Original Research

Artifacts in Functional Magnetic Resonance Imaging from Gaseous Oxygen[1]

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Unexpectedly large fluctuations in signal intensity were identified in the functional MRI (FMRI) of normal subjects breathing pure oxygen intermittently. To test the hypothesis that the signal changes were due to fluctuating concentrations of gaseous (paramagnetic) oxygen in the magnetic field, echo planar gradient echo images were acquired of a phantom contiguous to an oxygen mask through which pure oxygen was administered intermittently via plastic tubing. As a control, room air was administered intermittently or oxygen continuously in the same experimental protocol. Signal intensity changes of up to 60% temporally correlated with the administration of oxygen were produced in the phantom. In functional images prepared from the echo planar images, the signal intensity changes resulted in artifacts especially at interfaces in the phantom. The intermittent administration of pure oxygen during acquisition of data for FMRI may produce signal intensity changes that simulate or obscure function.

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Abbreviations: FMRI = functional magnetic resonance imaging, EPI = echo planar imaging, BOLD = blood oxygen level dependent.

ONE SOURCE OF CONTRAST in echo planar imaging (EPI) that is used in functional imaging is the oxyhemoglobin/deoxyhemoglobin ratio. One way to study the effect of deoxyhemoglobin on EPI is to change the concentration of O_2 in the inspired air. We noted that when pure oxygen was administered intermittently by mask to normal subjects during functional magnetic resonance imaging (FMRI) studies, signal intensity changes exceeded the predicted response. Similar changes were noted when the experiment was repeated with a phantom (that did not absorb oxygen) replacing the volunteer. To determine how gaseous oxygen in the magnetic field produced large signal intensity changes, we studied the effect of oxygen on the phantom dynamically and statically.

• METHODS

Phantoms consisting of polyethylene bottles containing 0.05*M* NaCl and 0.005*M* CuSO4. were imaged in a 1.5T imager (GE Medical Systems, Waukesha, WI) equipped with an experimental endcapped birdcage quadrature head coil and 3-axis gradient coil (Medical Advances, Inc., Milwaukee, WI). A standard plastic hospital face mask (with no metal components) used for oxygen delivery to patients was applied to the superior surface of the phantom. Typical acquisition parameters included 1-cm slice thickness, TR 600, TE 20, 128 × 256 matrix and 20-cm FOV. For the acquisition of the echo planar image series, the magnet was shimmed with room air in the mask. A sequence of 140 images was acquired with a blipped echo planar (EP) technique (1) with TR 1000, TE 40, slice thickness 1 cm, 64 × 64 matrix.

For the dynamic studies, oxygen (100% medical grade, bottled) was delivered through polyethylene tubing to the face mask at 6L/min during the acquisition of the 140 images. The oxygen was delivered either continuously, or intermittently for 20-sec periods alternating with 20-sec periods in which no gas was administered. For control studies, no oxygen was administered. The signal intensity in each pixel is plotted as a function of time. The time course plots are inspected for changes in signal intensity temporally correlated with the administration of oxygen. A cross-correlation technique (1) is used to identify pixels with a time course that correlates with a reference function. The reference

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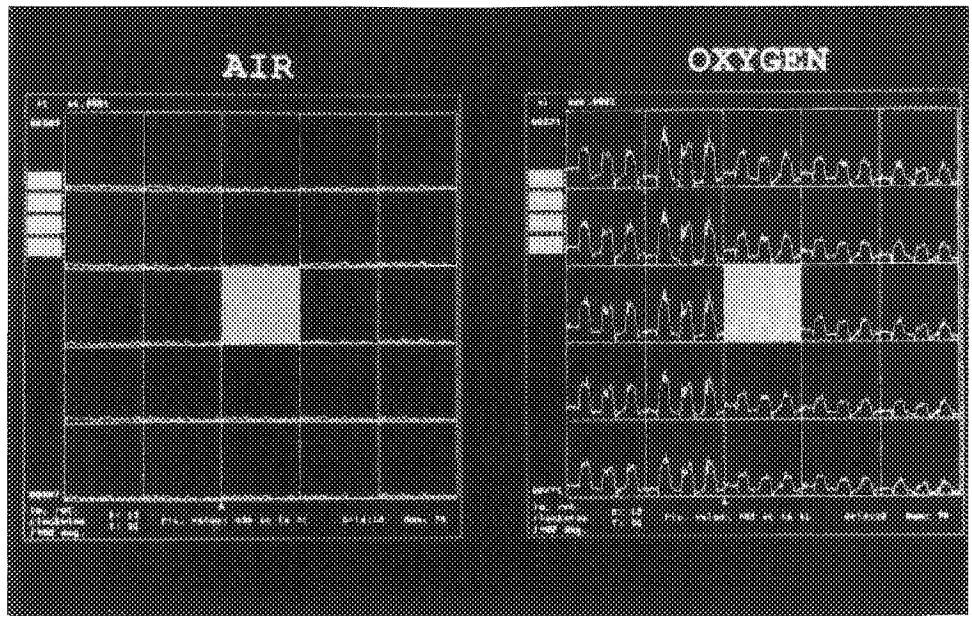


a. b.

Figure 1. FMRI acquisition of a phantom containing copper sulfate solution. Time course plots in 25 selected contiguous pixels are illustrated from a control (**a**) in which air was administered intermittently to the mask, and from an experiment (**b**) in which oxygen was administered intermittently to a mask adjacent to the phantom. Note in (**b**) that individual pixels demonstrate increased signal intensity during each of the three time intervals in which oxygen is administered. The signal intensity changes are characterized by steep rise and fall slopes and proximity to a border of the phantom.

function for this study is a square wave with values changing every 20 sec. The spatial relationship of "activation" to the phantom was studied by means of images of activated pixels (functional images) superimposed on the reference "anatomic" image.

Functional images obtained in the phantom were compared with functional images obtained in three human volunteers. For these experiments, the subjects were positioned in the scanner as for a functional experiment (2). The oxygen was applied either to the face or to the back of the head of the volunteer. The EPI sequences were obtained in sagittal planes during the intermittent and continuous administration of oxygen or of air to the mask as in the phantoms. The time course plots of signal intensity in each pixel were examined for evidence of signal intensity changes temporally correlated with the administration of oxygen. The functional images of "activated pixels" were compared with the anatomic reference images.

For the static experiment, the mask was placed on the top of the phantom. The magnet was shimmed on the phantom. With the shim program, the magnitude of the single echo was observed as oxygen delivery to the mask was initiated. The magnet was reshimmed to restore the magnitude of the echo and the magnitude of the single echo monitored while the oxygen was discontinued abruptly.

• RESULTS

In the pixel-by-pixel time course plots from the phantom, individual pixels were identified with changes in signal intensity temporally correlated with the intermittent administration of oxygen (Fig 1). Increases and decreases in signal intensity changes of 5% to 60% of baseline signal intensity were present at interfaces with spatially localized signal intensity variations (Fig 1b). The intensity changed from baseline to maximum or vice versa in 1 to 2 sec. Temporally correlated signal intensity changes of lower magnitude were also evident in regions of the phantom that had a homogeneous signal intensity. In some pixels signal intensity increased coincident with the administration of oxygen (positive or in-phase changes); in other pixels, it decreased (negative or out-of-phase). In control experiments, in which oxygen was not administered intermittently, the fluctuations in signal intensity were not noted. Pixels with signal intensity changes clustered near margins of the phantom. Some pixels with smaller signal intensity changes were present in bands through the image.

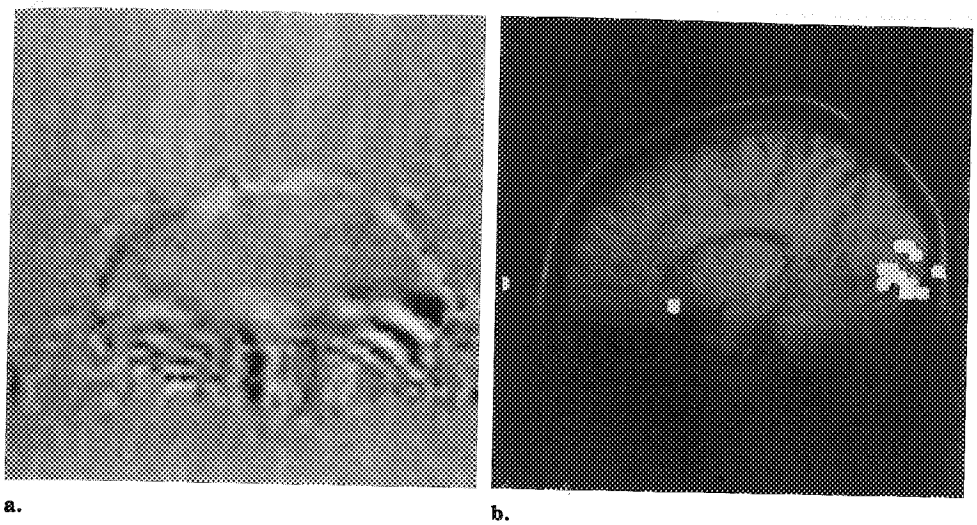
In the pixel-by-pixel time course plots of signal intensity of volunteers receiving pure oxygen intermittently without performing motor, sensory, or cognitive tasks, pixels with changes in signal intensity of 3% to 60% temporally correlated with oxygen administration were observed. The pixels with the greatest change were located near cerebrospinal fluid-brain interfaces. Other pixels with lower magnitude temporally correlated signal intensity changes were distributed in the image in the phase encoding direction from the pixels with the greatest changes. In the functional images bands of "activation" were noted at the interface of the brain and skull (Fig 2). Bands of "activation" were evident in regions of brain that normally demonstrate functional activation with appropriate tasks, such as the visual cortex (Fig 2b). Positive and negative changes were evident.

Pixels with temporally correlated signal intensity changes were identified in the functional data acquired with the mask over the subject's mouth and nose or with the mask on the subject's occiput so that the subject did not inspire the oxygen mixture. Pixels with temporally correlated signal intensity were not identified in the data acquired during the continuous administration of oxygen.

In the static experiment, introducing oxygen into the mask reduced the magnitude of the single echo by 5%. The magnitude of the echo was restored by shimming in the y direction. When the oxygen was discontinued, the magnitude of the single echo again diminished by 5%. The magnitude was restored by shimming again in the y direction.

• DISCUSSION

The study shows that pure gaseous oxygen inside the bore of the magnet causes the large changes in signal intensity on EPI acquisitions, which are sensitive to B_0



a. b.

Figure 2. Correlation image in a volunteer receiving oxygen intermittently to a mask placed over the mouth and nostrils. No task was performed. The functional image of the "activated pixels" (**a**) illustrates in and out of phase artifacts at the skull border. In (**b**) the functional image after thresholding is superimposed on the anatomic image. Note that the artifact simulates function in the visual cortex. Some of the artifacts simulate "activation."

uniformity. A change of 0.4 ppm in magnetic field homogeneity ($25H_2$) shifts the image one pixel in the phase encoding direction. In the dynamic phantom and patient studies, the spatial shift near interfaces may produce large temporally correlated signal intensity changes. The changes may simulate or obscure functional activation in FMRI. The effect of high concentrations of oxygen on blood oxygen level dependent (BOLD) contrast in FMRI cannot be studied without controlling for the effect of gaseous oxygen within the magnetic field. Although the BOLD is well known, the effect of gaseous oxygen on the magnetic field that is described in this report is to our knowledge not reported previously.

The effect of oxygen on signal intensity is explained by the static studies, in which none of the oxygen entered into the solution. In the static studies, the effect of oxygen on the magnetic field uniformity was observed during administration of oxygen continuously to the mask on the phantom. With the mask on top of the phantom to coincide with the y axis (phase encoding direction), a 5% decrease in the magnitude of the single echo was evident each time that the gas mixture in the mask was changed and was compensated by applying a small gradient in phase encoding.

Pure oxygen in the bore of the magnet changes the homogeneity of the field because of its paramagnetic properties. Changing the magnetic susceptibility changes the spatial relationship of the magnetic field and the object being imaged. The effect on the images is similar to moving the object with respect to the magnetic field. Voxels related to portions of the object in which signal intensity changes significantly with small spatial displacements experience large increases or decreases in signal intensity as the magnetic field is changed. These signal intensity changes may appear in the "functional images" as in-phase (positively directed changes) and out-of-phase (negatively directed changes) pixels. Similar signal intensity changes have been attributed to motion of the head temporally correlated with a stimulus (3). While ghosts are not produced in EPI by motion (4), nyquist ghosts, which represent 5% to 10% of baseline signal intensity, are present, explaining in part some of the signal intensity change temporally correlated with oxygen administration that occurs at a distance from interfaces.

References

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