Comparison of SQUID and MR detection for weak magnetic fields

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INTRODUCTION

The ability to perform direct neuronal detection would be a major advance for neuro-MRI, removing concerns about interpretation of the ambiguous BOLD response and associated hemodynamic changes. However, there are still a number of concerns about the sensitivity of MRI in comparison with SQUID based magnetic field measurement methods for detecting neuronal responses. This study aimed to compare the response of a 3T MRI system with a single channel SQUID system used outside a magnetically screened room for detection of weak low frequency magnetic fields from a calibrated test object and to try and detect axonal responses from the median nerve of a human subject using a TENS stimulator and the SQUID system.

METHODS

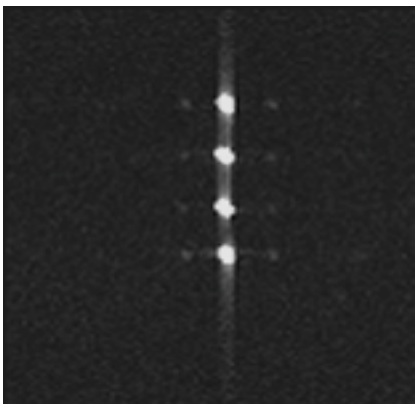
MRI: A set of four 32mm diameter loops were used as a magnetic field modulator fed with current from a programmable signal generator in series with a precision 50 Ohm variable switched attenuator. The voltage across the attenuator was measured using a digital oscilloscope for frequencies in the range 1-6Hz. The field at the centre of the loops was calculated from the Biot-Savart formula for a given current. The loop modulator was located at isocentre of a 3T Intera (Philips, Best, NL) and images were acquired from four oil capsules at the centre of the loops with a six channel SENSE head array coil. A 'GRACE' gradient echo sequence with TR 200 ms, TE 39 ms, matrix = 128x256, SLT 5 mm, FA = 90^0, FOV = 300mm, NEX =1 was used to measure field modulation ghosts (1). Image orientation was axial with horizontal phase encoding.

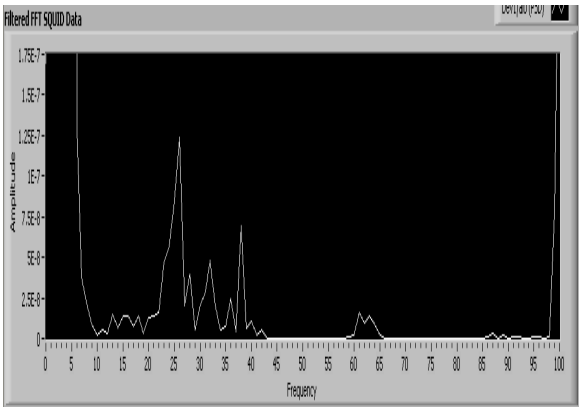
SQUID: A single channel SQUID system model MEG-6023-G (Cryoton Co. Ltd, Moscow, RU) was also used to detect weak fields from the loop phantom. The system features a fibreglass cryostat with a room temperature to LHe distance of only 6mm. The detection system uses a balanced 2nd order 8mm diameter gradiometer, a DC SQUID (Supratron Inc, Jena, DE) and a flux transformer of 10mm diameter. The system also has an XYZ reference magnetometer used for active electronic noise cancellation so the system can be used outside a screened room. The electronics uses a 24 bit ADC and the bandwidth of the system in closed feedback mode is 0-16Khz. The loop modulator was located immediately below the gradiometer at the warm surface of the cryostat. Figure 1 (left) shows the SQUID cryostat mounted in a non-magnetic stand allowing access for in vivo measurements. Measurements were also acquired using an independent data acquisition system programmed in Labview from the forearm of a volunteer with Transcutaneous Electrical Nerve Stimulation (TENS) applied to the hand at a range of frequencies up to 100Hz. Inverse Tchebyshev 5th order filtering was applied to band stop 50Hz interference to improve dynamic range.

Data Analysis: Data was analysed using an in-house Matlab programme. The SNR of the spectra were measured as a function of modulating field for both fMRI and the SQUID measurements and an SNR of 2:1 was used as a minimum detectable limit.

RESULTS

The SQUID system could detect fields of 15pT from the modulator while the lowest field detected by MRI using the GRACE ghost method at 3T was 270pT as shown in Figure 2 (middle). Figure 3 (right) shows SQUID data acquired from a volunteer's wrist with TENS applied at 25Hz. Similar data was acquired at frequencies in the range 1-100Hz. The spectral region within +/-8Hz of 50Hz has been effectively suppressed through the Tchebyshev filtering. Peaks at higher frequencies than the applied 25Hz are seen in the spectrum along with a low frequency peak due to physiological processes such as heartbeat and harmonics.





DISCUSSION

The non-magnetically screened SQUID system was approximately twenty times more sensitive than the 3T MR system for the geometrical arrangement used in these experiments. However, the volume of interest for MRI was much smaller and more clearly spatially localized than for the SQUID. 50Hz bandstop filtering was highly effective at improving the dynamic range of the SQUID system without a magnetically screened room. The TENS responses seemed to be detected in close proximity to the loop formed by the hand and the stimulation electrodes. Assuming axonal burst detection from TENS stimulation can be confirmed, future work will make the TENS system MR compatible and directly compare the SQUID and MR based methods using the same stimulation paradigms in the same subjects looking at both the median nerve and brain responses.