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Recommended Reading
MRI—Recording Physiology Data

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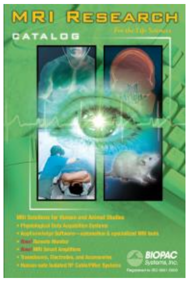

BIOPAC offers a series of magnetic resonance imaging compatible electrodes, electrode leads, transducers, and stimulus options for safe data acquisition of physiological signals in the MRI environment. Specialized cable systems provide isolated and RF filtered interfacing between the subject/chamber panel and the control room.

Review the MRI Catalog

- Safety Guidelines**:** Recording Biopotential Measurements in the MRI Environment—MRI Smart Amplifiers

- **CalTech Notes - SCR Recording During *f*MRI Acquisition**

  Antoine Bruguier, R. McKell Carter, Christof Koch and Steven Quartz.

  Abstract: Investigative methods in neuroscience increasingly combine functional magnetic resonance imaging (fMRI) with other measurement and stimulus-delivery systems. Many of these, such as electroencephalography (EEG), electrocardiography (ECG) and skin conductance response (SCR) measurements, attach electrodes to subjects inside the strong variable magnetic field of the scanner. This may induce dangerous voltages on the leads that often go unassessed. While burn injuries and electric shocks have been reported, there is surprisingly little available research describing these risks. This paper presents a simple model of the human body and a filtering system that aims to assess these burn risks and prevent electrical shocks. The electrical properties of this setup and the induced voltages on the leads as measured in a variety of configurations, including the effect of fMRI transmitting and receiving coils and lead composition, are presented. Since these combined methods introduce noise that requires additional filtering, we also studied the safety constraints of various filters. Even though the design methods and measurements are applied to a skin-conductance/shock delivery setup, they can be generalized to other systems for assessing and preventing risks associated with similar combined methods.

- **Safety Awareness Notes when using Cables and Electrodes during MRI**

  Susan Lange, Arrt, MPH, and Quynh Nhu Nguyen, BS, Nursing 2006, Volume 36, Number 11, P. 18

  Excerpt: The radiofrequency fields that occur during an MRI can heat ECG cables and electrodes, seriously burning skin under the electrodes, so the following precautions should be considered for any MRI research protocols.

- ICG & ECG in MRI

  - **Quantifying rapid changes in cardiovascular state with a moving ensemble average**

    Cieslak M, Ryan WS, Babenko V, Erro H, Rathbun ZM, Meiring W, Kelsey RM, Blascovich J, Grafton ST. Psychophysiology. 2018 Apr;55(4). doi: 10.1111/psyp.13018. Epub 2017 Oct 3.

    Abstract: MEAP, the moving ensemble analysis pipeline, is a new open-source tool designed to perform multisubject preprocessing and analysis of cardiovascular data, including electrocardiogram (ECG), impedance cardiogram (ICG), and continuous blood pressure (BP). In addition to traditional ensemble averaging, MEAP implements a moving ensemble averaging method that allows for the continuous estimation of indices related to cardiovascular state, including cardiac output, preejection period, heart rate variability, and total peripheral resistance, among others. Here, we define the moving ensemble technique mathematically, highlighting its differences from fixed-window ensemble averaging. We describe MEAP's interface and features for signal processing, artifact correction, and cardiovascular-based fMRI analysis. We demonstrate the accuracy of MEAP's novel B point detection algorithm on a large collection of hand-labeled ICG waveforms. As a proof of concept, two subjects completed a series of four physical and cognitive tasks (cold pressor, Valsalva maneuver, video game, random dot kinetogram) on 3 separate days while ECG, ICG, and BP were recorded. Critically, the moving ensemble method reliably captures the rapid cyclical cardiovascular changes related to the baroreflex during the Valsalva maneuver and the classic cold pressor response. Cardiovascular measures were seen to vary considerably within repetitions of the same cognitive task for each individual, suggesting that a carefully designed paradigm could be used to capture fast-acting event-related changes in cardiovascular state.

  - **Dynamics of the central and autonomic nervous systems preceding action and cognition**

    Matthew J. Cieslak, dissertation, Psychological & Brain Sciences, University of California Santa Barbara, June 2016

Excerpt: …changes in systolic time intervals, cardiac output and vascular resistivity are regularly used as cardiovascular indexes of the psychological processes occurring during motivated and stressful tasks. Moving ensemble analysis, a new method for characterizing these indexes, is introduced here. Its major innovation is the ability to detect both state and change of cardiovascular indexes during individual experimental trials. This technique is robust to radio frequency and magnetic field artifact present in an MRI environment (chapter 6) as well as respiratory and movement-related artifact normally present in noninvasive recordings.

- **Electrocardiogram in an MRI Environment: Clinical Needs, Practical Considerations, Safety Implications, Technical Solutions and Future Directions**

  Thoralf Niendorf, Lukas Winter and Tobias Frauenrath (2012). Advances in Electrocardiograms - Methods and Analysis, PhD. Richard Millis (Ed.), ISBN: 978-953-307-923-3, InTech, DOI: 10.5772/24340.

  Excerpt: ECG waveform acquisitions, ECG co-registration and ECG monitoring during MRI pose technical challenges and requires safety measures that will not be familiar to users of other conventional ECG technologies. For all those reasons, the basic principles of using ECG in an MRI environment and their implications for clinical MRI and MRI research are provided in this chapter. Key concepts, technical solutions, practical considerations and safety implications for cardiac gated MRI using electrocardiograms are outlined.

- **Magnetohydrodynamic distortions of the ECG in different MR scanner configurations**

  Johannes Krug, Georg Rose, Chair for Healthcare Telematics and Medical Engineering, University of Magdeburg, Germany

  Abstract: Diagnostic electrocardiograms (ECG) are required to ensure patient safety during minimal invasive interventions and cardiac stress testings. The ECG is corrupted by several other signals when performing these interventions under magnetic resonance (MR) guidance which makes it impossible to use the ECG as a diagnostic tool in MR guided interventions. The interfering signal that is caused by the static magnetic field of the MR scanner - namely due the magnetohydrodynamic (MHD) effect - is investigated within this work. The MHD effect is measured regarding different aspects like the strength and orientation of the static magnetic field as well as the patient's position and heart rate.

- **Magnetic Field Threshold for Accurate Electrocardiography in the MRI Environment**

  Mihaela Jekic,Yu Ding, Roger Dzwonczyk, Patrick Burns, Subha V. Raman, and Orlando P. Simonetti, Magn Reson Med. 2010 December ; 64(6): 1586–1591. doi:10.1002/mrm.22419.

  Abstract: Although the electrocardiogram is known to be nondiagnostic within the bore of any high-field magnet due to the magnetohydrodynamic effect, there are an increasing number of applications that require accurate electrocardiogram monitoring of a patient inside the MRI room but outside of the magnet bore. Magnetohydrodynamic effects on the ST segment of the electrocardiogram waveform were investigated in six subjects at magnetic field strengths ranging from 6.4 mT to 652 mT at the aortic midarch, and the electrocardiogram was found to be accurate at magnetic fields below 70 mT. This corresponds to a distance of 160 cm from the isocenter and 80 cm from the bore entrance for the 1.5-T MRI system used in this study. These results can be translated to any MRI system, with knowledge of the fringe field. Accurate electrocardiogram monitoring is feasible in close proximity to the MRI magnet, such as during and after pharmacologic or exercise stress, or interventional or surgical procedures performed in the MRI room.

- **Integration of motion correction and physiological noise regression in fMRI**
  Tyler B. Jones, Peter A. Bandettini, and Rasmus M. Birn
  Laboratory of Brain and Cognition, National Institute of Mental Health, NIH, Bethesda, MD, USA

  Abstract: Physiological fluctuations resulting from the heart beat and respiration are a dominant source of noise in fMRI, particularly at high field strengths. Commonly used physiological noise correction techniques, such as RETROspective Image CORection (RETROICOR), rely critically on the timing of the image acquisition relative to the heart beat, but do not account for the effects of subject motion. Such motion affects the fluctuation amplitude, yet volume registration can distort the timing information. In this study, we aimed to systematically determine the optimal order of volume registration, slice-time correction and RETROICOR in their traditional forms. In addition, we evaluate the sensitivity of RETROICOR to timing errors introduced by the slice acqusition, and we develop a new method of accounting for timing errors introduced by volume registration into physiological correction (motion-modified RETROICOR). Both simulation and resting data indicate that the temporal standard deviation is reduced most by performing volume registration before RETROICOR and slice-time correction after RETROCIOR. While simulations indicate that physiological noise correction with regressors constructed on a slice-by-slice basis more accurately modeled physiological noise compared to using the same regressors for the entire volume, the difference between these regression techniques in subject data was minimal. The motion-modified RETROICOR showed marked improvement in simulations with varying amounts of subject motion, reducing the temporal standard deviation by up to 36% over the traditional RETROICOR. Though to a lesser degree than in simulation, the motion-modified RETROICOR performed better in nearly every voxel in the brain in both high- and low-resolution subject data.

- **Detection of facial mimicry by electromyography during fMRI scanning**
  Gustav Nilsonne, Sandra Tamm, Paolo d'Onofrio, Johanna Schwarz, Göran Kecklund, Mats Lekander, Torbjörn Åkerstedt, Håkan Fischer

Presented at: 19th Annual Meeting of the Organization for Human Brain Mapping (OHBM) 2013, 16 - 20 Jun 2013, 3203
Background / Purpose: We investigated whether electromyography (EMG) could be used to detect facial mimicry during fMRI scanning.

Main conclusion: EMG activity in the superciliary corrugator muscle increased when participants viewed angry faces.

- **Neuropsychophysiological mapping: Concurrent psychophysiological recording and fMRI at 7T**
  Jennifer L. Robinson, Ph.D., Matthew Miller, Ph.D., Keith Lohse, Ph.D., Ronald Beyers, Ph.D., Kirk Grand, Lauren A. J. Kirby, Ashley C. Hill, Jerry E. Murphy, Alan Macy, M.S.E.E., Ken Graap, M.Ed.

  Presented at: Organization for Human Brain Mapping (OHBM) Annual Meeting 2015 (E-paper)

Overview: The presentation reviews data acquired using BIOPAC MR-compatible modules, leads, and electrodes during simultaneous ultra high field, high-resolution functional neuroimaging; fMRI scanning was carried out on a whole body 7T Siemens MAGNETOM scanner, outfitted with a 32-channel Nova Medical head coil. The poster clearly explains setup and shows neural correlates paired with ECG, EMG, EDA, and Grip, with results of EMG, EDA, and basic cardiovascular measures derived after signal processing to remove scanning artifacts. BIOPAC hardware included Electrocardiograph (ECG): ECG100C-MRI Smart Amplifier with EL509 electrodes, LEAD108, and GEL100; Electromyograph (EMG): EMG100C-MRI Smart Amplifier; Respiration: RSP100C Amplifier with TSD201 respiratory effort transducer; Electrodermal activity (EDA): EDA100C-MRI Smart Amplifier with EL509 electrodes, LEAD108, and isotonic GEL101

- **Simultaneous acquisition of corrugator electromyography and functional magnetic resonance imaging: A new method for objectively measuring affect and neural activity concurrently**
  Aaron S. Heller, Lawrence L Greischar, Ann Honor, Michael J Anderle, and Richard J. Davidson

Abstract: The development of functional neuroimaging of emotion holds the promise to enhance our understanding of the biological bases of affect and improve our knowledge of psychiatric diseases. However, up to this point, researchers have been unable to objectively, continuously and unobtrusively measure the intensity and dynamics of affect concurrently with functional magnetic resonance imaging (fMRI). This has hindered the development and generalizability of our field. Facial electromyography (EMG) is an objective, reliable, valid, sensitive, and unobtrusive measure of emotion. Here, we report the successful development of a method for simultaneously acquiring fMRI and facial EMG. The ability to simultaneously acquire brain activity and facial physiology will allow affective neuroscientists to address theoretical, psychiatric, and individual difference questions in a more rigorous and generalizable.