A Multi-Element Receive Coil Array for MRI/FMRI of Awake Behaving Marmosets

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Introduction

Animal models have been at the forefront of basic science research and are particularly advantageous in preclinical and translational studies of various models of brain disease. With the continued development of MRI and fMRI as a major technique to study brain anatomy and function, significant effort has been placed on the development of awake behaving animals that allow longitudinal studies to be carried out without the confounds of anesthesia. While traditionally the use of awake behaving animals in the MRI scanner has required a hard restraint of the animal's head by surgically installed head implants, we have designed an individualized and completely noninvasive restraint system that eliminates all of the disadvantages of the implants and which mimics to the full extent the way that human subjects are placed in the MRI scanner. Here we describe a 7-element receive coil array for MRI/fMRI scanning of awake behaving marmosets at 7T that takes full advantage of the latest advances in MRI technology for parallel imaging, such as the availability of multiple RF receive channels integrated to the use of low input impedance RF preamplifiers.

Methods

Adult marmosets of either gender were initially acclimatized to being restrained (Fig. 1a) according to protocol that consisted of three week-long phases: (1) Acclimatization of awake marmosets to a loosely-restraining body harness; (2) Acclimatization of the marmosets to the presence of MRI scanner noise without head restraint; (3) Acclimatization of the marmosets to the presence of MRI scanner noise with head restraint. Prior to beginning the acclimatization procedure, the marmosets were subject to a single MRI scan session in which 3D images of their head and torso were obtained. From these 3D images, the contour of the entire head was obtained and used to manufacture individualized helmets consisting of a top and a bottom piece (Fig. 1b) using Rhinoceros 3.0 (McNeel North America, Seattle, USA). After the helmet pieces were designed, they were printed into ABS plastic using a 3D printer (Dimension Elite, Stratasys, Inc., Eden Praire, USA). Seven circular groves, 11 mm ID and 15 mm OD and overlapped so that the center-to-center distance was 11.25 mm, arranged with their centers along an hexagon were made into the inner surface of the top piece of the helmet. Seven RF coils 13 mm ID were then built (Fig. 1c). The coil circuitry consisted of a resonant circuit and a pin-diode controlled detuning trap. Each coil was interfaced to home-built RF preamplifiers via λ/2 RF cables. The inner surfaces of the top and bottom pieces of the helmet were covered with 3 mm thick polyurethane foam (McMaster-Carr, Princeton, USA) to provide comfort to the animals.

MR images of a phantom and of a marmoset were obtained in a 7T/30cm USR magnet (Bruker-Biospin, Inc, Ettlingen, Germany) interfaced to an AVIII console running ParaVision Version 5.0 (Bruker-Biospin). The MRI system is configured with 8 receive channels. Noise correlation matrices were obtained to verify coil-to-coil isolation.

Results

Home-built RF preamplifiers were designed and built with the following characteristics: input impedance < 0.5 Ω; typical gain: 27.5 dB; output impedance: 50 Ω; noise figure < 0.6 dB. The RF coils were individually tuned to 300.4 MHz. Figure 2 shows the noise correlation matrix of the system. By definition, the diagonal elements were 1.0, but the highest noise correlation off-diagonal was 0.037, testifying to the excellent isolation between the coils. Figure 3 shows a horizontal spin-echo MRI of the marmoset brain, acquired with the following parameters: TR = 12s, TE_{eff} = 65ms, Rare Factor = 16, FOV = 38.4x38.4cm^2, Slice thickness = 1mm, Matrix = 128x128, NA = 1, GRAPPA acquisition with acceleration factor = 1. Excellent coverage of most of the brain was obtained with the 7-coil array. Figure 4 shows the individual coil images. The strongest signal comes from the two lateral coils, which are closest to the brain in the horizontal plane. Coverage of the lateral coils optimizes the use of this set for fMRI of the somatosensory and the motor cortex. On the other hand, the center coil, being the farthest away in the horizontal plane, yields the weakest signal.

Discussion

A multi-element receive coil array was built for MRI and fMRI experiments in awake behaving marmosets. The array was built into individualized restraint helmets, which allow for effective restraint of the animal with optimal comfort. Excellent coil-to-coil isolation was obtained by the use of custom-built low input impedance preamplifiers. The array provides good coverage over the whole brain of the animal, and SNR is optimized at the somatosensory and motor cortices. Further refinements of the helmet restraint will lead to additional coil geometries and allow even larger brain coverage.

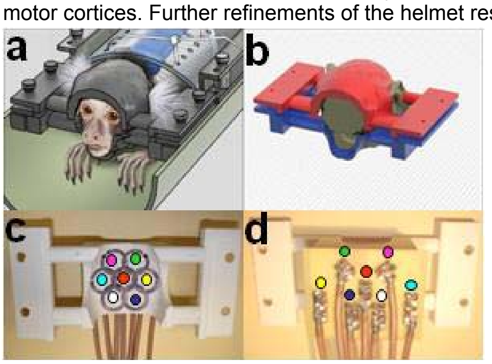

Figure 1: (a) Cartoon of the non-invasive restraint system. (b) Design of individualized helmet restraints. The helmets are composed of a head piece and a chin piece, which are lined up with foam to provide comfortable head support and restraint. (c) A 7-coil arrangement grooved on the inner surface of the head piece. All coils are symmetrically arranged in the head piece. (d) Top view of the helmet showing the coil circuitries and the λ/2 RF cables.

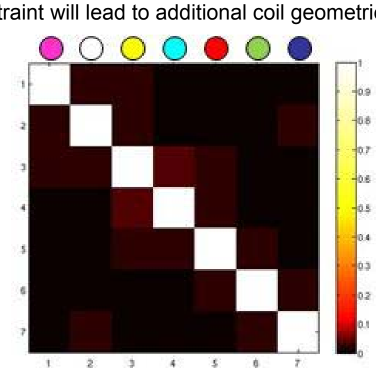

Figure 2: Noise correlation matrix. The highest off-diagonal correlation coefficient is 0.037.

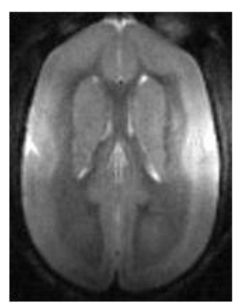

Figure 3: RARE horizontal MRI of the marmoset brain obtained with the 7-coil system and reconstructed with GRAPPA.

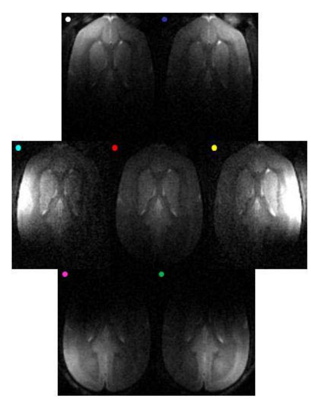

Figure 4: Individual coil images showing the spatial coverage and relative SNR of each coil.