Requirements for RT Shimming of the Brain at 3 Tesla

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Introduction

Room temperature (RT) shim coils are routinely used to remove global and local B0 field inhomogeneity introduced by samples in NMR or MRI systems. These coils are typically wound to produce fields which approximate to spherical harmonic basis functions [1]. Most clinical scanners only use second order spherical harmonic terms, however with the increasing availability of very high field systems, third and fourth order terms are a serious consideration. However, choosing appropriate coil strengths is of critical importance in shim coil design. Inductive coupling of the shim coils can lead to severe resonances between coils, for example between the Z^3 coil and the main Z gradient. Over-specification of the shim strengths can increase the risk of this happening, and such high shim fields may never be used in practice. Despite the widespread use of RT shims in human MRI, there is little published data as to the strength that is required to optimally shim the head. In 2003, Cline *et al.* published values based on a fit of 1st to 4th order spherical harmonics to a B0 field map obtained on a single head [2]. Here we analyze B0 field map data obtained on our 3T scanner obtained over a period of 6 months (over 400 brain images), in order to find the mean and standard deviation fields required to effectively shim these brains. These data can therefore be used to specify the coil requirements to effectively shim the human brain.

Methods

All data were acquired on a 3 Tesla, Varian INOVA scanner. B0 field maps were acquired on 458 subjects over a period of 6 months, covering a wide range of ages (18 years and above), recruited for a range of fMRI studies at our centre. The method for acquisition and analysis of the data follows the protocol outlined by Wilson et al. [3]. A symmetric/asymmetric spin echo sequence was used for quantifying B0, the phase information from which was unwrapped using the 'Prelude' algorithm [4]. The threshold data were then fit to the spherical harmonic basis functions (see Table 1) using a shim current constrained algorithm [5], to obtain the field requirements for each coil in order to minimise the B0 field variation over the brain. To ensure that only successful fits to the data were included any field map whose standard deviation was greater than 12 Hz after removal of the calculated fit terms were excluded from the final analysis. A total of 40 data sets were rejected in this way. To account for the magnet's intrinsic B0 inhomogeneity (as opposed to head-induced inhomogeneity), a 28 cm diameter spherical phantom was also imaged and the terms from the fit to this data set were subtracted from the head results. For each term the mean and standard deviation was computed across all heads scanned. Shim coil requirements were specified by taking the mean + 2 standard deviations, thereby including 95% of the population.

Results

The results of the fit on 418 data sets are shown in Table 1. The mean + 2 standard deviation column is shown as absolute values. The magnet showed significant Z2, Z3 and Z4 terms before the insertion of the head. All these magnet terms are subtracted from the figures shown in Table 1.

Shorthand	*Spatial function*	***Mean*** *(μT at 400 mm DSV)*	***Mean+2 Std dev*** *(μT at 400 mm DSV)*
Z	z	-5.28	**9.99**
X	x	0.41	**3.65**
Y	y	0.16	**1.38**
Z2	$z^2 - (x^2 + y^2)/2$	-9.58	**19.43**
ZX	$3\,z\,x$	-4.85	**11.82**
ZY	$3\,z\,y$	-0.34	**6.30**
X2-Y2	$3\,(x^2 - y^2)$	2.93	**6.37**
XY	$6\,x\,y$	2.70	**6.12**
Z3	$z^3 - 3\,z\,(x^2 + y^2)/2$	-8.77	**24.08**
Z2X	$6\,z^2x - (3/2)\,x\,(x^2 + y^2)$	-1.49	**7.49**
Z2Y	$6\,z^2y - (3/2)\,y\,(x^2 + y^2)$	-1.39	**4.21**
Z(X2-Y2)	$15\,z\,(x^2 - y^2)$	-0.46	**2.28**
ZXY	$30\,z\,x\,y$	-0.31	**1.03**
X3	$15\,x^3 - 45\,y^2x$	0.05	**0.50**
Y3	$-15\,y^3 + 45\,x^2y$	0.07	**0.31**
Z4	$z^4 - 3\,z^2\,(x^2 + y^2) + (3/8)\,(x^2 + y^2)^2$	3.40	**25.59**

Table 1. Fit of B0 field map data to spherical harmonic terms.

Discussion

Values for the coil strength requirements for shimming the human brain are specified in this abstract. Whilst these are measured at 3 Tesla, the figures should be directly scalable to higher field strengths. It is at high field strengths (≥3 T) that appropriate specification of the shims is of critical importance. Since many of these high field applications are used for fMRI, the need to optimally correct field inhomogeneity becomes even more important. However, the over-specification of shim coils can also be problematic due to the risk of shim resonances. The only published data to date are those produced by Cline et al. [2] who fitted their data only over an elliptical region of interest within the brain. Our data correspond well to these values, although there are discrepancies in some 3rd order terms and the Z4 term, which could be accounted for by the difference in ROI over which the field inhomogeneity is minimised between the two studies. The advantage of our data is that, since we have based our numbers on the mean and standard deviation of over 400 brain images, we have a high confidence that these values are sufficient for whole brain shimming the vast majority of the population.

References

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