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Interactive comment on "Spatio-temporal encoding by quadratic gradients in magnetic resonance imaging" *by* Sina Marhabaie et al.

Anonymous Referee #1

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mr-2019-2, Marhabaie et al

The paper present a method of SPEN imaging that replaces the frequency-swept CHIRP pulse with a quadratic gradient, claiming advantages in SAR and echo time. Results of quadratic gradient SPEN are shown from a phantom.

No quantitative comparisons of image metrics (including SNR, resolution artefacts etc) are provided vs standard methods: chirped SPEN, or conventional MRI. Thus the conclusions concerning advantages are unsubstantiated. Significant artefacts associated with the encoding are evident but the dependence of these on practical instrumental factors are not elaborated. The authors do not provide a compelling case for using the proposed method vs existing SPEN or regular MRI methods. Moving the author's approach forward would basically require new sets of comparative studies and analyses.

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Discussion paper

1. Abstract. (i)line 12. “In this work, we show that it can be advantageous. . .” Advantageous compared to what? (ii)No quantitative comparison of performance metrics are documented or summarized. SAR and TE are mentioned–these only relate to the RF chirp pulse. What about the whole new gradient system required? “Resolution, FOV, SNR are the same” how was this tested? (iii)Why are quadratic gradients–which are virtually non-existent for spatial encoding in NMR systems, advantageous compared to linear gradient systems that virtually all NMR imaging systems have?

2. Introduction p1 line 21. If the SPEN method requires “sequential excitation” and “sequential detection”, it is surely at a disadvantage in MRI efficiency (SNR per unit time) to conventional MRI methods wherein certain multi-dimensional encoding can be performed concurrently. Same would be true of the dephasing effect. Is this correct or should the text be better clarified?

3. Introduction p2 lines 36-50. It seems that the authors are basically exchanging the high SAR/RF problems required to swamp out the phase variations due to Bo inhomogeneity, for problems with generating quadratic gradients which aren’t acknowledged.

4. Introduction, last para. Please summarize what you plan to show in this paper.

5. Theory. Fig 1. (i)The presence of the quadratic Z gradient during regular slice selection in the x-direction will degrade SNR, slice selection and distort the imaging plane excited in a way that varies quadratically along the Z-axis. This is not “sequential excitation”. The same appears true for the y-direction with linear encoding gradients and Zˆ2 encoding running currently. (ii)The caption says “. . .linear gradients like in Fourier imaging sequences.” This appears to contradict the statement “there is no need for a Fourier transformation in the spatio-temporal encoding direction” (p1). The authors have both phase-encoding gradient steps and a quadratic gradient in the same dimension. (Why is this advanatgeous to not applying the quadratic gradient?)

6. Theory p3 line 63, “. . .while spatio-temporal encoding is achieved with quadratic encoding gradients”. I have an issue with the term “spatio-temporal encoding (direc-

tion)" as some kind of differentiator vs. conventional spatial encoding in MRI. All conventional MRI methods encode in the time domain (which is equivalent to k-space). Phase-encoding cause position dependent changes in the time (temporal) domain. So does the regular read-out gradient, and slice selection. That is, in Fig 1 spatio-temporal encoding is achieved with all of the gradients in all dimensions, not just the quadratic one.

7. Theory p3. (i)Not turning the gradients off when encoding with other gradients is a serious deficiency for a "proof of principle demonstration". This means someone would have to come along and implement the method properly and redo any comparisons in another paper on the same idea–basically a redo. (ii) The method of correcting the "non-negligible" misregistration error" is not documented.

8. Theory. There are no theoretical analyses concerning the practical limits and requirements of the quadratic gradients: strength, fidelity and their relationship between to spatial resolution, spatial distortion, bandwidth per point, SNR per point, the potential variation of SNR and resolution with position from "the vertex", and system dynamic range.

9. Method section, p4. The quadratic gradient is not specified. The image metrics being measured are unstated. No comparisons are specified. In particular, improvements are being claimed vs the chirp pulse method, but no such comparison is apparently being performed (according to the methods). Therefore the claims of advantage cannot be substantiated.

10. Method. I expect the use of the Bruker shim coil is not optimal for quadratic encoding but no information is provided concerning its fidelity over the imaging volume.

11. Results. It is problematic that no image performance metrics (SNR, resolution distortion, artefacts etc) are being provided or compared in any quantitative fashion. The appropriate comparisons here are the author's new method with quadratic gradients vs. (a) the CHIRP pulse against which the authors are claiming advantage; and (b) a

regular MRI sequence employing linear gradients. Without that the work is anecdotal.

12. Results p5, Line 149, Fig 7. What is the RASER sequence? Why is this being compared? (Is this the best SPEN sequence that there is?) It is a major detriment to the paper that no comparison with a CHIRP pulse sequence is mentioned until one arrives at the caption of figure 7. But there are still no quantitative comparisons here, and the results seem to show that neither SPEN sequences are suitable for MRI (vs. Fig 3a, say).

13. Discussion, p6. (i)line 155. The authors have not documented any advantages of their method. (ii)They have not characterized the theoretical dependence of image performance metrics on the gradient system properties which would be needed for practical implementation. They attribute artefacts (eg in Fig 6) to such limitations, but basically it is arguable looking at the qualitative results, that the method just exchanges an SAR problem (which would probably not exist for their small-bore system) with CHIRP pulses for a reduction in image quality and performance, but which are still inferior to existing MRI methods.

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