Numerical Assessment of Human Near-Field Exposure in the EU GOLIAT project: A Multi-frequency Analysis across Different Anatomical Models

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INTRODUCTION

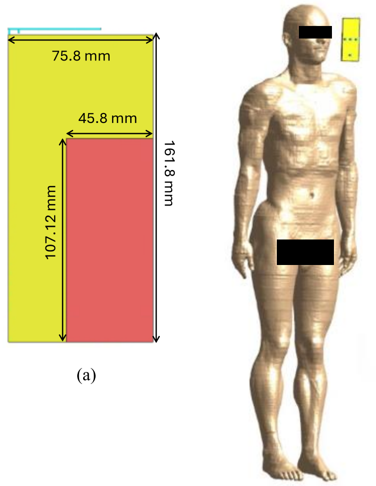
One of the main objectives of EU GOLIAT project is to quantify and characterize the radiofrequency electromagnetic field (RF-EMF) exposure patterns and levels, in young people and workers, in the context of the deployment of new generation radio-communication networks, in particular 5G.
This study, performed in the framework of EU GOLIAT project, therefore aims to assess the near-field exposure emitted by personal devices across eight frequencies (from 700 MHz to 5800 MHz) by a numerical approach, employing four anatomically detailed virtual human models of different age and gender covering the age range of the GOLIAT study population for a total of 704 simulations in total, corresponding to 176 use cases of wireless device for each anatomical model. The exposure was assessed by in-body absorptions estimation, in particular by the quantification of the whole-body average SAR (SAR_{wb}, W/kg), placing the devices on 3 locations near the phantom (i.e. device near the ear, in front of the eyes, and at the belly level) with different positions for each location, thus also considering the exposure variability. In this activity, the exposure assessment question is addressed, for the first time, in a comprehensive way through the involvement of four different human phantoms and, moreover, the EMF is generated by a mock-up phone in order to mimic a scenario as realistic as possible.

METHODS

The generic mock-up phone was composed of an antenna (Planar Inverted-F Antenna (PIFA) or Inverted-F Antenna (IFA)), a printed circuit board (PCB) and a battery, as shown in Fig. 1a. The antennas were modeled with two different typical geometries, determined by their operating frequency due to the radiative element size. The PIFA geometry was used for antennas tuned at f_1 = 700 MHz and f_2 = 835 MHz, whereas IFA geometry was used for antennas tuned at f_3 = 1450 MHz, f_4 = 2140 MHz, f_5 = 2450 MHz, f_6 = 3500 MHz, f_7 = 5200 MHz, and f_8 = 5800 MHz. The dimensions of each IFA radiative element were chosen according to the frequency of interest. The PCB was modeled as a thin (1 mm) conducting plate ($\varepsilon_r = 1$, $\sigma = 5.8 \times 10^7$ S/m), following commercial device dimensions: 161.8 x 75.8 mm and the battery was modelled as a 1 mm thick metal box (45.8 mm x107.12 mm). All antenna models were tuned in free space, achieving reflection coefficients (S_{11}) ranging from -15 dB for f_3 to -21 dB for f_5.

To study the variability of exposure levels due to anatomical characteristics, four human models from the Virtual Population (ViP) [1] were selected: Duke (age = 34 y.o., height = 1.77 m, weight = 70.2 kg, BMI = 22.4 kg/m^2), Ella (age = 26 y.o., height = 1.63 m, weight = 57.3 kg, BMI = 21.6 kg/m^2), Thelonius (age = 6 y.o., height = 1.16 m, weight = 18.6 kg, BMI: 13.8 kg/m^2), and Eartha (age = 8 y.o., height = 1.36 m, weight = 29.9 kg, BMI = 16.2 kg/m^2). These models represent adult male, adult female, child male, and child female subjects, respectively. The dielectric properties of all human tissues were defined according to the literature [2] and depending on the frequency of the EMF.

Three main locations of the mock-up phone relative to the human model were considered. The *Ear* position refers to the mock-up phone place in the cheek and tilt position as described in the IEC standard [3]. The *Eyes* position refers to the mock-up phone placed 20 cm from the nasion, while the *Belly* location corresponds to a distance of 20 cm from the belly button. To simulate realistic scenarios, the position of the phone was varied for each location: 10 degrees up and down in the case of *Ear* location (which corresponds to 3 positions for cheek and 3 for tilt) and horizontally within a 30 cm range and vertically within a 10 cm range for the other two locations (which corresponds to 4 positions for the *Eyes* and 4 positions for the *Belly*). *Eyes* and *Belly* location were analyzed with the antenna in both vertical and horizontal polarization, encompassing all possible realistic phone positions. An example of one exposure condition is shown in Fig. 1b for the Duke model.



(a) (b)

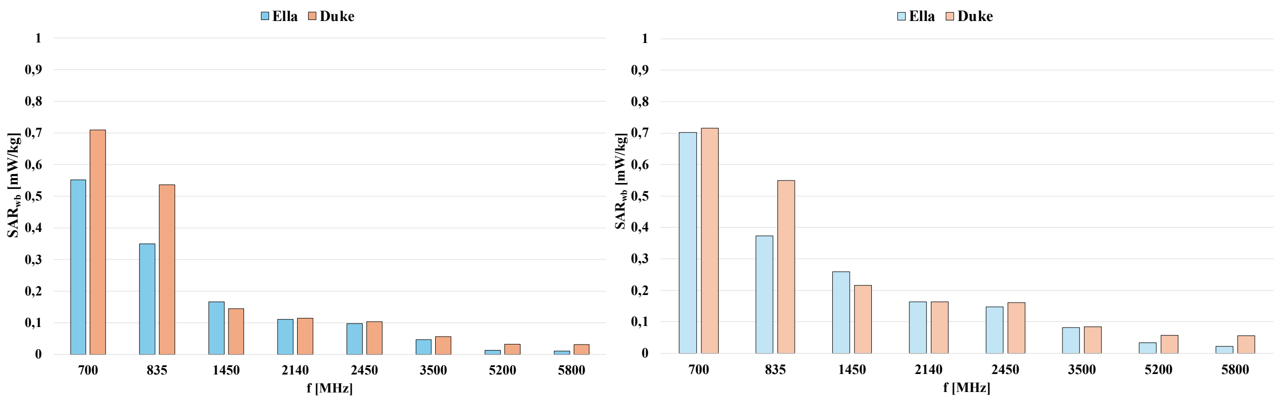
Figure 1 Panel (a) Front view of the mock-up phone. Panel (b) *Eyes* locations indicated in yellow and dots with vertical polarization here reported as example of the positionings.

For solving Maxwell's equations, the study employed the Finite-Difference Time-Domain (FDTD) method implemented in the Sim4Life v.8.2 simulation platform. The computational domain was discretized using a non-uniform grid, with minimum voxel size chosen to ensure a spatial sampling of 10-20 per wavelength (λ) at each frequency. The computational domain was truncated using 8 layers of Perfectly Matched Layer (PML) material.
To simulate the worst-case exposure, homogeneous tissue simulating flat phantoms (300 mm x 300 mm) were exposed to each of the forementioned mock-up phones. The thickness of phantoms was roughly five skin depths at the frequency of operation. The distance between the phone model and the phantom was 5 mm. The electromagnetic properties of the tissue simulating liquids were taken from IEC 62209-1 [4]. The input power of the phone models was increased until 1 W/kg SAR averaged over 10 g was induced in the flat phantom. This obtained value of input power was used to normalize the simulation results when the human models were exposed to the mock-up phones in all the configuration tested. For the exposure assessment, the whole-body average Specific Absorption Rate (SAR_{wb}, W/kg) was evaluated according to ICNIRP Guidelines [5] and compared with the Basic Restriction of 0.08 W/kg for general public and occupational exposure (i.e., 0.4 W/kg).

RESULTS

Simulations are currently on-going; therefore, here only preliminary results will be presented as examples.
Figure 2 shows, as an example, the whole-body average SAR (SAR_{wb}, W/kg) evaluated for the two adult models in the *Eyes* and *Belly* location in the vertical polarization. Data in the figure show the mean of the values calculated across the variation of the position (i.e. four positions for *Eyes* and four positions for *Belly* location) for each frequency. Primarily, all SAR_{wb} values remain well below the ICNIRP Guidelines limits: 0.08 W/kg and 0.4 W/kg for general public and occupational exposure, respectively. Considering the adult models, the highest estimated value occurred in the Duke *Belly* configuration at 700 MHz, measuring 0.73 mW/kg, thus representing a 99% deviation from the lowest limit that is for general public exposure.
A notable trend emerges in the frequency-dependent absorption characteristics. As frequency increases, a clear decrease in absorption levels is observed. Moreover, from the comparison of the SAR_{wb} values in Ella and Duke, it is clear that they are very similar, especially when the highest frequencies are involved. The greatest difference occurs at 835 MHz, and it is of about 34%. Otherwise, the entity of this deviations decreases with the increase of the frequency.
Concerning the variability of the exposure levels due to the different location of the antenna with respect to the human model, Figure 3 shows, as an example, the SAR_{wb} values obtained in all the location here considered for three frequencies and the Duke model. Again, the data are the mean value of SAR_{wb} values across the variation of the position. Clearly, the figure shows that SAR_{wb} in the *Ear* location is always the highest, and

this is obviously due to the minimum distance between the source and the human model, i.e., 0.8 cm from the tragus to the PCB. Moreover, by comparing the other two main positions, i.e. *Eyes* and *Belly*, the SAR_{wb} estimated in the *Belly* configurations are always slightly higher than the SAR_{wb} in the *Eyes* location and the reason is mainly the distance between the human model and the source.
Focusing on the two polarizations, Figure 3 shows that the exposure levels obtained in case of the vertical polarization are about 30% higher than those with horizontal polarization at least for the three frequencies here shown.



(a) (b)

Figure 2. Panel (a) represents the SAR_{wb} values averaged over the SAR_{wb} obtained in all the variations of *Eyes* location. Panel (b) represents the SAR_{wb} values averaged over the SAR_{wb} obtained in all the variations of the *Belly* location. Both panels refer to vertical polarization and adult models (Duke and Ella).

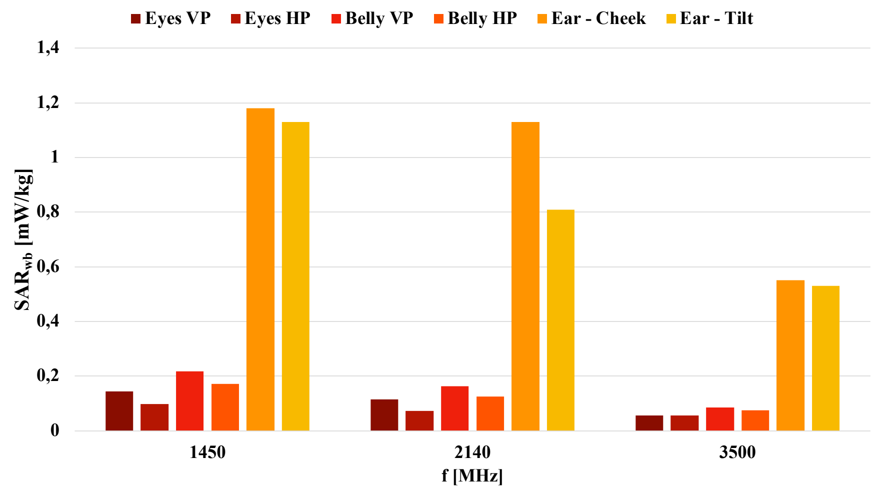


Figure 3. Values of the whole-body SAR in all the simulated configurations for three frequencies evaluated in the Duke model. The SAR_{wb} are the mean values calculated across the variations of each location.

CONCLUSIONS

This study, conducted within the EU GOLIAT project framework, presents the numerical dosimetric assessment of near-field exposure emitted by personal devices across eight frequencies (from 700 MHz to 5800 MHz) in four different anatomical models for 176 use cases of wireless device for each anatomical model. Preliminary results demonstrate that exposure levels remain substantially below ICNIRP Guidelines. The investigation revealed significant frequency-dependent variations in absorption characteristics, with notably higher exposure levels observed at sub-1 GHz frequencies compared to higher frequency bands. The whole set of data of this study will provides crucial insights into human exposure patterns in realistic communication scenarios.

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REFERENCES

[1] M.-C. Gosselin *et al.*, "Development of a new generation of high-resolution anatomical models for medical device evaluation: the Virtual Population 3.0," *Phys. Med. Biol.*, vol. 59, no. 18, pp. 5287–5303, Sep. 2014, doi: 10.1088/0031-9155/59/18/5287.

[2] S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Phys. Med. Biol.*, vol. 41, no. 11, pp. 2251–2269, Nov. 1996, doi: 10.1088/0031-9155/41/11/002.

[3] Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz - Part 3: Specific requirements for using the finite difference time domain (FDTD) method for SAR calculations of mobile phones," in *IEC/IEEE 62704-3:2017* , vol., no., pp.1-76, 27 Oct. 2017.

[4] "IEC/IEEE International Standard - Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 1528: Human models, instrumentation, and procedures (Frequency range of 4 MHz to 10 GHz)," in *IEC/IEEE 62209-1528:2020* , vol., no., pp.1-284, 19 Oct. 2020.

[5] ICNIRP, "Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)," *Health Physics*, vol. 118, no. 5, pp. 483–524, May 2020, doi: 10.1097/HP.0000000000001210.