Determination of Shims Needed for Correction of Tissue Susceptibility Effects in fMRI

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INTRODUCTION

Air-tissue-bone interfaces give rise to susceptibility effects in fMRI data acquired using GR-EPI sequences, including anatomic distortion and signal dropout from intravoxel dephasing. In addition, these effects contribute to T2*, which gives rise to variation of fMRI contrast-to-noise across the brain. These variations in local field are on too small a distance scale to be corrected using conventional whole body current shims. Furthermore, the asymmetry of the human head and shoulders as a whole - anterior to posterior and inferior to superior - gives rise to larger scale susceptibility effects that are not corrected by conventional shims. The purpose of this study was to characterize these susceptibility effects over a large number of subjects. We sought to determine which higher order polynomials are needed and to make a judgement concerning the usefulness of local passive and/or current shims in fMRI. Such shims might, for example, be placed on a 30 cm diameter cylindrical form that surrounds the head.

METHODS

All experiments were carried out on a 3 T BIOSPEC 30/60 Bruker scanner equipped with a home made balanced torque three-axis local head gradient coil (1) and endcapped bandpass birdcage rf head coil. Image reconstruction was done on an SGI Challenge 10000 workstation equipped with Pentek 16 bit A/D converters. Data conversion was performed at 1 M samples/second with additional digital filtering. In the first step of all fMRI studies, automatic 3D shimming was performed using the method described in ref. 2. This procedure is robust and requires about three minutes to adjust currents of 14 polynomial shim coils. Raw data from these procedures were routinely saved for further statistical analysis. The results presented here were obtained on 45 volunteers. An off-line program was created to decompose the magnetic field distribution inside the head in the same fashion as during the real time procedure, but the number of polynomials was increased to 35 - to include all up to the 5^{th} order. For reference, the same shimming procedure was done on a cylindrical phantom filled with a saline solution. All synthetic polynomials were scaled to the real Z^4 shim coil polynomial at a distance 87.5 mm from the isocenter, which corresponds to the edge of the cube used in the real-time shimming. The amplitudes of synthetic components in Fig. 1 are in percent of maximum strength of the Z^4 gradient. The results from 45 studies were averaged and standard deviations for all polynomials were calculated.

RESULTS

The decomposition of the 45 human head magnetic field maps showed that of the 21 polynomials remaining after neglecting the 14 used in the system, only nine play a role in the shimming. They are, in order of importance: $Z^2(X^2 - Y^2)$, Z^3X, ZY^3, Z^3Y, $Z^2(2XY)$, $Z^2(3X^2Y - Y^3)$, Z^4X, Z^4Y, $Z^3(X^2 - Y^2)$. Polynomials that did not contain a Z component such as X^5 or Y^5 were of no importance. Subjects with shorter necks where the tip of the head barely reached the gradient coil isocenter required increased values of the first four polynomials on the list. In contrast, for the phantom, which exhibit cylindrical symmetry, no polynomial coefficient exceeded 5% of the maximum of the real Z^4 gradient. Generally, standard deviations exceeded the average values of polynomials. Only $Z^2(3X^2Y - Y^3)$ and Z^4Y were exceptions. These gradients are candidates for ferroshim inserts which could be positioned inside the head gradient coil to reduce the amount of needed current.

DISCUSSION

The standard deviations of amplitudes in higher order shims tended to be proportional to the mean values. This variability is not only due to the diversity of human head shapes but also to variability of the separation of the region of interest (i.e., the brain) and the shoulders. Use of ferroshim inserts to bring the mean value of the coefficients of the higher order polynomials close to zero is desirable. However, this strategy will not in itself be sufficient because of high standard deviations of seven of the polynomials as enumerated above. It is concluded that additional current shims corresponding to these seven polynomials are necessary.

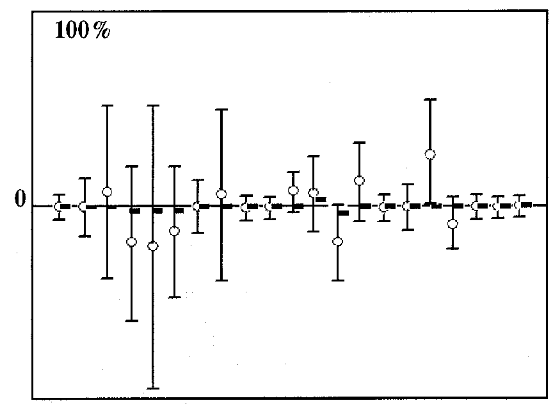

Fig 1. Average values and standard deviations of 21 polynomials. Circles are for heads, rectangles (size of std. dev.) are for the phantom. The polynomials are (in symbolic notation from left to right): $(X^3 - 3XY^2)$, $(3X^2Y - Y^3)$, Z^3X, Z^3Y,- $Z^2(X^2 - Y^2)$, $Z^2(2XY)$, $Z(X^3 - 3XY^2)$, $Z(3X^2Y - Y^3)$, $(X^4 - 6X^2Y^2 + Y^4)$, $4(X^3Y - Y^3X)$, Z^5, Z^4X, Z^4Y, $Z^3(X^2 - Y^2)$, $Z^3(2XY)$, $Z^2(X^3 - 3XY^2)$, $Z^2(3X^2Y - Y^3)$, $Z(X^4 - 6X^2Y^2 + Y^4)$, $Z(4(X^3Y - Y^3X))$, $(X^5 - 10X^3Y^2 + 5XY^4)$, $(Y^5 - 10X^2Y^3 + 5X^4Y)$.

REFERENCES

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