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USE OF A SUPERCONDUCTING INSTRUMENTATION FOR BIOMAGNETIC MEASUREMENTS PERFORMED IN A HOSPITAL(x)

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Abstract

A superconducting instrumentation has been set up to perform biomagnetic measurements for screening analysis in one of Rome hospitals. The magnetic detector is a 2nd derivative gradiometer, which can be balanced against both spatially uniform fields and field gradients. The overall noise level is $\sim 4\times10^{-14}\,T\cdot Hz^{-\frac{1}{2}}$ in the frequency range 0.5÷3000Hz. Main efforts are devoted to the recording of magnetocardiographic maps of normal and abnormal subjects while a detailed analysis of some segments of the heart cycle is carried on in subjects previously investigated by means of other techniques. Magnetomyograms of normal and abnormal subjects are detected and studied in the frequency domain. Magnetoencephalographic power spectra of various subjects have been mapped as well. Most remarkable results so far collected are presented. Some of the measurements have been performed in the hospital and some in the laboratory, always without the aid of any shielding.

Introduction

In the last few years, superconducting instrumentation for biomagnetic measurements has been gaining more and more feasibility and reliability. This allows to shift from the purely experimental stage in the laboratory to the first clinical applications in hospital environments. In order to fit this target without the aid of high-cost magnetically shielded rooms, it is necessary to rely on utmost sophysticated apparatuses, to reject heavy magnetic disturbances always present in a hospital[1]. Following this policy we have recently developed[2,3] a superconducting biomagnetic instrument featuring characteristics which allow its use in a hospital. During the present year several tests have been performed in a university hospital located in the central area of Rome. Despite the many difficulties encountered and the fact that not all problems have been yet solved, interesting results have been collected. These are shown in the present paper together with others achieved in our laboratory, which is located in the industrial area of Rome.

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Experimental Apparatus

Our experimental apparatus has been extensively reported in a recent paper[3], therefore we will only describe here the latest modifications which have led to remarkable improvements in the overall performances. Fig. 1 shows the

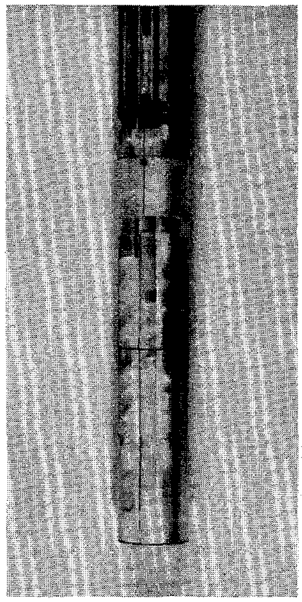

Fig. 1 - View of the 2nd derivative gradiometer. The upper coil can be moved up and down along the gradiometer vertical axis

new version of the 2nd derivative gradiometer coupled to the SQUID detector. It differs from the previous one in the following items:i) the gradiometer support is entirely of plexiglas as well as all the cryogenic mechanical balancing assembly; ii) the balance against spatially uniform magnetic field gradients is obtained by appropriately positioning the upper coil of the gradiometer; this is achieved by means of an externally adjustable screw providing a finesse of 0.1mm per turn. This configuration shows to be very stable and shock resisting during transportation of the dewar.

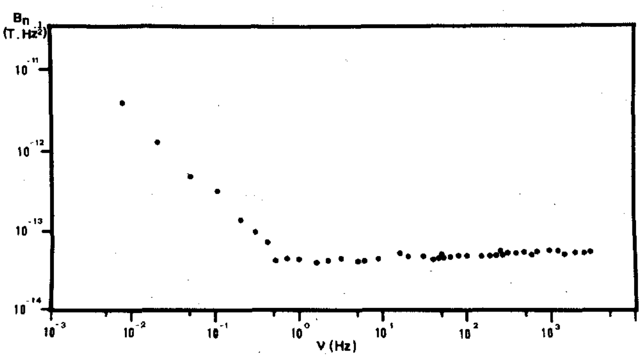

Fig. 2 - Noise spectrum of the 2nd derivative gradiometer recorded after the SQUID electronics plus the COMB Filter.

Fig. 2 shows the typical noise spectrum of the gradiometer recorded in our laboratory during rush hours. The field noise spectrum is referred to the pick-up coil and measured at the output of the SQUID electronics[4] after a COMB filter to reject the residual 50Hz noise and harmonics[5]. The possibility of finely balancing against spurius gradients seems to have reduced the noise level in the low frequency range. The 1/f like behavior, starting at 0.4 Hz (instead of 2 Hz of the previous version), may be due to a residual overall unbalance of the gradiometer which still keeps sensitive to geomagnetic fluctuations. As far as the field balancing is concerned, see Ref. 3. A typical value for the balance obtained is 1ppm. In order to balance against uniform field gradients a pair of square coils, 2m x 2m, oppositely wound and accurately positioned with respect to the gradiometer is used. A typical value of the gradient balance is $\leqslant 1$ part per 10^4.

Experimental Methods and Results

A schematic of the basic recording set up is shown in Fig. 3. In every kind of biomagne-

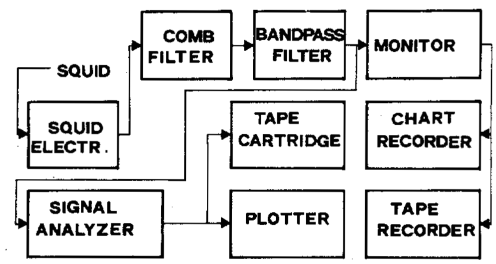

Fig. 3 - Schematic of the room temperature experimental set up and recording system

tic measurements analog tracings are monitored, recorded on paper and stored with a tape recorder for successive data analysis. If necessary signals can be on line digitally analyzed either in the time or in the frequency domains by means of an HP-5420A Signal Analyzer.

The following kinds of biomagnetic measurements have been performed: standard and high resolution (HR) magnetocardiography (MCG), magnetomyography (MMG) and magnetoencephalography (MEG). For HRMCG the external trigger required for signal averaging is provided by the first derivative of the standard ECG lead with the highest QRS complex. Usually an averaging over 100÷200 cardiac cycles is made in a detecting bandwidth of 0.1÷250 Hz. Magnetomyograms are generally analyzed in the frequency domain (bw. 0.1÷400 Hz). In order to obtain intra-and inter-individual comparable recordings, a simple device is used for calibrating the muscle efforts and to trigger the signal analyzer for a single shot recording. Only recordings during maximal voluntary effort have been up to now performed. As far as MEG is concerned, in this paper we only deal with recordings of spontaneous brain activity of normal awake subjects. Here again the signals are analyzed in the frequency domain averaging over 10 samples 16sec long in a bandwidth of 0.1÷32 Hz. The corresponding frequency resolution is 62.5 mHz.

MCG and HRMCG

Standard MCG recordings have been performed in the hospital, but the S/N ratio is still unsatisfactory for high resolution recordings. Therefore this kind of investigation has been performed in the laboratory. Ten subjects have been studied so far: 7 normals and 3 patients affected by conduction disturbances. Standard 36 spots MCG maps[6] have been recorded in all subjects. Examples of normal MCG maps have been published elsewhere[3, 7, 8]. In one patient with left ventricular hypertrophy and complete left bundle branch block (LBBB) additional recording points were used (Fig. 4).

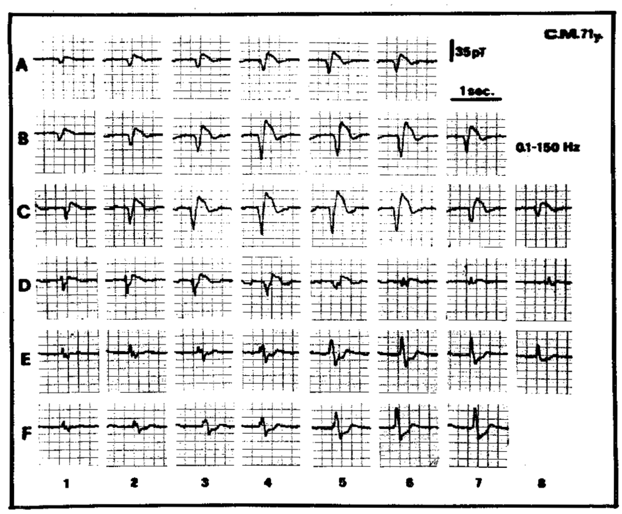

Fig. 4 - Real time MCG map of a patient with left ventricular hypertrophy and complete LBBB. 8 additional recording points have been used

In HRMCG recordings the P-R segment was accurately investigated. In the case of the three patients a comparison between high resolution recordings and previously performed invasive His bundle electrograms (HBE) was attempted. HRMCG recordings of normal subjects have widely been reported elsewhere[7, 8, 9, 10]. A 5 spot HRMCG map of a 22ys.old male patient with 2nd degree Wenckebach-type block localized in the A-V node and normal intraventricular conduction (H-V = = 50ms) is shown in Fig. 5. A correspondence between the duration of the MCG 'ramps' and that of the H-V interval is evident. Moreover a coincidence between the H wave of the HBE and a structure appreciable at the onset of the MCG 'ramp' (pos. E3) seem to suggest that this signal is not an artifact. The HRMCG map of the patient with complete LBBB and abnormal intraventricular conduction (H-V=75ms) is shown in Fig. 6. The absence of a clearcut 'ramp'

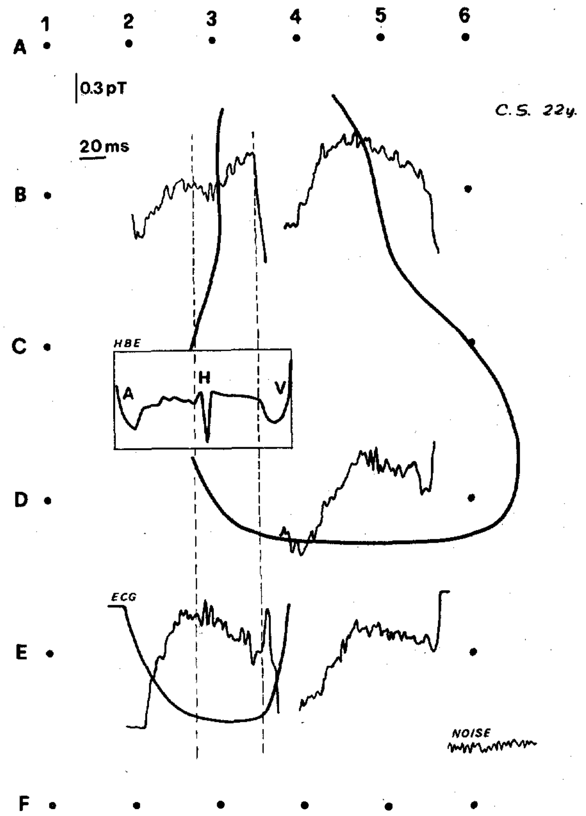

Fig. 5. - HRMCG map of a patient with normal intraventricular conduction. An H-V interval of 50ms is appreciable from the His bundle electrogram shown in inset

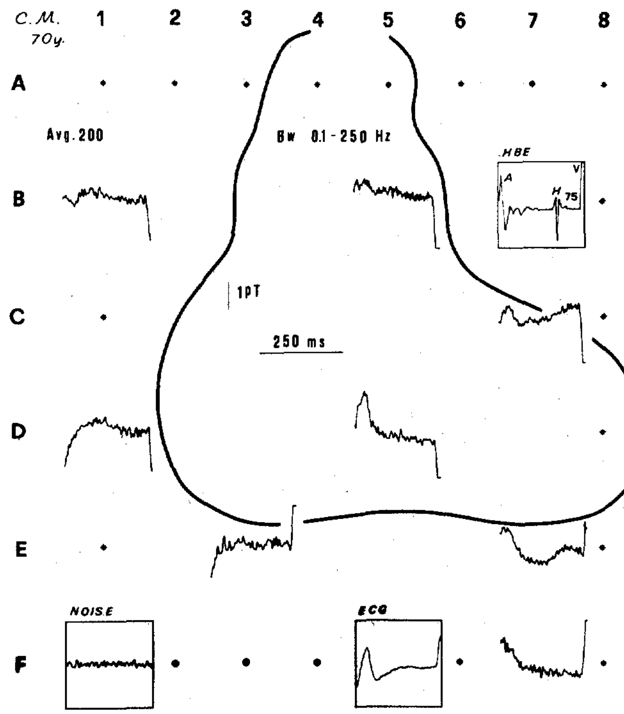

Fig. 6. - HRMCG map of the same patient whose MCG map is reported in Fig. 4. The HBE (upper left) shows a pathological intraventricular conduction (H-V=75ms). The 'ramp' pattern is almost completely absent.

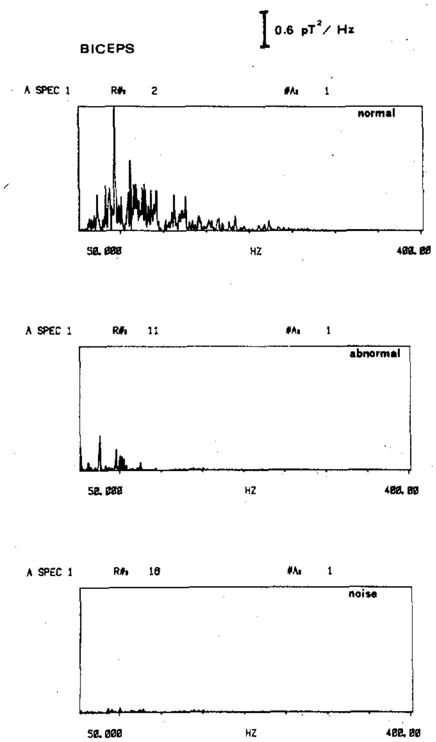

Fig. 7 - MMG power spectra of a patient affected by spinal amyotrophy compared with the MMG of a normal subject The sensor was located over the biceps and the maximal voluntary effort was calibrated. The lowest trace is the noise level recorded keeping the muscle released.

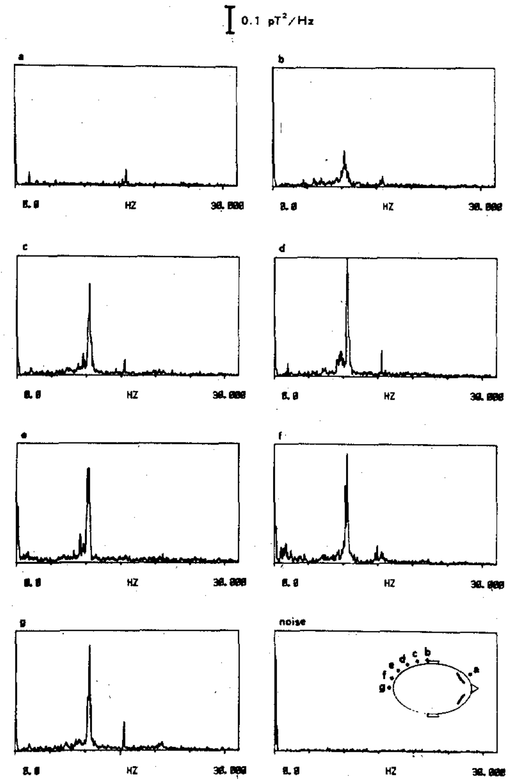

Fig. 8. - MEG power spectra map of a normal awake subject (eyes closed). The map was obtained placing the sensor over the spots indicated at bottom right.

pattern is the main finding in this patient.

MMG

Magnetomyographic recordings have been performed in the hospital on 4 normal subjects and one patient affected by a severe form of hereditary progressive spinal amyotrophy (Kugelberg-Welander desease). Different muscolar groups of the superior right limb have been studied in each subject. A comparison between the power spectra of the MMGs of a 35 ys. old male and those of the patient (29 ys. old male) recorded on the biceps during maximal voluntary effort is shown in Fig. 7. A remarkable difference both in the amplitude and in the frequency pattern is evident.

MEG

A map of MEG power spectra in one awake normal 23 ys. old male is presented in Fig. 8. Seven different positions of the left hemisphere from the inion to the frontal region were studied (Fig. 8). A 10.6Hz α-rhythm component is observed at all sites but for the frontal one (Fig. 8a). Wide interindividual variability in the amplitude of the spectrum was often observed.

Discussion and Conclusions

As far as HRMCG is concerned, the ramp pattern which appears to be a constant feature in normal subjects[7, 8, 9, 10], has been interpreted as related to the activity of the His-Purkinje System on the basis of a theoretical model[11]. Our present comparison between HRMCG and invasive HBE recordings seems to clinically support this hypothesis.

The possibility of recording magnetic signals in the P-R segment is still questionable and under discussion[7, 8, 9, 10]. In two of three patients we have observed a coincidence between the H wave of the HBE and MCG signals emerging from the noise level about a factor of two. A further improvement of the S/N ratio and other validation tests (e.g. drug administration to delay conduction at different levels) are probably required to clarify this point.

The absence of ramp pattern and distortion of the PR waveform[12] (Fig. 6,E7) has been observed only in the patient with pathological intraventricular conduction. This suggests that the HRMCG may to some extent add diagnostic power to the non-invasive evaluation of the activity of conduction system in man.

So far, for diagnostic purposes human electromyograms have been usually invasively recorded by means of needle electrodes[13]. In fact, with surface techniques[14] the recordings are considered less accurate and useful only to demonstrate the mere presence of muscle activity[13].

On the basis of our preliminary observations between pathological and normal myograms MMG power spectra seem to provide particularly detailed information from this point of view. In the patient studied a clearcut correspondence between the activity of the clinical damage and the abnormality of the MMGs is present. In fact, as is known from conventional invasive electromyography[13], in severe neurogenic paresis a compromising reduction of the number of simple motor units takes place. Furthermore the discharging frequencies are confined to a lower range with respect to the case of the normal muscles. Indeed the power spectrum MMG analysis seems to be most suitable to evidentiate this phenomenon.

Despite the wide interindividual variability in the MEG patterns, we have easily recorded α-rhythm brain activity in all subjects. Large amplitude variations are also shown by the same subject in different recordings. The absence of significant signals in the frontal area is however a general feature of all the studied subjects. This is in disagreement with other authors' observations[15]. Furthermore, within the explored bandwidth and in the limit of our present sensitivity, no 1/f behavior to be connected with a possible brain activity, has been observed. This is in contrast with a recent estimation of the MEG power spectrum[16]. Finally all recorded power spectra did not show any sharp resonance-like peaks[17], but rather broader peaks (∿1 Hz bw) which seems to agree with the findings reported in Ref. 18.

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