MR-compatible normobaric gas mixer for hypercapnic vasoreactivity studies on humans

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Purpose/Introduction: Hypercapnic challenges provide a means to explore cerebral vasoreactivity. The latter is key to approach quantitative fMRI¹. By itself, it is a bio-marker of several cerebral diseases^{2,3}. To improve hypercapnic BOLD or ASL perfusion fMRI experiments, SMTEC (Nyon, Switzerland) developed a normobaric gas mixer system, called VarioCap, respecting our specifications to allow safe operation in a 3 T environment with performances compatible with block-designed stimuli. We describe and demonstrate functionality of the developed device in a BOLD vasoreactivity experiment. The VarioCap mixes air and CO₂ to prescribed CO₂ fraction, FiCO₂. To reduce dead gas volume and speed up transitions, it was designed to operate close to the magnet. FiCO2 can be chosen from 0 % up to 10 % and changed with short response time (T_{90} < 10 sec). An airtight mask covering mouth and nose administers the gas and receives physiologic monitoring canula. The system allows remote operation through a USB link to the controlling PC. The driving software recognizes trigger pulses from the scanner, and sequentially maintains FiCO₂ values for specified numbers of

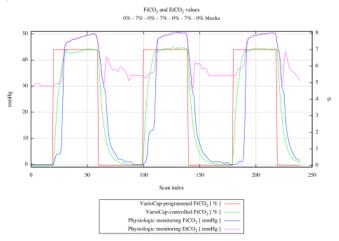
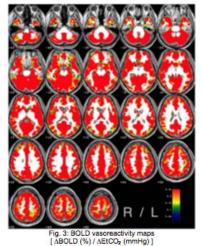


Fig. 1: Example of FiCO₂ and EtCO₂ values measured vs dynamic scan index (TR = 3 s) for a 0% - 7% - 0% - 7% - 0% 7% - 0% CO₂ concentration block-designed stimulus. VarioCap target (programmed) and internally measured control FiCO₂ values are in % while values measured with the physiologic monitoring unit are in mmHo.

pulses, as prescribed in a programmable list. An emergency button allows aborting program execution. Internally measured control parameters including respiratory flow rate can be continuously logged.

Subjects and Methods: A healthy volunteer gave informed consent to participate to the protocol, approved by the institutional review



board. fMRI was performed at 3.0T (Philips Achieva 3.0T TX), using the standard 32 channel head coil which features an inner volume compatible with mask installation. Medical air and CO₂ gases alimented the VarioCap. Physiologic parameters were continuously monitored (Precess Blue, InVivo) and derived values (especially Fi/Et-CO₂) recorded at 1 Hz. Connection to the controlling PC used an optical fiber USB extender (USB-Ranger-2224, Icron). After localizer and anatomic scans, a GE-EPI series was

1.59 1.58 1.57 1.54 1.53 1.52 1.51 0 50 100 150 200 250

acquired: TR/TE=3000/30, SENSE-factor=3, (220mm)² FOV, 2.29 mm reconstructed resolution, 2.25 mm slice thickness (0.25 mm gap), 53 slices. A trigger was sent every TR. Programmed FiCO₂ alternated between 7% and 0% every 40 TRs, with starting and ending periods at 0 % for 20 TRs, totalling 240 TRs. Standard SPM8 processing for block designs followed: rigid motion

realignment, coregistration to anatomy, 6 mm spatial smoothing, temporal filtering. Physiologic regressor as in Ref.2. **Results**: Fig. 1 and 2 show FiCO₂ and EtCO₂, and BOLD, signals *vs* dynamic scan time (in TRs) while Fig. 3 illustrates vasoreactivity maps obtained.

Discussion/Conclusion: BOLD time course (fig. 2) shows that rapid transitions between hypercapnia and normoxia states are achieved. Good quality BOLD vasoreactivity maps (fig. 3) are obtained. Monitored inhaled/end-tidal CO₂ values demonstrate effective regulation of applied gas mixture by the VarioCap (fig. 1).

References: 1) Mark et al., Neurolmage 54:1102-11 (2011); 2) Cantin et al., Neurolmage 58:579-87 (2011); Attyé et al. Human Brain Map. doi:10.1002/hbm.22255 (2013)