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Information technology - Brain-computer interfaces - Vocabulary

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FOREWORD

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INTRODUCTION

Brain–computer interface (BCI) is an emerging technology that facilitates direct communication between the brain and external devices, such as computers and robotic limbs. It links the brain's neural activity with the external world to repair, replace, or enhance human capabilities in interacting with the physical environment.

BCI has revolutionized and positively impacted several industries, including entertainment and gaming, automation and control, education, neuromarketing, and neuroergonomics. It has restored the capabilities of physically challenged people, improving the quality of their lives. Researchers have demonstrated human neuroprosthetic control of computer cursors, robotic limbs, and speech synthesizers.

Currently, the BCI represents a rapidly growing field of research, with a broad range of application scenarios. Its contributions span across the medical and health industry to entertainment and educational technology. For a more comprehensive and unified understanding of BCI technology, there is a need for a vocabulary to ensure that contributions can be understood and coordinated.

1 Scope

This document 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.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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 often referred to as brain–computer interfaces; invasive systems using implanted sensors are often referred to as brain machine interfaces.

3.1.2
brain–computer interface
BCI
brain machine interface
BMI
<engineered systems> direct communication link between the activity of the central nervous system of humans or other animals and an external software and hardware system

Note 1 to entry: A brain–computer interface allows a single or bi-directional communication between the brain and external devices, enabling controlling or feedback capabilities or both.

Note 2 to entry: Non-invasive systems are often referred to as brain–computer interfaces; invasive systems using implanted sensors are often referred to as brain machine interfaces.

3.1.3
active brain–computer interface
brain–computer interface (3.1.2) that requires a user to change brain activities intentionally

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

Note 1 to entry: A passive brain–computer interface monitors the user's mental states and psychological activities.

3.1.5
reactive brain–computer interface
brain–computer interface (3.1.2) in which a user's response to a specific stimulus is embedded in the response signal to external stimulation

Note 1 to entry: A reactive brain–computer interface decodes specific neural response to environmental stimulations.

3.1.6
affective brain–computer interface
brain–computer interface (3.1.2) that decodes emotional experience into corresponding states

3.1.7
synchronous brain–computer interface
brain–computer interface (3.1.2) that requires a synchronization stimulus given to the user to start each task

Note 1 to entry: Information is presented to cue the user to elicit certain brain signal responses.

3.1.8
asynchronous brain–computer interface
self-paced brain–computer interface
brain–computer interface (3.1.2) that detects when the user intentionally changes brain activity without any external stimuli

Note 1 to entry: An asynchronous brain–computer interface is continuously analysing the ongoing brain activity of both intentional control states and non-control states (e.g. idling state).

3.1.9
bidirectional brain–computer interface
brain–computer interface (3.1.2) that both encodes and decodes neural activities

Note 1 to entry: A bidirectional brain–computer interface system can acquire and decode the neural activities, and also encode stimuli to stimulate the central nervous system for specific responses.

3.1.10
unidirectional brain–computer interface
brain–computer interface (3.1.2) that decodes neural signals to control external devices

3.1.11
multi-user brain–computer interface
brain–computer interface (3.1.2) that allows multiple users to interact with the brain–computer interface independently

Note 1 to entry: Tasks in a multi-user brain–computer interface system are typically performed in a digital or virtual environment, such as controlling a cursor on a screen, manipulating a virtual object, or playing a video game.

3.1.12
collaborative brain–computer interface
brain–computer interface (3.1.2) that integrates and interprets brain signals from multiple individuals to perform tasks or actions

Note 1 to entry: A collaborative brain–computer interface system uses brain signals from more than one person to perform tasks or actions. Any conflicts result in no action being taken until the conflict is resolved.

3.1.13
competitive brain–computer interface
brain–computer interface (3.1.2) that incorporates brain activities from multiple tasks where each set of users is competing with other users

3.1.14
independent brain–computer interface
brain–computer interface (3.1.2) that does not rely on the brain's natural output pathways

Note 1 to entry: The brain signals used by an independent brain–computer interface are not dependent on muscle activity.

EXAMPLE In brain–computer interfaces (3.1.2) based on electroencephalogram sensorimotor rhythms, mental imagery can be employed to modify sensorimotor rhythms so as to control the brain–computer interface output.

3.1.15
dependent brain–computer interface
brain–computer interface (3.1.2) that uses brain signals that depend on muscle activity

EXAMPLE A brain–computer interface (3.1.2) that uses movement information from a user's eyes, like muscle activities to gaze at the visual stimuli, to determine what the user is looking at.

3.1.16
invasive brain–computer interface
brain–computer interface (3.1.2) in which neural activities are recorded using a surgically implanted device

Note 1 to entry: To inject contrast medium into body or brain is neither invasive nor surgical implant.

EXAMPLE Brain–computer interfaces (3.1.2) using intracranial electroencephalography, electrocorticography, stereotactic electroencephalography, intracortical microelectrodes and endovascular electrodes.

3.1.17
non-invasive brain–computer interface
brain–computer interface (3.1.2) in which neural activities are recorded using sensors that rest outside the skull

Note 1 to entry: Non-invasive brain–computer interface does not require the surgical implantation of a device. For example, it can involve the user wearing a device with electrical sensors that serve as two-way communication channels between the user's brain and a machine.

EXAMPLE Brain–computer interfaces (3.1.2) using scalp electroencephalography, functional near-infrared spectroscopy, functional magnetic resonance imaging, and surface electromyography.

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

3.1.19
hybrid brain–computer interface
combination of brain–computer interface (3.1.2) which incorporates multiple paradigms or systems

3.1.20
human brain–computer interface
brain–computer interface (3.1.2) designed for human brain communication

3.1.21
speech brain–computer interface
brain–computer interface (3.1.2) that captures and decodes neural signals related to user thoughts intended to be articulated but which cannot be vocalized

Note 1 to entry: Speech brain–computer interface can be utilized to assist individuals with speech impairments or those who are unable to physically produce speech because of medical conditions.

3.1.22
wearable brain–computer interface
portable brain–computer interface
brain–computer interface (3.1.2) that is designed to be worn on the body to detect, analyse, and utilize brain activity in near real time

Note 1 to entry: Wearable brain–computer interfaces 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, and therapeutic interventions.

3.2 System components

3.2.1
transducer
device that converts brain signals into electrical signals or vice versa

Note 1 to entry: Some transducers can be bidirectional.

Note 2 to entry: A transducer converts one form of energy into another, for example, from electrical energy into an analogue signal.

3.2.2
sensor
specific type of transducer (3.2.1) that detects or measures a physical quantity of an object and converts it into an electrical signal

Note 1 to entry: When the brain–computer interface (3.1.2) operates in the direction from external world to the brain, the sensors can operate on the compromised sensory channels (visual, acoustic, etc.).

EXAMPLE A sensor can be an electrode in the case of electroencephalography, but also a Hall effect sensor in the case of magnetoencephalography.

3.2.3
effector
specific type of transducer (3.2.1) that converts electrical signals into physical actions

3.2.4
electrode
specific type of transducer (3.2.1) that establishes electrical contact with a physical part of a circuit

3.2.5
channel
pathway through which the brain signal is collected, transmitted, and processed

Note 1 to entry: Channel often refers to a specific electrode placed on the scalp in electroencephalogram-based brain–computer interface (3.1.2) or an array of electrodes in invasive brain–computer interface (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
specific type of transducer (3.2.1) that converts a small input signal into a larger output signal

EXAMPLE An electroencephalogram amplifier.

3.2.7
headset
wearable device equipped with sensors (3.2.2) to detect and record brain signals

Note 1 to entry: Headsets are used to read and interpret brain signals, not to control or manipulate the user.

3.2.8
EEG cap
device embedded with multiple electrodes to record electrical activity of the brain

Note 1 to entry: An EEG cap is a wearable device designed to fit on the head.

3.2.9
brain implant
neural implant
device that is surgically implanted into the brain

Note 1 to entry: Brain implants are made up of electrodes that capture electrical signals. A decoder system then analyses these signals and translates them into commands or questions.

3.2.10
analogue-to-digital converter
component that receives analogue signals from a transducer (3.2.1) and converts them into digital signals

3.2.11
processing unit
component that interprets signals received from the brain

Note 1 to entry: A processing unit can perform signal pre-processing.

Note 2 to entry: A processing unit analyses the ingested data to extract features and translates the extracted features into commands.

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: IEC 60050-891:1998 [1], 891-04-23]

3.3.2
intracranial electroencephalogram
iEEG
graphic record of the variation with time of voltages taken from electrodes (3.2.4) placed onto or deeply inserted into the brain to directly record electrical activities of the brain through sensors (3.2.2)

Note 1 to entry: Intracranial electroencephalogram is known as electrocorticogram when using subdural grid electrodes.

Note 2 to entry: Intracranial electroencephalogram is known as stereotactic electroencephalogram or local field potential when using depth electrodes.

3.3.3
electromyogram
EMG
graphic record of the variation with time of voltages associated with the electrical activity of skeletal muscle

[SOURCE: IEC 60050-891:1998 [1], 891-04-30]

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: Functional magnetic resonance imaging 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 light for the purpose of functional neuroimaging

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

3.3.6
magnetoencephalogram
MEG
topographic record, or graphic record as a function of time, of magnetic fields associated with the electrical activity of the brain

[SOURCE: IEC 60050-891:1998 [1], 891-04-27]

3.4 Experimental designs and setups

3.4.1
subject
person about whom an investigator obtains information for study and analysis

Note 1 to entry: A participant is a subject that gives voluntary consent to following a specific regimen or also answering questions from the researcher or both.

3.4.2
user
person that is using a brain–computer interface (3.1.2) product or service

3.4.3
trial
specific instance of a procedure or task performed by a subject (3.4.1)

3.4.4
clinical trial
study involving multiple subjects (3.4.1) that assesses the efficacy of a proposed intervention

Note 1 to entry: A clinical trial can include alternatives, such as placebos.

3.4.5
trial session
specific period during which a subject (3.4.1) engages in study activities

Note 1 to entry: A trial session can include multiple trials if the study design requires repeating tasks.

3.4.6
clinical trial session
specific time period during which a subject (3.4.1) receives an intervention or undergoes an assessment or both

Note 1 to entry: A clinical trial session does not include multiple clinical trials, since each clinical trial is its own separate study, with separate enrolment and consenting processes.

3.4.7
epoch
single segment of time-series data

Note 1 to entry: An epoch is typically a part of a longer continuous signal that involves a specific event of interest.

Note 2 to entry: Epochs are used to isolate the brain’s response to specific events.

3.4.8
stimulus
event or signal presented to the subject (3.4.1) to elicit a specific response

Note 1 to entry: Stimuli are used to make inferences about various cognitive processes.

Note 2 to entry: These are tasks that the subject can 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.

EXAMPLE Stimulus can be visual, auditory, tactile, or somatosensory.

3.4.9
inter-stimulus interval
ISI
period of time between the end of one stimulus (3.4.8) and the start of the next stimulus (3.4.8)

3.4.10
inter-trial interval
ITI
period of time between separate trials (3.4.3)

3.4.11
sampling rate
sampling frequency
number of samples of a signal taken per unit time

[SOURCE: IEC 60050-704:1993 [2], 704-23-03]

3.4.12
bit rate
measurement of speed at which information is transferred from the subject (3.4.1) to the processing unit (3.2.11)

Note 1 to entry: Bit rate depends on the accuracy of the brain–computer interface (3.1.2), the number of possible selections (i.e. mental states) and the time required to make each selection.

Note 2 to entry: Bit rate is typically measured in either bits per minute, bits per second, or bits per symbol.

Note 3 to entry: Bit rate can be calculated by multiplying the classification speed in symbols per minute by the information carried in one symbol in bits per symbol.

3.5 Protocols and paradigms

3.5.1
operating protocol
set of specific rules and procedures that define how the brain–computer interface (3.1.2) interacts with the subject (3.4.1) and its environment

Note 1 to entry: Rules and procedures include methods for recording neural activity, algorithms for translating neural activity into requests and commands, and how feedback mechanisms are used to enable the subject to learn to control the brain–computer interface.

Note 2 to entry: Operating protocol is dependent on the goals of the study.

3.5.2
event
specific occurrence or change in the state of a system that is significant to the operation of the brain–computer interface (3.1.2)

3.5.3
mental imagery
imagination of a specific scenario or action by the subject (3.4.1)

3.5.4
motor imagery
MI
generation of neural activity from the motor cortex by imagining movements without any physical limb movement or external stimulus (3.4.8)

3.5.5
auditory imagery
imagination of the generation of sounds without any external auditory stimulus

3.5.6
action potential
AP
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
sequence of action potentials (3.5.6) that a single neuron produces

Note 1 to entry: Spike trains are important because they can be used to encode and transmit information from the brain to an external device.

Note 2 to entry: Spike trains can be fed into machine learning algorithms, such as a spiking neural network.

3.5.8
local field potential
LFP
measure of brain activity recorded from a small group of neurons in a specific area of the brain

Note 1 to entry: Local field potential is measured within the brain, and it captures the electric potentials generated by the collective activity of neurons in a local area.

Note 2 to entry: Local field potentials have a higher fidelity than electroencephalogram signals, and are more stable than action potentials from individual neurons and cover a wider range of frequencies than electrocorticogram signals.

3.5.9
evoked potential
EP
measure of neural response to a specific stimulus (3.4.8)

Note 1 to entry: An evoked potential is different from a spontaneous potential or an induced potential, which are potentials generated by the superimposition of a pattern of neural or synaptic activity.

Note 2 to entry: Evoked potentials are used for understanding the relationships between physical stimuli, brain activity, and human cognition.

3.5.10
visual evoked potential
VEP
evoked potential (3.5.9) in response to visual stimuli

Note 1 to entry: Visual evoked potentials 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 2 to entry: In brain–computer interface (3.1.2), visual evoked potentials can be used to decode user intentions or to detect attentional shifts based on the brain's response to visual cues.

3.5.11
steady state visual evoked potential
SSVEP
visual evoked potential (3.5.10) in response to repetitive stimuli with a light source flickering at a constant frequency

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 frequency as the visual stimulus or multiples of this frequency.

3.5.12
transient visual evoked potential
visual evoked potential (3.5.10) that occurs at a relatively low rate

3.5.13
auditory evoked potential
AEP
evoked potential (3.5.9) in response to audio stimuli

Note 1 to entry: Auditory evoked potentials 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 brain–computer interface (3.1.2), auditory evoked potentials can be used to decode user intentions or to detect attentional shifts based on the brain's response to auditory cues.

3.5.14
steady state auditory evoked potential
SSAEP
auditory evoked potential (3.5.13) in response to a repetitive audio stimuli

Note 1 to entry: A steady state auditory evoked potential is produced when the auditory system is stimulated at a rapid and constant rate. The brain generates a continuous oscillatory response that matches the frequency of the auditory stimulus.

Note 2 to entry: Steady state auditory evoked potentials are often used in brain–computer interfaces (3.1.2) because they can provide a continuous measure of the brain's response to a stimulus.

3.5.15
click-evoked auditory evoked potential
auditory evoked potential (3.5.13) in response to a click stimulus

Note 1 to entry: The click stimulus is a brief, sharp sound that is used in auditory testing.

3.5.16
tone-evoked auditory evoked potential
auditory evoked potential (3.5.13) in response to a tone stimulus with a specific frequency

3.5.17
somatosensory evoked potential
SEP
evoked potential (3.5.9) in response to a tactile or proprioceptive stimulus

Note 1 to entry: This type of stimulus elicits a steady state response of the somatosensory system that can be detected in a recorded electroencephalogram. The oscillatory and phase-locked voltage component characterizing this response is called a steady state somatosensory evoked potential (3.5.18).

3.5.18
steady state somatosensory evoked potential
SSSEP
somatosensory evoked potential (3.5.17) measured during selective attention tasks

Note 1 to entry: Steady state somatosensory evoked potential is a useful tool for exploring the spatio-temporal dynamics of neural processes involved in tactile attention.

3.5.19
tactile evoked potential
TEP
somatosensory evoked potential (3.5.17) which is evoked by tactile stimuli

Note 1 to entry: Touch and vibration are examples of tactile stimuli.

3.5.20
event-related potential
ERP
consistent neurophysiological response in the brain's electrical activity that is time-locked to a specific external or internal event (3.5.2)

Note 1 to entry: In brain–computer interface (3.1.2), event-related potentials 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 components of event-related potential in brain–computer interface (3.1.2) are P300, N100, P200, etc.

Note 3 to entry: There are two types of event-related potential: external event-related potential responses to a sensory stimulus external to the subject, and internal event-related potential responses to a cognitive or physiological process that occurs within the subject.

3.5.21
event-related desynchronization
ERD
decrease in oscillatory brain activity due to an external or internal event (3.5.2)

3.5.22
event-related synchronization
ERS
increase in oscillatory brain activity due to an external or internal event (3.5.2)

3.5.23
event-related spectral perturbation
ERSP
measure that reflects changes in power spectral density over time in a specific frequency band

Note 1 to entry: Event-related spectral perturbation 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 brain–computer interface (3.1.2), event-related spectral perturbation can be used to decode user intentions, attention or cognitive states based on these time-locked spectral changes.

Note 3 to entry: Event-related spectral perturbation is typically generated from electroencephalogram signals, and can consist of event-related synchronization or desynchronization.

3.5.24
P300
positive event-related potential (3.5.20) caused by a cognitive process appearing approximately 300 milliseconds after a stimulus (3.4.8)

Note 1 to entry: The P300 reflects cognitive processes involved in stimulus evaluation or categorization, and not to the physical attributes of the stimulus.

3.5.25
P300 speller
brain–computer interface (3.1.2) that presents a user with a matrix of alphanumeric symbols and translates the user’s selection by interpreting a P300 (3.5.24) waveform in neural activities

Note 1 to entry: The P300 speller can sometimes include punctuation marks or special characters.

Note 2 to entry: When the user focuses on a specific symbol, the rows and columns of the matrix are flashed randomly, causing a P300 wave to be generated in the user's electroencephalogram signal.

3.5.26
sensorimotor rhythm
SMR
oscillation in electric or magnetic fields recorded over sensorimotor the cortex in specific frequency bands

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

3.5.27
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 brain–computer interface (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: Physiological stress can include different types of stress, such as mental stress, physical stress, etc.

3.5.28
mental load
workload
amount of cognitive resources used when the subject (3.4.1) is performing a task

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

3.5.29
fatigue
state characterized by reduced cognitive efficiency, attention, and alertness

Note 1 to entry: Within the brain–computer interface (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.

Note 2 to entry: Fatigue often results from prolonged activity or attention.

Note 3 to entry: Fatigue is typically evaluated by means of electroencephalogram signals.

3.5.30
emotion
transient, intense response to a specific stimulus that typically has clear cause or trigger

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

3.6 Feedback and stimulations

3.6.1
feedback
continuous comparison of the output from performing a task with its desired output

Note 1 to entry: Feedback is used to control the state of the system to converge to a desired state.

3.6.2
biofeedback
process of gaining greater awareness of various physiological functions of the user’s own body

Note 1 to entry: The goal of biofeedback is to be able to manipulate the body’s functions at will.

3.6.3
neurofeedback
biofeedback (3.6.2) that provides immediate feedback (3.6.1) from a computer-based programme that assesses a user’s brain activity

Note 1 to entry: A typical implementation can be used in a therapy to assess brainwave activity of the subject.

Note 2 to entry: Neurofeedback typically uses auditory or visual signals to help the subject recognize his or her thought patterns and try to modify them.

3.6.4
human-in-the-loop
characteristic of a system in which a human is an integral part of the system's control loop

Note 1 to entry: Human-in-the-loop means that the human operator is involved in the learning, analysis, computation, and improvement process of the system.

3.6.5
closed-loop
characteristic of a system whose control action is dependent on the output of the task and its deviation from a reference or ideal state

Note 1 to entry: A closed-loop brain–computer interface records neural activity and processes it in near real-time to decide when to stimulate the brain directly or indirectly.

3.6.6
open-loop
characteristic of a system whose control action is independent of the output of the task

Note 1 to entry: An open-loop brain–computer interface does not provide any feedback to the subject using the device. Control actions must be done manually.

3.6.7
neurostimulation
method that directly stimulates nerves via electrical impulses

Note 1 to entry: Neurostimulation typically targets pain relief. In neurostimulation, nerves are only stimulated and not inhibited.

EXAMPLE Neurostimulation includes electrical, magnetic, optical, mechanical, and chemical methods, or a combination of these methods.

3.6.8
neuromodulation
method that alters nerve activity by delivering electrical or chemical signals

Note 1 to entry: Neuromodulation affects various bodily functions, including pain relief and motor control. Neuromodulation can either stimulate or inhibit nerve function.

3.7 Signal processing and analysis

3.7.1
signal processing
transformation, extraction and classification of brain signals to interpret the user's intent and control an external device

Note 1 to entry: Signal processing involves noise removal, feature extraction, and classification. Feature extraction involves identifying and extracting important characteristics from the pre-processed signals. Classification involves using the extracted features to classify or decode the user's intent.

3.7.2
neural coding
method by which neurons encode and process information

Note 1 to entry: Neural coding considers that neurons act as information-processing channels. Neurons take incoming information, integrate it, and produce a signal that contains information encoded in the neuronal electrical activity pattern.

3.7.3
neural decoding
process of interpreting the electrical signals generated by the brain's neurons and translating them into meaningful information

Note 1 to entry: Neural decoding information is typically used to estimate target variables in near real time from observations of neural spiking activity.

Note 2 to entry: Neural decoding forms the basis for correctly interpreting the user's intent.

3.7.4
rate coding
neural coding scheme where the information is encoded in the frequency or rate of neuronal action potentials (3.5.6)

Note 1 to entry: Rate coding uses the frequency or rate of action potentials to encode information. The rate of these action potentials is often used to represent continuous variables such as the intensity of a sensory stimulus or the desired movement direction.

Note 2 to entry: In rate coding, the assumption is that the most important piece of information conveyed by a neuron is the total number of action potentials it fires over a certain period of time.

Note 3 to entry: Rate coding scheme is often used in models of sensory processing, where the intensity of a stimulus is directly proportional to the firing rate of the neuron.

3.7.5
spike count rate
measure of the average firing rate of a neuron in a specific time interval

Note 1 to entry: The spike count rate is calculated by counting the action potentials of a given neuron in a specific time interval, and then dividing the total number of action potentials by the duration of that interval.

3.7.6
feature extraction
process of identifying and isolating relevant signals from brain activity data

Note 1 to entry: In feature extraction, raw brain signals are transformed into a reduced set of features that are of interest.

3.7.7
feature classification
using extracted features to classify or decode the user’s intent

Note 1 to entry: Feature classification is typically the next step after feature extraction (3.7.6), and uses algorithms to categorize the extracted features into meaningful classes for brain–computer interface (3.1.2) applications.

Note 2 to entry: A class is the category of output data based on the features of the data belonging to that class.

Note 3 to entry: In brain–computer interface (3.1.2), classes can correspond to mental states. For example, this enables the differentiation between using the right or the left hand.

3.7.8
component
distinguishable and separable neural signal source or pattern identified within the raw neural data

Note 1 to entry: A component 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: brain area (like data from the frontal cortex), muscle component, eye component, etc.

3.7.9
temporal domain analysis
observing how the amplitude or value of the neural signals changes as a function of time

Note 1 to entry: Temporal domain analysis is used for many tasks, such as understanding event-related potentials.

3.7.10
spatial domain analysis
computing the physical layout or spatial distribution of brain activity as measured by sensors

Note 1 to entry: Spatial domain analysis is used for many tasks, such as helping to locate neural activity.

3.7.11
frequency domain analysis
transforming time-domain signals into the frequency domain to analyse the signals' characteristics at different frequencies

Note 1 to entry: The transformation converts brain signals as they occur over time into the frequency domain so that the signals' characteristics can be analysed at different frequencies.

Note 2 to entry: Frequency domain analysis examines the information (amplitude, phase, power, etc.) of a signal at different frequencies.

Note 3 to entry: Frequency domain analysis is particularly useful in brain–computer interfaces (3.1.2) as it allows for the examination of specific frequency bands in electroencephalogram signals for example, which are often associated with different mental states or tasks.

3.7.12
phase locking value
PLV
measure that quantifies the consistency of the phase difference between two signals over time

Note 1 to entry: A phase locking value evaluates how stable the relative phase relationship is between two signals across multiple epochs or time instances. A phase locking value close to one suggests strong phase synchronization (consistent phase difference) between the two signals, whereas a value close to zero indicates weak or no synchronization.

3.7.13
phase lag index
PLI
measure that quantifies the phase synchrony, or the consistency of the phase difference between two signals

Note 1 to entry: Phase lag index values range from zero to one. A value of zero indicates either no synchronization or synchronization with a phase difference centred around zero, which can be due to volume conduction or common sources. A value of one indicates perfect non-zero phase synchronization.

Note 2 to entry: Phase lag index is computed by taking the mean value of the sign of the imaginary part of the cross-spectral density. This measure can be useful in a sensorimotor rhythm-based brain–computer interface (3.1.2).

3.7.14
filter
signal processing tool used to enhance the quality of the recorded brain signals

Note 1 to entry: Filters work by allowing certain frequencies to pass through while reducing or eliminating others. This helps to reduce noise and enhance the signal-to-noise ratio, making it easier to detect and interpret the user's intent from the brain signals.

3.7.15
artifact
unwanted signal that is not related to the brain activity of interest

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

Note 2 to entry: Artifacts can significantly distort the recorded brain signals and make it more difficult to accurately interpret the user's intent.

3.7.16
artifact removal
process of identifying and eliminating unwanted signals that are not related to the brain activity of interest

Note 1 to entry: Artifact removal ensures that the resulting data more accurately represent the underlying neural activity.

3.7.17
artifact rejection
process of identifying and discarding segments of data that contain artifacts

Note 1 to entry: While straightforward when artifacts are confined to specific segments of data, artifact rejection can lead to a significant loss of data, especially if the artifacts are frequent.

3.7.18
brain imaging data structure
BIDS
standard for organizing, annotating, and describing data collected during neuroimaging experiments

Note 1 to entry: Brain imaging data structure defines a formalized file and directory structure and metadata files based on JavaScript object notation and tab separated values file formats with a controlled vocabulary.

Note 2 to entry: Brain imaging data structure can be extended in a backwards compatible way and is still evolving.

3.8 Applications

3.8.1
neuroengineering
neural engineering
multidisciplinary field for understanding, repairing, replacing and enhancing neural systems

Note 1 to entry: Neuroengineering encompasses computational neuroscience, experimental neuroscience, neurology, electrical engineering, robotics, cybernetics, computer engineering, materials science, nanotechnology, and signal processing of living neural tissue.

3.8.2
neuroprosthetic
biomedically engineered device linked to the peripheral or central nervous system to enhance the cognitive, motor or sensory abilities

3.8.3
neurorobotics
multidisciplinary field consisting of the science and technology of embodied autonomous neural systems

Note 1 to entry: Neurorobotics combines neuroscience, robotics, and artificial intelligence with a focus on designing and building robot computational structures inspired by the study of the nervous systems of humans and other animals.

EXAMPLE Rehabilitation exoskeletons and embodied neural robots.

3.8.4
augmented reality
AR
reality-based interactive technology in which the digital content is overlaid onto the real world to enhance the user's perception of and interaction with reality

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

Note 2 to entry: Perception of reality is increased by mixing physical objects with digital information, and providing the necessary feedback to the user. Augmented reality can be used to provide a first-person view of the real world, augmented with contextual visual commands.

Note 3 to entry: Digital content includes graphics, sounds, haptic feedback, or a combination of these.

3.8.5
virtual reality
VR
reality-based interactive technology in which the user is immersed in a completely simulated digital environment

Note 1 to entry: Users can interact with the digital environment using various input devices, such as controllers, haptic gloves or brain–computer interface (3.1.2).

Note 2 to entry: Brain–computer interface (3.1.2) can be used to enhance virtual reality experiences by allowing direct brain to virtual reality interactions. This can include navigating the digital environment, selecting items, or even experiencing feedback from the digital environment that aligns with the user's cognitive or emotional state.

3.8.6
extended reality
XR
all real and digital combined environments and human–machine interactions generated by computer technology and wearables

Note 1 to entry: Extended reality includes augmented reality, virtual reality and everything in between, like mixed reality. Extended reality captures the continuum of experiences from fully immersive digital environment to enhancements of the real world with digital content.

Note 2 to entry: In extended reality, brain–computer interface (3.1.2) can offer a broad spectrum of interactions. As extended reality blurs the lines between the real and digital worlds, brain–computer interface (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
use of telecommunications technologies to deliver medical, diagnostic, and treatment-related services

EXAMPLE Remote clinical services, such as monitoring a patient’s progress after treatment or therapy, and facilitating access to specialists that are remote from the patient.

3.8.8
telehealth
digital technology to deliver healthcare services remotely

Note 1 to entry: Telehealth enables users to access care virtually, anytime and anywhere. It includes a wider variety of remote healthcare services beyond the doctor–patient relationship, such as services provided by nurses, pharmacists, or social workers, who can help with patient health education, social support and medication adherence, and troubleshooting health issues for patients and their caregivers.

3.8.9
neuroergonomics
application of neuroscience to ergonomics for optimizing human–computer interaction and performance

Note 1 to entry: Neuroergonomics takes into account the user's cognitive and affective state to develop systems and work environments compatible with the subject’s capabilities and limitations.

3.8.10
biocompatibility
ability of a material used in the brain–computer interface (3.1.2) to perform its intended function without causing any adverse effects to the surrounding biological tissues of the user (3.4.2)

Note 1 to entry: Biocompatible materials used in brain–computer interfaces (3.1.2) do not harm the body or tissue. They include biocompatible polymers, metals, and semiconductors, which are used to reduce the risk of inflammation and rejection when in contact with neural tissue.

3.8.11
safety
assurance that the brain–computer interface (3.1.2) and its associated procedures will not cause harm to or adverse effects on the user (3.4.2)

3.8.12
physical safety
assurance that the brain–computer interface (3.1.2) and its associated procedures will not cause physical harm to the user (3.4.2)

Note 1 to entry: Physical safety includes safe surgical procedures for implantation, ensuring the device does not malfunction, and preventing any electrical discharges that can cause damage.

3.8.13
neurological safety
assurance that the brain–computer interface (3.1.2) and its associated procedures will not cause harm to neurological functions of the user (3.4.2)

Note 1 to entry: Neurological safety includes ensuring that the brain–computer interface (3.1.2) and its operation does not interfere with normal brain activity, does not exacerbate any existing neurological conditions, and does not introduce new neurological risks.

3.8.14
psychological safety
assurance that the brain–computer interface (3.1.2) and its associated procedures will not cause psychological distress or harm to the user (3.4.2)

Note 1 to entry: Psychological safety includes ensuring that the brain–computer interface (3.1.2) and its operation does not lead to negative psychological effects such as anxiety, depression, or identity issues. Psychological safety also involves considering the psychological impact of living with a device that is directly connected to a person's brain.

3.8.15
functional safety
assurance that the brain–computer interface (3.1.2) and its associated procedures function correctly, reliably, and predictably

Note 1 to entry: Functional safety means that the brain–computer interface (3.1.2) operates as intended, and that it has mechanisms in place to prevent or mitigate any harm in case of a malfunction.

Note 2 to entry: The objective of functional safety is freedom from unacceptable risk of physical injury or damage to the health of people either directly or indirectly.

3.8.16
misuse
inappropriate or incorrect use of the brain–computer interface (3.1.2)

Note 1 to entry: Misuse can include using the brain–computer interface (3.1.2) for purposes it is not designed for, or operating the system in a way that is contrary to its intended use. Misuse can lead to unintended consequences, including potential harm to the user or others.

3.8.17
overuse
excessive use of the brain–computer interface (3.1.2)

Note 1 to entry: Overuse can potentially lead to negative effects such as cognitive fatigue, decreased performance, or even dependence on the brain–computer interface (3.1.2).

EXAMPLE Adverse effects can result if the subject relies too heavily on the brain–computer interface (3.1.2), uses it for extended periods without breaks, or uses it in ways that can lead to physical or mental fatigue.

3.8.18
information security
preservation of confidentiality, integrity and availability of information

Note 1 to entry: In addition, other properties, such as authenticity, accountability, non-repudiation, and reliability can also be involved.

[SOURCE: ISO/IEC 27000:2018 [3], 3.28]

3.8.19
vulnerability
weakness of an asset or control that can be exploited by one or more threats

[SOURCE: ISO/IEC 27000:2018 [3], 3.77]