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# Reduction in channel stimulus current under electroconvulsive therapy using multi-channel modes: A numerical simulation study

Traditional bitemporal (BT)-electroconvulsive therapy (ECT) can successfully generate the stimulation required for treatment in the medial temporal lobes (MTLs) [1–3]. However, local overstimulation in the lateral temporal lobes may result in suboptimal outcomes and cognitive risks [4–7]. To reduce the large difference in stimulation strength between the cortical and deep parts of the brain, we propose these innovative multi-channel modes: 1) the bi-channel mode, wherein the BT electrodes and a pair of electrodes on both sides of the coronal suture are used; and 2) the tri-channel mode, wherein the same configuration under the bi-channel mode is followed with the additional placement of another pair of electrodes on both sides of the lambdoid suture. We believe that the stimulation generated by multiple channels can be superimposed in deeper intersectional regions of the brain; multi-channel modes can apply a lower channel current to reduce or eliminate the overstimulation in the cortical areas, including the lateral temporal lobes, while still retaining the desired stimulation strength in the MTLs. Therefore, these modes have the potential to balance the therapeutic effect of BT-ECT and the associated cognitive risks [8,9]. We further estimated the extent of reduction of the channel current through these modes by numerical simulation under individualized realistic head models.

## 1. Methods

The details of the modeling, simulation, and statistical analysis are described in the Supplementary Methods.

## 2. Results

Fig. 1(A) presents the simulated current density distributions on the cortical surface of 10 participants under three electrode modes wherein a channel current of 200 mA has been applied; the distributions clearly show that the ECT results are greatly influenced by the anatomical variability among the participants.

The left and right amygdalas and the left and right hippocampi in the MTLs have been selected as the four regions of interest (ROIs) because they are considered the brain regions most susceptible to seizures [10,11]. We set 50 V/m in the ROIs as the desired stimulation strength for the seizure induction. Fig. 1(C) and (D) show that when generating the desired stimulation in the right amygdala and right hippocampus, the minimal channel currents of all the ten participants decrease with the increasing number of channels and differ greatly among the participants.

The average channel currents decreased significantly (all $p < 0.001$) as the number of channels increased, regardless of the ROIs, as shown in Fig. 1(D). However, there were no significant differences between the ROIs under the same electrode modes. More importantly, the average minimal current amplitudes required by the bi- and tri-channels were approximately ($87.50 \pm 3.22$) and ($80.37 \pm 4.09$)%, respectively, of that under the BT mode when the stimulation of the desired strength was generated in the amygdala; and these amplitudes were approximately ($83.36 \pm 3.99$) and ($73.18 \pm 8.48$)%, respectively, of that under the BT mode when the stimulation of the desired strength was generated in the hippocampus.

Fig. 1(E) presents the current density distribution of PA0 in the sections containing the left amygdala when minimal channel current amplitudes are applied under the three modes. Although the cortical current density distributions were quite different, the electric fields (E-fields) around the amygdala were almost the same under the three modes (pointed out by the arrows in Fig. 1(E)).

The average ratio of the maximal cortical E-field to the hippocampal E-field was used to quantify the attenuation characteristics of the E-field from the cortex to the deeper brain regions under different modes. The average ratios decreased significantly from $25.23 \pm 14.66$ under the BT mode to $20.61 \pm 10.32$ and $18.12 \pm 8.59$ under the bi-channel and tri-channel modes, respectively (all $p < 0.001$). Under the generation of the same stimulation strength in the amygdala, the average ratios of the maximal cortical and hippocampal E-fields under the bi-channel and tri-channel modes reduced to ($85.17 \pm 6.21$) and ($76.12 \pm 9.42$)%, respectively, of that under the BT mode.

A. Current density distributions on the brain surface of the ten participants under three channel modes with the same channel current stimulus. Minimal channel currents of the ten participants under the three electrode modes under generation of E-field with a strength of approximately 50 V/m in the B. right amygdala and C. right hippocampus. D. Average minimal channel currents under the three modes under generation of E-field with strength of approximately 50 V/m in the four regions of interest (ROIs) (RH: right hippocampus; LH: left hippocampus; RA: right amygdala; and LA: left amygdala). E. Current density distributions of PA0 in the sections containing the left amygdala under application of minimal channel currents under the three modes.

## 3. Discussion

As per our assumption, the multi-channel electrode modes can apply a reduced channel current to generate the stimulation necessary for treatment in the MTLs. The simulation results revealed that the channel currents under the bi-channel and tri-channel modes decreased to (83.36–87.50) and (73.18–80.37)%, respectively, of

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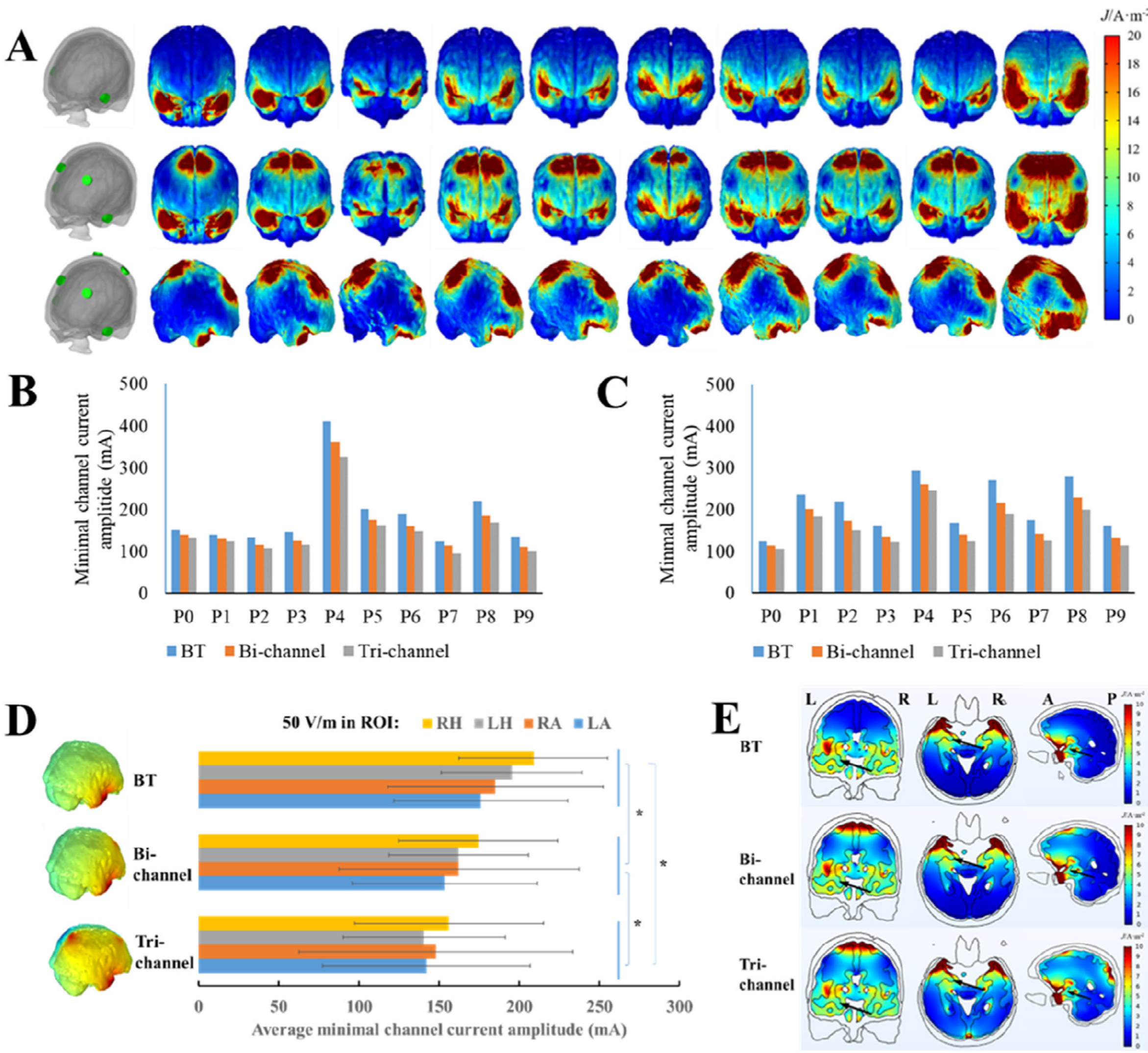


**Fig. 1.** Electric field (E-field) distributions and minimal channel currents under three electrode modes.

that under the BT mode. Correspondingly, the ratios of the maximal cortical and hippocampal E-fields under the bi-channel and tri-channel modes were reduced to 85.17 and 76.12%, respectively, of that under the BT mode. These results implied that the reduced channel current would also significantly reduce stimulation in the lateral temporal lobes. In addition, the multi-channel electrodes generated stimulations in more cortical and subcortical areas. According to the new understanding of the mechanism behind the physiology of seizures based on MTL and the associated cortical-limbic networks [12–14], multi-channel modes are more conducive to treating seizures effectively and can thereby provide a better therapeutic response under ECT. Overall, it can be concluded that multi-channel modes have the potential to solve the problem faced by existing BT modes in effectively balancing both the efficacy and cognitive side effects of ECT treatments.

In addition, the anatomical variability between the participants had a great impact on the ECT results. For instance, under the same conditions, the largest value of the minimal channel current was 325 mA for PA4, which was more than three times the smallest value of 95 mA for PA7. Such results have highlighted the necessity and importance of individualized realistic human head models for the simulation analysis of ECT-induced E-fields in the brain. Moreover, the practical ECT amplitude-titration method is time-consuming and inconvenient. The simulation method discussed in the study and the corresponding results can provide valuable empirical data and support the development of a feasible approach for the improvement of BT-ECT treatments, overcoming the shortcomings of the existing practical method.

## Declaration of competing interest

There are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brs.2023.01.835.

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