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HOW SIGNAL-TO-NOISE RATIO IMPACTS THE APPARENT STIFFNESS OF BRAIN TISSUE IN MR ELASTOGRAPHY AT 7T

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INTRODUCTION

Magnetic resonance elastography (MRE) is a technique for determining the mechanical response of tissues using applied harmonic deformation and motion-sensitive MRI[1]. Studies using MRE to investigate the mechanical properties of the human brain are most commonly performed at conventional field strength (3 Tesla (T) or 1.5T), although there have been a few attempts at the ultra-high field strength, 7T[2,3]. Aiming for higher resolution scans of the human brain at 7T, MRE presents unique challenges of decreased signal-to-noise ratio (SNR) and lower shear wave motion sensitivity. Additionally, it has been shown that quantitative values of MRE, i.e., the magnitude of the complex shear modulus estimate (|G*|), are sensitive to changes in SNR[4], so 7T MRE can present a challenge of not only quality, but accuracy. While applying commonly-used filtering techniques (e.g., Gaussian, Median) to MRE phase data can increase SNR (to combat low SNR in high-resolution scans), this can also blur fine physiological features, decrease the effective resolution[5], resulting in artificially increased |G*|[4]. We increase the SNR of our MRE acquisition without comprising the anatomical accuracy and spatial resolution by utilizing a Marchenko-Pastur Principal Component Analysis (MP-PCA) denoising algorithm[5]. In this technique, we are exploiting the intrinsic redundancies in MRE acquisition to identify and remove noise-only principal components[5].

In the most recent studies comparing 1.5T, 3T, and 7T MRE of the human brain, MRE at 7T and 1mm resolution resulted in significantly lower stiffness values than MRE at 1.5T and 3T at 2mm resolution[3,6]. However, one study indicated that when down sampled to 2mm, the 7T MRE results matched the traditional MRE field strength results, but in a second study, the difference remained[3,6]. In the past, we have shown that changes in resolution and field strength do not inherently change the value of |G*| in a linear elastic phantom[7]. However, MRE of phantoms typically have very high SNR, even at high resolutions, so this decrease in SNR as resolution increases may not have a large effect on scans with inherently high SNR. For MRE of the human brain however, SNR drastically drops with increasing resolution, very likely causing an artificially low |G*| calculation.

In this abstract, we will be investigating the effect of SNR on calculated |G*| in both a linear elastic phantom and the human brain using 7T MRE. We will therefore also be investigating how increasing SNR using MP-PCA denoising will change |G*| in scans that have inherently high SNR (phantom) and scans that have low SNR (human brain).

METHODS

Full brain coverage MRE was performed on one healthy human subject at 1.7mm, 1.3mm, and 1.1mm isotropic resolutions at 50Hz vibration frequency, using a 32-channel head coil (Nova Medical) on a 7T Siemens Magnetom MRI Scanner. MRE was also performed on a custom silicone MRE phantom (CIRS 049) at 2.5mm, 1.3mm, and 1.1mm isotropic resolutions. The designed MRE sequence was a modified single-shot multi-slice spin-echo 2D-EPI sequence with trapezoidal flow-compensated motion encoding gradients (MEGs)[8], synchronized with the pneumatic acoustic actuator (Figure 1)[7] by TTL triggering at the beginning of every TR (TR/slice=140ms, TE=65ms,

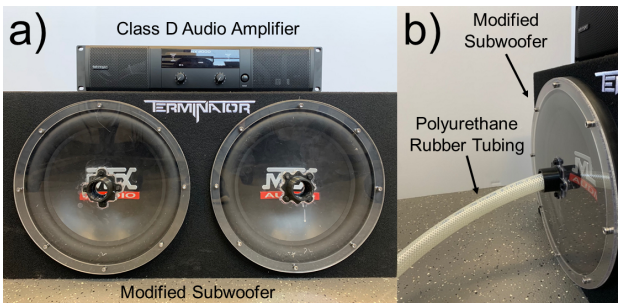

Figure 1: Custom pneumatic actuator

GRAPPA=3). Human brain images were masked using BET (Brain Extraction Tool) of FSL package[9] while phantom images were manually masked, denoised using a MP-PCA algorithm[5], and unwrapped using a Laplacian-based technique[10]. Curl filtering, Fourier decomposition, and a quartic smoothing kernel (scaled for resolution based on our previous investigation[7]) were used to acquire wavefield images, before Algebraic Inversion of the Helmholtz Equation was used to calculate the complex shear stiffness[11]. For the human brain, whole brain average stiffness was calculated (Figure 2), while for the phantom scans the mean of each stiffness map of five homogeneous slices per scan were calculated and compared using a one-way ANOVA. We then calculated the average octahedral shear strain-based SNR (OSS-SNR) for both original and denoised displacement data at each resolution[12].

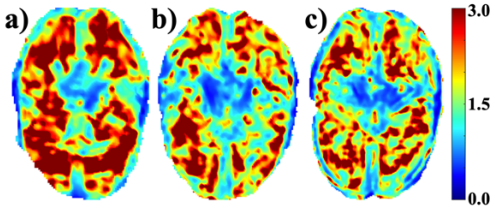

Figure 2: Elastograms showing |G*| in kPa at (a) 1.7mm, (b) 1.3mm, and (c) 1.1mm isotropic resolution.

RESULTS

Looking at our average |G*| for the phantom results, we find no statistically significant difference between any resolution, nor between original and denoised. We also find that while denoising does increase the average OSS-SNR for a specific resolution, the average OSS-SNRs for all data sets are above 100 (Table 1).

Table 1: Average |G*| and OSS-SNR in Phantom

		2.5mm	1.3mm	1.1mm
|G*| (kPa)	**Original**	1.425±0.007	1.430±0.005	1.423±0.012
	Denoised	1.425±0.005	1.430±0.005	1.423±0.110
OSS-SNR	**Original**	953.7±248.1	195.8±39.8	115.9±23.9
	Denoised	980.6±274.5	247.5±50.0	153.7±20.9

For the human brain, on the other hand, average OSS-SNR ranges from 3.5 through 11.5. Once again, applying denoising increases the average OSS-SNR for each resolution. Also different from the phantom results, the average |G*| differ both between resolutions and between original and denoised data. Generally, |G*| increases with increasing OSS-SNR, but it appears to not be a perfectly linear relationship between resolutions (Figure 3).

DISCUSSION

Based on the whole-brain stiffness estimates (|G*|) and SNR values, within-resolutions, denoising using the MP-PCA algorithm substantially increases the OSS-SNR and therefore increases |G*|. It also appears, based on the results of the phantom experiments, that increasing OSS-SNR only increases |G*| to a point, at which point additional increases in OSS-SNR using denoising will not significantly affect the |G*|. The benefit of using PCA-based denoising as opposed to other filtering techniques is that denoising maintains the physiological structures within the human brain and helps prevent over-smoothening/overfitting (Figure 4). This increased accuracy and sensitivity is of particular importance for smaller brain features, for example, the hippocampus when investigating changes due to Alzheimer's disease or dementia.

However, there appears to be a more complex relationship between OSS-SNR and |G*| between resolution likely due to the post-processing

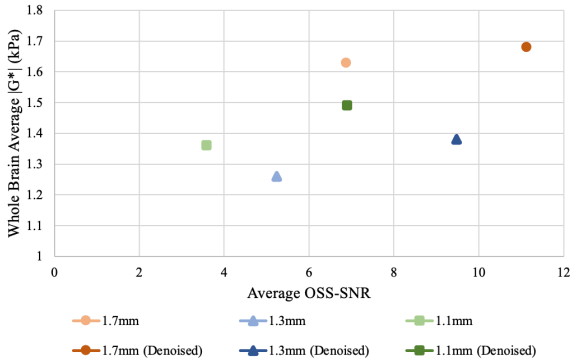

Figure 3: The relationship between whole brain stiffness (kPa) and average OSS-SNR

steps taken between displacement calculation and stiffness estimation. Additionally, the 1.7mm resolution scan appears to have an overall higher average |G*| than the 1.3mm and 1.1mm resolution scans, somewhat matching the increase in OSS-SNR values, which can be confirmed with further replicates. This potentially implies that additional fine viscoelastic features are detected at higher resolutions, decreasing the wavelength-based stiffness estimate, supporting the hypothesis of Barnhill, et al.[3]. Overall, to better understand these trends,

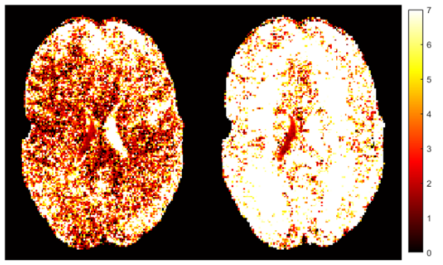

Figure 4: OSS-SNR map comparison between original (left) and MP-PCA denoised (right) data at 1.1mm resolution

we will continue to perform MRE at 7T on healthy human subjects at these three representative resolutions to better characterize the effects of both differing resolutions, change in field strength (3T versus 7T), and denoising on complex stiffness estimations of the human brain. Additionally, we will also implement a more complex segmentation algorithm to both investigate stiffness of specific subregions of the human brain.

In conclusion, our pilot study has shown a substantial increase in OSS-SNR after the use of MP-PCA denoising algorithm on the complex displacement data generated during MRE at 7T, and has shown a relationship between resolution, OSS-SNR, and |G*| that requires further investigation with a larger cohort of subjects.

ACKNOWLEDGEMENTS

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