Published in final edited form as:
Brain Stimul. 2016 ; 9(4): 625–626. doi:10.1016/j.brs.2016.05.002.

The Proof is in the Pudding: Does tDCS Actually Deliver DC Stimulation?

Pratik Y. Chhatbar[*],
Department of Neurology, College of Medicine, Medical University of South Carolina, 19 Hagood Avenue, HOT-501, Charleston, SC 29425, USA

James R. Sawers, and
Department of Psychiatry and Behavioral Sciences, College of Medicine, Medical University of South Carolina, 19 Hagood Avenue, HOT-501, Charleston, SC 29425, USA

Wuwei Feng
Department of Neurology, College of Medicine, Medical University of South Carolina, 19 Hagood Avenue, HOT-501, Charleston, SC 29425, USA. Department of Health Science & Research, College of Health Professions, Medical University of South Carolina, 19 Hagood Avenue, HOT-501, Charleston, SC 29425, USA

Dear Editor

Transcranial direct current stimulation (tDCS) is an increasingly used investigational modality for a variety of disease conditions worldwide, including stroke [1]. It is relatively easy to use, low-cost, and has a reasonable safety profile with currents up to 2 mA. The effect of tDCS on membrane potentials has been demonstrated *in vitro* [2] as well as *in vivo* through simulation of tDCS-generated electric fields [3]. Real-time monitoring of applied voltage and injected current in tDCS application is offered as an inbuilt feature of many tDCS devices and can be achieved with a simple data acquisition setup. Many research groups, including our own, use such real-time monitoring circuitry during tDCS application. tDCS devices operate by using solid-state circuitry designed to produce a "current clamp", e.g., to maintain a constant current irrespective of effective body resistance at the selected current setpoint. This approach to electronic circuitry design has been proven to be reliable.

We were surprised with the findings presented in the recently accepted *Brain Stimulation* paper entitled "Does transcranial direct current stimulation actually deliver DC stimulation?" by Dr. Salimpour et al [4]. Dr. Salimpour interpreted his results as demonstrating that tDCS is contaminated by other electrical stimulation waveforms resembling transcranial alternating current stimulation (tACS), transcranial random noise stimulation (tRNS), and transcranial pulsed current stimulation (tPCS). While we appreciate that his findings are of preliminary nature, there seem to be several potential deficiencies in both methodological and conceptual levels that could be discussed, addressed, and mitigated:

---

[*] Corresponding author. Department of Neurology, Medical University of South Carolina, 19 Hagood Avenue, HOT-501, Charleston, SC 29425, USA. Tel.: 843-792-3112; fax: 843-792-2484.: chhatbar@musc.edu (P.Y. Chhatbar).

First, the tDCS device was categorized as DC-to-DC converter. A preferable designation is that these devices are battery-powered, constant-current “generators” (or “sources”), and not “converters”. This functionality is more precisely described as a “current clamp”

Second, the methodology of tDCS measurements and analyses were not described in detail, making it difficult to replicate. Salimpour et al. describe ramping up and down tDCS current maxima, but fig. 1A fails to show ramping at the beginning and end of this 300-s stimulation. Importantly, the time series displayed in fig. 1A shows many big surges, not typical of steady 1 mA current that researchers consistently observe during tDCS applications. In other words, fluctuations of more than 10 3A are not common during tDCS application; therefore, current values beyond the range of 0.99 mA–1.01 mA are not typically observed. However, the recordings by the authors appear to have multiple fluctuations ranging from ~0.3 to ~1.9 mA. This raises the issue of the quality of tDCS stimulation device and/or measurements themselves as well as the recording instrumentation.

Third, fig. 1B shows the highest power near 0 Hz signifying predominance of DC stimulation during tDCS, with the harmonics around 15, 30, 60 (mains hum?), 80 Hz, etc. with virtually no signal in other frequency bands. No clear explanation was provided of these findings and with the lack of explanation concerning methods, it is difficult to interpret the source of such signals/artifacts. Importantly, variation in the frequency spectrogram is tightly correlated with noise in the injected tDCS current (note tightly aligned current “spikes” in fig. 1A with increased power across all frequency bands in spectrogram in fig. 1B). In our humble view, the take-home message here is that tDCS is actually offering the highest power at 0 Hz but negligible signal at other frequencies.

Lastly, assuming 10 μA peak-to-peak variability in injected current typically means about $10/\sqrt{2}$ or ~ 7 μA root mean square (RMS) [5] variability assuming sinusoidal waveform pattern or $10/\sqrt{3}$ or ~ 5.8 μA RMS variability assuming a triangle/sawtooth waveform. Thus, the random noise or pulsed current stimulation will have even smaller RMS values. Since the body resistance remains relatively unchanged, according to Ohm’s law [6] ($V = IR$, where V is the applied voltage, I the resultant current, and R is the body resistance – a near constant), the fractional variability in voltage for DC application should be the same as that of the current. Decibel [7] is a commonly used term in describing ratio of two values of a physical quantity. Power ratio expressed in decibels (L_P) can be calculated as follows:

$$L_P = 10\log_{10}\left(\frac{P}{P_0}\right)$$

A ratio of 2 is presented by 3 decibels (dB) and a ratio of 0.5 or 1/2 is presented by −3 dB. Likewise, ratio of 1/32748 or $(1/2)^{15}$ or about thirty three thousandth fold is presented by −45 dB. Using the following formula, the logarithmic value of such variability can be calculated:

$$P=20\log_{10}\left(\frac{\nu_n}{V}\right)=20\log_{10}\left(\frac{i_nR}{IR}\right)=20\log_{10}\left(\frac{i_n}{I}\right)$$

where ν_n is variability in applied voltage V, I_n is the variability of the injected current I across body resistance R. Note that multiplication by 20 and not 10 for decibel calculation is because voltage is being used rather than power. We will get −43 dB for ~7 3A RMS variability (sinusoidal) and −45 dB for ~5.8 3A RMS variability (triangular/sawtooth) when 1 mA current is applied (the dB values will be even smaller for higher tDCS currents). This is about the decibel value that is demonstrated as an average power spectrum (right panel of fig. 1C), with power spectrum at individual frequency with even lower values ranging from −50 dB to −80 dB.

In other words, the decibel values that the authors present to demonstrate that tDCS is contaminated with tACS, tRNS, and tPCS can be more logically explained by only a 10 3A, or <1% variability in the injected current. The decibel value of −45 dB in literal terms means a power ratio of 1/32748, which offers perspective of how small tACS, tRNS, and tPCS power contamination of tDCS currents actually is when compared with the power of DC stimulation during tDCS application. In our view, the findings by Dr. Salimpour et al. are actually displaying robustness of tDCS stimulation with minimal artifacts of contamination by tACS, tRNS, and tPCS (<−40 dB) despite their apparently sub-optimal stimulation/recording setup. This rigorous mathematical analysis explains why actual frequency characteristics of tDCS systems have not been reported in previous studies: the tDCS output is flat and constant for all practical purposes!

Acknowledgments

PYC receives grant support from SC-CoAST/NIH StrokeNet (U10NS086490), the National Institutes of Health (P20GM109040) and the South Carolina Translational Research Discovery Grant (UL1 TR001450); WF receives grant support from the American Heart Association (14SDG1829003), the National Institutes of Health (P20GM109040) and the South Carolina Translational Research Discovery Grant (UL1 TR001450).

References

1. Fregni F, Nitsche MA, Loo CK, Brunoni AR, Marangolo P, Leite J, et al. Regulatory considerations for the clinical and research use of transcranial direct current stimulation (tDCS): review and recommendations from an expert panel. Clin Res Regul Aff. 2015; 32:22–35. [PubMed: 25983531]
2. Bikson M, Inoue M, Akiyama H, Deans JK, Fox JE, Miyakawa H, et al. Effects of uniform extracellular DC electric fields on excitability in rat hippocampal slices in vitro. J Physiol. 2004; 557:175–90. [PubMed: 14978199]
3. Rahman A, Reato D, Arlotti M, Gasca F, Datta A, Parra LC, et al. Cellular effects of acute direct current stimulation: somatic and synaptic terminal effects. J Physiol. 2013; 591:2563–78. [PubMed: 23478132]
4. Salimpour Y, Wei Z, Duy PQ, Anderson WS. Does transcranial direct current stimulation actually deliver DC stimulation? Brain Stimul. 2016; 9:623–4. [PubMed: 27160469]
5. Kenney, J., Keeping, E. Mathematics of statistics. Princeton, NJ: Van Nostrand; 1962. Root mean square; p. 59-60.
6. Millikan, RA., Bishop, ES. American Technical Society. Chicago, IL: University of Chicago Press; 1917. Elements of electricity: a practical discussion of the fundamental laws and phenomena of electricity and their practical applications in the business and industrial world.

7. Institute of Electrical and Electronics Engineers. The authoritative dictionary of IEEE standards terms (IEEE 100). 7. New York: Institute of Electrical and Electronics Engineers (IEEE) Press; 2000.