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Editorial

Cutaneous perception during tDCS: Role of electrode shape and sponge salinity

See Article, pages 803–807

Transcranial direct current stimulation (tDCS) is a noninvasive method of brain modulation that is increasingly tested for the treatment of neuropsychiatric disorders (Murphy et al., 2009) and cognitive enhancement (Paulus, 2004; Talelli and Rothwell, 2006). Conventional tDCS protocols apply 1–2 mA of current, for several minutes, through conductive-rubber electrodes inserted in sponge wrappers, which are typically soaked in saline, before being placed on the scalp. tDCS has many useful characteristics including low cost, ease of use, portability, and absence of significant side-effects. Indeed, during tDCS, mild tingling or itching sensation are the most common adverse effects (Poreisz et al., 2007), and though isolated cases of skin burns have been reported (Lagopoulos and Degabriele, 2008; Palm et al., 2008), relatively large scale experiences from several active centers, including at Gottingen, suggest that under proper protocols, significant adverse events can be avoided (Dundas et al., 2007; Loo et al., 2010; Poreisz et al., 2007).

Acute sensation under electrodes during DC stimulation is well established (Leeming et al., 1970; Mason and Mackay, 1976) and is highly dependent on both stimulation intensity and electrode design (Dundas et al., 2007; Forrester and Petrofsky, 2004; Martinsen et al., 2004; Minhas et al., 2010). Sensation does not simply correlate with either skin damage or brain modulation (Bikson et al., 2009) because of the importance of electrode design and montage (for example, decreasing the distance between electrodes decreases total brain but not skin current). None-the-less, sensation is clinically significant in itself for several reasons including tolerability (especially in vulnerable populations), confounding of experimental and clinical results, and blinding. The report in this issue by Ambrus and colleagues in Gottingen evaluated sensation differences for surface-area matched (35 cm^2) rectangular and round electrodes. For anodal and cathodal tDCS, as well as tRNS, they found no substantial differences in detection threshold, detection rate, false-positive rate, or quality of sensation.

It is well established, including through computational modeling studies, that during electrical stimulation, current distribution at the electrode-tissue (skin) interface is not uniform, with high current density at the electrode edges (Miranda et al., 2006). The current density at an electrode edge is generally undesirable for safety reasons (especially for implanted electrodes; (Merrill et al., 2005)) and may increase sensation during transcutaneous stimulation. Note that during transcranial electrical stimulation, subsequent current dispersion across deeper tissues results in no evident electrode-edge related current concentrations at the brain (Miranda et al., 2006; Datta et al., 2008; Datta et al., 2009a). Various strategies for normalizing current distribution at the electrode-tissue interface have been developed focusing on the materials and/or shape of the electrode (Krasteva and Papazov, 2002; Gilad et al., 2007; Minhas et al., 2010) – motivating the tDCS/tRNS electrode shape study by Ambrus et al. (2010).

We modeled the current density at the electrode–skin interface under conditions approximating those tested by Ambrus et al. (2010). Consistent with previous results, for both rectangular and round electrodes, the current density was significantly higher at the electrode edges (Fig. 1). For the same average current density (total current applied to equally sized electrodes), there was a moderately higher peak concentration of current for the rectangular electrodes than for the circular electrodes (Fig. 1a2 and b2), but only at the rectangular electrode corners (Fig. 1a3 and b3). Given the scale (peak) and nature (distribution) of these differences, it is not surprising that difference in sensation could not be resolved clinically by Ambrus and colleagues – especially when considering that, practically, the effect of sharp rectangular edges would be reduced by hair wetting. We further modeled changing the saline concentration in the electrode; as expected decreasing sponge salinity significantly decreased peak current density at the electrode corners (Fig. 1a4 and b4), consistent with the clinical finding by Dundas et al. (2007) – peak current densities for the circular and rectangular electrode were relatively matched.

To allow direct comparisons across electrode shapes, our simplified (planar) model does not address: (1) realistic head shapes and anatomy (which may lead asymmetric current distribution at electrode edges, at different stimulation sites); (2) potential difference in skin properties (skin micro-architecture). Indeed, Ambrus and colleagues report significant differences in sensitivity of perception across stimulation sites.

The simplest explanation for sensation and discomfort during transcutaneous electrical stimulation is the excitation of peripheral nerves; electrochemical processes (Minhas et al., 2010), but not heating, (Nitsche et al., 2003; Datta et al., 2009b) may also contribute during tDCS. Regardless of the mechanism(s), hot spots of current density around the electrode edges, and perhaps around skin inhomogeneities (e.g. sweat glands), are considered to increase sensitivity, and thus approaches to increase uniformity of current density at the electrode–skin interface are rational.

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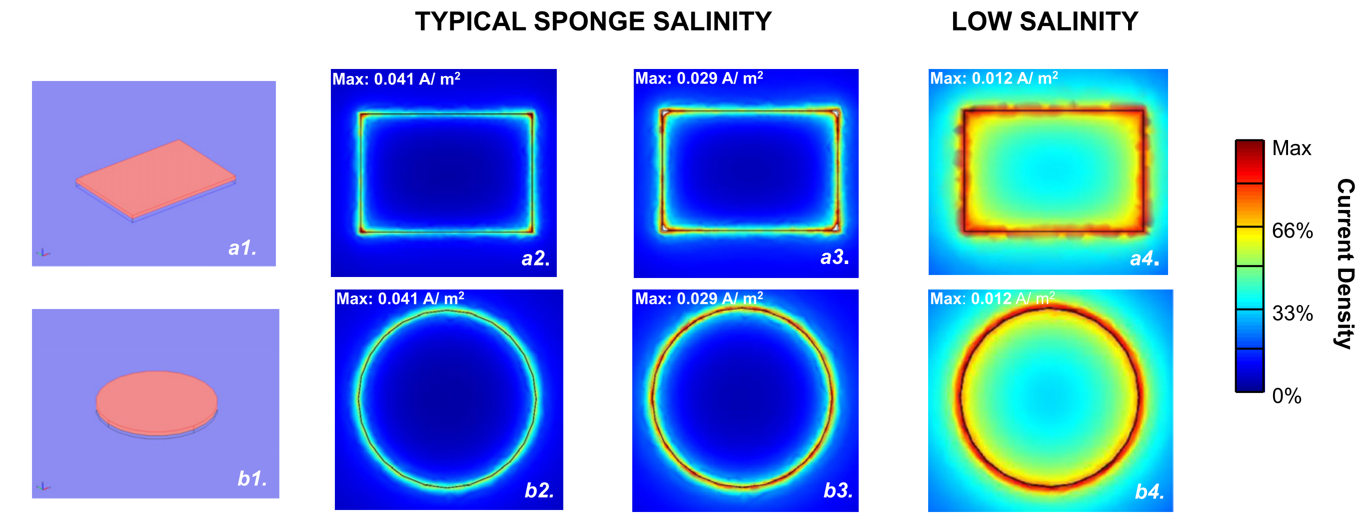

Fig. 1. Comparison of the skin current density profiles for area matched rectangular and circular pads. (a1 and b1): Modeled electrode-sponge finite element geometry. The head model comprised of 4 concentric blocks (skin, skull, CSF, brain). The electrode and sponge pad had 0.5 and 2.5 mm thickness, respectively. 2 mA of total current was applied to 35 cm^2 pads (boundary current density 0.0057 A/m^2). (a2 and b2): For saline soaked sponge (1.4 S/m), current density was concentrated at electrode edges, with higher values observed at the rectangular electrode corners. Both panels plotted to the peak current density for the rectangular electrode (0.041 A/m^2). (a3 and b3): Re-plotting these panels to a maximum current density of 0.029 A/m^2, emphasize that outside of the rectangular electrode corners, the typical current density around the circular electrode is higher. (a4 and b4): Decreasing sponge salinity (0.05 S/m) resulted in significantly more uniform electrode current densities, and reduced peak current densities for both rectangular and circular pads to approximately the same values.

In conclusion, it is important to emphasize that current technologies and protocols in transcranial stimulation, which have been largely incrementally and empirically derived, can likely be further optimized and refined. For example, electrolyte fluids and gels optimized specifically for tDCS have only recently been explored (Dundas et al., 2007; Minhas et al., 2010). The ultimate goal of such design efforts would be electrodes that minimize (if not eliminate) all sensation and prevent skin irritation, even under non-optimal conditions, while maintaining the simplicity and cost-effectiveness of existing designs. The report in this issue by Ambrus and colleagues is a valuable step toward this goal.

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