Infrared Transfer of Electrophysiologic Signals
During Magnetic Resonance Imaging


Departments of Neurobiology, *Physiology and **Radiological Sciences, and the ***School of Nursing
University of California at Los Angeles, Los Angeles, CA 90095

Assessment of electrophysiological signals is essential for determination of states during functional magnetic resonance brain imaging for sleep-related challenges. Such assessment is hindered by introduction of artifacts on the electrophysiological signals by the magnetic fields of the scanner, and, conversely, images can be distorted by contamination from artifacts introduced through metallic signal cables. We describe a low-cost infrared system for transferring electrophysiological signals from amplifiers near magnetic resonance scanners. The system consists of a multi-channel consumer infrared audio system, modified to respond to DC electrophysiological signal levels. The device transmits signals to externally-located receivers through an observation window. The exceptionally low-cost system minimizes induction of noise into magnetic resonance images, and reduces contamination of electrophysiological signals by the scanner.

CURRENT CLAIM: Instrumentation for transferring electrophysiological signals necessary for state definition from a magnetic resonance scanner to external areas using low-cost infrared technology has been developed.

Transfer of electrophysiological signals by metallic cables from amplifiers located near magnetic resonance imaging (MRI) scanners to peripheral sites can introduce noise or severely distort scanned images. Image noise arises through electromagnetic radiation from cables induced by external sources, and from signals induced in cables by the changing magnetic fields of the scanner. Conversely, the magnetic field changes during scanning can induce significant artifactual signals in amplifier cables, and thus the physiologic signals, making acquisition of electroencephalographic (EEG), electrocardiographic (ECG), electromyographic (EMG) and respiratory signals difficult. Functional MRI provides a unique means to visualize widely-distributed neural activation, and is rapidly becoming a desirable procedure for assessment of brain activation during state-related challenges. Since acquisition of EEG and other physiological signals is essential for identification of sleep state, procedures which reduce artifact in images and electrophysiological signals are necessary. We earlier (Parker et al., 1999) developed optically-coupled amplifiers to acquire physiologic signals during MRI. The amplifier output used multiple optic fiber cables that required a break in scanner room shielding to reach the external recording devices. The multiple cables also created clutter within the confines of recording areas.

Infrared transmission of physiologic signals offers a means to avoid electromagnetic interference on the signals from the magnetic field of scanners, and minimizes the potential for artifacts to return from external devices to affect scanned images. Procedures for infrared transmission of physiologic signals have been developed for circumstances where signals must be obtained from freely moving animals (De Simoni et al., 1990), or from ambulatory children (Yeung, 1998). The technique is sufficiently robust to even allow transmission of signals from subcutaneous sources (Inoue et al., 1998). However, most such devices must be constructed from elementary electronic components, requiring significant knowledge of circuitry. Alternatively, commercial devices are available at high cost.

We developed a device, based on low-cost commercial audio components, that can be easily constructed for infrared transfer of signals from physiological amplifiers in an MRI scanner through a shielded observation window to receivers located outside the scanner room. This device provides relative immunity from changing magnetic fields, minimizes interference to the MR images, and can transfer four signals.

METHODS

The device uses circuitry from low-cost infrared-based dual stereo (four discrete channels) audio transmitters and two headphone receivers (Model UAH-S2, Unwired Technology LLC, 500 Eastern Parkway, Farmingdale, NY). Normally, the devices are used in an automobile for transmitting two separate stereo music channels to two individuals with headphones. Circuitry for the normal audio bandwidth (40-18000 Hz) was modified to extend signals to DC levels on both the transmitter and receiver.

The original consumer plastic chassis containing the transmitter circuitry for four separate channels with infrared light-emitting diodes (LEDs) is retained and mounted on a 6" x 4" x 4" aluminum chassis (Figure 1A,B) that contains a 7
amp/hr 12-volt lead acid gel battery as a power supply (available from many suppliers). Four BNC connectors are added to the chassis for electrophysiological signal input. The input capacitors of each channel, C15, C16, C53 and C56 (not shown, but labeled on the circuit board) were removed to eliminate high pass filtering. The + pads of those capacitors become the DC inputs, and are coupled through 10K resistors to the BNC input connectors. While the total input impedance of the device is higher than 10K, the input is designed to be driven by a low impedance source, such as an operational amplifier, to minimize noise susceptibility.

The infrared photodetectors and circuitry from the two headphones are placed into a separate 6" x 4" x 2" aluminum chassis with four 1/2" cutouts for infrared reception at each channel and four BNC connectors added for output (Figure 1C). Pin 19 of each of the four CX 20111 integrated circuits contained in the original headphone receiver circuitry (also labeled on the receiver circuit board) is coupled through 2.7 K resistors to the BNC output connectors for electrophysiological signals. The output impedance of 2.7 K is designed to drive a high impedance amplifier. The receiver power supply consists of two 1.5-volt "D" batteries, connected in series; current drain is very low. The center node of the two batteries is the output (BNC ground) reference. The manufacturer’s specification for signal-to-noise is 40-50 db, with channel separation of 35 db.

The system was evaluated by acquiring electroencephalographic (EEG), electrocardiographic (ECG), oxygen saturation, and thoracic wall movement signals concurrently with anatomical magnetic resonance images and with Echo Planar functional images using a GE 1.5 Tesla scanner. Signals were led from the subject electrodes to the amplifiers with non-ferrous wires. A time series of ten 256 x 192 pixel Spoiled Gradient Echo Recall (SPGR) image sets, composed of 124 sagittal sections, was acquired (TR=24.0, TE=9.0 msec, Flip angle=22°, FOV=30 cm, Thickness=1.2 mm). In addition, a set of Echo Planar functional images, composed of 20 axial sections (Repetition time=6.0 sec, Time of excitation=60 msec, Flip angle=90°, Field of view=30 cm, Thickness=5 mm), was acquired during a baseline with subjects breathing room air. Images were examined using MedX software (Sensor Systems, Sterling, VA).

The procedures for imaging and signal acquisition were approved by the Institutional Review Board, and subject informed consent was obtained.

RESULTS

A range of electrophysiological signals acquired with the infrared links is shown in Figure 2A. All were relatively unaffected by the scanner field. The changing magnetic field during scans induced transient noise on both the EEG and ECG signals, but artifacts could be separated post-acquisition with digital filters. An anatomical image acquired during operation of the device is shown in Figure 2B, and a functional image in 2C. No significant artifacts were introduced by the device or by external signals in either anatomical or functional images.

DISCUSSION

The system uses a very low-cost consumer audio device that requires minimal modification (removal of 4 capacitors, and installation of 8 resistors), and imparts no detectable noise to the MR images. The transmitter is placed on one side of an observation window of the scanner area, with the receiver on
the other side; such windows are omni-present in scanners, allowing universal use of this infrared device. The system avoids interruption of shielding and the potential introduction of external electrical noise into the scanner area from metal physiological leads, and minimizes clutter from extraneous wires.

Magnetic resonance scanning induces significant transient noise on physiologic signals in the leads from the transducers to the preamplifiers prior to transmission through the infrared device. The infrared device minimizes noise from the preamplifiers to the area in the external field. The noise initially introduced is of significantly higher frequency than typical physiological signals of interest (e.g., ECG, 0.5-40 Hz; EEG, 0.5-20 Hz) and such artifacts can be readily separated post-acquisition with digital filters (Parker et al., 1999).

Although comparable commercial devices for signal transfer are available for selected physiological signals (e.g., ECG) in some human scanners, devices for other signals, such as the EEG, are unavailable or extremely costly. Infrared transfer devices also can be constructed from components; however, use of off-the-shelf consumer devices avoids the high construction costs of complex circuitry. The cost for the consumer device is US $150; for data acquisition from fewer channels, less expensive stereo ($39, US retail) or monaural ($25, US retail) devices are available (Models 3500IR and 3000R, respectively, from the same manufacturer).

Many functional imaging studies require concurrent acquisition of physiologic signals to verify state; the system provides an extremely low-cost means to allow such signal acquisition.

ACKNOWLEDGMENTS

We thank Rebecca Harper and Amy Kim for technical assistance. This work was supported by NHLBI HL-60296.

REFERENCES