UNIVERSITY OF THE SOUTHERN QUEENSLAND

NUMERICAL INVESTIGATION OF TRANSCRANIAL DIRECT CURRENT STIMULATION ON CORTICAL MODULATION

A dissertation submitted by

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Abstract

Transcranial direct current stimulation (tDCS) is a non-invasive and sub-convulsive functional stimulation technique with applications in both clinical therapy and neuroscience research. The technique provides researchers and clinicians with a unique tool capable of modulating the neural excitability in both the central and peripheral nervous system. On a clinical level, the procedure has been used quite extensively for its potential therapeutic applications in a number of neurological disorders. Despite the advantages of being safe, low cost and easy to administer, our limited understanding on interaction mechanisms between the stimulation parameters and biological materials has impeded the development and optimisation of tDCS based therapies.

The focus of this thesis is to develop a realistic finite element based human head model to address the problems involved in the forward modelling of transcranial direct current stimulation. The study explores the effects of model complexities and anisotropic material properties on field estimations. The sensitivity of electric field and current density on accurate modelling of cortical and non-cortical structures, and the influence of heterogeneously defined anisotropic electric conductivity on field parameters were analysed in an incremental manner. Using the averaged and the subject specific Magnetic Resonance Imaging (MRI) and Diffusion Tensor Imaging (DTI) data, the head models with detailed anatomical features and realistic tissue conductive properties, were developed and employed to specifically address the role of stimulation parameters, such as: morphological variations, structural details, tissue behaviour, inter-subject variations, electrode montages and neural fibre pathways for defining the site and strength of modulation/stimulation.

This thesis demonstrates the importance of human head modelling in elucidating the complex electric field and current density profiles instigated by the non-invasive

electric stimulation. The results of this study strongly support the initial hypothesis that model complexity and accurate conductivity estimation play a crucial role in determining the accurate predictions of field variables. The study also highlighted the inadequacy of scalar field maps to decipher the complex brain current flow patterns and axonal/neural polarization. With the proposed refinements, model based strategies can be employed to optimally select the required stimulation strength and electrode montage specific to individual dose requirements. Therefore, the work conducted in this study will bridge the gap between the current clinical practices and the subject specific treatments by providing accurate physiologically representative simulation.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Signature of Candidate Date

ENDORSEMENT

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Signature of Supervisors Date

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List of related publications

The following papers, associated with the research contained in this dissertation, have been published or submitted for publication.

JOURNAL PAPERS

Shahid, S, Wen, P and Ahfock, T 2013, 'Numerical investigation of white matter anisotropic conductivity in defining current distribution under tDCS', Journal of Computer Methods and Programs in Biomedicine, vol. 109, no. 1, pp. 48-64.

Shahid, S, Wen, P and Ahfock, T 2012, 'Effects of model complexity and tissue anisotropic conductivity on cortical modulation during tDCS', IET Science, Measurement & Technology, vol. 6, no. 6, pp. 464 – 473

Shahid, S, Wen, P, Ahfock, T and Leis, J 2011, 'Effects of head geometry, coil position and CSF displacement on field distribution under transcranial magnetic stimulation', Journal of Medical Imaging and Health Informatics, vol. 1, no. 3, pp. 271-277

PEER-REVIEWED CONFERENCE PAPERS

Shahid, S, Wen, P and Ahfock, T 2011, 'Effect of fat and muscle tissue conductivity on cortical currents - a tDCS study', In: CME 2011: IEEE/ICME International Conference on Complex Medical Engineering, 22-25 May 2011, Harbin, China.

Shahid, S, Wen, P, Ahfock, T and Leis, J 2011, 'Effects of head geometry and coil position on field distribution under transcranial magnetic stimulation', In: MECBME 2011: Connecting Professionals in Biomedical Sciences and Technology, 21-24 Feb 2011, Sharjah, UAE.

Shahid, S and Wen, P 2010, 'Analytic and numeric evaluation of EEG forward problem using spherical volume conductor models', In: CME 2010: IEEE/ICME International Conference on Complex Medical Engineering, 13-15 Jul 2010, Gold Coast, Australia.

JOURNAL MANUSCRIPTS UNDER REVIEW/SUBMITTED

Shahid, S, Wen, P and Ahfock, T, 'Assessment of electric field distribution in cortical and sub-cortical regions under the influence of tDCS', under review at the Journal of Bioelectromagnetics, submitted on 19-10-2012 (under review).

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