Brain Stimulation 12 (2019) 1349–1366

Contents lists available at ScienceDirect

Brain Stimulation

journal homepage: http://www.journals.elsevier.com/brain-stimulation

Transcranial electrical stimulation nomenclature

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ARTICLE INFO

Article history:
Received 8 February 2019
Received in revised form
25 June 2019
Accepted 14 July 2019
Available online 17 July 2019

Keywords:
Transcranial electrical stimulation (tES)
Terminology
Nomenclature
Classification
Brain stimulation

ABSTRACT

Transcranial electrical stimulation (tES) aims to alter brain function non-invasively by applying current to electrodes on the scalp. Decades of research and technological advancement are associated with a growing diversity of tES methods and the associated nomenclature for describing these methods. Whether intended to produce a specific response so the brain can be studied or lead to a more enduring change in behavior (e.g. for treatment), the motivations for using tES have themselves influenced the evolution of nomenclature, leading to some scientific, clinical, and public confusion. This ambiguity arises from (i) the infinite parameter space available in designing tES methods of application and (ii) varied naming conventions based upon the intended effects and/or methods of application. Here, we compile a cohesive nomenclature for contemporary tES technologies that respects existing and historical norms, while incorporating insight and classifications based on state-of-the-art findings. We consolidate and clarify existing terminology conventions, but do not aim to create new nomenclature. The presented nomenclature aims to balance adopting broad definitions that encourage flexibility and innovation in research approaches, against classification specificity that minimizes ambiguity about protocols but can hinder progress. Constructive research around tES classification, such as transcranial direct current stimulation (tDCS), should allow some variations in protocol but also distinguish from approaches that bear so little resemblance that their safety and efficacy should not be compared directly. The proposed framework includes terms in contemporary use across peer-reviewed publications, including relatively new nomenclature introduced in the past decade, such as transcranial alternating current stimulation (tACS) and transcranial pulsed current stimulation (tPCS), as well as terms with long historical use such as electroconvulsive therapy (ECT). We also define commonly used terms-of-the-trade including

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https://doi.org/10.1016/j.brs.2019.07.010
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electrode, lead, anode, and cathode, whose prior use, in varied contexts, can also be a source of confusion. This comprehensive clarification of nomenclature and associated preliminary proposals for standardized terminology can support the development of consensus on efficacy, safety, and regulatory standards.
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Scope and approach

The motivations for this classification document are multifold. There is a need to develop and implement standard language describing transcranial electrical (or electric) stimulation (tES) devices and methods in order to foster the advancement of clinical trials, regulation, and informed medical treatment. Such a consensus is currently lacking, reflecting a dearth of definitions for even extensively tested and apparently straightforward techniques like "tDCS" or for terms like "electrode" which are ubiquitous yet not well defined in the context of tES. A consensus on definitions helps inform clinicians and researchers on how to control tES delivery features relevant for safety and efficacy [1]. The historical lack of standardization in nomenclature has been identified as one potential impediment to the broader adoption of tES [2]. The ongoing advancement of tES science and clinical trials would be facilitated by consensus on protocols across groups based around a common nomenclature. Namely, when group A describes using what they term technique X, and group B describes the safety and efficacy of approach X, it should be clear by nomenclature if they are, in fact, discussing comparable tES techniques. Similarly, regulatory agencies and ultimately patients rely on classification to make informed decisions.

We present the first comprehensive analysis of contemporary tES nomenclature. Our approach is explicitly limited to the explanation of terminology used contemporaneously in tES publications, and thus not to suggest creation, revision, or embargo of terminology. Nonetheless, we provide context to terminology that may be ambiguous or specious. The compiled classifications consider features of stimulation such as indication for use, electrical waveform, electrode montage, and treatment schedules as relevant to define specific approaches. This document is specific to tES methods and does not address electrical stimulation using invasive electrodes, transcranial magnetic stimulation (TMS), transcranial ultrasound, or transcranial photonic stimulation. Terminology here is explicit to human tES use only, as animal models may adopt varied naming conventions. For a review of historical nomenclature that is uncommon in contemporary peer-reviewed publications (such as electrosleep) see Guleyupoglu et al. [2].

The outcomes of tES are not simply dependent on the nomenclature used but on the complete details of the administered dose [3], any combined task, subject state, clinical population being treated, inclusion/exclusion criteria, methods of assessment, as well as specific medical and subject factors [4,5]. Therefore, each study or clinical trial should also be evaluated based on integrating all these factors. For this reason, the use of any nomenclature does not reduce the need to fully report the dose used [3] as explained below (Section 2). Classification remains inevitable for practical purposes (i.e. there is a natural tendency to group and name technologies), and useful when applied rationally and consistently. The development of definitions may be guided by bridging across variations of a technique that theoretically inform each other. For example, two studies of "tDCS" with distinct electrode positions may result in different outcomes but, they may have a similarity in the general approach that allows these studies to closely inform each other and future efforts on "tDCS". Conversely, a study that claims to examine "tDCS" but in fact, used an unrelated and incompatible protocol will produce outcomes not relevant to the broader understanding of "tDCS". Though each classification developed here encompasses a range of related techniques that presumably inform each other, even when minor variations exist there may be differences in safety or efficacy.

There are two approaches [2] to defining classification of tES:

(i) **Physical: Method of stimulation application (dose)**, such as current waveform shape (e.g. direct current, alternating current) and amplitude, electrode montage, and timing of application (see Section 2); and/or

(ii) **Intended Use: Empirical or perceived outcome/site/target of stimulation,** which can span several non-exclusive categories:
   a. Hypothesized mechanism of action on the body (e.g. "excitability modulation", "network synchronization", "functional connectivity" changes); and/or
   b. Hypothesized anatomical target (e.g. "transorbital", "deep"), which reflects the region of interest rather than the (only) region influenced; and/or
   c. Expected outcomes/medical indication (e.g. neurorehabilitation)—this could be the primary outcome of interest in a given clinical trial, rather than the main/only outcome.

While a definition based strictly on physical method of application (e.g. DOSE as defined by Ref. [3]) reduces ambiguity), in practice most classifications of tES imply, to some degree, the expected mechanisms of action, nominal anatomical target, outcome of interest, or a combination of these. This is the case even when the technique name seems to derive purely from a physical dose definition. For example, tACS indicates sinusoidal rather than any biphasic ac waveform, and tACS further suggests low intensities. Thus, use of tACS implies a more restricted parameter space than just "ac" which in engineering may be any current amplitude and can refer to non-sinusoidal waveforms as well. Most tES classifications adopt an approach combining parameters (dose), intended mechanism, target, indication and/or outcome. In some cases, even the components of the stimulation device involve intent in their naming, such as the terms "active" electrode (the electrode, which is *presumed* to produce the intended outcome) and "reference" electrode (the electrode, which is *presumed* to not directly produce the intended outcome).

Our approach defines terms as used in the current scientific literature (see glossary Table 1); we avoid new terminology. Nonetheless, inconsistent and ambiguous use of terms required us to constrain or refine classification (rather than try to develop definitions inclusive of all historical uses of a given term). In defining classifications for tES, there is a compromise between broad classification (which allows for needed dose exploration and optimization) and more restrictive classification that creates the least possible ambiguity. In general, we adopted broader definitions, even including dose ranges yet to be tested, while also describing "conventional" practices that are limited to the common current uses. This nomenclature guidance is intended neither as a safety nor an efficacy review. The inclusion or exclusion of a

Table 1
Glossary of selected tES terms. These definitions should be understood as specific to usage in the tES literature only. Consult the text for a full definition.

Term	Abbreviated Definition	Section
Dose	Electrode montage and waveform (including shape, pulse width, polarity, frequency, duration, and amplitude of current as well as number and frequency of sessions)	2
Electrode montage	Number, size, shape, and position of all electrodes	2.1
Electrode, Electrode assembly	The electrochemical electrode (metal or conductive-rubber), electrolyte (gel, fluid, cream), and supporting structures (sponge, holder)	2.2, 2.3
Electrolyte	Electrically conductive fluid, gel, or cream that fills the space between the skin and the metal/conductive-rubber electrochemical electrode	2.4
Active, Stimulating, Return, Reference electrode	Related to presumed importance (active, stimulation) or unimportance (return, reference) of an electrode for a given brain target or outcome	2.5
Resistance, impedance	Total resistance of all electrodes and body in tested path before session (static) or during session (dynamic)	2.6
Headgear	Non-conductive accessory used to fix electrodes in position	2.7
Lead	Insulated conductor connecting electrodes to stimulator	2.8
Anode (Electrode)	Electrode where current enters body	2.9
Cathode (Electrode)	Electrode where current exits body	2.10
Monophasic, Unidirectional, Biphasic, Multiphasic (Waveforms)	If waveform has a single polarity (Monophasic, Unidirectional) or alternating polarity (Biphasic, Multiphasic)	2.11
Unipolar, Monopolar, Bipolar, Bilateral, Unilateral (Electrode montages)	Related to positions of electrodes relative to nominal target; if a single (unipolar, monopolar) or two (bipolar, bilateral, lateralized) electrodes are considered important for a given outcome	2.12
Non-invasive electrical stimulation	Electrical stimulation with non-invasive device; tES is non-invasive	2.13
Stimulation duration/Session duration	Time period from initiation to end of current flow, may exclude any amplitude ramp-up and ramp-down	2.14
Repetitive	Multiple sessions of tES	2.15
1×1 (Montage)	Only two electrodes	2.16
Limited output tES/tDCS	Stimulation meeting regulatory standards of limited output	2.17
Sham	Intended to not produce a given outcome while blinding subjects	2.19
Transcranial Electrical Stimulation (tES)	Non-invasive device intended to directly change brain function by passing electrical currents to the brain through at least one electrode on the scalp	3
Transcranial Direct Current Stimulation (tDCS)	tES with sustained direct current (dc) waveform	3.1
Dual tDCS	1×1 symmetric bilateral tDCS	3.1
High-Definition tES/tDCS	tES with small electrodes, a center electrode surrounded by a ring of electrodes of opposite polarity	3.1.1
Transcranial Pulsed Current Stimulation (tPCS)	tES with pulsed waveform	3.2
Transcranial Electrical Stimulation (TES, capitalized “T”)	tPCS with few, low-frequency, suprathreshold pulses	3.2.1
Cranial Electrotherapy Stimulation (CES)	Low-intensity tPCS FDA cleared as CES	3.2.2
Electroconvulsive therapy (ECT)	High-intensity tPCS sufficient to produce seizure	3.2.3
(Slow) Oscillating transcranial Direct Current Stimulation (so-tDCS), transcranial Sinusoidal Direct Current Stimulation (ts-DCS)	tES using monophasic current stimulation where the amplitude of stimulation is slowly modulated	3.3
Transcranial Sinusoidal Direct Current Stimulation (ts-DCS)	o-tDCS where the waveform is a monophasic sinusoid	3.3
Transcranial Alternating Current Stimulation (tACS)	tES using sinusoidal current waveform	3.4
Interferential Stimulation, Temporal Interference Stimulation	Two sine waves, both at high but slightly different frequencies, applied via two pairs of electrodes	3.4.1
Repetitive transorbital alternating current stimulation (rtACS), transcorneal electrical stimulation (TcES), transscleral electrical stimulation (TsES)	Electrodes are positioned near the eye with the aim to inject current to the eyeball to reach the nervous tissue of the retina and brain	3.5
Transcranial Random Noise Stimulation (tRNS)	tES with a noise waveform	3.6

protocol in a classification or a “conventional” range does not imply any judgment of safety or efficacy.

Following conventions of use in the field, tES classifications are not simply literal – meaning, a classification is rarely the amalgamation of the physical meaning of each word, with nothing less and nothing more. The classifications here are therefore proper names. Thus, tES classifications are typically more restrictive based on both dose and intent than implied by the broadest technical interpretation of its name (e.g. tACS). For this reason, we respect capitalization norms for acronyms – notably the common use of a lower case “t”. While we follow common practices for capitalization of names of techniques, we do not endorse strict criteria for lower/upper case acronyms.

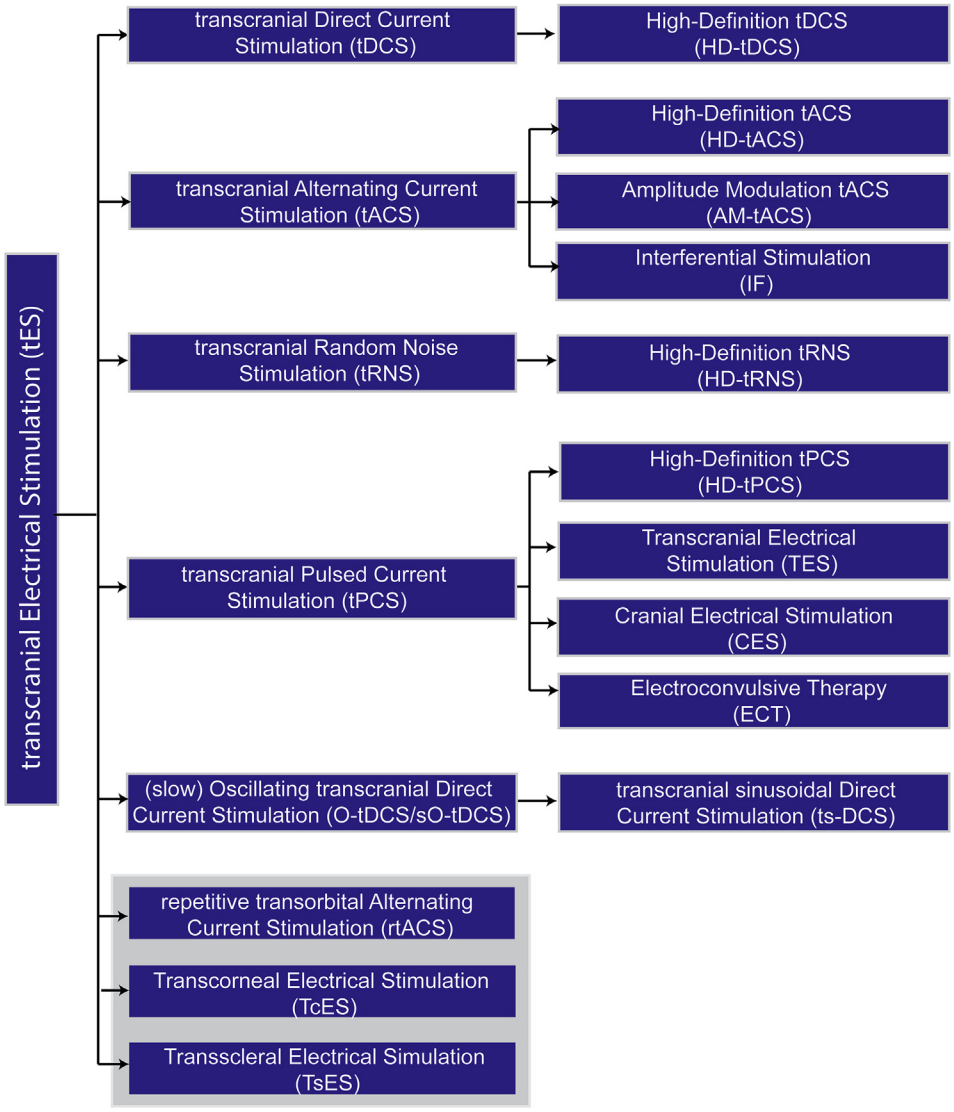

Fig. 1. Tree chart of transcranial electrical stimulation (tES) classification. The terms are organized here as defined in this consensus paper based on principles we developed including referencing both method of stimulation application (dose) and/or intended use, with reference to how terms are primarily used in tES literature rather than strict definition of each word. The categories are therefore not mutually exclusive (e.g. a technique may be both IF and HD-tACS) and a full report of stimulation dose (see Section 2) is always required in each publication for reproducibility. As explained in our classification approach, terms can reflect aspects of electrode montage, waveform, and/or intended outcome (e.g. if a technique is classified as rtACS or as tACS can depend on indication) – terms are defined here as commonly used in the literature without adding new qualifications or terminology. However, this organization of terminology into a classification tree is original to the present paper (e.g. ECT is typically not referred to as a type of tPCS). The grey box groups methods for techniques focused on vision rehabilitation.

The classifications of tES defined here are not mutually exclusive since they may involve overlapping dose and/or mechanism of action. For example, a stimulation protocol defined by the intent to restore visual function ("transorbital"), may in fact be identical to a stimulation protocol using ac current defined by its waveform ("tACS"). In some cases, definitions are a dependent sub-class (e.g. HD-tDCS is a type of tDCS). Fig. 1 summarizes tES definitions with their dependencies.

Though tES produces current densities at the scalp that are higher than in the brain [6], such that outcomes can also derive from stimulation of cranial and peripheral nerves, here "tES" is adopted to encompass all forms of cranial non-invasive electrical stimulation where at least some action is presumed to derive from current flow to the brain (a "direct" change in brain function). Electrical stimulation approaches *intended* to only activate peripheral nerves (e.g. trigeminal nerve stimulation) are thus not in the scope of this document. This distinction can be controversial since there is expected overlap between these two categories. Yet, it allows this document to be focused on transcranial techniques. Approaches intended to stimulate the eye (e.g. transorbital stimulation) are included here.

The paper is organized by first defining dose (Section 2)—the terms used to describe the tES stimulation parameters, which should always be reported, and which can qualify or describe the type of tES. The paper then defines classification of transcranial electrical stimulation methods (Section 3).

Stimulation parameter (dose) reporting for tES reproducibility

According to the definition by Peterchev et al. [3], tES DOSE comprises all parameters of the stimulation device that affect the

Table 2
Parameters of tES dose and related factors (adapted from Ref. [3]).

Stimulation Waveform Parameters[a]	Examples[b]	Section
For transcranial Direct Current Stimulation (tDCS): current amplitude, duration, and details of ramp up/down.	Amplitude of 2 mA applied for 20 min duration, with 30 s linear ramp up/down.	3.1
For transcranial Alternating Current Stimulation (tACS): current amplitude, frequency, and offset (dc bias) or details of ramp up/down.	10 Hz sinusoidal current with peak amplitude of 1 mA (peak to baseline), applied for 30 min, with no dc bias and a linear ramp up/down over 15 s.	3.4, 2.11
For transcranial Pulsed Current Stimulation (tPCS): pulse shape, amplitude, duration, polarity, inter-pulse-interval (pulse repetition frequency), inter-train interval (duration between pulse trains), total number of pulses.	Monophasic rectangular pulse, 4 mA peak current, 1 ms pulse width, train of 100 pulses at 100 Hz frequency, 10 s between pulse trains, 2000 total pulses (20 pulse trains).	3.2, 2.11
For Electroconvulsive Therapy (ECT): pulse shape, directionality, amplitude, width, train frequency, train duration, number of sessions, and interval between sessions.	Rectangular current pulses with 800 mA amplitude, 1.0 m s width, and alternating polarity, delivered at 40 Hz (pulse-pairs per second) for 4 s.	3.2.3
For repeated sessions, duration of all sessions, interval between sessions, and total number of sessions.	20 min daily, 5 days per week (weekdays only), for 4 weeks. OR Repeated within 18–26 h with 5 sessions completed in 5 days	2
If the dose is individually titrated for efficacy or safety: Describe the titration procedure method (formula) and how the final dose is determined. Ideally, report dose per subject, but at a minimum descriptive statistics on the dose across the whole population of subjects/patients participating in the study should be provided. Optionally, the dose applied at each iteration and the final dose applied may be reported.	Subject 1: 2.0 mA amplitude Subject 2: 1.5 mA amplitude OR Increase amplitude by 0.5 mA increments every 30 s until subject reports sensation. Experimentally resulting in amplitude range of 1.0–2.0 mA with an average amplitude of 1.5 mA and a SD of 0.5 mA	2
Montage and Electrode Assembly (including conductive solution)		
All electrode assembly components including electrode, conductive solution (electrolyte), and any supporting materials (e.g. sponge). If a well-defined manufacturer/model is used, it may be sufficient to report it, but to reduce ambiguity key features should be specified. The reporting of a unique product model may allow collection of manufacturing details not apparent to the researcher (e.g. product materials); however, basic electrode assembly description should still be provided to minimize ambiguity.	7 × 5 cm sponge; sponge material – e.g. cellulose pocket area, 2 cm thick per sponge; 3 × 5 cm area conductive rubber electrode centered inside sponge pocket with 0.9% isotonic saline. Electrode Model Z and Gel Model Y by Company X.	2.2, 2.3
Electrode position on the scalp relative to a clearly defined (reproducible) system (e.g. 10–10, landmarks, imaging, or evoked neurophysiology). This must be specified for all electrodes.	Pad centered on F4 (EEG 10-10) and oriented orthogonal to vertex, OR The position labeled "F4" on Company X, Cap Y, OR Centered on motor "hot spot" as identified by TMS, OR Positioned on forehead with the bottom center of the pad directly above the eyebrow and centered on the eye.	2.1
Electrode composition, head-gear, equipment, and subject preparation		
Skin preparation techniques.	Gentle alcohol wipe, OR Abrasion, OR None.	–
Head gear	Two 5.1 cm wide elastic fasteners made with hypoallergic rubber, affixed with 2 plastic joints.[c]	2.6

[a] Complete characterization of waveform of electrode voltage (for voltage-controlled devices) or current (for current-controlled devices).
[b] Examples are intended to illustrate how to apply/report parameters and are not intended to prescribe any specific or preferred implementation.
[c] Researchers apply different forms of head-gear which may vary outcomes even if dose is maintained; for example, variations in pressure on scalp can influence adverse events such as pressure headache or erythema [8].

electromagnetic field generated in the body. Dose thus includes the stimulation waveform (e.g. ac/dc or pulse shape); its frequency, amplitude, and duration; the number of electrodes and their size and shape, as well as the number and frequency of stimulation sessions (see summary and examples in Table 2). To allow for the interpretation and reproduction of tES methods, it is critical to report the complete dose with *all* relevant parameters of stimulation (Table 2). Complete details of the electrode assembly must also be provided, including electrode material, coupling medium, electrode size (surface area), electrode thickness, and any relevant details on electrode single-use or re-use [7].

The classification (name) of an approach usually reflects only a subset of the dose parameters, and perhaps the intended outcome. For example, tDCS may be defined by only the waveform parameters (e.g. low amplitude dc), irrespective of electrode montage. Of course, knowledge of the electrode montage is needed to reproduce a given tDCS method. Therefore specifying only the classification of a method is insufficient to allow for reproducibility. Classifications may also reflect the process used to select the dose (e.g. subject titration, prior experience) and summary metrics (e.g. electrode current density or total charge), but this still does not reduce the need to report the complete final dose applied.

This section attempts to disambiguate terms that are used to describe technical aspects of tES methodology and specify the dose in a given protocol.

Electrode montage/configuration

Electrode Montage (or Configuration) typically refers to the number of electrodes (minimum 2), their respective size and shape, and the method by which they are fixed on the head. Electrode position on the scalp (and body for extracephalic electrodes) should be defined using any principally reproducible system, which can include EEG 10–10 (e.g. "electrode position C4"), anatomical landmarks (e.g. "supraorbital"), imaging, or evoked neurophysiology (e.g. "over the motor hotspot identified by TMS"). Montage

should be specified for all electrodes. As defined here, electrode montage, includes, therefore all aspects of dose except waveform. However, in some publications electrode montage may be used interchangeably with dose. This is discouraged to the extent that it leads to ambiguity between dose, which includes waveform, and montage, which does not.

Electrode assembly

The ELECTRODE ASSEMBLY refers to all components that carry current between the connector-end of device lead wire and the scalp such as metal electrode, conducting rubber electrode, electrolyte, sponge, as well as materials used to shape these components or otherwise direct current flow (casing, sponge, rivets). The headgear used to position the electrodes on the body or scalp is typically distinct from the electrode assembly (e.g. non-conductive headstrap), but in some designs the components of the electrode assembly may be embedded into the headgear. In tES the term "electrode" (see Section 2.3) is commonly used to designate the entire electrode assembly.

Electrode

PHYSICAL ELECTRODE (not a term standard in the tES literature) refers to the material (or surface) where charge carried by electrons is converted to charge carried by ions. For tES, this is limited to the surface of the metal and/or conductive rubber in contact with the electrolyte (such saline or gel). In tES, however, ELECTRODE is used to refer to the entire electrode assembly (see definition in Section 2.2). In electrochemistry, electrode refers only to the interface of the "physical electrode" metal/conductive-rubber (or other electron carriers) with saline/gel (or another electrolyte). In some forms of tES, especially tDCS, this physical electrode does not touch the skin for safety reasons, whereas in other forms of tES, such as ECT, the physical electrode may be pressed directly against the scalp depending on the device type. Reproducibility can be limited by ambiguities in referencing either the whole electrode assembly or just the physical electrode. For example, it should be made clear if the provided dimensions (e.g. 5×5 cm) refer to just the physical electrode (e.g. the conductive rubber or metal surface contacting the ionic medium) or to the overall electrode assembly (e.g. gel surface of sponges contacting the skin).

It is customary to discuss montage (placement) and waveform applied with respect to a specific electrode. For example, delivery of 1 mA to an electrode implies delivery of 1 mA through the electrode assembly and the electrode interface. Use of an electrode as an "anode" is physically correct and implies the electrode assembly functions as an anode. In most forms of tES, electrode size conventionally refers to the overall electrode-assembly surface area in contact with skin, unless otherwise indicated (see Electrolyte). Therefore, the convention in the literature of calling the entire electrode-assembly the "electrode" is manageable provided: (i) the distinction between the physical electrode and electrode assembly is clear; and (ii) overall details of the electrode assembly, including the electrode design, are explicit.

Electrolyte

The ELECTROLYTE is the component of the electrode assembly where charge is carried by ions. It is in contact with both the physical electrode and the skin and also completes a circuit of electrical current flow. The electrolyte may be saline or another salt-containing solution [9], hydrogel, or fatty (oily) cream. To prevent spread, fluid electrolytes may be suspended in a porous material like a sponge and/or contained by a holding vessel like a cup. In some cases, such as with fatty creams, the electrolyte may be sufficiently viscous not to require a suspension. In some application, such as tDCS, the electrolyte is a barrier between the physical electrode and the skin such that the minimum distance between the physical electrode and the skin is the electrolyte thickness. This minimum distance may be determined by a non-conductive (e.g. plastic) separator or holder, by sponge thickness, or by the thickness of the paste. When the physical electrode is in direct contact with the skin, as in ECT, the electrolyte fills in any air gaps between electrode and skin surfaces.

Some studies have used water to saturate tES electrodes; in such cases the water contains ions and/or absorbs them from the skin. "Salt-free" gels and creams have also been evaluated for tES [10], but often have other chemical substitutes for supporting charge transfer.

The total surface area where the physical electrode and/or electrolyte interface with the skin is typically referred to in tES as the electrode size (e.g. "5×5 cm^2 electrode" or "5 cm diameter disk electrode"). The surface area where the electrolyte interfaces with the physical electrode is typically different than where the electrolyte interfaces with the skin area.

"Active"/"stimulating", "return"/"reference" (electrode)

The terms RETURN or REFERENCE electrodes have been typically used to describe an electrode that is presumed to be less relevant to the intervention outcomes of interest. For example, an electrode may be given this designation if it is not in proximity to brain regions of interest for a particular intended use. Similarly, the physiological activity of electrodes can be reduced for example by increasing the electrode size or using a ring of electrodes, which reduces the current density in the vicinity of these electrodes [11,12]. However, all electrodes are functional in the engineering sense if they are used to carry current. Even if they are assumed to be unimportant to the hypothesis being tested, the configuration and polarity of these electrodes will affect current distribution in the brain and must, therefore, be explicitly reported. This applies to extra-cephalic electrodes as well, since they also affect the current flow in the brain [13,14]. For voltage-controlled stimulation [15], the term "reference" may also be used to define polarity in an engineering sense (e.g. "5 V relative to the reference electrode"). In all these scenarios, the configuration and position of the "return" electrode can influence current flow near/under the "active" electrode.

Analogously, the terms ACTIVE, STIMULATING, or TARGET ELECTRODE have been typically used to refer to the electrode presumed to be physiologically active in regard to the primary intervention outcome – or more specifically that the physiological or behavioral outcome of interest is due to current passing through these electrodes. In stimulation systems with multiple electrodes (three or more), there can be the ability to use some electrodes and not others for stimulation; for example, in a three-electrode system to pass +1 mA at one electrode, −1 mA at another electrode, and 0 mA (no current) at the third electrode. Electrodes without current are unused and, in this context, referred to as INACTIVE, any electrode with non-zero current considered ACTIVE. Such a situation is typical for implanted systems, where extra electrodes provide for programming flexibility. For those tES systems where electrodes are applied individually (one at a time), the placement of unused (inactive) electrodes would be generally unnecessary. Multichannel (HD) tES systems that include head-gear embedded with an electrode array may operate using a selective sub-set of electrodes for stimulation (active electrode) with the remainder inactive [16–18], but this use of terminology is rare in the tES literature.

"Active", "stimulating", "target", "return", and "reference" are thus terms that relate to the "intent" of stimulation, or (less

commonly) used casually with no specific functional implication. If these terms are used it should be with (i) the recognition that despite intent, the physiological actions of stimulation are exerted by a complex distribution of electrical current flow between the two (or more) electrodes, and (ii) the complete documentation of the stimulation dose (e.g. it is never appropriate to omit details of reference electrode size, placement, and materials). Generally, using objective engineering terminology such as "anode" and "cathode" (see definitions in Sections 2.8 and 2.9) can reduce the implication of intent or assumed physiological role of electrodes.

Resistance and impedance

Resistance is a ubiquitous term in tES and considered important in pre-testing and monitoring of stimulation. When tES is current-controlled, the voltage output of the stimulator (between two electrodes or between an electrode and a reference) is adjusted to maintain a controlled current. In the context of tES, the term RESISTANCE usually refers to this voltage at the output of the device divided by the applied current, per Ohm's law. To measure resistance prior to stimulation, the stimulator applies a small test current and the resulting voltage is recorded. The resistance is then calculated through Ohm's law by dividing the voltage by the test current.

The resistance measured is the sum of the resistance of the electrodes [19] and the body, including the skin and the skin–electrode interface. A high resistance may, therefore, reflect a high resistance of one (or more) electrodes, or the skin contact. An atypically high resistance can be a sign of a setup problem such as poor electrode contact or insufficient electrolyte. Therefore, when resistance is tested before stimulation, it helps the operator to identify suboptimal set-up and take corrective actions that could lower the resistance. Similarly, during stimulation, an atypically high resistance may indicate non-ideal conditions at the electrode or skin. However, once stimulation begins there are fewer options by the operator to correct the setup, and in some cases, stimulation is aborted.

A subtle point is that resistance can change with the applied current and waveform. For this reason, the resistance measured before stimulation by the low-test current (which can be referred to as STATIC impedance) would be different than the resistance measured using application-specific currents during stimulation (which can be referred to as DYNAMIC impedance). Nonetheless, the test resistance before stimulation is considered a meaningful predictor of resistance during stimulation—a suboptimal set-up will usually result in atypical resistance already in the pre-stimulation test period. Still, because static resistance and dynamic resistance vary, and also conditions may change over time during a session, resistance during stimulation is monitored.

What qualifies as a "high" resistance is application-specificed. It is important to emphasize that a relatively low resistance is not a guarantee of optimal setup. Rather it is incumbent on the operator to employ best practices in electrode preparation and setup, and subject and device monitoring [20], with resistance measurement serving as a secondary marker. In addition to potentially indicating non-optimal electrode–skin contact, a high resistance would increase the stimulator output voltage required to provide a given current. If the required output voltage is too high, it may exceed the maximum (compliance) voltage of the tES device, which may result in current reduction or the device aborting stimulation [21].

As a technical note, the electrode and tissue are never simply "resistive" (either before or during stimulation). For example, the calculated "resistance" depends on the strength of the current, meaning that the resistance is nonlinear [22]. The term "impedance" refers to the broader relation between the applied current and the voltage needed to maintain this current flow. The impedance also includes frequency-specific responses (e.g. the response to sinusoids of varied frequency or brief pulses). Moreover, electrodes, tissues, and their interfaces have complex nonlinear impedances that may vary over time (i.e. are time-variant) [23–26]. However, "resistance" and "impedance" are often used interchangeably and nonspecifically in the tES literature, typically relying on how a given tES device tests and reports values. While across tES devices, resistance/impedance is typically calculated in devices by dividing the peak voltage measured by the peak current applied, the static resistance (or impedance) reported by two different tES devices on the same electrode set-up may differ because tES devices do not use a consistent test current—different tES devices use various test current intensities or waveforms (e.g. dc vs brief pulses).

Headgear

All components that are used to position and hold the electrode assembly to the body are part of the HEADGEAR. As defined here, the headgear is primarily fabricated using non-conductive components (e.g. elastic or fabric). However, some conductive components like the electrode assembly and/or the lead wires may be (partially) integrated into the headgear. The headgear serves to hold these components in place, position them relative to the scalp, and/or facilitate set-up. In some applications, the electrodes are held in place by the operator, such as the plastic handles that support steel-disk electrodes in ECT. In such cases, there is no headgear but details of how electrodes are supported should be provided.

Lead

The LEAD is a wire used to connect the electrode to the stimulator output. The wire is insulated except at the device (proximal) and electrode (distal) terminal. The distal terminal is typically connected to the electrode in a manner such that the material of the lead wire does not contact the electrolyte or skin. If the lead contacts the electrolyte, then the lead terminal becomes an electrode.

Anode/anode electrode/anode electrode assembly

At the ANODE, positive current enters the body. For two-electrode systems the anode has a positive voltage relative to the cathode. If a current-controlled waveform applied to any given electrode changes polarity (for example if a biphasic sinusoid is applied such that the current direction to any given electrode changes direction), then the electrode may technically not be an anode for the entire waveform of stimulation. Thus, for tPCS biphasic pulses, the polarity of a specific (e.g. the initial) phase of the pulse should be specified (e.g. "anodic-first"). For this reason, "anode" is not used in biphasic stimulation. Rather, if the waveform is symmetric, polarity may be ignored (e.g. sinusoid with zero offset) as the electrodes are interchangeable in this sense. If the waveform is asymmetric, the polarity of the waveform should be specified relative to specific electrodes (e.g. 5 mA square pulse applied from electrode 1). In tDCS, electrode polarity does not change by definition. The separate terms of "anodal" and "anodic phase" are used to describe the hypothesized mechanism of stimulation or pulsed waveform detail, respectively (See Section 2.11).

Cathode/cathode electrode/cathode electrode assembly

At the CATHODE, positive current exits the body. See also polarity notes in Anode definition above. The separate terms of "cathodal" and "cathodic phase" are used to describe the hypothesized

mechanism of stimulation or pulsed waveform, respectively (See Section 2.11).

Monophasic, unidirectional, biphasic, multiphasic (waveform)

If during a session any given electrode functions always as either a cathode or an anode (meaning the current through each electrode is in a fixed direction, though the magnitude may change) then the stimulation is MONOPHASIC (Fig. 2). Monophasic should not be confused with stimulation with only an anode or only a cathode, which is technically impossible since all stimulation involves at least one anode and one cathode. UNIDIRECTIONAL is used to indicate monophasic. A monophasic waveform must be defined relative to one electrode (e.g. "1 mA, 1 ms monophasic pulse with electrode A as anode and electrode B as cathode," or "1 mA, 1 ms monophasic pulse from electrode A to electrode B").

If during a stimulation session any electrode changes from an anode to a cathode for any period of time, then the stimulation is MULTIPHASIC. BIPHASIC typically indicates stimulation with two phases (modes) that are alternated (e.g. anode and cathode switch) during stimulation (Fig. 2). The importance of clarifying waveform polarity relative to electrodes can depend on the waveform. For example, for tACS the symmetry and continuous nature of the waveform suggests the waveform does not need to be defined respective to one electrode (e.g. it is sufficient to say "2 mA peak, 20 Hz sinewave current between electrodes A and B"). However, for asymmetric waveforms (e.g. two pulse phases with different amplitude and duration, Fig. 2) it is important to specify waveform relative to one electrode (e.g. "leading pulse phase of 1 mA for 1 ms with electrode A as anode and electrode B as cathode, and a recovery phase of 2 mA for 0.5 m s with electrode B as anode and electrode A as cathode").

Monophasic or biphasic pulses are typical waveforms used in some forms of tES like tPCS. Pulses are applied repetitively in a train, with the inverse of the time between pulses as the stimulation frequency. Unless otherwise specified, individual pulses are assumed to be rectangular. Individual pulses have a pulse duration (width) and amplitude. A waveform of pulses can be monophasic or biphasic. Monophasic waveforms have pulses of a single polarity (Fig. 2), while biphasic waveforms have pulses that invert polarity, typically in paired opposite-polarity phases [19]. Wave types beside pulses typically take the form of a simple periodic waveform, such as a sinusoid (Fig. 2). In the case that pulses are not evenly spaced in time, any burst patterns or on/off times should be reported (Fig. 2).

When waveforms are monophasic, asymmetric biphasic, or symmetric biphasic but with importance of phase (e.g. phase order), then the polarity of the waveform needs to be defined with respect to the electrodes (e.g. "monophasic square wave with 5 V

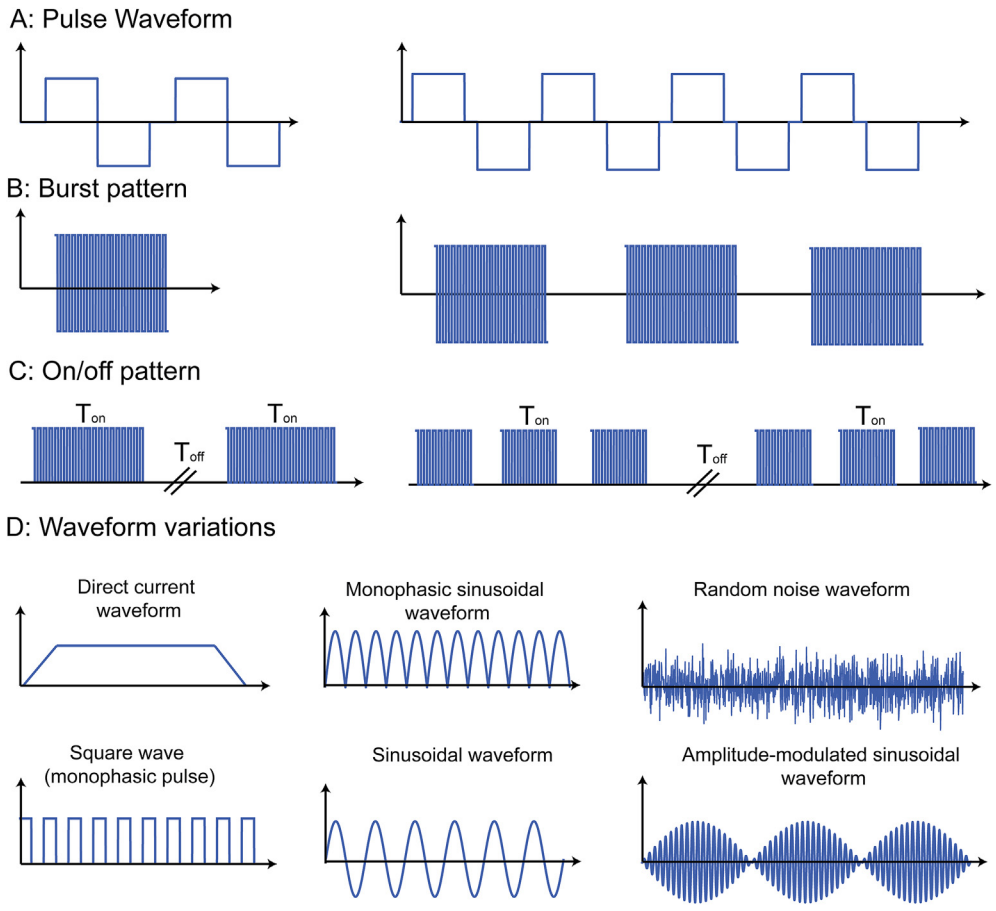

Fig. 2. Overview of terms used to describe waveform in tES. A–C address waveforms composed of rectangular pulses with expanding temporal scale, while D shows additional waveform types. A: The pulse train waveform is specified by parameters including the frequency, pulse shape, width, amplitude, and interphase delay as well as the pulse repetition frequency. B: The burst stimulation pattern includes the repetition time and number of pulses or cycles per burst; if no burst pattern is reported then the stimulation pattern is continuous. C: The on/off period (duty cycle) describes the time the stimulation pattern—continuous or burst—is active/inactive. D: Direct current has a fixed amplitude but may include ramp up/down and is, by definition, monophasic. Unless otherwise indicated, sinusoidal stimulation has a single frequency and is symmetric biphasic (no dc offset). Monophasic sinusoidal/pulse waveforms have single polarity. Amplitude-modulated sinewave is a high-frequency sine modulated by a low-frequency envelope. There are various types of noise-based stimulation, conventionally with no dc offset.

peak from electrode A to electrode B″). As noted (Section 2.8), in electrical stimulation an anode electrode always indicates an electrode where, a given moment in time, current (defined as flow of positive charge) enters the body and the cathode electrode indicates an electrode where current simultaneously exits the body [19]. Since in all electrical stimulation there is always an anode and a cathode present, the terms "anodal stimulation" can simply indicate that the nominal target is near the anode electrode [7]. Similarly, "cathodal stimulation" is also a statement of hypothesis indicating that the nominal target is near the cathode electrode (e.g. "cathodal stimulation of motor cortex" indicating that the cathode electrode is placed proximal to the motor cortex; see anodal/cathodal in tDCS (Section 3.1). Alternatively, in some cases like bilateral monophasic stimulation, "anodal"/"cathodal" indicates the polarity of the waveform (e.g. "an electrode was placed on each mastoid with anodal right stimulation"). Finally, in some applications where biphasic stimulation is used (such that each electrode can alternate between anode and cathode), the terms "anodic phase" and "cathodic phase" will be used (e.g. a cathodic pulse phase is followed by an anodic pulse phase). In this sense, when brain stimulation is assumed to be driven by one phase, the terms "anodic stimulation" and "cathodic stimulation" are used (e.g. monopolar cathodic stimulation, where a cathodic activating phase is followed an anodic phase used for charge recovery) [19].

Unipolar, monopolar, bipolar, bilateral, unilateral (electrode montage)

Conventionally, UNIPOLAR or MONOPOLAR indicate an electrode configuration with one relatively small electrode near a nominal target and another (e.g. "return") electrode that is relatively large and/or some distance from the nominal target (e.g. extracephalic location). In contrast, a BIPOLAR montage indicates two electrodes of the same size and both relatively near the target and/or intentionally across the target [27]. While for invasive stimulation the use of unipolar/bipolar are well defined and related to stimulation outcomes, for tES these terms may reflect more the intent of stimulation than the resulting brain current flow patterns (see also "Active", "Stimulating", "Return" or "Reference" electrode). In tES, the rationale for unipolar/monopolar montage terminology is typically the assumption that an electrode position closer to the nominal target and/or a relatively smaller size electrode will play a key role in producing the intended outcomes compared to the other, farther and/or larger electrode. In tES, however, if and how a larger electrode reduces its relative potency depends on details of dose and the selected outcome measures [28–34]. For the case of 4×1 HD-tDCS, the polarity set by the center electrode and diffusion of return current to the four surrounding electrodes may produce a functionally unipolar current flow [35].

We emphasize that all tES must have an equal amount of current entering and exiting the brain. This includes montages with extracephalic electrodes, where current under the cephalic electrode is balanced by current through the inferior surface of the brain (and across deep and mid-brain structures). For example, in tDCS, the total magnitude of inward direct cortical current is equal to the total magnitude of outward direct cortical current. Thus, while some terminology such as cathodal-tDCS or anodal-tPCS suggest a unipolar mode of action, these are rather statements of hypothesized mechanisms of action based on proximity to the nominal physiological target.

Since all tES has (at least) two electrodes, the rationale for explicit "bipolar" montage terminology may relate the intention to stimulate two regions near both electrodes or a larger region spanning both electrodes. When electrodes are placed on the head, especially to target structures in both hemispheres, the montage may be referred to as BILATERAL. This typically symmetric electrode placement on each hemisphere [36]. When only two electrodes are used for bilateral montages, it is also bipolar. More electrodes (e.g. four [37]) can also be used in bilateral montages. Bifrontal typically indicates a symmetric bilateral montage on the scalp across frontal brain regions; bitemporal—across the scalp overlying temporal cortex of both hemispheres; and bifrontotemporal—an intermediate position between these two. For ECT, bifrontal and bitemporal further refer to specific electrode placements (see Section 3.2.2).

In summary, biphasic/monophasic refer to waveform (defined separately) and are independent of the bipolar/unipolar/bilateral electrode configuration (i.e. bilateral indicates placement of electrodes while biphasic indicates waveform). With monophasic waveforms, each electrode in a bipolar montage may be assumed to have distinct effects since it is either an anode or a cathode.

tDCS is by definition monophasic, with the anode and cathode (defined in Sections 2.8, 2.9) considered functionally distinct, thereby leading to specialized terminology. Bilateral tDCS is also called DUAL-TDCS where both electrodes are considered "active", which may be symmetric or not symmetric [38]. LATERALIZED tDCS typically refers to a symmetric bilateral bipolar (two-electrode) montage with the intention to differentially modulate hemispheres [39–42]. BIHEMISPHERIC tDCS may be used interchangeably with bilateral tDCS when two electrodes (bipolar) are used [43–48]. Or bihemispheric tDCS can indicate the case when electrodes of the same polarity are placed on both hemispheres (e.g. two anodes, one on each hemisphere) and a third electrode of opposite polarity is placed elsewhere (e.g. extra-cephalically)—this can be further specified as BIHEMISPHERIC ANODAL/CATHODAL tDCS or referred to as BILATERAL BICEPHALIC tDCS.

Technically, any montage with an electrode on the contralateral supra-orbital (SO) region is non-symmetric bilateral (if only two electrodes are used, it is also bipolar), but is not typically referred to as such in publications as the SO electrode (which can be anode or cathode) is considered the "return". In such cases the term UNIHEMISPHERIC is used to indicate the relative asymmetry [49,50]; but like many terms, this should be understood as a statement of functional hypothesis. UNILATERAL may indicate the nominal brain targets are in one hemisphere, which may be implemented in tES by placing all cephalic electrodes over one hemisphere, or more commonly using extracephalic electrodes [51,52]. Terminology can easily get convoluted, for example when electrodes of the same polarity are placed on the same hemispheres (e.g. two anodes on the same hemisphere) and a third electrode of opposite polarity is placed elsewhere (e.g. extra-cephalically), the configuration can be referred to as UNILATERAL MULTIPLE MONOPOLAR [53]. Moreover, in some studies, "unilateral" (like "unihemispheric") is used to refer to a montage with a contralateral supra-orbital (SO) position of the "return" electrode, especially when the goal is to contrast with symmetric bilateral bipolar montages [54–56]. A 4×1 HD-tDCS montage (defined in Section 3.1.1) can be used when the goal is to actually restrict current flow to one hemisphere [57–59].

In summary, tES current flow patterns are more diffuse and complex than with invasive stimulation. Many terms relating to electrode montage are indicative of presumed mechanisms of action (e.g. a nominal brain target and mechanism of neuromodulation) rather than the physics of current flow patterns.

Non-invasive (electrical stimulation)

NON-INVASIVE medical procedures are typically defined as not breaking the skin or entering a body cavity. Non-invasive medical devices do not involve an invasive medical procedure. tES is thus non-invasive. While the current delivered by any form of tES (including ECT) crosses into the body and produces physiologic

responses (including changing skin properties), this does not meet the standard for an invasive medical procedure/device any more than a stone used for massage (which transfers physical force into the body) or a heating blanket (transferring heat into the body).

Stimulation duration/session duration

STIMULATION DURATION refers to a limited (fixed) time period of administration of a set program of tES. In some uses, stimulation duration is defined as the time period from initiation to end of current flow, which may include amplitude ramp-up or ramp-down periods that are used to enhance tolerability. In typical uses, the duration of tES is limited to the period of time when tES is at the target maximal amplitude (e.g. 2 mA), thereby omitting ramp up/down periods. To avoid ambiguity, protocols should clearly define the content of "duration". For example, one could state that "the overall duration of the current flow was 21 min including ramp-up and ramp-down periods for 30 s each" or "the overall duration of the stimulation was 20 min, with an additional 30 s ramp-up and 30 s ramp-down."

When a waveform is defined as part of a classification, this conventionally refers to the waveform after ramp-up and before ramp-down, though typically assuming that during the ramp-up/ramp-down the waveform is the same but of increasing/decreasing peak amplitude (e.g. 10 min of 2 mA 10 Hz tACS starting/ending a ramp-up/down of 10 Hz ac for 30 s each). Some waveforms may have no ramp-up/down, especially those of very brief session duration (e.g. ECT, Section 3.2.3) or where the waveform is itself modulated (e.g. so-tDCS, Section 3.3).

Session duration may be defined in various ways. In some uses, it may be equivalent to stimulation duration, whereas in other uses it may also encompass the overall time of an experimental or clinical procedure, including subject set-up, instructions, application of electrodes, tests unrelated to tES, anesthesia administration, removal of electrodes, etc. Potentially, multiple tES classifications with specified durations could be applied within the duration of a single session.

Repetitive

The phrase REPETITIVE is uncommon in the context of tES classifications, and when used typically refers to multiple sessions. For example, repetitive transorbital alternating current stimulation (rtACS) is specific to multiple sessions of stimulation, with an intended outcome of neurorehabilitation that depends on multiple sessions. In other electrical stimulation applications, "repetitive" may alternatively be used when describing pulsed waveforms within a single session—this is the typical use in repetitive transcranial magnetic stimulation (rTMS) as it differentiates from single-pulse TMS. But for tES, repetition of sessions is usually not incorporated in the classification, except for a few rare cases where specifically relevant. The schedule of multi-session tES will be described by the number of sessions and rate of repetition (e.g. "daily on weekdays for a total of 10 sessions over 2 weeks"). There is evidence that repeated sessions across days or within days can produce cumulative effects [60,61]; however, describing a protocol with multiple (repeated) sessions (e.g. 2 sessions of tDCS per day) typically does not warrant new terminology.

1 × 1 (montage)

The 1 × 1 MONTAGE refers to tES deployment with only two electrodes. For monophasic stimulation, like tDCS, this indicates one anode electrode and one cathode electrode.

Limited-output tES

LIMITED-OUTPUT tES was previously defined for the purposes of reconciling regulatory controls (following FDA conventions to reduce the regulatory burden for limited-output devices) with tES dose used in modern clinical trials [21]. Limited-output tES restricts dose including:

a) A maximum charge per phase that does not exceed Q, where $Q = 20 + 28 \times t$ μC, where t is the phase duration expressed in ms and measured at 50% of the phase amplitude.
b) A maximum average current that does not exceed 10 mA.
c) A maximum primary phase duration that does not exceed 500 μs except as specified in (g).
d) The current is minimized when no stimulation is being applied.
e) A maximum current density that does not exceed an rms value of 2 mA/cm^2 on the physical electrode surface.
f) A maximum average power density that does not exceed 0.25 W/cm^2 on the physical electrode surface.
g) For devices using direct current or continuous sustained current passage greater than 1 s, or square wave, or rectified or bias sinusoidal, or pulses with >25% duty cycle including all phases, if the maximum average current does not exceed 4 mA (average absolute value) then criteria (a), (c), and (d) are waived.
h) A maximum peak output current that does not exceed 30 mA (at any instant for all electrodes combined).
i) A maximum time per individual session that does not exceed 60 min.
j) A maximum total charge per session that does not exceed 6000 mC.

Limited-voltage tDCS

LIMITED-VOLTAGE TRANSCRANIAL DIRECT CURRENT STIMULATION includes devices and protocols that meet all the criteria of (i) tDCS; (ii) Limited-Output tES; and (iii) maximum output below 20 V [22].

Sham

In tES studies, SHAM indicates a dose and ancillary procedural features (e.g. device appearance and sounds, application procedure) which are intended to serve as a control arm against an active condition, for example in testing the efficacy of a tES intervention (active condition against sham condition). Conventionally, tES sham is intended to produce experiences in the subjects that limits the ability of subjects to guess (greater than chance) which study arm they are participating in (supporting single-blind experiments), while removing or reducing the aspect of stimulation that is thought to mediate the intended effects of tES [7]. For example, a common objective of tES sham is to replicate the scalp sensation of stimulation while minimizing the delivery of an electric field to the brain. A common sham approach is the "fade in and out" where the current is increased gradually (as typical in the active arm) but then ramped back down, thereby creating a transient sensation that is not expected to produce significant neuromodulation. The fade in and out can be applied at the start of the session [62,63], at the end of the session, and/or at random intervals during the session [64]. Because current is applied, this is also referred to as "active sham", which is not to be confused with "active control" when the same waveform is applied using a different electrode montage.

Additional approaches to sham, such as using two adjacent High-Definition electrodes, have been proposed [65]. It is important in any discussion about the appropriateness of a given sham condition [66,67] to consider the explicit goals of the sham arm [63,68]. It is also important to recognize that the effectiveness of a sham depends on the degree of sensation produced in the active arm, which in turn depends on the electrode design; thus, better electrode design that reduces sensation in the active arm can enable more reliable sham-controlled experiments.

Transcranial electrical stimulation (tES)

The term TRANSCRANIAL ELECTRICAL (OR ELECTRIC) STIMULATION (tES) is the preferred nomenclature for any non-invasive device intended to directly change brain function by passing low- or high-amplitude electrical currents, of any waveform, through at least one electrode on the scalp [1]. The total amount of current entering the body at one (or the sum of several) electrodes must be equal to the total current exiting the body at one (or the sum of several) electrodes – i.e. the total current in and out of the body must be equal at any instant. This is true when the current does not change polarity in monophasic stimulation or when current does change polarity in biphasic stimulation. For this reason, it is possible to describe the current strength, at any given instant or the peak amplitude over the course of a session as one number (e.g. 2 mA) rather than needing to specify independently the positive and negative current (e.g. +2 mA and −2 mA for the anode and cathode, respectively).

Though variants to tES as a global classification have been proposed, inspection of relevant historical [2] and modern literature confirms tES is the most conventional terminology [1]. "Non-invasive brain stimulation" (NIBS) and "transcranial brain stimulation" are not specific to electrical techniques. The alternative term "transcranial current stimulation" (first used in only 2008 [12]) is comparatively rare. While upper-case first letter, "TES", may be used, it could be confused with the specific variant using supra-threshold single pulse waveforms [69].

The intended outcome of tES includes direct actions on the central nervous system (even if peripheral actions such as cranial nerve stimulation, peripheral vascular effects, and/or muscle activation cannot be excluded). Specific intended outcome often appears, alongside dose characteristics, as part of tES classification. Devices that use any implanted electrodes, including intra-cranial or subcutaneous, should not be included in tES (regardless of whether such techniques result in current passage across the cranium).

Transcranial direct current stimulation (tDCS)

TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS) is a tES technique in which the stimulus waveform is a sustained direct current (dc) applied to the head for the purpose of producing a direct change in brain function. The current amplitude of tDCS is limited with the intention to produce modulation of excitability and/or to change ongoing activity rather than to trigger directly action potentials (as the brain is active, tDCS will change the ongoing firing rate of neurons activated for other reasons [70]). The sustained waveform of tDCS reflects this intention. Though not required, when used, the lower-case "t" in tDCS emphasizes a proper name.

In any given session, tDCS uses a single current amplitude with minimal variation during the course of stimulation except for one ramp-up and one ramp-down period (typically a 10–30 s linear ramp). Since tDCS dose is defined as a waveform of a sustained direct current, only the amplitude (in mA), duration (in seconds or minutes), and ramp up/down details are needed to specify the waveform associated with each electrode (Table 2).

Trains of monophasic pulses are not tDCS, but rather transcranial Pulsed Current Stimulation, even when a dc offset is included. An oscillating tDCS (a monophasic square waveform), or a rectified or monophasic sinusoidal waveform are not included in tDCS as defined here (e.g. see oscillating transcranial Direct Current Stimulation, otDCS).

All practical tDCS devices produce an imperfect signal, such that a stimulator produces both a dc signal and some small superimposed noise. The level at which this fractional non-dc noise component no longer meets the definition of tDCS is unclear [71,72] and, as a result, there are no clear noise thresholds based simply on output (e.g. noise amplitude of 1% or 0.1% of dc). Rather, the point at which a method is no longer considered tDCS may be: when the outcome of a noisy-tDCS source fails to reproduce the effects of a high quality tDCS source.

The terminology "anodal-tDCS" (a-tDCS) and "cathodal-tDCS" (c-tDCS), though common, should be used with caution. All tDCS methods involve at least one anode and one cathode (to complete a minimal circuit), and all current entering the cortex must exit (and also pass through intermediate brain regions). There is no pure unipolar tDCS (i.e. anodal or cathodal effects exerted under one electrode only), as may be implied by these terms. The terms "anodal" and "cathodal" in this context thus reflect the intended outcome of stimulation by that electrode and should be used and understood as only an expected outcome (or hypothesis). The extent to which anodal and cathodal sources produce net effects on excitation and inhibition, especially in the context of brain state, are complex. The preferred language should be "anode electrode *over* brain region X" [73] or "anode electrode at scalp coordinate Z defined by the EEG 10–20 system" rather than "anodal tDCS of brain region X″ since the latter incorrectly implies anodic current delivered to just that brain region [74] and moreover over-simplistic intended outcomes. The terms "anodal" and "cathodal" in tDCS may be combined with terminologies related to electrode montage (such as unilateral, defined elsewhere) which are similarly an expression of hypothesized mechanisms. The terms "anode" and "cathode" (defined in Sections 2.9 and 2.10) are not ambiguous in electrical stimulation, as they indicate only if current enters or exits the scalp, respectively, at the electrode.

DUAL-TDCS (bilateral tDCS [38]) indicates that both the anode electrode and cathode electrode are positioned to intentionally produce excitation and inhibition, respectively, typically symmetrically on the head [75–78], thereby explicitly leveraging the inherent mixed polarity of tDCS. However, we emphasize that both electrodes are active in all tDCS configurations. Less commonly used, UNIHEMISPHERIC CONCURRENT DUAL-SITE A-TDCS (a-tDCSUHCDS) uses two anode electrodes positioned over nominal targets (e.g. M1 and S1, or M1 and DLPFC, or M1 and V1) with two supraorbital cathode electrodes [79,80]. Dual-site High-Definition transcranial direct current stimulation has been verified in computational models [81,82].

The application of direct current dates back centuries to the earliest batteries [2,83] with reported clinical trials from at least the 1960's [84]. Interestingly, these efforts used a dose with less current (e.g. 0.3 mA) but significantly higher duration (e.g. hours), corresponding to higher net charge, than modern tDCS studies [84]. Such paradigms are outside the scope of conventional tDCS as described next.

CONVENTIONAL tDCS includes those protocols (e.g. waveform intensities and durations) that are commonly used in modern (post 2000) human trials including exploratory studies and clinical trials. Most conventional efforts used two electrodes (though some efforts used 3 or even 4 [85]) with current intensities spanning

1.0–2.5 mA (though 3–4 mA has been tested as well [86]). Conventional durations span 4 s (used only for transient changes [87]) to tens of minutes (typically 10–40 min used for durable changes [5]). Under this conventional dose and when proper technology and protocols are used [7], tDCS is well tolerated [6,10,88–90].

Conventional tDCS uses rectangular electrode assemblies of 5×5 cm to 5×7 cm skin–electrolyte contact area, though both smaller and larger electrode assemblies have been explored [11]. Conventional tDCS electrode assemblies use either metal or conductive rubber electrodes [91]. To provide safe, low-impedance contact with the skin, isotonic saline (saturated in a sponge) or other electrolytes such as gels and/or creams are used. The details of electrode assembly design (see Sections 2.1–2.4) are considered important for tolerability. For example, it is important to maintain a minimal distance between the electrode and skin, as well as the area of the electrode compared to the electrolyte–skin area.

High-Definition transcranial electrical stimulation (HD-tES), High-Definition electrodes, High-Definition transcranial direct current stimulation (HD-tDCS), 4 × 1 montage

High-definition transcranial electrical stimulation (HD-tES) is conventionally defined as a tES montage using compact electrodes (e.g. < 5 cm^2 total electrode–skin contact area, typically defined by a rigid gel holder) arranged in an array with a center electrode surrounded by a "ring" of electrodes, where the center and ring electrodes have opposite polarities. This design is intended to restrict current predominantly to the cortex circumscribed by the ring [92]. The 4×1 HD-tES montage comprises a center electrode surrounded by a ring of 4 electrodes of polarity opposite to that of the center electrode [59,74]. The increased current density necessitates the use of specially designed electrodes [93] that are called High-Definition electrodes; stimulation at tDCS relevant intensities with other forms of small electrodes that are poorly designed can result in skin irritation.

Stimulation that meets the definition of both tDCS and High-Definition tES is called HD-tDCS [94,95], including 4×1 HD-tDCS. Stimulation that meets the definition of both tACS and High-Definition tES is called HD-tACS [58,82]. Current waveforms, intensities and durations used for HD-tES typically mirror those used with the corresponding pad-based technique. For example, like tDCS, HD-tDCS generally uses intensities of 1–2 mA [96–99] with a few using higher currents [100].

A montage with at least one HD electrode and other non-HD (pad) electrodes has been described as a hybrid-HD montage [101]. HD-tES/tDCS has also been used to describe an electrode surrounded by an annulus pad electrode [102]. HD-tDCS has been used to describe approaches that optimize stimulation strength or focality [103]. HD-tES has also been used to describe approaches targeting multiple brain regions [18,58,81,82,104]. HD-tDCS to two targets has been called Dual-site High-Definition transcranial direct current stimulation [81].

A feature of smaller electrodes is the potential to use a higher number of electrodes and/or electrodes in closer proximity; this, in turn, provides increased flexibility in montage design [95] and facilitates simultaneous recording of EEG during tES [105].

Transcranial pulsed current stimulation (tPCS)

Transcranial pulsed current stimulation (tPCS) is a form of tES where a train of pulses is applied. A wide variety of pulsed waveforms may be used (see Fig. 2). Pulses may be monophasic or biphasic [106]. tPCS may or may not include a dc bias – a waveform with dc and pulsed components would be classified under tPCS, not tDCS.

Historically, the term "tPCS" is uncommon but has gained popularity in recent years [107–110] in alignment with terms such as tACS and tDCS. However, the use of devices delivering tPCS spans well over a century [2] with many variants that hold unique names (e.g. ECT, CES).

When monophasic tPCS is applied, it is reasonable to refer to one electrode as the anode and the other as the cathode. The terms "Anodal-tPCS" (a-tPCS [111]) and "cathodal-tPCS" (c-tPCS) may be used per convention, but as with a-tDCS and c-tDCS they should be used with caution and recognizing there is no pure unipolar tPCS, as may be implied by the terms. It is preferred to state this matter as follows: "the tPCS anode electrode is positioned over brain region X" and not "anodal tPCS of brain region X is applied" since the latter incorrectly implies current delivered to just that brain region [74].

If tPCS is biphasic and perfectly symmetric (e.g. biphasic simple square wave), then it may not be necessary to define current polarity per electrode or which electrode is the reference for the waveform (unless information on phase is relevant). However, if the waveform is asymmetric then, even if it is biphasic, the reference electrode (term used here in the mathematical sense) used to specify the waveform should be identified (e.g. +1 mA for 1 ms, and −0.1 mA for 10 ms through electrode 1, or +15 V for 3 ms and −5 V for 1 ms from electrode 1 relative to electrode 2).

tPCS is not restricted by pulse pattern or intensity (amplitude). Therefore, approaches as diverse as forms of electroconvulsive therapy (ECT; any tPCS that is intended to produce a seizure) and forms of cranial electrotherapy stimulation (CES; any tPCS that meets the FDA statutes) may be considered tPCS (Fig. 1).

Transcranial electrical stimulation (TES with capital "T")

A specific form of tPCS is one involving application of one or a few high-amplitude pulses with the goal of directly activating brain tissue which is referred to simply as transcranial electrical (or electric) stimulation (TES). Examples of TES include application over the motor cortex to induce a motor response [92] or visual cortex to produce phosphenes. To reach motor threshold, TES typically uses a pulse amplitude in the hundreds of mA with durations of tens to hundreds of μs [92]. The "T" is conventionally capitalized. This form of TES is currently used mostly during intraoperative monitoring when the patient is anesthetized. Because it produces significant discomfort, TES is used rarely in awake subjects [92], sometimes as a comparison to TMS, since TES is understood to activate different neural populations than TMS [112,113]. The electrode configurations used for TES are typically bipolar [92], though 4×1 HD has been tested as well [92]. TES uses too few or low-frequency pulses to produce a seizure, so it does not overlap with ECT (another form of suprathreshold tPCS).

Cranial electrotherapy stimulation (CES)

Cranial electrotherapy stimulation (CES) in modern use is derived from an FDA classification for a specific form of tES. CES is thus defined legally in the USA as any device which the FDA has designated CES. Per the FDA, CES is defined as "a device that applies electrical current to a patient's head to treat insomnia, depression, or anxiety" (21 CFR 882.5800). CES waveforms are a form of tPCS using high-frequency pulse trains with electrodes applied across the forehead, mastoids, or ear-lobes using clips [114].

Electroconvulsive therapy (ECT)

electroconvulsive therapy (ect) involves the delivery of repetitive current stimuli to induce a therapeutic seizure [115]. Whereas older forms of ECT used sinusoidal currents, modern ECT relies on brief current pulses. Modern ECT is, therefore, a subclass of tPCS. In standard ECT devices, the stimulus pulses are current-controlled, rectangular, and monophasic with polarity alternating from pulse to pulse, forming pulse pairs of opposite polarity. Modern ECT is administered under general anesthesia and muscle relaxants. The

seizure is typically determined by motor activity in a limb and by seizure activity in electroencephalography (EEG). Under current recommendations, the waveform is titrated relative to the individual's seizure threshold [116]. Typical ECT parameters are amplitude of 800–900 mA (although lower currents have been used experimentally), pulse width of 0.25–1 ms, train duration $\leq$ 8 s, and train frequency of 10–120 Hz (pulse-pairs per second). The FDA limits the dose of ECT devices cleared in the USA to 576.0 mC and 101.4 J into a 220 Ω load, whereas in some other countries the limit is twice as high. Typical electrodes are either 5-cm-diameter stainless steel disks used with electrolyte gel or disposable adhesive conductive pads.

The term ECT is often used with modifiers that specify the delivery approach, especially electrode placement and pulse width. Standard electrode placements include right unilateral (RUL), bitemporal (BT), and bifrontal (BF) [117]. Note that "bilateral" includes both bitemporal and bifrontal, though, before the introduction of bifrontal ECT, it was used to denote bitemporal placement. In some cases, other electrode configurations, such as left unilateral (LUL), are used. Conventionally, pulse width is classified as brief ($\geq$0.5 ms, typically 0.5–1 ms) or ultra-brief (UB, < 0.5 ms, typically 0.25–0.3 ms). Over the years a wide variety of ECT paradigms have been explored, and there is ongoing research in alternative ECT parameters including individualized current amplitude, lower or higher current amplitude, unidirectional pulse trains, extended trains, and various electrode configurations [118–126].

(Slow) oscillating transcranial direct current stimulation (so-tDCS), transcranial sinusoidal direct current stimulation (ts-DCS)

(slow) Oscillatory transcranial direct current stimulation (o-tDCS/so-tDCS) is a form of tES using direct current stimulation where the amplitude of the stimulus is regularly modulated, but which remains monophasic (such that the polarity of stimulation is never inverted) and where the intensity remains limited with the intent to produce subthreshold modulation. The waveform is typically monophasic square, trapezoidal, or monophasic sinusoidal wave. o-tDCS and its variants conventionally use electrode montages adapted from tDCS. Slow oscillatory tDCS (so-tDCS) conventionally refers to a signal with a frequency below 1 Hz (e.g. 0.75 Hz) [127]. The on-off time of o-tDCS and its derivatives may be varied (e.g. 5 intervals with 1 min gap [128]). so-tDCS may also be qualified as anodal or cathodal [127], though this infers a hypothesized anatomical target as discussed above (see anodal/cathodal in tDCS).

Transcranial sinusoidal direct current stimulation (ts-DCS) is a form of o-tDCS where the waveform is a monophasic (biased) sinusoid. so-tDCS may also be used to describe protocols with sinusoids when the frequency is low [127,128]. ts-DCS frequencies and intensities span those used in tACS [129]. Slow oscillatory stimulation (SOS) or transcranial slow oscillatory stimulation may refer to variants of so-tDCS or ts-DCS [130,131].

The distinction between modes of o-tDCS from tDCS (which in principle may be applied briefly and intermittently, e.g. 15 s on tDCS, 15 s off tDCS, repeated [132]) and from tPCS (where pulse duration can in principle be increased to hundreds of ms) is, as defined here, one of intended outcome. o-tDCS is expected to produce changes in part through the *change* in current (namely the neurophysiologic intended outcomes are assumed to reflect the non-static nature of current flow), *and* a sustained phase of stimulation (namely the neurophysiologic outcomes are assumed to reflect actions when the current is sustained). tPCS is presumably focused only on transient effects while tDCS only on sustained effects. We caution that this distinction of intention is subtle, subject to change/interpretation, and that the rationale for o-tDCS (as opposed to tPCS) is often not explicitly stated in o-tDCS publications. Nonetheless, based on current understanding and use of conventions, we categorize o-tDCS and its variants as a category that is district from tPCS or tDCS (Fig. 1). We emphasize that all studies should report the dose applied regardless of the terminology used.

Transcranial alternating current stimulation (tACS)

Transcranial alternating current stimulation (tACS) is a form of tES involving application of sinusoidal current across the scalp to the brain [133–135]. The sinusoid may be biased (which should be specified relative to a reference electrode) but must have at least some biphasic components. A combination of sinusoids (summation) may be used. tACS is sub-convulsive as the applied intensities are at least an order of magnitude less compared to intensities produced by devices intended to induce seizures as part of the therapeutic outcome. Thus, ECT is not a form of tACS. As conventionally used in the neuromodulation literature, tACS does not include any waveform that is non-sinusoidal. While other waveforms may be "alternating current" in the engineering sense (i.e., current flow direction at the electrode (and therefore the brain) reverses direction), tACS classifies a specific method using only sinusoids.

Conventional intensities are typically limited to 1–2 mA or less [136]. Conventional tACS uses a single peak current amplitude with minimal variation during the course of stimulation, except for conventional ramp-up and ramp-down periods (typically 10–30 s linear). However, some forms of tACS intentionally modulate the amplitude: Amplitude Modulation tACS (AM-tACS) [137].

The interval from the initiation of current flow (start of ramp-up of sinusoid) to the end of current flow (end of sinusoid ramp-down) is a single tACS session; when specifying the duration of a tACS session, it should be made clear if this is inclusive or exclusive of the ramp-up and ramp-down period.

Conventional tACS methods are adapted from tDCS, such that electrode assemblies use either metal or conductive rubber electrodes with typical area of 5 × 5 cm to 5 × 7 cm skin–electrolyte contact area. Like in tDCS, electrolytes are more commonly saline (saturated in a sponge) but gels and creams have been used as well.

For tACS, the current frequency and amplitude and the duration of the stimulation are the major parameters that are known to shape the direction and duration of the after-effects. Conventionally, tACS employs frequencies or combinations of frequencies in the physiologic EEG range (below 200 Hz), in some cases with the intention to interact with or influence these oscillations [70,138–142]. However, higher frequencies in the kHz range have also been studied [116,143,144]. When kHz frequencies are applied across multiple electrodes [145], with a slight difference in frequency across different electrode pairs, this is classified as Interferential Stimulation (defined separately in Section 3.4.1).

Interferential Stimulation/temporal interference stimulation

Interferential stimulation or temporal interference stimulation (IF) is the simultaneous application of two (or more) sinewaves, both at high but slightly different frequencies via two (or more) pairs of electrodes. IF is, therefore, a subtype of tACS. The summation of two high-frequency (e.g. ~ 2 kHz) sine waves of slightly different frequencies results in a waveform that is a high-frequency carrier-wave (average of the two sine waves) modulated by a low frequency (e.g. 10 Hz) envelope oscillating at a "beat" frequency. This beat frequency is the difference of the frequencies of the two sinusoids (Fig. 2D). There is a long-standing interest in IF [2] and recent work has focused on the possibility of stimulating deep targets [145].

Repetitive transorbital alternating current stimulation (rtACS), transcorneal electrical stimulation (TcES), transscleral electrical stimulation (TsES)

In REPETITIVE TRANSORBITAL ALTERNATING CURRENT STIMULATION (rtACS) stimulating electrodes are positioned near the eye (2–4 per orbit) [146–150] with the aim to inject current to the eyeball to reach the nervous tissue of the retina and brain. rtACS has been proposed to induce vision restoration by activating residual visual functions in patients with damage to the retina, optic nerve, or brain [151]. rtACS requires multiple sessions (typically at least 10); rtACS thus reflects a classification where the intended outcome (rehabilitation) forms the definition.

Transcorneal electrodes have the shapes of contact lenses [152–156]. Transcorneal hair-like DTL electrodes [157] directly contact the cornea [158–163] or the cornea and sclera [155]. Studies, where electrodes are positioned on the scalp, use the terminology rtACS, but those not positioned on the scalp use the terminologies TRANSCORNEAL ELECTRICAL STIMULATION (TcES) or TRANSSCLERAL ELECTRICAL STIMULATION (TsES).

Transcranial random noise stimulation (tRNS)

TRANSCRANIAL RANDOM NOISE STIMULATION (tRNS) is a form of tES that was developed with the intent to desynchronize pathological cortical rhythms [164] but additional putative mechanisms, such as stochastic resonance [165,166], may be relevant. Stimulation is conventionally multiphasic (current has both polarities) and various forms of noise may be applied. In typical examples, during tRNS a frequency spectrum between 0.1 Hz and 640 Hz (full spectrum) or 100–640 Hz (high-frequency spectrum) is applied. During one embodiment of "random noise" stimulation, the random levels of current are generated by an internal random number generator 1280 times per second; the probability function of the random noise current stimulation follows a Gaussian or bell-shaped curve with zero mean and a variance, where 99% of all generated current levels are between ±1 mA (when 1 mA stimulation amplitude is used). In the frequency domain, all coefficients of the random sequence have a similar size ("white noise"). tRNS is adapted from tDCS and tACS, such that electrodes and related application paradigms are the same as mentioned above.

Because there are many forms of "noise" (and the neurophysiologic effects are specific) it is important for dose reproduction (Section 2) to provide sufficient details on how the waveform was formulated to allow reproduction.

Summary

This consensus expert report provides the first comprehensive and integrated classification of terminology used in contemporary transcranial electrical stimulation. Such a list cannot be exhaustive and for each classification, there can be publications that apply the term differently. Reflecting how terms are used, our approach to classification considers both the dose of stimulation (electrode configuration and stimulus waveform) and the intended outcomes of stimulation. No part of this paper should be taken as an endorsement of one approach over another, and, as emphasized, the use of terminology in a publication does not substitute the need to fully document dose [3]. Individual researchers may acquaint themselves with existing terminology and acronyms and adopt existing (as opposed to creating new) terminology as appropriate. Any analysis or review of tES technology, safety, or efficacy should clearly (re)define the dose range of any terminology used or reference a classification such as the one provided here.

This paper was motivated by the value of cataloging common terms used in the tES literature. Our explicit scope and approach (Section 1) was to explain standing usage rather than to propose modified or new terms or to ban specific usage of terms. Nevertheless, our classification draws attention to ambiguous terminology, particularly terms that rely heavily on speculative modes of action. To the extent the field as a whole will adopt (and enforce) clarified terminology, our review of existing conventions is an important contribution. However, an immediate remedy is available: publications should fully document dose [3] in a reproducible manner (cognizant of how basic terms are used; see Section 2 and Table 2). Only referencing a specific tES category (Section 3) fails to fully convey such information.

It is incumbent on the tES field (through societies, working groups, and conferences) to consider the development of revised classifications and standards, including if any terminology should be formally discouraged. Prospectively, this paper contributes to this process by cataloging standing nomenclature and conventions. Retrospectively, understanding and leveraging the historical publication record evidently requires understating terminology as used contemporaneously – the explicitly limited scope of the present paper.

Disclosures

The City University of New York has inventions on tES with MB as inventor. MB has equity in Soterix Medical and serves on the scientific advisory boards of Boston Scientific and GlaxoSmithKline. AVP is inventor on patents and patent applications and has received research and travel support as well as patent royalties from Rogue Research, research and travel support, consulting fees, as well as equipment donation from Tal Medical/Neurex, research and patent application support from Magstim, as well as equipment loans from MagVenture, all related to technology for transcranial magnetic stimulation. CKL has received research equipment support from Soterix Medical, and honoraria and travel support from Mecta for teaching in an International ECT course. BWB is an inventor on tES patents and patent applications, has equity in Bodhi NeuroTech and serves as a consultant to eQuility. MAN is an advisor for Neuroelectrics. AA has received research equipment, honoraria and travel support from support from NeuroConn/NeuroCare. HK has received research equipment support from Soterix Medical Inc, as well as research support and a single-event travel support from Ybrain, Inc.

Acknowledgement

The contributions of A. V. Peterchev were supported by the NIH under grants R01MH091083, R21MH106772, and R01MH111889. The contributions of A. J. Woods were supported by the NIH under grants R01AG054077, K01AG050707, and R21MH112206. The contributions of M. Bikson were supported by the NIH under grants MH111896, NS101362, U54CA137788/U54CA132378, and NS054783. The contributions of B. M. Hampstead were supported from the VA (IRX001534) and NIA (R01AG058724). The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies.

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