Reproducibility of fMRI for the definition of functional margins in radiotherapy planning

R. Garcia-Alvarez[1], G. Liney[1], A. Beavis[2], L. Turnbull[1]

[1]Centre for MR investigations, University of Hull, Hull, United Kingdom, [2]Princes Royal Hospital, Hull, United Kingdom

Introduction

Functional MRI is being increasingly used for clinical applications such as surgical and radiotherapy planning. fMRI can be combined with intensity modulated radiotherapy (IMRT) to significantly reduce the radiation delivered to proximal functioning cortices [1]. For fMRI to be routinely adopted in clinical practice it needs to be proven to be robust and reliable. Factors affecting its specificity include inter-patient BOLD variability, draining vein effects [2], and scanner performance [3], although studies examining the reproducibility of the technique are seldom performed. The goal of this study is to evaluate the degree of reproducibility of the primary motor cortex as a way of providing margins of error for the radiotherapy planning stage.

Methods

A total of 15 right-handed volunteers (Edinburgh Handedness Inventory) were scanned on a 1.5 T GE Signa scanner operating with 23mT/m, 190 µs gradients. Three plane localising images were followed by 3 consecutives fMRI studies using the BOLD technique. Single-shot gradient-echo EPI images were acquired at 8 slice locations (5mm thickness and 1.5 mm gap) using a TE = 40 ms, TR = 3000 ms, matrix size = 64 x 64, FOV = 24 cm and 60 phases. In order to assess intrasession reproducibility of dominant and non-dominant primary motor cortex [4], three consecutive experiments were performed which involved alternate right and left finger-thumb opposition. Following the fMRI acquisitions a high-resolution 3D T_1-weighted scan was acquired in the sagittal plane (TE/TR/flip=4.2/11 ms/20^0) with near isotropic 1mm resolution for anatomical referencing. All images were analysed using Brain voyager 2000™. Analysis of the functional data included 3D motion correction and slice scan time correction. The three functional datasets from each subject were individually registered in Talairach space onto a common high-resolution 3D anatomical dataset. From the functional analysis, the volumes (in pixels) of each of three functional clusters, mc1, mc2 and mc3, were determined. These were used to calculate a matching index of reproducibility (MI) for both the left and right hand, defined as follows:

$$matching\ i = 1 - \frac{Union^*(mc1, mc2, mc3) - (mc1 \cap mc2 \cap mc3)}{Union^*(mc1, mc2, mc3)} \quad ; Union^* = \sum_{i=1}^{3} mci + (mc1 \cap mc2 \cap mc3) - (mc1 \cap mc2) - (mc1 \cap mc3) - (mc2 \cap mc3)$$

The matching index values ranged from 0 to 1, where MI = 1 demonstrates a perfect reproducibility, and MI = 0 indicates zero intersection between mc1, mc2 and mc3.

Results

The matching index for each of the three consecutive clusters ($p<0.001$) of the primary right-hand motor cortex varied from 0.45 to 0.8 with an average of 0.66 and a standard deviation of 0.11, while for the left-hand, the value varied from 0.2 to 0.76 with an average of 0.55 and a standard deviation of 0.17. Figure 1 shows 2D axial images from each experiment in one male subject, together with a 3D rendering of each activated volume. In this case MI was equal to 0.66. Figure 2 shows an amalgamation of mc1 (in red), mc2 (in blue) and mc3 (in green) for both right and left motor cortex (MI = 0.76 for both left and right hand). Figure 3 illustrates the variability of MI for right (blue line) and left (red line) between different subjects. Results demonstrate that 80 % of the subjects have a value of MI ≥ 0.6 for their dominant hand but only 20 % for their left hand.

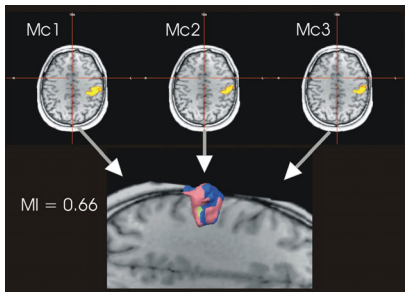

Figure 1: Right primary motor activation from three experiments in a typical subject (MI = 0.6)

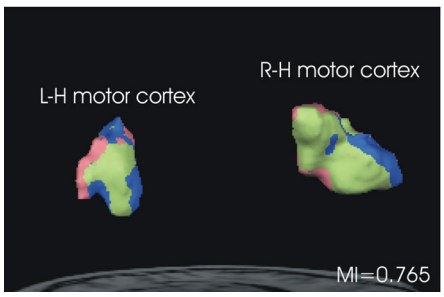

Figure 2: 3D rendering of each experiment for left and right hand.

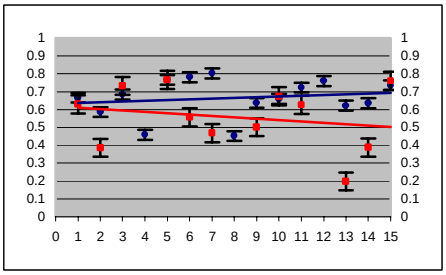

Figure 3: MI values for each subject using right hand (blue line) and left hand (red).

Conclusion

The results reveal that MI values for the dominant hand are greater than for the non-dominant hand. These lateralised differences need to be taken into account when defining radiotherapy margins for the primary motor cortices. This work is part of an on-going project through which we intend to incorporate biological information into our radiotherapy treatment planning [5], and will enable us to establish functional margins at the planning stage to account for patient and BOLD related variability.

References

[1] R Garcia-Alvarez, GP Liney, A Beavis, "Use of functional magnetic resonance imaging in the treatment planning of intensity modulated radiotherapy", *Journal of Radiotherapy in Practice* 2003; 3:63-69.

[2] R. Turner, "How Much Cortex Can a Vein Drain? Downstream Dilution of Activation-Related Cerebral Blood Oxygenation Changes", NeuroImage 2002; 16:1062-1067.

[3] G.P Liney, R.Garcia-Alvarez et al, "Inter and intra-system quality assurance of fMRI". Proceedings of the 20th Annual meeting ESMRMB, 2003, 148.

[4] Papke K, Reimer P, Renger B, Schuierer G, Knecht S, Schulz M, Heindel W, "Optimized activation of the primary sensorimotor cortex for clinical functional MR imaging." American Journal of Neuroradiology 2000; 21:395-401.

[5] M. Chalmers, "Brainwave for radiotherapy", *PhysicsWorld.* 2003; 16: 22-23.