORMATION TECHNOLOGY-BRAIN-COMPUTER INTERFACES-VOCABULARY

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The text of this International Standard is based on the following documents:

Draft	Report on voting
XX/XX/FDIS	XX/XX/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, [and the ISO/IEC Directives, JTC 1 Supplement] available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

Brain-computer interface (BCI) allows a link for subjects to control a computer or a machinery device by using only brain activities without any body movement required. Besides, BCI also involves in a two-way interaction, which includes the feedback from a computer or environment that can shape up the brain activity in the context of neuromodulation. BCI system can “measure activity of the central nervous system (CNS) and convert it into artificial output that replaces, restores, enhances, supplements, or improves natural CNS output, and thereby changes the ongoing interactions between the CNS and its external or internal environment”.

Brain activities could be translated into voluntary choices. Currently, brain electrical signals are frequently used in BCI scenarios. These systems could record and measure the electroencephalogram (EEG) activity on or beneath the scalp or the cell level activities from individual neurons and implanted electrodes. Spontaneous activities and evoked potentials are used to activate commands. Various BCI protocols including motor imagery (MI), P300, steady-state visual evoked potential (SSVEP), were implemented to utilize subject’s sensory information (auditory, visual, somatosensory, etc.) for controlling purpose.

In the other end of computer/machinery devices, BCI is designed to enable the subject who may suffer from stroke or other neurological disorders to communicate with other people or to operate a computer or even a neuroproteins. As the development of BCI, lives of people with disabilities or elderly community could be significantly improved.

Nowadays, Brain-computer interface demonstrates a highly growing field of research, as well as widely extended application scenarios. Its contributions range from medical and health industry to entertainment and educational technology. For a better and more unified understanding of BCI technology, Information technology-Brain-computer Interfaces-Vocabulary is needed for the growing audience.

INFORMATION TECHNOLOGY-BRAIN-COMPUTER INTERFACES-VOCABULARY

1 Scope

This document of IEC 8663 specifies the terms and definitions commonly used in the field of Brain-Computer Interface (BCI), including basic concepts and classifications of BCI, hardware, experiment setups and protocols used in BCI, related neuroscience concepts of BCI (e.g., coding and decoding, feedback and stimulation), and its applications etc.

This document is applicable to the understanding of Brain-Computer Interface concepts and the exchange of information and to regulate the usage of terms.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-704:1993, *International Electrotechnical Vocabulary (IEV) - Part 704: Transmission*

IEC 60050-891:1998, *International Electrotechnical Vocabulary (IEV) - Part 891: Electrobiology*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 Basic concepts and types

3.1.1
brain-computer interface (BCI)
brain machine interface (BMI)
<discipline> study of theories, mechanisms, developments, and applications related to interfacing of engineered systems with the brain

Note 1 to entry: Non-invasive systems are referred to as BCIs in few papers, and invasive systems using implanted sensors are often referred to as BMIs.

3.1.2
brain-computer interface (BCI)
brain machine interface (BMI)
<engineered systems> technology designed to enable direct exchange of information between the central nervous system (CNS) and the software and/or hardware

Note 1 to entry: BCI allows a single or bi-directional communication between the brain and external devices, enabling controlling and/or feedback capabilities.

Note 2 to entry: BCI can be set up between human-human or human-animal(s) through software and/or hardware.

Note 3 to entry: Non-invasive systems are referred to as BCIs in few papers, and invasive systems using implanted sensors are often referred to as BMIs.

3.1.3
active BCI
BCI (3.1.2) that requires a user to change brain activities intentionally

3.1.4
passive BCI
BCI (3.1.2) that does not require a user to change brain activities intentionally

Note 1 to entry: Passive BCI monitors the user's mental states and psychological activities.

3.1.5
reactive BCI
BCI (3.1.2) in which a user's intention is embedded in the response signal to external stimulation

Note 1 to entry: Reactive BCI decodes specific neural response to environmental stimulations.

3.1.6
affective BCI
BCI (3.1.2) that decodes emotional experience into corresponding states for control purpose

3.1.7
synchronous BCI
BCI (3.1.2) that needs a synchronization cue for a user to start each task

Note 1 to entry: Synchronous BCI is time-locked.

Note 2 to entry: Information is presented to cue the user to elicit certain brain signal responses.

3.1.8
asynchronous BCI
self-paced BCI
BCI (3.1.2) that detects when the user intentionally changes brain activity without the need of synchronization cues

Note 1 to entry: Asynchronous BCI is self-paced.

Note 2 to entry: Asynchronous BCI is continuously analysing the ongoing brain activity of both intentional control states and non-control state (e.g., idling state).

3.1.9
bidirectional BCI
BCI (3.1.2) that decodes neural signals to control external devices and simultaneously provides external feedbacks by encoding environmental or task information to stimulation patterns delivered to the brain

3.1.10
unidirectional BCI
BCI (3.1.2) that decodes neural signals to control external devices

3.1.11
multi-user BCI
multi-mind BCI
BCI (3.1.2) that incorporates brain activities from multiple users to perform tasks

3.1.12
collaborative BCI
BCI (3.1.2) that incorporates brain activities from multiple users to perform tasks for a common goal

3.1.13
competitive BCI
BCI (3.1.2) that incorporates brain activities from multiple users to perform tasks in which the users are competing against each other or are given individual goals that do not require collaboration

3.1.14
independent BCI
BCI (3.1.2) that only requires neural activity of central nervous system

3.1.15
dependent BCI
BCI (3.1.2) that requires neural activity of central nervous system and peripheral neural pathway for sensory stimulation and the ability to attend the stimuli

Note 1 to entry: For example, muscle activity to gaze at the visual stimuli.

3.1.16
invasive BCI
BCI (3.1.2) in which neural activities are recorded with puncturing the skin or entering a body cavity

Note 1 to entry: For example, invasive BCI usually uses sensing technology like iEEG, ECoG, sEEG, etc.

3.1.17
non-invasive BCI
BCI (3.1.2) in which neural activities are recorded without puncturing the skin or entering a body cavity

Note 1 to entry: For example, non-invasive BCI usually uses sensing technology like scalp EEG, fNIRS, fMRI, surface EMG, etc.

3.1.18
partially-invasive BCI
semi-invasive BCI
invasive BCI (3.1.16) in which neural activities are recorded by sensors that are implanted inside the skull but rest outside the brain

3.1.19
hybrid BCI
combination of BCI (3.1.2) which incorporates multiple BCI (3.1.2) paradigms or systems

3.1.20
human BCI
BCI (3.1.2) designed for human brain communication

3.1.21
speech BCI
BCI (3.1.2) that captures and decodes neural signals related to intended or imagined speech, allowing users to communicate or control external devices without vocalizing

Note 1 to entry: It can be utilized to assist individuals with speech impairments or those who are unable to physically produce speech due to medical conditions.

3.1.22
natural brain-computer interface (nBCI)
BCI (3.1.2) which is a hands-free, non-invasive, natural and intuitive link between brain and machines, which is a disruptive technology that can be used in everyday life, replacing current human-computer and human-machine interfaces such as keyboards, touchscreens and hand-gesture recognition

Note 1 to entry: nBCI will be able to understand "‘silent speech", i.e. what a user is "saying" when it is still a thought, and be able to "see" the object that a user is focused on.

3.1.23
wearable BCI
portable BCI
portable and typically wireless BCI (3.1.2) designed to be worn on the body (often the head) to detect, analyze, and utilize brain activity in real-time

Note 1 to entry: Wearable BCIs are designed for convenience, mobility, and continuous or prolonged use, and they can be used in a range of contexts from daily life to specific applications like gaming, meditation, or therapeutic interventions.

3.2 System components

3.2.1
transducer
<brain-computer interface> component that converts brain signals into electrical signals and vice versa

3.2.2
sensor
part of a <brain-computer interface> transducer directly in contact with the physical quantity of interest to record neural activities

Note 1 to entry: It can be an electrode in the case of EEG and fMRI, but also a Hall effect sensor in the case of MEG.

Note 2 to entry: When the BCI (3.1.2) operates in the direction from external world to the brain, the sensors may operate on the compromised sensory channels (visual, acoustic, etc.).

3.2.3
effector
<brain-computer interface> device or application that reacts to an input in a predefined way

3.2.4
electrode
<brain-computer interface> conductor that is used to establish electrical contact with a non-metallic part of a circuit

3.2.5
channel
<brain-computer interface> designated pathway or point of data collection in a BCI (3.1.2)

Note 1 to entry: It often refers to a specific electrode placed on the scalp (in EEG-based BCI (3.1.2)) or an array of electrodes (in invasive BCI (3.1.16)).

Note 2 to entry: Each channel provides a time series of voltage measurements representing neural activity from a particular region of the brain.

Note 3 to entry: Channel information indicates the locations of the recording electrodes, which is necessary for estimating source locations of data components.

3.2.6
amplifier
<brain-computer interface> device used to amplify the neural signals collected by various sensors

EXAMPLE An EEG amplifier.

3.2.7
headset
<brain-computer interface> wearable device, typically worn on the head, equipped with sensors (often electrodes) that detect neural activity, allowing for communication between the brain and an external device or system

Note 1 to entry: Headsets can be used for monitoring, analysis, interaction, or control purposes in various BCI (3.1.2) applications.

3.2.8
EEG Cap
electrode cap
cap used to aid in the precise placement of electrodes on the scalp

Note 1 to entry: It usually made up of electrodes with connected wires.

3.2.9
brain implants
neural implants
functional unit that is attached to or inserted through the surface of the central nervous system parts and collects neural activities

Note 1 to entry: It can be temporary or permanent.

3.2.10
analog to digital converter
<brain-computer interface> component that receives analog signal from a transducer, converts it into digital signal, before sending it to the processing unit (3.2.11)

3.2.11
processing unit
<brain-computer interface> component that operates on digital or analog signals and performs pre-processing, processing, and transmission

3.3 Modalities

3.3.1
electroencephalogram (EEG)
graphic record of the variation with time of voltages taken from electrodes on the scalp, whose positions are specified

[SOURCE: IEV 891-04-23]

3.3.2
intracranial electroencephalography (iEEG)
electrophysiological monitoring system placed onto or deeply inserted into the surface of the brain to directly record electrical activities of the brain through sensors

Note 1 to entry: Known as electrocorticography (ECoG) when using subdural grid electrodes or stereotactic EEG (sEEG) when using depth electrodes.

3.3.3
electromyography (EMG)
technique for investigating the electrical activity of skeletal muscles, based on the recording and interpretation of the electromyogram

[SOURCE: IEV 891-04-32]

3.3.4

functional magnetic resonance imaging (fMRI)

magnetic resonance imaging technique on brain that registers blood flow to functioning areas of the brain

Note 1 to entry: It relies on the fact that cerebral blood flow and neuronal activation are coupled.

3.3.5

functional near-infrared spectroscopy (fNIRS)

optical brain monitoring technique that uses near-infrared spectroscopy for the purpose of functional neuroimaging

Note 1 to entry: With fNIRS, brain activities are measured by using near-infrared light to estimate cortical hemodynamic activities that occur in response to neural activities.

3.3.6

magnetoencephalography (MEG)

technique for investigating the electrical activity of the brain, based on recording and interpretation of the magnetoencephalogram

[SOURCE: IEV 891-04-29]

3.4 Experimental designs and setups

3.4.1

subject

user

participant

<brain-computer interface> person connected to a certain type of BCI (3.1.2) that records the person’s neural activities and/or sends stimulation to the person’s neural system

Note 1 to entry: “User” usually refers to the person who utilizes the BCI (3.1.2) for practical applications, while “subject” usually refers to the person who participates in BCI (3.1.2) studies, especially in clinical scenarios.

3.4.2

trial

<brain-computer interface> single testing period of experiment under specific conditions

Note 1 to entry: It is usually the smallest testing unit in an experiment design.

3.4.3

session

<brain-computer interface> testing period of experiment under specific conditions

Note 1 to entry: It usually includes multiple trials.

3.4.4

epoch

<brain-computer interface> single time window that is extracted and segmented from continuous neural recording

3.4.5

stimulus

<brain-computer interface> external or internal cue, signal, or event specifically designed to elicit a measurable and consistent neural response, which can be detected and processed by a BCI (3.1.2) to execute a specific function or command

Note 1 to entry: Stimulus can be visual, auditory, somatosensory.

Note 2 to entry: These are tasks that the user might be instructed to perform mentally, such as imagining moving a limb, performing arithmetic calculations, or visualizing specific scenarios. The associated neural patterns resulting from these tasks serve as the "stimulus" response.

Note 3 to entry: The key is that the stimulus, in the BCI (3.1.2) context, is designed to produce a neural response that can be distinctly recognized and then interpreted by the BCI (3.1.2) to perform a particular action or command.

3.4.6
inter-stimulus interval (ISI)
<brain-computer interface> temporal interval between the offset of one stimulus to the onset of next one

3.4.7
inter-trial interval (ITI)
<brain-computer interface> temporal interval between separate trials

3.4.8
sampling rate
sampling frequency
the number of samples of a signal taken per unit time

[SOURCE: IEV 704-23-03]

3.4.9
bit rate
<brain-computer interface> amount of information transferred by a BCI (3.1.2) in a specific application

3.5 Protocols and paradigms

3.5.1
operating protocol
<brain-computer interface> rules that define the onset, timing, and tasks of an experiment, the details of signal processing and device controlling, and the evaluation of performance

3.5.2
event
<brain-computer interface> marker in neural recording, which is time-locked and is associated to behaviour activity

Note 1 to entry: When a user imagines moving a part of their body, the associated change in brain activity is an "event" that some BCI (3.1.2) applications can detect and decode.

3.5.3
mental imagery
BCI (3.1.2) enabling users to control by solely performing mental imagery tasks

3.5.4
motor imagery (MI)
mental process in which an individual rehearses or simulates a given action

3.5.5
auditory imagery
form of mental imagery that is used to organize and analyse sounds when there is no external auditory stimulus present

3.5.6
action potential (AP)
nerve impulse
spike
sudden, fast, transitory, and propagating change of electric polarization of the membrane of a neuron, which is the result of a very rapid rise and fall in voltage across a cellular membrane

3.5.7
spike train
time series of action potentials in temporal sequence

3.5.8
local field potential (LFP)
electrophysiological signal generated by the summed electric current flowing from multiple nearby neurons within a small volume of nervous tissue

Note 1 to entry: LFP is the electric potential recorded in the extracellular space in brain tissue, typically using micro-electrodes (metal, silicon or glass micropipettes)

3.5.9
evoked potential (EP)
electrophysiological neural response following presentation of a stimulus

Note 1 to entry: It distinct from spontaneous neural activities.

3.5.10
visual evoked potential (VEP)
neurophysiological response that results from the presentation of a visual stimulus

Note 1 to entry: Visual stimulus can be a flashing light or changing pattern.

Note 2 to entry: VEPs are specific patterns of electrical activity measured typically over the occipital region of the scalp, representing the brain's processing of the visual stimulus.

Note 3 to entry: In BCI (3.1.2), VEPs can be used to decode user intentions or to detect attentional shifts based on the brain's response to visual cues.

Note 4 to entry: There are different types of VEPs, depending on the nature of the visual stimuli and the elicited brain response: steady state visual evoked potentials, P300-based VEPs, and transient VEPs, etc.

3.5.11
steady state visual evoked potential (SSVEP)
neural activities that are natural responses to visual stimulation at specific frequencies

Note 1 to entry: When the retina is excited by a visual stimulus ranging from 3.5 Hz to 75 Hz, the brain generates electrical activities at the same (or multiples of) frequency of the visual stimulus.

3.5.12
auditory evoked potential (AEP)
neurophysiological response resulting from the presentation of an auditory stimulus

Note 1 to entry: AEPs represent the brain's processing of the auditory information and can be observed as specific patterns of electrical activity over the auditory cortex, typically captured via electrodes placed on the scalp.

Note 2 to entry: In BCI (3.1.2), AEPs can be used to decode user intentions or to detect attentional shifts based on the brain's response to auditory cues.

Note 3 to entry: Several types of AEPs are based on the nature of the auditory stimulus and the timing of the brain's response: click evoked AEPs, tone evoked AEPs, P300-based AEPs, and steady state auditory evoked Potentials, etc.

3.5.13
steady state auditory evoked potential (SSAEP)
continuous and oscillatory neural responses that occur in synchrony with the modulation frequency of a repetitive or continuous auditory stimulus

Note 1 to entry: In BCI (3.1.2), SSAEPs can be measured and decoded to identify user attention or intention based on the specific frequency of the auditory cue to which they are attending.

3.5.14

somatosensory evoked potential (SEP)

type of electrophysiological neural responses of the brain that results from the electrical or mechanical stimulation through skin

Note 1 to entry: A usually non-invasive way for assessing somatosensory system functioning.

3.5.15

event-related potential (ERP)

consistent neurophysiological response in the brain's electrical activity that is time-locked to a specific external or internal event

Note 1 to entry: In BCI (3.1.2), ERPs are used to decode user intentions, attention, or reactions based on the specific characteristics of these brain responses following certain stimuli or cognitive tasks.

Note 2 to entry: Several key features and types of ERPs in BCI (3.1.2) include: P300, N100, P200, etc.

3.5.16

event-related desynchronization (ERD)

decrease in oscillatory brain activity due to endogenous or evoked stimulus

3.5.17

event-related synchronization (ERS)

increase in oscillatory brain activity due to endogenous or evoked stimulus

3.5.18

event-related spectral perturbation (ERSP)

measure of the event-related changes in the power spectrum of neural activity over time

Note 1 to entry: ERSP quantifies the dynamic shifts in power within specific frequency bands (e.g., alpha, beta, gamma) as they relate to a particular event or task.

Note 2 to entry: In BCI (3.1.2), ERSP can be used to decode user intentions, attention, or cognitive states based on these time-locked spectral changes.

3.5.19

P300

event related potential component elicited in the process of decision making

Note 1 to entry: It is considered to be an endogenous potential, as its occurrence links not to the physical attributes of a stimulus, but to a person’s reaction to it.

Note 2 to entry: P300 is the ERP measured with latency of 300 ms after stimulation.

3.5.20

P300 speller

BCI (3.1.2) that presents a user with a matrix of symbols and translates the user’s selection by interpreting P300 waveform in neural activities

3.5.21

sensorimotor rhythms (SMR)

oscillations in electric or magnetic fields recorded over sensorimotor cortex in the mu (8-12Hz), beta (18-30Hz), and gamma (30-200Hz) frequency bands

Note 1 to entry: SMR decrease or desynchronize with movement or preparation of movement and increase or synchronize in the post-movement or relaxation period.

3.5.22

physiological stress

observable and quantifiable bodily responses, particularly in neural activity patterns, due to perceived stressors, challenges, or strains

Note 1 to entry: Within the BCI (3.1.2) framework, such responses can be derived from analysing specific patterns, changes, or anomalies in the neural signals to infer an individual's stress state.

Note 2 to entry: It usually includes mental stress, physical stress, etc.

3.5.23
mental load
work load
<brain-computer interface> cognitive demand or mental effort exerted by an individual during a task or interaction with a system, as inferred from the analysis of neural signals captured by BCI (3.1.2)

Note 1 to entry: This can encompass aspects like attention, memory load, decision-making complexity, or other cognitive processes.

3.5.24
fatigue
state characterized by reduced cognitive efficiency, attention, and alertness, often resulting from prolonged activity or strain

Note 1 to entry: Within the BCI (3.1.2) framework, fatigue is inferred from particular patterns or changes in neural signals, indicating a decline in cognitive performance or increased effort to maintain the same level of performance.

3.5.25
emotions
mental states associated with situational feeling deriving from one’s circumstances, moods, or relationships with others

Note 1 to entry: Emotions are the results of thoughts, feelings, actions, and psychological states and learned experiences to a stimuli or changes in a contextual environment.

3.6 Feedbacks and stimulations

3.6.1
feedback
<brain-computer interface> information about reactions to the output of performing previous task or command, which is used as a basis for improvement

3.6.2
biofeedback
<brain-computer interface> process of gaining greater awareness of various physiological functions of the user’s own body, with a goal of being able to manipulate the body’s functions at will

3.6.3
neurofeedback
neurotherapy
neurobiofeedback
<brain-computer interface> type of biofeedback (3.6.2) that uses real-time displays of brain activities to a user, with the purpose to train and self-regulate of the user’s brain function

Note 1 to entry: A typical implementation displays the brain waves of the user’s EEG signals.

3.6.4
human-in-loop
human-in-the-loop
<brain-computer interface> experimental or system design that emphasizes that the signals and information from one or more users are employed to influence the environment and other function units in the system

3.6.5
closed-loop
closed-loop control
<brain-computer interface> experimental or system design that employs feedback mechanisms to achieve self-regulation and compensatory capability

3.6.6
open-loop
open-loop control
<brain-computer interface> experimental or system design without feedback mechanisms

3.6.7
neurostimulation
neuromodulation
<brain-computer interface> technology that modulates neural activities on a specific goal by invasive or non-invasive means

Note 1 to entry: Stimulation may include: electric, magnetic, optic, mechanic, and chemical methods, also the combination of the methods above.

Note 2 to entry: The targeted delivery of neurostimulation usually aims at alternating neural activities.

3.7 Signal processing and analysis

3.7.1
signal processing
<brain-computer interface> set of computational methods and techniques applied to neurophysiological data, with the aim of enhancing signal quality, extracting relevant features, reducing noise and artifacts, and translating these signals into actionable outputs or insights related to brain function or user intent

3.7.2
neural coding
neural encoding
<brain-computer interface> neuroscience field concerned with characterizing the hypothetical relationship between the stimulus and the individual or ensemble neuronal responses and the relationship among the electrical activity of the neurons in the ensemble

Note 1 to entry: It usually refers to the mapping from stimulus to response.

3.7.3
neural decoding
neural decipher
<brain-computer interface> neuroscience field concerned with the hypothetical reconstruction of sensory and other stimuli from information that has already been encoded and represented in the brain by networks of neurons

3.7.4
rate coding
frequency coding
<brain-computer interface> model of neuronal firing, which interprets the neuronal communication in terms of the intensity of neural activities

3.7.5
spike count rate
<brain-computer interface> temporal average of spike counts in a specified time window

3.7.6
feature extraction
<brain-computer interface> procedure that derives observations from neuroimaging data into values and vectors which represents neural characteristics and pattern classifications

3.7.7

component

<brain-computer interface> distinguishable and separable neural signal source or pattern identified within the raw neural data

Note 1 to entry: It is often extracted using signal decomposition techniques to isolate specific aspects of the brain's electrical activity or to remove noise and artifacts.

Note 2 to entry: Component information indicates the source of data, e.g., brain area (like data from frontal cortex), muscle component, eye component, etc.

3.7.8

temporal domain

<brain-computer interface> representation of neural signals with respect to time, illustrating the changes in signal amplitude or value as a function of time

Note 1 to entry: In this domain, signals are typically visualized as waveforms, where the x-axis represents time, and the y-axis represents the signal amplitude or voltage.

3.7.9

spatial domain

<brain-computer interface> representation and analysis of neural signals based on their spatial distribution or location

Note 1 to entry: In the spatial domain, signals are typically visualized or processed considering their origin or influence in different brain areas or electrode locations.

Note 2 to entry: It often across various recording sensors, electrodes, or estimated brain regions.

3.7.10

frequency domain

<brain-computer interface> representation and analysis of neural signals based on their constituent frequency components, detailing how the power or amplitude of a signal is distributed across different frequencies

Note 1 to entry: In this domain, signals are often visualized as spectra, where the x-axis represents frequency, and the y-axis represents amplitude or power.

3.7.11

phase locking value (PLV)

<brain-computer interface> measure that quantifies the consistency of the phase difference between two signals over time

Note 1 to entry: It evaluates how stable the relative phase relationship is between two signals across multiple epochs or time instances.

Note 2 to entry: A PLV value close to 1 suggests strong phase synchronization (consistent phase difference) between the two signals, whereas a value close to 0 indicates weak or no synchronization.

3.7.12

phase lag index (PLI)

<brain-computer interface> measure that quantifies the asymmetry of the distribution of instantaneous phase differences between two signals

Note 1 to entry: It helps identify true phase synchronization by minimizing the effects of common sources or volume conduction, which is a common issue in EEG data.

Note 2 to entry: PLI values range from 0 to 1. A value of 0 indicates either no synchronization or synchronization with a phase difference centred around 0 (which might be due to volume conduction or common sources). A value of 1 indicates perfect non-zero phase synchronization.

3.7.13
filter
<brain-computer interface> processing tool or technique used to selectively pass, attenuate, or eliminate specific frequency components of a neural signal, aiming to enhance the signal-to-noise ratio, isolate relevant neural information, or remove artifacts

Note 1 to entry: Types of filters include: low-pass filter, high-pass filter, band-pass filter, notch filter, etc.

Note 2 to entry: In BCI (3.1.2) applications, it could be used for artifact removal, isolation of frequency bands, etc.

Note 3 to entry: Filters can be implemented in hardware (analog filters) or software (digital filters). Digital filters are more common in modern BCI (3.1.2) due to their flexibility and precision.

3.7.14
artifact
<brain-computer interface> non-neural signal interference or disturbance present in the recorded neural data

Note 1 to entry: It often comes from sources such as muscle movements, eye blinks, power line interference, or equipment malfunction.

3.7.15
artifact removal
<brain-computer interface> process or set of techniques used to identify, reduce, or eliminate unwanted non-neural interference or disturbances from neural recordings

Note 1 to entry: It ensures that the resulting data more accurately represents the underlying neural activity.

3.7.16
artifact rejection
<brain-computer interface> process of identifying segments of neural data that contain substantial unwanted non-neural interference or disturbances, and subsequently excluding or discarding these segments from further analysis to ensure the remaining data more accurately reflects true neural activity

3.7.17
brain imaging data structure (BIDS)
community standard for organizing, describing, and annotating collections of neuro-imaging datasets

3.8 Applications

3.8.1
neural engineering
neuroengineering
research field in biomedical engineering, which applies engineering techniques to understand, repair, replace, or enhance neural systems

3.8.2
neuroprosthetics
neural prosthetics
multidiscipline of neuroscience and biomedical engineering, which focuses on developing neural prostheses to replace missing biological functionality

3.8.3
neurorobotics
multidiscipline of neuroscience, robotics, and artificial intelligence, which focuses on building computational models and hardware mimicking the structure, function, and behaviour of the nervous system

Note 1 to entry: It usually includes rehabilitation exoskeletons and embodied neural robots.

3.8.4
augmented reality (AR)
type of reality-based interactive experiences, overlaying of digital content, such as graphics, sounds, or haptic feedback, onto the real world, enhancing the user's perception of and interaction with reality

Note 1 to entry: BCI (3.1.2) can be integrated with AR systems to provide users with direct brain interaction capabilities. For instance, users might control AR objects, receive neurofeedback, or alter AR displays based on cognitive states, emotions, or focus levels detected by the BCI (3.1.2).

3.8.5
virtual reality (VR)
type of reality-based interactive experiences, immersing users in a completely digital environment, shutting out the real world and replacing it with a simulated one

Note 1 to entry: Users can interact with this environment using various input devices, such as controllers, haptic gloves, or BCI (3.1.2).

Note 2 to entry: BCI (3.1.2) can be used to enhance VR experiences by allowing direct brain-to-VR interactions. This might include navigating virtual environments, selecting items, or even experiencing feedback from the virtual world that aligns with the user's cognitive or emotional state.

3.8.6
extended reality (XR)
umbrella term that encompasses all the various forms of reality-based interactive experiences

Note 1 to entry: It includes AR, VR, and everything in between, like Mixed Reality (MR). XR captures the continuum of experiences from fully immersive virtual environments to enhancements of the real world with digital content.

Note 2 to entry: In XR, BCI (3.1.2) can offer a broad spectrum of interactions. As XR blurs the lines between the real and digital worlds, BCI (3.1.2) can provide seamless interaction methods, interpret user intent, emotions or states, and provide biofeedback, enhancing the overall experience.

3.8.7
telemedicine
tele medicine
telehealth
application of BCI (3.1.2) to deliver remote healthcare services, allowing for the monitoring, analysis, and interpretation of neurophysiological data, or providing communication and control solutions for patients

Note 1 to entry: It is usually facilitated through digital and telecommunication platforms.

Note 2 to entry: Given the sensitive nature of brain data, ensuring the security and privacy of transmitted information is paramount in BCI (3.1.2) telehealth applications.

3.8.8
neuroergonomics
application of neuroscience to ergonomics, which studies the human brain in relation to performance at work and in everyday settings

3.8.9
biocompatibility
<brain-computer interface> ability to be in contact with a living system without producing an unacceptable adverse effect

Note 1 to entry: Medical devices may produce some level of adverse effect, but that level may be determined to be acceptable when considering the benefits provided by the medical device.

3.8.10
safety
<brain-computer interface> aspect of brain-computer interface design, implementation, and usage that ensures no harm or adverse effects occur to the user, including protection against physical injuries, psychological distress, and breaches of data privacy and security

Note 1 to entry: It is usually involving physical safety, neurological safety, psychological safety, data privacy and security, functional safety, and ethical conditions, etc.

Note 2 to entry: Whenever participant is not in a position to give/provide his/her consent, the caretaker/guardian/parent need to provide their assent.

3.8.11
physical safety
<brain-computer interface> aspect of brain-computer interface design and operation that ensures the user is protected from physical harm, discomfort, or injury resulting from the interface's hardware components or related interventions

3.8.12
neurological safety
<brain-computer interface> aspect of brain-computer interface design and operation that ensures the user's brain is not subjected to harmful (physical or psychological) treatment due to result of intervention including signal acquisition, interpretation, or any form of neural stimulation

Note 1 to entry: Whenever participant is not in a position to give/provide his/her consent, the caretaker/guardian/parent need to provide their assent.

3.8.13
psychological safety
<brain-computer interface> aspect of brain-computer interface design, usage, and interaction that ensures the user's mental well-being is preserved and that they are not exposed to experiences that could lead to psychological distress, anxiety, diminished self-efficacy, protection from non-consensual manipulation of memory, emotion, affect, perception, cognition, volition, and behaviour as well as protection from other threats to mental integrity

Note 1 to entry: Whenever participant is not in a position to give/provide his/her consent, the caretaker/guardian/parent need to provide their assent.

3.8.14
functional safety
<brain-computer interface> attribute of a brain-computer interface system or component that ensures it operates correctly, reliably, and predictably, preventing malfunctions or failures that could lead to harmful or unintended consequences for the user or surrounding environment

3.8.15
mis-use
<brain-computer interface> Using a brain-computer interface in ways that are not consistent with its intended purpose, manufacturer's instructions, or safety guidelines, leading to risks of malfunction, inaccurate outputs, or harm to the user

3.8.16
over-use
<brain-computer interface> excessive or prolonged use of a brain-computer interface beyond its recommended operational limits or durations, which could result in user fatigue, reduced system performance, or other unintended physiological or psychological effects

Bibliography