COST EMF - MED (Action BM1309):
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STSM Report:

Electric field distribution in anatomical head models during transcranial Direct Current Stimulation for post-stroke rehabilitation

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Abstract:

The techniques of transcranial direct current stimulation (tDCS) are widely adopted in clinical cases such as stroke recovery, neuropsychiatric diseases etc. Until now there is scarce knowledge about the impact of the lesion on the electric field distributions inside the brain of a stroke patient receiving tDCS treatment. Our study intends to shed light on this subject by estimating computationally the electric field distributions inside anatomical head models, including the pathological condition of stroke. A secondary objective is to examine the variations in the electric field, due to the different electrode montages (a novel hypothesis is used), head models, the volume and the phase of the stroke lesion, as they are used in the respective literature of clinical studies.

A. Purpose of the STSM

The main aim of the STSM was to study the electric field distributions inside brain tissues in anatomical head models of different gender and age, including a modeled stroke lesion. Moreover, a secondary objective was to investigate, apart from the classic electrode montages stimulation of the primary motor cortex, a novel approach that examines the role of secondary motor areas such as supplementary motor area (SMA). These will help the individualized rehabilitation of patients with acute or chronic stroke.
To achieve this aim, the following steps were performed:

- Modeling and placement of the stroke lesions inside the anatomical human head models: Choice of the numerical models (one old male, one young female), choice of the lesion volume (10 cm^3, 50 cm^3), selection of the stroke phase (acute, chronic), definition of the electrode montages (M1 stimulation, SMA stimulation), registration of results in specific brain areas by placing electric field sensors.
- Numerical calculations: assignment of the tissues dielectric properties, discretization of the calculation domain, choice and run of the appropriate solver.
- Data post processing: export of the electric field distributions and the corresponding volumes with electric field intensity over 50% and 70% of the 99^{th} percentile value of the field distribution in grey and white matter, cerebellum and hypothalamus. Export of the aforementioned values, only for grey and white matter, from the specific brain areas sensors (i.e. M1 and SMA area).

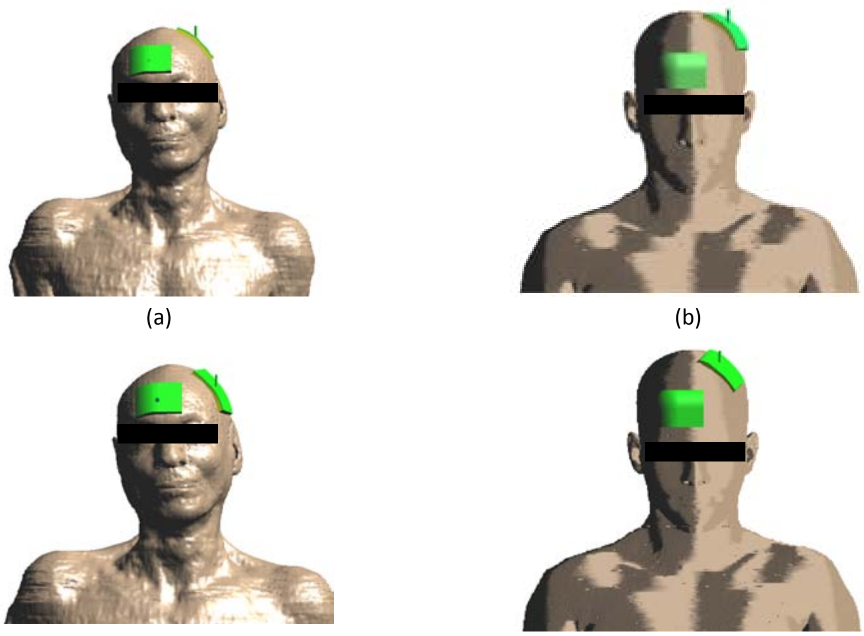
B. Work Description

First of all, a comprehensive review of the literature regarding tDCS in stroke rehabilitation was performed. As a result, the dielectric properties most commonly used, were assigned to the numerical anatomical models. The conductivities at 0 Hz are the same with those given by Gabriel and co-workers [1] at 10 Hz for all modelled tissues except for the conductivities of grey matter, white matter and CSF, for which the values used by Datta and co-workers [2] were assigned. Moreover, the differentiation of the stroke phase led to the assignment of different conductivity values to the stroke lesion [3-4]. Two human anatomical head models of different age and gender were examined. “Glenn” (male 84 years old) and “Ella” (female 26 years old) from the Virtual Population were chosen [5]. The purpose of our choice was to investigate the differences of the electric field distributions inside brain areas between an elderly stroke patient and a young one.

For the lesion volume the upper and lower limits found in the literature were assigned [6]. The lesion was placed in the primary motor cortex (M1) in both anatomical head models. Initially, the electrodes were placed over the lesion area. The anode electrode was placed over the M1 and the reference electrode at the contralateral supra-orbital region, which corresponds to position Fp2 according to the 10/20 EEG international system. However, a novel hypothesis for the electrode montage was reported in [7-9], even if this montage has not yet been used in post stroke rehabilitation. In this case, the electrodes were placed over the SMA area (anode) and the contralateral supra-orbital region (cathode). The whole surface of the electrodes was in touch with the skin (Figure 1).

With the aim to analyze the induced electric field distributions inside specific brain areas, we identified the M1 left and right area and the SMA left and right area in both human head models, by comparison with the MR images based on a brain atlas.

In order to perform the simulations, a computational platform SEMCAD X (v14.8) was used. In particular, the stationary currents electro quasi-static low- frequency solver was used. The Laplace equation was solved and the electric potential (ϕ) distribution inside the human head models was determined. We assumed that the conduction currents dominate with respect to displacement currents ($\sigma \gg \omega\varepsilon$). A bipolar configuration was used. At the outer boundaries of the computational domain a Dirichlet boundary of grounding (ϕ = 0 V) was assumed, whereas the lower boundary was set to a homogeneous Neumann condition (insulation) to separate the head from the rest of the body. The mesh step was set at 1 mm to allow a good discretization of the human head models, the lesion area and the electrodes.



(a) (b) (c) (d)

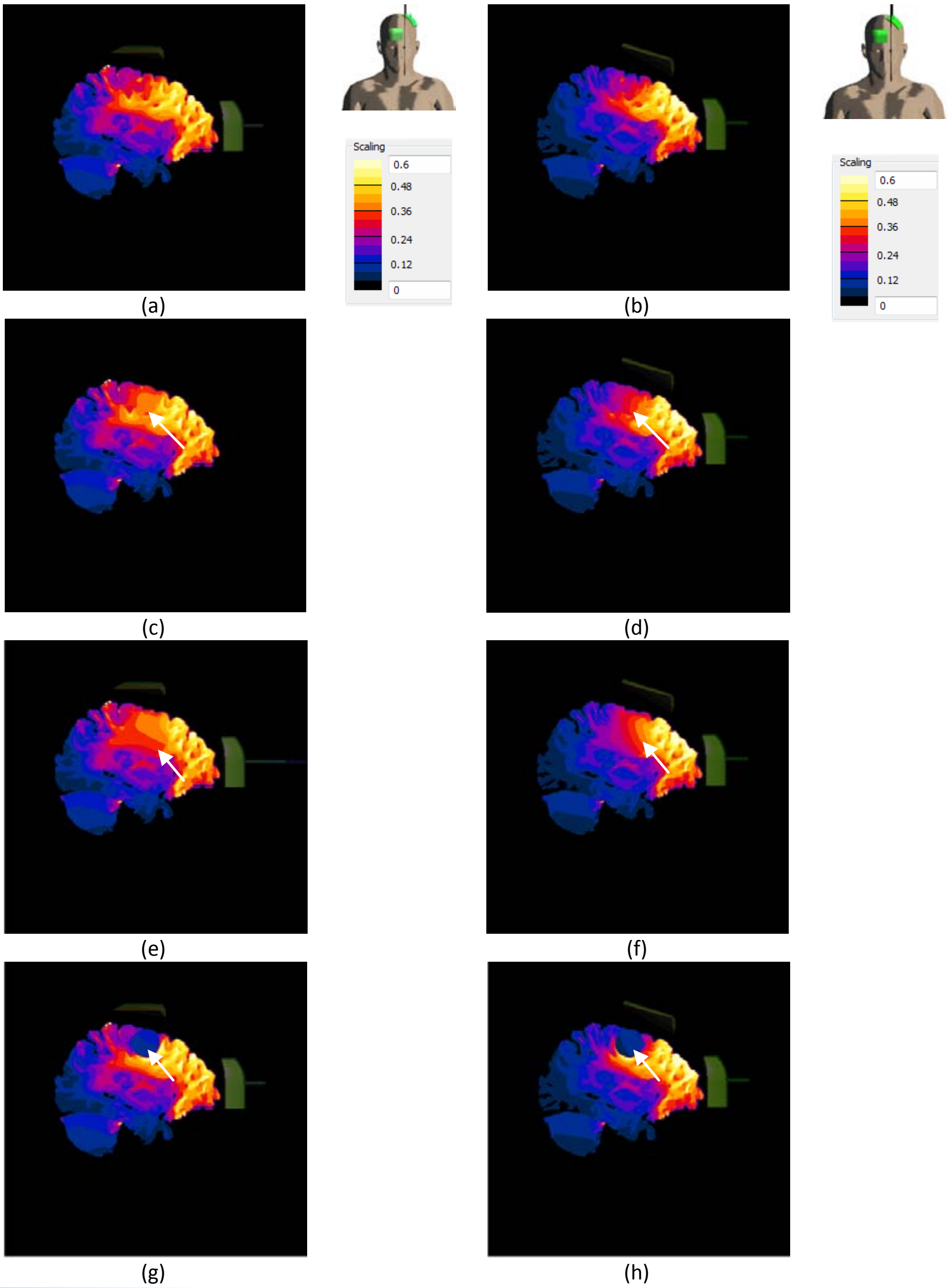
Figure 1. Schematic of the electrode montages on the human model: (a) “Glenn” model - anode electrode on M1 region, cathode electrode on the contralateral supra-orbital region; (b) “Ella” model -

anode electrode on M1 region, cathode electrode on the contralateral supra-orbital region; (c) “Glenn” model- anode electrode on SMA region, cathode electrode on the contralateral supra-orbital region; (d) ”Ella” model - anode electrode on SMA region, cathode electrode on the contralateral supra-orbital region.

C. Results

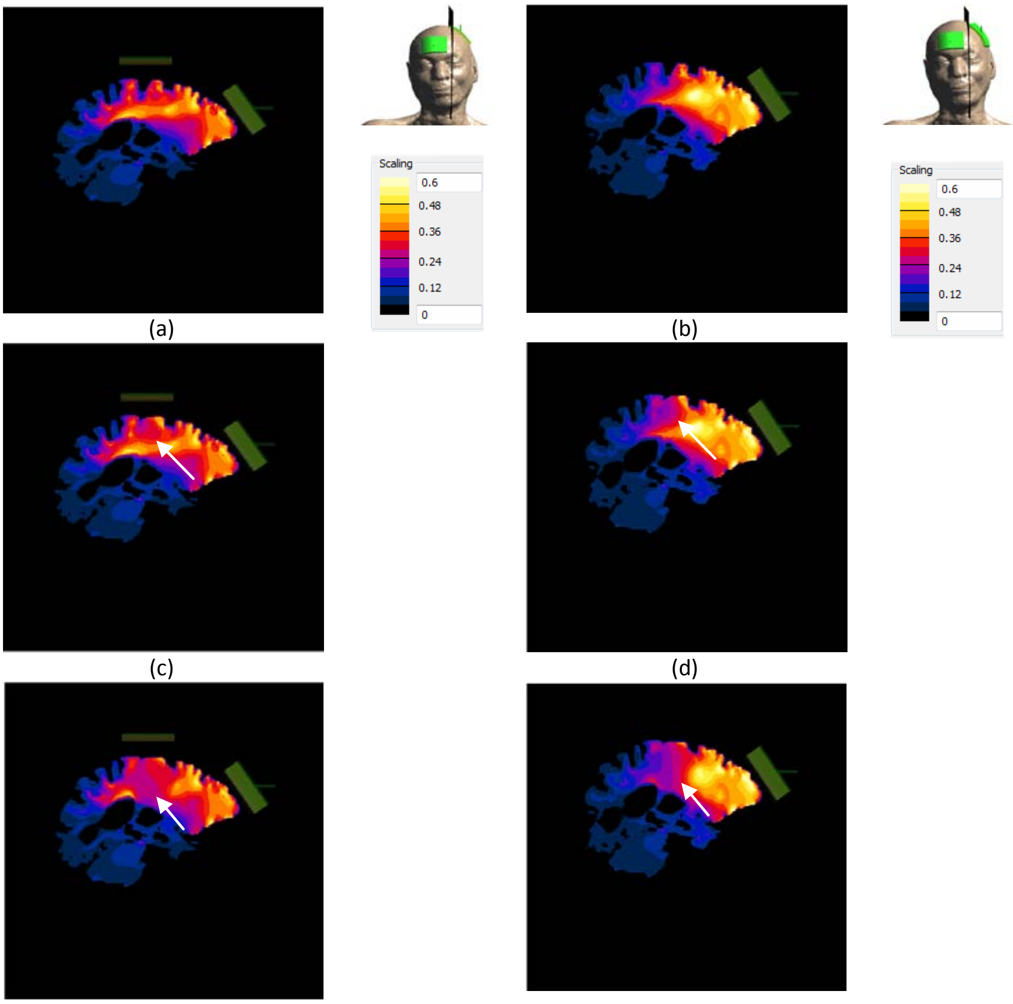
Figure 2 and 3 show the electric field distributions inside the head models of Ella and Glenn, respectively. The electric field distributions are shown for the brain tissues of grey and white matter, cerebellum, hypothalamus and the stroke lesion volume.The arrows point to the lesion volume.

It is clear that in the acute phase of an ischemic stroke the induced electric field does not differ noticeably compared to the electric field in the brain of a healthy person. The difference becomes significant for the chronic phase of an ischemic stroke and, in particular, for the chronic phase of a 50 cm^3 volume lesion.



(i) (j)

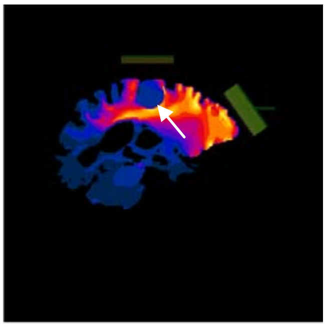
Figure 2. Electric field distributions in the head model of “Ella”. Left column shows the results where the anode electrode is over the M1 region and the cathode electrode over the contralateral supra-orbital region for (a) healthy person (c) patient with an ischemic stroke at the acute phase (of 10 cm^3 in volume), (e) patient with an ischemic stroke at the acute phase (of 50 cm^3 in volume),(g) patient with an ischemic stroke at the chronic phase (of 10 cm^3 in volume) (i) patient with an ischemic stroke at the chronic phase (of 50 cm^3 in volume). Right column shows the results where the anode electrode is over the SMA region and the cathode electrode over the contralateral supra-orbital region for (b) healthy person (d) patient with an ischemic stroke at the acute phase (of 10 cm^3 in volume), (f) patient with an ischemic stroke at the acute phase (of 50 cm^3 in volume), (h) patient with an ischemic stroke at the chronic phase (of 10 cm^3 in volume), (j) patient with an ischemic stroke at the chronic phase (of 50 cm^3 in volume). The arrows point to the periphery of the lesion. The scale is linear.



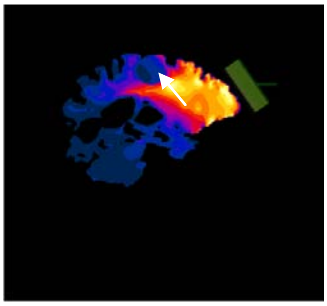
(a) (b)

(c) (d)

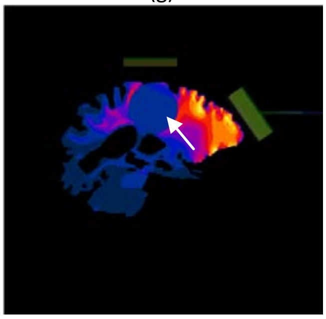
(e) (f)



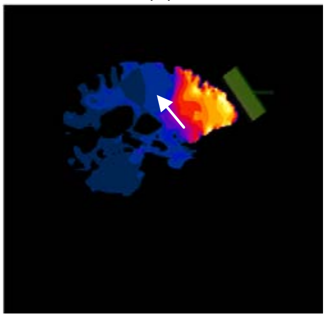
(g)



(h)



(i)



(j)

Figure 3. Electric field distributions in the head model of "Glenn". Left column shows the results where the anode electrode is over the M1 region and the cathode electrode over the contralateral supra-orbital region for (a) healthy person, (c) patient with an ischemic stroke at the acute phase (of 10 cm^3 in volume), (e) patient with an ischemic stroke at the acute phase (of 50 cm^3 in volume), (g) patient with an ischemic stroke at the chronic phase (of 10 cm^3 in volume), (i) patient with an ischemic stroke at the chronic phase (of 50 cm^3 in volume). Right column shows the results where the anode electrode is over the SMA region and the cathode electrode over the contralateral supra-orbital region for (b) healthy person, (d) patient with an ischemic stroke at the acute phase (of 10 cm^3 in volume), (f) patient with an ischemic stroke at the acute phase (of 50 cm^3 in volume), (h) patient with an ischemic stroke at the chronic phase (of 10 cm^3 in volume), (j) patient with an ischemic stroke at the chronic phase (of 50 cm^3 in volume). The arrows point to the periphery of the lesion. The scale is linear.

D. Future collaboration with host institution

Both institutes are interested in future collaboration concerning the use of tDCS for post-stroke rehabilitation, by testing any possible variation such as other electrode montages, different anatomical models (age and gender) and volume of the stroke lesion.

E. Expected Publications

1. A manuscript entitled "Electric field distribution in anatomical head models during transcranial Direct Current Stimulation for post-stroke rehabilitation" will be submitted to a journal, as a result of the STSM reported here.

2. Some results of the STSM will be submitted for presentation at the BioEM 2016 Conference.

F. References

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Confirmation by the host institution of the successful execution of the STSM:

See annex

Contact Person of Host Institution

Marta Parazzini

Signature

Name of researcher

Zoi Manoli

Signature