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Analysing Specificity of a Bipolar EEG Measurement

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Abstract— **The objective in bioelectric measurements such as ECG and EEG is to register the signal arising from sources in the region of interest. It is also desired that signal-to-noise ratio (SNR) of a measurement is high. The sensitivity of an ideal measurement should focus on and be greater on the target areas in comparison to other areas of the volume conductor. Previously the half-sensitivity volume (HSV) has been applied to describe how focused the measurement is. In this paper we introduce a concept of the half-sensitivity ratio (HSR) which describes how well the sensitivity is concentrated in HSV compared to other source regions i.e. how specific the measurement is to the sources in HSV. Further we may have different region of interests (ROI) to which the measurements are wanted to be specific. Then the concept is called region of interest sensitivity ratio (ROISR). We present here an application of the HSR in analysing sensitivity distributions of bioelectric measurements. We studied the effects of interelectrode distance and the scalp/skull/brain resistivity ratio on the HSR of a bipolar EEG measurement with a three-layer spherical head model. The results indicate that when the focus of interest is on cortical activity more specified and concentrated sensitivity distributions are achieved with smaller interelectrode distances. Further a preliminary measurement with visual evoked potentials provides evidence of the relationship between HSR and SNR of a measurement.**

I. INTRODUCTION

In the present paper we apply the concept of half-sensitivity ratio (HSR) [1] to characterise how well the measurement sensitivity of a bipolar electroencephalography (EEG) measurement, is concentrated in the half-sensitivity volume [2] and thus how specific the measurement is to the sources in this volume.

In clinical EEG the traditional electrode system has been the 10-20-electrode system, in which the average interelectrode distance is 60 mm [3]. Today there are also commercial systems with up to 512 electrodes. In these high resolution systems the average interelectrode distance can be as short as 11 mm [4]. The question is which electrode system would be most suitable for a given measurement as different numbers of electrodes are suitable for different measurement purposes or conditions. We should thus be able to select easily the optimal electrode system for a particular measurement. The information to support this selection could be achieved by comparing the properties of measurement sensitivity distributions of different measurement setups. The information is essential especially in the cases where the multielectrode systems are not applicable and thus it would be important to know how to arrange limited number of electrodes to achieve best possible results.

When measuring activity of a certain source region it is desired that the measurement sensitivity is high on target region and as low as possible on the other source regions. Therefore there is a need for a parameter which defines how specific the measurement is in assessing the sources in the region of interest defined by the observer. We assume that the specificity of a measurement system also correlates with signal-to-noise ratio of a measurement.

In the present study we apply the concept of the half-sensitivity ratio (HSR) in analysing how specific the bipolar EEG measurement is to the sources in the HSV compared to other sources outside the HSV. We demonstrate here with the spherical head model the capabilities of HSV and HSR applied in the analysis of EEG measurements detecting cortical sources. We studied the parameters as a function of the scalp/skull/brain resistivity ratio and interelectrode distance.

We present here also the results from preliminary experiment which was carried out to investigate the assumed correlation between HSR and SNR. The experiment was visual evoked potential study with 6 bipolar leads.

II. MATERIAL AND METHODS

A. The Concept of Half-Sensitivity Volume

In [2, 5] the concept of half-sensitivity volume (HSV) was applied to define the volume in which the sensitivity of measurement lead is concentrated. The HSV is the size of the volume within the volume source where the magnitude of the detector's sensitivity is at least half of its maximum [2, 5, 6]. The smaller the HSV is, the smaller is the region from which the detector's signal arises. The half-sensitivity volume is thus applied to compare the detectors' ability to concentrate its measurement sensitivity. It has been recognized that the interelectrode distance and scalp/skull/brain resistivity ratio affect to the size of the HSV [5].

B. The Concept of Half-Sensitivity Ratio

The concept introduced in [1] provides new parameters to

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analyse properties of measurement sensitivity distribution. One of these is the specificity of a measurement system which would provide the difference in sensitivity between the region of interest (e.g. HSV) and the rest of the source volume. Equation 1 defines the HSR as a ratio between the average sensitivity in the HSV and the average sensitivity in the rest of the source volume.

$$HSR = \frac{mean(S_{HSV})}{mean(S_{nonHSV})} \qquad (1)$$

S_{HSV} is the sensitivity in the half-sensitivity volume

S_{nonHSV} is the sensitivity in the rest of the source volume

In more general matters the parameter described above can be considered to describe the capacity of measurements for having high relative measurement sensitivity in the region of interest depending on the particular application, and it could thus be called region of interest sensitivity ratio (ROISR) if the region of interest is not the HSV [1].

C. *Model and computations*

We calculated the sensitivity distributions in a three-layer spherical head model. The model includes the layers of scalp, skull and brain, the radii of the spheres being 92, 85 and 80 mm, respectively [7]. Calculation of the sensitivity distribution was based on the principle of reciprocity [6] and the analytical solution of EEG electrode sensitivity [7]. Since there is no certainty as to the real scalp/brain/skull resistivity ratio, and many values have been introduced in different studies we executed our calculations with 5 different scalp/skull/brain resistivity ratios (1/1/1, 1/8/1, 1/15/1, 1/30/1, 1/80/1) [8-10].

We calculated sensitivity distributions in the brain region for the bipolar electrode configurations attached to the scalp. We had 35 different interelectrode distances for all five resisitivity ratios, varying from 289 mm to 8.26 mm (180 degrees to 5.14 degrees, respectively). The change in distance between two cases was 8.26 mm (5.14 degrees). We calculated distributions also for 6 additional electrode distances which correspond to the leads applied in clinical measurement presented in Table 1.

D. *Preliminary Clinical Experiment*

We made a preliminary visual evoked potential (VEP) experiment with 6 bipolar leads to study how well the HSRs and SNRs of different leads correlate. VEP experiment was chosen because the responses generated in the brain are known to be located on the cortex region and the HSR concerns how specific the measurement is to the HSV which lies on the cortex.

The VEP experiment was based on checkerboard stimulation procedures described in [11]. We had one measurement electrode Oz over the occipital lobe and 6 different reference electrode locations which are illustrated in Fig. 1. Table 1 presents the distances between different reference electrodes and measurement electrode Oz. In the experiment we measured 350 responses (hereafter epochs).

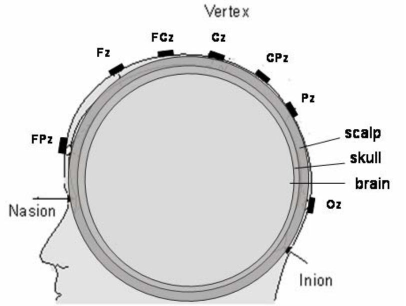

Fig. 1. Locations of electrodes and a three-layer spherical head fitted into the head (modified from [6])

Table 1

Distances between reference electrodes and Oz

Lead	FPz -Oz	Fz -Oz	FCz -Oz	Cz- Oz	CPz- Oz	Pz- Oz
Angle(°)	110	82	67	56	42	31

The measured response contains lots of noise and thus some averaging of the repeated epochs is normally applied to reveal the actual signal of interest. The amount of noise decreases when epochs are averaged and thus the signal-to-noise ratio increases. The SNR of an epoch was calculated with method introduced by Raz *et. al.* [12]. We calculated the SNR for each measurement lead as a function of averaged epochs.

The HSRs of different leads were calculated with spherical head model with same electrode distances than those adopted in VEP measurement. In Fig. 1. the spherical model is fitted into the head to show that the electrode locations in the model and real life have fairly good correlation and thus these methods can be combined.

We calculated the correlation coefficient [13] between the HSRs and SNRs of each lead with different amount of averaged epochs. We calculated also the average p-value for the correlation to find out the significance of it.

III. RESULTS

A. *Analysing the specificity*

The behaviour of the HSR as a function of electrode distance is presented in Fig. 2. The half-sensitivity volumes (HSV) for the same electrode distances are presented in Fig. 3. From the behaviour of the HSR and HSV as a function of electrode distance it will be observed that even though the half-sensitivity volumes (i.e. the spatial resolution) of two measurement setups are equal or close to each other, there might be differences in the half-sensitivity ratios (i.e. in the specificity of the measurement) of these same measurement setups. This may have an influence on the quality of the measurement. We may observe that HSR increases continuously as the electrode distance is reduced and thus more specific measurements will be achieved with shorter electrode distances.

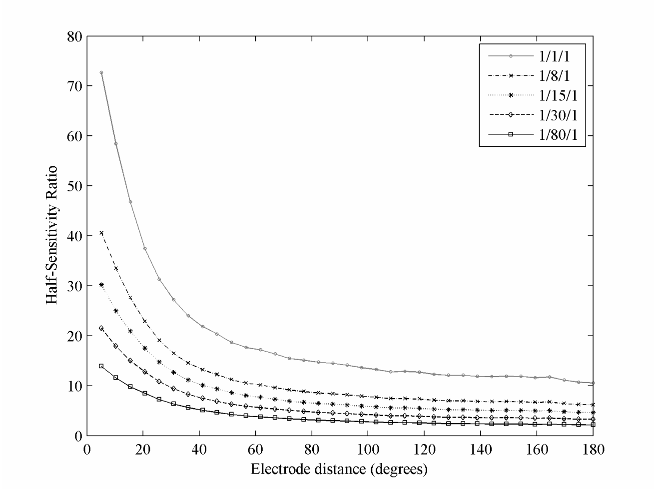

Fig. 2. The HSR as a function of electrode distance for 5 scalp/skull/brain resistivity ratios

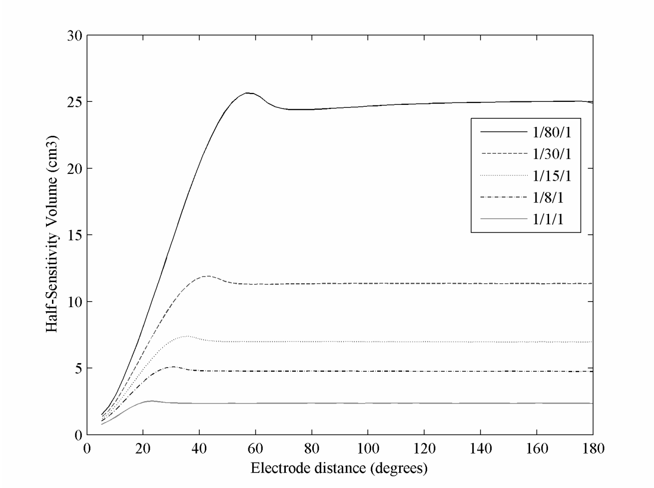

Fig. 3. The HSV as a function of electrode distance for 5 scalp/skull/brain resistivity ratios

As seen in Fig. 3, HSV remains unchanged when the electrode distance is long and thus the spatial resolution of two measurements might be the same even though their specifities differ. We may observe that both HSV and HSR change dramatically when the electrode distance is smaller than 50 mm, and both thus have an effect on measurements with these lower electrode distances.

B. *Correlation between HSR and SNR*

Fig. 4 presents the signal-to-noise ratios of 6 bipolar EEG leads as a function of averaged epochs. It can be observed that the SNR is higher with shorter electrode distances, which is the case also with HSR. The correlation between the SNRs and HSRs of these 6 leads with different number of averaged epochs is presented in Fig. 5. It is observed that the correlation is almost 100 % when over 50 epochs are averaged and already with 10 averages it is close to 90 %. The average p-value is 0.0022 which means high significance because in general the significance is thought to be high if the p-value is <0.05.

The behaviour of HSR between different resistivity ratios have almost 100% correlation and the resistivity ratio behaves as a scaling factor. Thus the correlation between HSR and SNR presented here is not dependent on the scalp/skull/brain resistivity ratio.

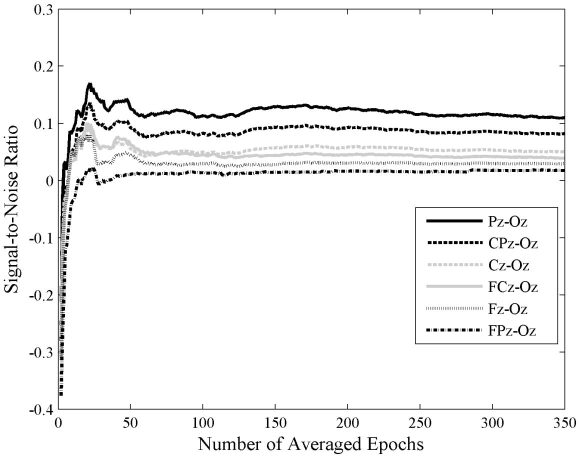

Fig. 4. The Signal-to-noise ratios as a function of averaged epochs for 6 bipolar EEG leads

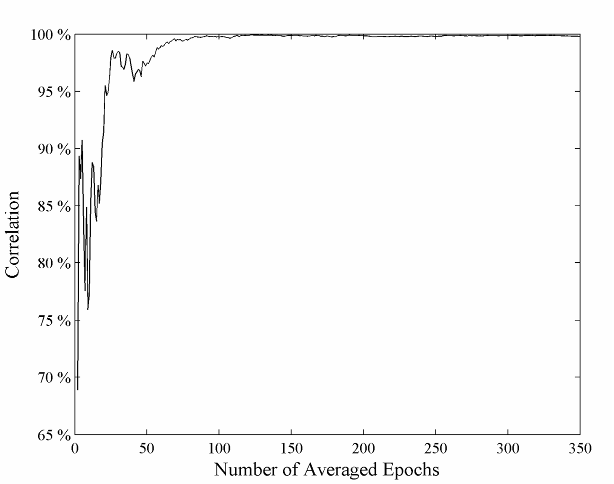

Fig. 5. The correlation between HSRs and SNRs of the bipolar EEG leads as a function of averaged epochs.

IV. DISCUSSION

A. *Analysis with HSR*

In this paper we present an application of a concept for analysing the ability of measurement setup to concentrate relatively high sensitivity on the region of interest, here HSV. Although the concept is here applied only to bioelectric measurement it may as well be applied to biomagnetic measurements. As a ratio of average values the HSR is most suitable for cases where the signal and noise sources may be considered to be homogeneously distributed within their regions. This is not the case in real life and therefore some additional parameters are presented in [1] to define how homogeneously the magnitude of sensitivity is distributed outside the region of interest and what the variation between the lowest and best possible sensitivity ratios is.

B. *Effect of electrode distance*

Electrode distance affects many properties of measurement sensitivity, and these effects are also dependent on the location of the region of interest, here HSV [1]. The effect of electrode distance on measurements is different for different relative skull resistivities. For different electrode distances the locations of noise sources are more important than for others. Based on this study it can be said that if the target region is on the cortex the measurement becomes less sensitive to the "brain noise" when the electrode distance is smaller.

C. *Effect of resistivity ratio*

In the present study it was observed that if the relative skull resistivity is lower than previously assumed, the different electrode systems are less sensitive to "brain noise". The behaviour of the HSR and HSV as a function of electrode distance is not affected by the scalp/skull/brain resistivity ratio, but more specific and more concentrated measurement is achieved if the resistivity ratio is lower and the electrode distances are the same. This is the case at least with measurements concentrated on cortical sources but changes when the region of interest is deeper in the brain [1, 14].

D. *Correlation between HSR and SNR*

It was shown here with a preliminary experiment that the HSRs of the leads have strong correlation to the leads' SNRs. The results presented here might be over optimistic while we had just a single measurement and the HSRs were calculated with spherical head model. Also, the orientation of the lead and the source have effect on HSR and thus on the correlation [14]. Despite of these facts it was shown that some connection exist and the concept presented might be a powerful tool when estimating the qualities of measurement setups. The correlation will be investigated in the future with a number of more realistic simulations and different clinical experiments.

V. CONCLUSIONS

The choice of electrode system has significant effects on the outcome of a measurement. To select the optimal electrode system for a given measurement we need to ascertain a number of characteristics which define the properties of the electrode system. In the present paper we applied a concept of HSR to describe how well the measurement is focused on the cortex. It was also shown a promising result from preliminary experiment that HSR could be applied to predict the relative signal-to-noise ratio of a measurement. We conclude that this parameter may be applied when the properties of measurement systems are studied and their sensitivity distributions are modeled. By utilizing these methodswe may achieve more concentrated and specific measurements.

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