

# The influence of open loop currents on bioelectric and biomagnetic measurements: a phantom study

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**Abstract.** Closed loop currents are discussed as possible sources of differential information in the magnetocardiogram and the electrocardiogram. It is, however, unclear if also open loops, such as spiral activation in the heart, can contribute to these differences. We model two types of open loops, based on the heart geometry, with the help of twelve artificial current dipoles in a physical torso phantom. Electric potentials and magnetic fields were measured simultaneously for an increasing number of active dipoles in the two source geometries. We found for the magnetic fields a continuous increase of the measured amplitudes up to a plateau value at ten active dipoles. For the electric potentials, we found increasing amplitudes up to six or eight active dipoles and thereafter decreasing amplitudes. We conclude that also open loop currents can contribute to the experimentally observed differences in magnetocardiograms and electrocardiograms. Combined bioelectric and biomagnetic measurements will provide greater insight into heart activity than do single modality measurements.

**Keywords:** Magnetocardiography, MCG, Electrocardiography, ECG, Vortex Currents, Ischemia

## 1. Introduction

Closed loop currents, also referenced as vortex currents, are discussed for a long time as possible sources of differential information in the magnetocardiogram (MCG) and the electrocardiogram (ECG) [Wikswo and Barach, 1982; Roth and Wikswo, 1986; Barach, 1993]. Clinical observations indicate a diverging of the MCG and the ECG during exercise [e.g. Brockmeier et al., 1997].

According to the theoretical concept, closed loop currents produce biomagnetic fields but no bioelectric potentials. Previously, we demonstrated that both active and passive vortex currents can be produced experimentally in a torso phantom and that the theoretical concept can be validated [Liehr et al., 2005; Dutz et al., 2006].

Besides closed loop currents in the heart, also open loop currents can occur, e.g. due to the spiral arrangement of muscle fibers. It is unclear whether such open loop currents have different sensitivities in ECG and MCG and potentially contribute to the differences observed in the patients. Thus, the aim of this study is to analyze the influence of open loop currents on the electric and magnetic signal strength. For this, we simultaneously record electric and magnetic data produced by dipole setups in a human torso phantom.

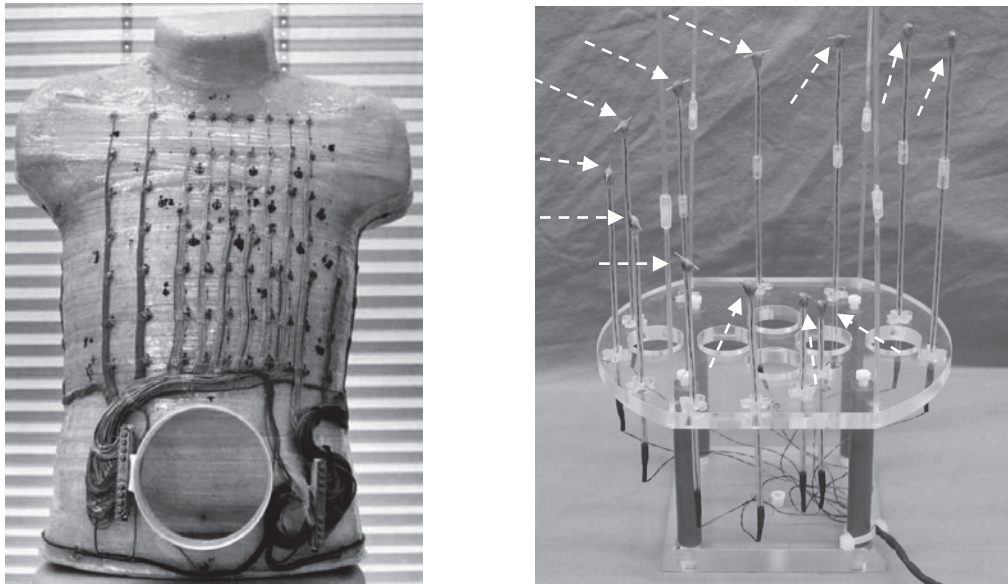
## 2. Material and Methods

### 2.1. Phantom setup

We used a realistically shaped torso phantom, build from resin with glass fiber [Tenner et al., 1999]. 138 Ag/AgCl electrodes for electric data acquisition were embedded in the surface of the phantom (Fig. 1, left). The phantom was filled with saline solution to reproduce a physiological conductivity inside the phantom (conductivity of 0.335 S/m).

We produced two different open loop source setups. The first setup consisted of 12 dipoles forming a planar spiral and the second setup consisted of 12 dipoles forming a spatially extended spiral (Fig. 1, right). The single dipoles were built from platinum with a length of  $10 \pm 0.5$  mm. The feed lines for all

dipoles were made from twisted copper wire. The dipoles were feed with a constant current power supply with twelve galvanically separated channels. During all measurements a sinusoidal current of 0.5 mA with a frequency of 20 Hz was applied. The dipoles were switched on one by one, starting from one single dipole up to all 12 dipoles. With these different arrangements we were able to examine the progression of the electric and magnetic signal strength for a more and more looped current.



**Figure 1.** Left: Front view of the physical torso phantom with in total 138 electrodes. 63 electrodes are integrated in the anterior chest wall. Right: Dipole setup of the spatially extended open loop source (the white dashed arrows indicate the positions of the dipoles).

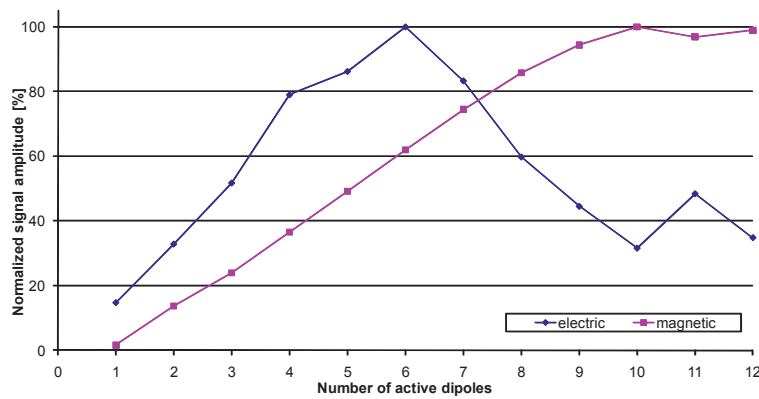
## 2.2. Measurements and data analysis

The measurements took place in a magnetically shielded room (AtB SrL, Pescara, Italy) using the vector-biomagnetometer ARGOS 200 (AtB SrL, Pescara, Italy) and the built in ECG system. Only the 63 ECG channels on the anterior chest wall were recorded. The electrodes are arranged according to the NEMY standard [Hoekema et al., 1995]. All of the 195 Superconducting QUantum Interference Devices (SQUIDs) of the vector-biomagnetometer were used in the recordings. The intrinsic noise level of the SQUIDs was below  $5 \text{ fT Hz}^{-1/2}$  at 10 Hz. Electric and magnetic signals were simultaneously recorded with a sampling rate of 1025 Hz.

The raw data were filtered by employing a 10 Hz to 35 Hz Butterworth band pass filter. In the channel exhibiting the maximum magnetic amplitude, the time instant of the positive peak amplitude was determined in 20 consecutive artifact-free periods of the sinusoidal signal. Thereafter, for the magnetic and the electric channel that showed the maximum signal amplitude, the mean value and the standard deviation of the signal strength were computed over these 20 instants in time. Note that the magnetic and electric signals were in phase. Normalization was applied in order to make electric and magnetic signal strength comparable.

## 3. Results

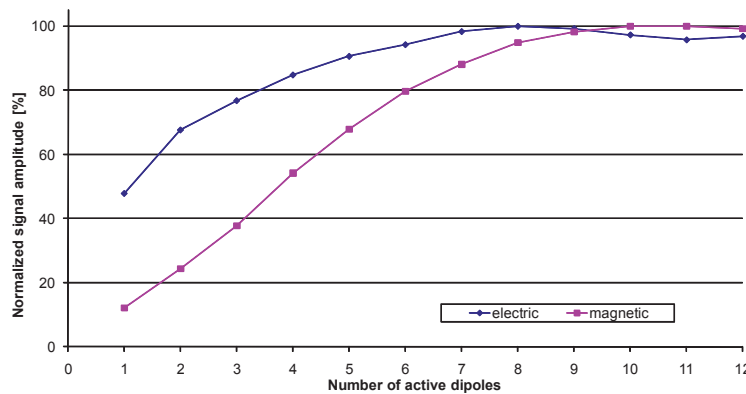
The normalized amplitudes of the magnetic and electric signals over the number of active dipoles for the planar open loop current are displayed in Fig. 2. All standard deviations were below 0.1 % and thus not displayed. With the increase in the number of enabled dipoles, also the loop is more complete. The electric signal strength is increasing up to 6 active dipoles, which represents a semi loop (similar to a semi circle). Thereafter, up to 10 enabled dipoles, the signal strength is decreasing to a value less than for two active dipoles. Also for the full loop the electric signal strength is similar to the value at two active dipoles. On the contrary, the magnetic signal strength increases almost linearly up to 10 active dipoles. Thereafter, up to the full loop, the signal strength stays approximately constant.



**Figure 2.** Normalized electric and magnetic signal strength over der number of enabled dipoles for the planar open loop source configuration.

The results for the spatially extended open loop source setup are displayed in Fig. 3. Again, the normalized amplitudes of the magnetic and electric signal strengths over the number of active dipoles are presented. The amplitude increases for the electric signal up to 8 active dipoles and slightly decreases starting with the 9<sup>th</sup> active dipole. The variation of the signal strength between a half loop and a full loop is less than 5 %. The amplitude of the magnetic signal increases up to 10 active dipoles and thereafter stays approximately constant.

Please note the different starting values for the magnetic and electric signal strength at one active dipole in both Fig. 2 and 3.



**Figure 3.** Normalized electric and magnetic signal strength over der number of enabled dipoles for the spatially extended open loop source configuration.

## 4. Discussion

We modeled a spirally shaped open loop current distribution with a set of twelve single dipoles. We found a highly differential influence for the open loop currents on the electric and magnetic signal strengths. The differential effect is more pronounced for the planar setup compared to the spatially extended setup.

For the magnetic signal strength, we observe a plateau for higher number of active dipoles. This plateau is somewhat more pronounced for the spatially extended loop. The plateau can be explained with the increasing symmetry of the dipole arrangement and was similarly found in [Liehr et al., 2005]. The decreasing electric signal strength shows clearly the influence of getting close to a closed loop for electric signals. Similar to the circular arrangement in [Liehr et al., 2005], the decrease begins when the dipole arrangement exceeds a semi loop.

When compared to the experimental results of active and passive vortex currents in [Liehr et al., 2005; Dutz et al., 2006], the influence on the electric signal strength is reduced for the open loop

current distributions in this study. Our results are supported by the simulation study of Kosch and colleagues [Kosch et al., 2000], who suggested that curved currents (e.g. semi circles) can already lead to differential effects in magnetic field and electric potential distributions.

## 5. Conclusions

Our study provides quantitative data for the differential influence of open loop currents on magnetocardiographic and electrocardiographic recordings. Such open loop currents may explain, at least in part, the experimentally observed differences between magnetocardiographic and electrocardiographic recordings. Combined bioelectric and biomagnetic measurements provide greater insight into heart activity than do single modality measurements.

## Acknowledgements

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