Quality Control for Functional MRI Using Automated Data Analysis and Shewhart Charting

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Aim

To develop a sensitive automated analysis method for regular quality control (QC) of functional MRI studies.

Introduction

fMRI experiments can be compromised by system drifts, low SNR and artifacts including Nyquist ghosts. Despite fMRI relying on detecting very small signal changes, the subject of quality control for fMRI has received little attention. We believe that standardised QC measures are an essential part of fMRI studies and have therefore developed an acquisition protocol and automated analysis system for this purpose. We compare results from 2 MR systems used for fMRI, and discuss the success of the protocol in detecting hardware faults and system drifts. The method provides a first step towards standardised objective QC for fMRI.

Methods

The quality control programme is operated daily as follows. Data Acquisition consists of two components each using a CuSO₄ loading phantom. A single T₂* weighted gradient echo echoplanar image (TR=3s, TE=40ms, Θ=90°, 128x64 matrix, 40x20cm FOV, 5mm thick, 0.5mm gap) is acquired in each orthogonal plane with phase-encoding in each perpendicular direction (6 images in total). Subsequently, three temporal datasets are acquired using a standard fMRI protocol with 100 images per slice from 10 near-axial planes over a period of 5 minutes. Data Analysis: Since manual data analysis can be time consuming and an impediment to practical regular QC, an automated data processing scheme has been developed in-house. Initially the orientation and phase encoding direction of each image is automatically determined. Fast imaging methods can be susceptible to ghosting (for example "Nyquist ghosts" with EPI). Based on prior knowledge of the position of ghosts, a mean phantom signal, mean noise signal and maximum ghost signal are determined. From these, signal to noise ratios (SNRs) and signal to ghost ratios (SGRs) are calculated. A battery of statistical tests is applied to the short term temporal stability measurements including determining maximum signal change, calculating regression fits to the data and applying the method of Weisskoff et al. (1). A key component of the method described here is the automatic comparison of daily results to computerised records of these values for previous days and the manufacturers' specifications using Shewhart charting (2,3). This enables statistically significant changes in key performance parameters (e.g. SNR, maximum temporal signal change) to be robustly detected. Finally visual checks are made for other artifacts by the operator.

Results

The table shows typical results for two 1.5 T MR systems used for fMRI; a 2-plane EPI system (System 1, 4 years old) and a 3-plane EPI system (System 2, 2 years old). The manufacturers' specifications are also given in brackets where available. Both systems demonstrate high SNRs. The SGRs of the two systems are very different with System 1 outperforming System 2 by a factor of five. A maximum signal change of under 0.5% for System 1 should have little effect on most fMRI studies but the 2.0% change for System 2 is greater than those observed in more subtle cognitive paradigms. The temporal nature of the signal change is also important; linear drifts are easier to compensate for during statistical time series analysis than random changes.

The figure illustrates the variation of SGR for axial R/L data from system 1 over 3 months. The first 20 measurements were used to provide a baseline for Shewhart charting. A drift in performance (solid diamonds) was first identified on day 82, and was followed by the system dropping out of specification on day 100. The fault was resolved by replacement of the charging capacitor bank. During the lifetime of the two systems several major hardware faults have necessitated a RF receiver circuitry replacement, a gradient coil replacement, and a gradient eddy-current compensation scheme re-calibration. Our fMRI QC programme successfully detected each fault at an early stage, which were missed by a conventional less elaborate QC programme. Downward trends in system performance have also allowed us to alert service engineers earlier than otherwise possible.

Discussion

The quality control programme described here has proved effective at identifying hardware faults which standard QC measures failed to detect. The automated nature of the analysis of both a single days data and comparison to historical data facilitates regular quality control. This is particularly important for serial fMRI studies, and activation tasks producing only small signal changes. For this reason we advocate that standardised objective QC measures are reported in fMRI publications. The automated methods reported here are an initial step towards this goal. The measures described here are also appropriate for comparing the suitability of different MR systems for fMRI, as well as for determining performance specifications when purchasing new systems.

REFERENCES

(3) Shewhart WA, Economic control of quality of the manufactured product, Van Nostrand, New York, NY, 1931