Improved response to face recognition in UHF fMRI through parallel transmission RF pulse design

Hai Zheng[1], Tiejun Zhao[4], Kathryn Edelman[2], Yongxian Qian[3], Tamer S. Ibrahim[1,3],
Howard Aizenstein[1,2], Fernando E. Boada[1,3]
[1]Department of Bioengineering, [2]Department of Psychiatry, [3]Department of Radiology,
University of Pittsburgh PA USA, [4]Siemens Medical Solutions USA, Pittsburgh PA USA

Introduction

The amygdala plays an important role in normal memory, attention (Phan et al., 2002) and identified as a key structure to understand disorders with emotions such as depression (Posse et al., 2003), autism (Howard et al., 2000), and schizophrenia (Gur et al., 2002). Ultra high magnetic field (UHF) MRI has been used to depict anatomical details in the brain that are not attainable at lower field strengths. Unfortunately, UHF fMRI is problematic due to large magnetic susceptibiity-induced (SI) artifacts. This SI artifact manifests signal loss near important functional regions, such as the amygdala and limits the reliability of UHF fMRI studies in this region due to the coupling between the artifact level and the subject's underlying anatomy. People have proposed to restore the SI signal loss (Stenger et al., 2000; Yip et al., 2006), RF pulse durations are impractically long. In this study, we demonstrate a whole-brain, practical and robust RF pulse design to reliably recover the fMRI signal from the amygdala at ultra high field

Theory

The improved response is accomplished using the phase precompesation approach introduced by Stenger et al (Stenger et al, 2000) using a fast-Kz, excitation trajectory (Saekho et al., 2006) in which the RF pulse duration is brought to practical levels with the use of parallel transmission (PTX). With this formulation, the set of concatenated equations can be solved for RF pulse via Conjugate Gradient optimization.

We combine the principle of 3DTRF method and parallel transmission to formulate the RF pulse design. To control the excitation at a set of N different slices, we extend the set of equations in Ref. (Grissom et al. 2006), and concatenate the modified desired patterns $D_{precom}\{D_{Slice1},\ldots,D_{SliceN}\}$ where z_n $(n=1,\ldots,N)$ is the location of the slice-selective peak, $S_{total}\{S_{Slice1},\ldots,S_{SliceN}\}$ is the spatial sensitivity (B_1^+) maps of all slices and the encoding matrix of total slices is $A_{total}\{A_{Slice1},\ldots,A_{SliceN}\}$ Finally, we can formulate the following concatenated equation,

$$\begin{bmatrix}[D_{slice1}]\\ [D_{slice2}]\\ \vdots\\ [D_{sliceN}]\end{bmatrix}_{z_n} = \begin{bmatrix}[S_{slice1}A_{slice1}]\\ [S_{slice2}A_{slice2}]\\ \vdots\\ [S_{sliceN}A_{sliceN}]\end{bmatrix}_{z_n} \times B_{1,z_n}$$

RF pulses for improving signal at the slice location of z_n can be efficiently solved via CG optimization. RF pulses of signal recovery for other slices can be obtained by repeating the procedure with the location of excited peak (z_n) shifting slice 1 to slice N.

Methods

The faces-shapes task was chosen because this has been used extensively in functional imaging studies of emotion processing (Hariri et al., 2006), and has been shown to reliable engage the amygdala. The fMRI task consisted of matching of target shapes/faces on two sides of the visual field (left/right). The subjects were required to use the left/right index finger to elicit the corresponding response. This procedure was repeated in the following patterns, S-F-S-F-S-F-S-F-S, (S: shape, F: face), resulting in a 4 mins scan when a TR of 2 secs was used. All human brain studies were performed on a Siemens (Erlangen, Germany) 7T whole body scanner equipped with a PTX RF extension. The spoke trajectory was employed to design the RF pulses with the following imaging parameters: slice thickness=5mm, flip angle=20º, TE=16ms. In our design, the computational time for 1-spoke, 3-spoke and 5-spoke trajectories were 3.3mins, 9.2mins and 15.8mins. The resulting RF pulse durations were 1.03ms, 3.47ms and 5.91ms, respectively.

Figure 1. GRE excited by SINC pulse, PTX pulse designed with 1-spoke, 3-spoke and 5-spoke trajectories, respectively.

Results and Discussion

Figure 1 shows the comparison of excitations from different pulses. Significant signal loss can be observed with SINC pulse excitation. The lost signals are significantly restored with the three PTX pulses. Furthermore, the improvement of signal recovery is more evident in the 5-spoke trajectory design because adding phase-encoding locations increases the ability to accommodate for in-plane excitation variation, albeit at the expense of moderately increased RF pulse duration and computational time. Significantly increased BOLD activation at the amygdala is demonstrated when this excitation approach is used (Figure 2). Clearly, as the number of spokes increases, the performance is improved at the expense of increased computational time as noted above.

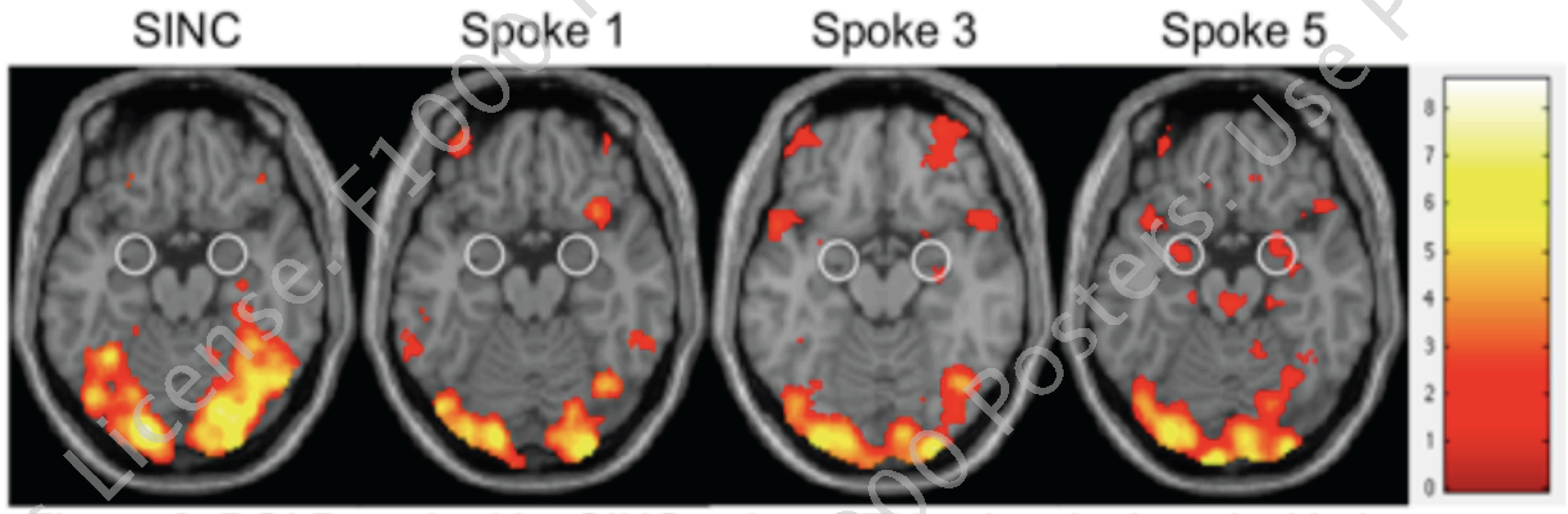

Figure 2. BOLD excited by SINC pulse, PTX pulse designed with 1-spoke, 3-spoke and 5-spoke trajectories, respectively. The approximate location of amygdala has been outlined.

Conclusion

We have successfully demonstrated that PTX 3DTRF design can be used for improving the fMRI signal response in amygdala. This is the first time that whole-brain, tailored RF methodology in conjunction with PTX RF has been demonstrated for this purpose. Overall, the proposed methodology was found to be robust across volunteers, especially when the 5-spoke trajectory was used.

Reference

Grissom, W.A. (2006) Magnetic Resonance in Medicine 56, 620- 629.
Gur, R.E.(2002) Am. J. Psychiatry 159 (12), 1992–1999.
Hariri A.R., (2006) Trends in Cognitive Sciences Apr;10(4):182-191.
Howard, M.(2000), NeuroReport 11 (13), 2931–2935.
Phan, K. (2002), NeuroImage 16 (2), 331–348.
Posse, S.(2003), NeuroImage 18 (3), 760–768.
Saekho, S. (2006), Magnetic Resonance in Medicine 55, 719-724.
Stenger, V.A.(2000), Magnetic Resonance in Medicine 44, 525- 531.
Yip, C.Y.(2006), Magnetic Resonance in Medicine 56,1050-1059