Phased Array Combination of Maximum-Echo Sampled 2D JPRESS Using Unsupressed Water Signal

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Background: The localized 2D J-resolved spectroscopy (JPRESS) sequence can be obtained by repeating the traditional 1D PRESS localization pulse sequence with varying echo times [1]. This spreads out the J-coupled multiplets along the indirect dimension, resulting in reduced spectral overlap. This property has been exploited for detecting and measuring some of the weaker metabolites like GABA and Glutamine [2], which are difficult to detect with 1D pulse sequences at clinical field strengths. The clinical adoption of 2D JPRESS has been limited by the long acquisition times and the lack of commercial tools for processing and quantitating 2D spectra. Phased array coils have been widely used for accelerating the acquisition and improving the signal to noise ratio (SNR) in 1D MRS [3]. However, very few works have focused on phased array signal combination methods for 2D pulse sequences like 2D JPRESS [2]. In this work, we show that the maximum-echo sampled variant [1] of the traditional JPRESS has some advantages from the perspective of phased array signal combination.

Method: The RF signal received at the n^{th} element of a phased array coil, at each echo time of a 2D JPRESS sequence can be modeled as $S_n(t)=A_n exp(\phi_n+\theta_n(t))s(t)+\varepsilon(t)$, where $s(t)$ is the FID signal emitted by the voxel at that echo time, A_n is proportional to the sensitivity of the coil element to the magnetization within the voxel, ϕ_n is a phase offset which is a function of the location of the element with respect to the voxel, $\theta_n(t)$ is a time-varying phase distortion caused by the gradient induced eddy-currents [6], and $\varepsilon(t)$ is an additive thermal noise component. The factors A_n and ϕ_n are identical at each echo time, as long as the voxel is fixed at the same location. Note that, the above two parameters are also identical for an unsuppressed water signal from the same voxel. In the traditional JPRESS sequence, the sampling starts at the echo-top. Since the distance between the final crusher gradient and the echo-top is different for each echo encoded in the indirect dimension, the resulting eddy current distortion is also different. In the maximum-echo sampled JPRESS sequence, the sampling starts immediately after the final crusher gradient, and hence the eddy current distortion remains identical for different echo times. When the spectrometer frequency is at the water resonance, the phase of the unsuppressed water signal received at the at n^{th} coil element can be given by $(\phi_n+\theta_n(t))$ [6]. Subtracting the phase of the unsuppressed water signal from the phase of the water suppressed signal effectively compensates for both the eddy current distortion as well as the coil element's phase offset. The relative sensitivities of the coil elements can be estimated from the peak height of the unsuppressed water signal. The SNR of the phased array can be maximized by weighting each element by its sensitivity and compensating for the different phase offsets of the individual channels, so that the weighted channels can be coherently summed up in the time domain [1]. A single echo of the unsuppressed water signal can be thus used for both weighting and phase compensation.

The above hypothesis was verified using a 32-channel head coil on a Siemens 3T Tim Trio scanner. The maximum-echo sampled 2D JPRESS experiments were performed on a 2.5x2.5x2.5 cm^3 voxel in the temporal lobe of three healthy male volunteers, with ages ranging from 26 to 30 years. The sampling rates along the t_1 and t_2 dimensions were 2000 Hz and 500 Hz respectively. The acquisition parameters are as follows: TR = 2s, TE of first echo =30 ms, 100 echoes in the indirect dimension, 2048 complex samples in the acquisition dimension, 8 signal averages and an acquisition time of 26 min. The shimming water line-widths ranged between 14-18 Hz. A CHESS sequence with a water suppression bandwidth of 75 Hz was used for suppressing the large water peak. A single echo without water suppression was obtained with the same parameters as the first echo. Coil elements with a unsuppressed water peak height less than a third of the best coil element (in terms of peak height) were discarded from the signal combination process, due to their low contribution of metabolite signals. The 2D JPRESS SNR can be defined as ratio of the NAA peak height and RMS noise value between -2 and -1 ppm in the real part of the phase corrected [4] 2D JPRESS spectrum. The SNR of the best coil element (in terms of the unsuppressed water peak height), R_B, and the combined signal, R_{comb}, has been compared in Table 1. Since, the SNR improves as a square root of the acquisition time, the acquisition acceleration factor provided by the phased array coil with respect to the best coil element can be given by $(R_{comb}/R_B)^2$, and is tabulated in Table 1. The eventual goal of a MRS study is to extract the metabolic information by quantitating the individual metabolites. To verify the quality of the combined spectra, the ProFIT 2D fitting algorithm [4], was used to fit the truncated spectra (Fig. 1) between 1.3 to 4.1 ppm in the F_2 dimension and -30 to 30 Hz in the F_1 dimension. The average concentrations expressed in terms of the Total Creatine Ratio and the average Cramer Rao lower bounds (CRLB) of the fit for each metabolite are given in Table 2.

Table 1 - SNR and Acceleration factor (AF)

Set	R_B	R_{comb}	AF
1	244.63	289.99	1.40
2	157.34	328.58	4.36
3	161.60	283.38	3.07

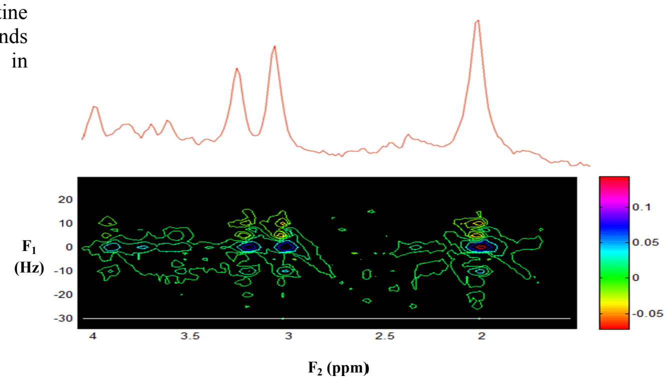

Fig. 1 Truncated JPRESS spectrum from a temporal lobe voxel, using a 32 channel head coil, along with the corresponding F_2 (magnitude) sum projection .

Table 2 - ProFIT fit results for a 32 -channel phased array coil

Metabolites	Cr ratio	CRLB
Cr	1	1.048
NAA/NAAG	1.732	0.668
PCh/GPC	0.333	1.296
Asp	0.243	19.872
GABA	0.563	4.432
Glu/Gln	1.45	2.576
Glc	0.586	7.354
Gly	0.141	13.203
GSH	0.289	4.426
mI	0.947	3.315
PE	0.340	10.265
Tau	0.448	6.697
Scy	0.052	11.170
Asc	0.270	10.969

Conclusion: The implicit phase compensation that occurs while performing an eddy current correction using the unsuppressed water signal was shown to be a viable strategy for time domain phased array signal combination of the maximum-echo sampled 2D JPRESS sequence. The average acceleration factor of 2.94 implies that, using just the best coil element would require the acquisition time to be increased by a factor of 2.94 times to achieve the same SNR as the phased array coil. Alternatively, the phased array acquisition time could be reduced by the same factor, while maintaining the same SNR as best coil element. This is significant, since each JPRESS experiment currently takes 26 min. The quality of the combined signal was verified using the ProFIT 2D fitting algorithm.

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