# Real Diffusion Weighted MRI Enabling True Signal Averaging and Increased Diffusion Contrast

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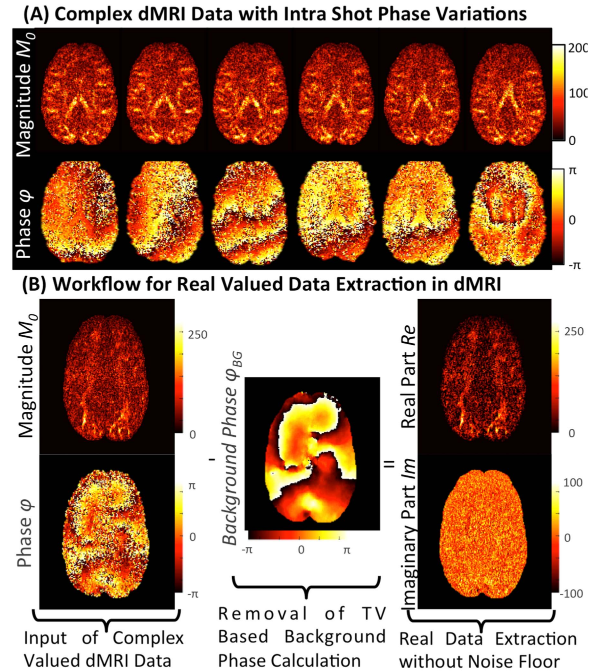
**Target Audience:** MR Scientists and Neuroscientists with interest in diffusion imaging with high resolutions or strong diffusion weightings

**Purpose:** This project aims at removing the Rician noise floor, to allow acquisition of diffusion MRI (dMRI) data with higher resolutions and/or stronger diffusion weightings. The Rician noise is a well-known problem for traditional magnitude-based dMRI data, leading to biased diffusion model fits and inaccurate signal averaging (1). Diffusion data are known to be contaminated by spatially smooth background phase contaminations arising from subject movement, cardiac pulsation and blood flow (2,3). Here, we employ a total-variation (TV) based algorithm to eliminate shot-to-shot phase variations of complex-valued dMRI data, as seen in Fig. (A). The intention of this rephasing procedure is to extract coherent real-valued dMRI datasets that are no longer superimposed by Rician noise but, instead, by a zero-mean Gaussian noise distribution, yielding dMRI data without noise bias.

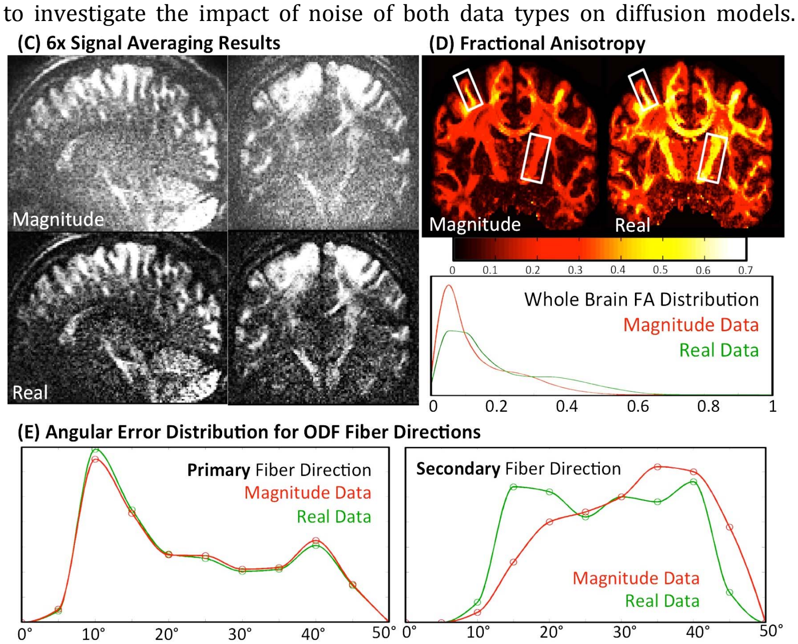
**Methods:** Data were acquired on a 3T MRI system (MAGNETOM Skyra CONNECTOM, Siemens Healthcare, Erlangen, Germany) with a gradient strength of 300mT/m using a custom-built 64-channel phased-array head coil. Single-refocused dMRI data were acquired with following parameters: 1.2mm isotropic resolution, FoV=210x210mm, 98 slices, Partial Fourier=6/8, TR=4600ms, TE=54ms, GRAPPA=3, SMS=2 (4). We acquired six repetitions of 128 diffusion directions at b=5000s/mm² with 10 interspersed b=0 images. Extraction of real valued data was performed using Matlab. We estimated the varying background phase of diffusion data using TV denoising of the complex dataset (Fig. B). The estimated smooth background phase was removed from the complex dataset. The real part of the rephased complex dataset contains all image information and can be extracted for further analyses. In contrast to magnitude, real valued data are not superimposed by Rician noise but follow a zero mean Gaussian noise distribution. We compared signal averaging for both traditional magnitude and the extracted real valued data. A DTI fit was performed with FSL for both averaged datasets to investigate the impact of noise of both data types on diffusion models. Furthermore, we performed a bootstrapping analysis of real and magnitude data to investigate the impact of noise in angular errors of estimated diffusion directions, using a recently published method (5). During this procedure, six acquired repetitions were resampled to synthesize 500 datasets. Orientation density functions (ODF) were computed for these data (6) and the standard deviations of their first and second fiber directions were calculated as the angular error of fibers.




**(A)** Complex dMRI data are varying in phase for each shot. **(B)** We use TV to gain real valued dMRI data, thereby removing impact of Rician noise to signal averaging and diffusion model fitting.

**Results:** Our results show that real-valued diffusion data enable ideal condition for signal averaging (Fig. C) and DTI model fitting without noise bias (Fig. D). We detected an increased in sensitivity in resolving crossing-fibers with real valued data (Fig. E). For a specified angular uncertainty of less then 50°, real valued data could identify 25% more crossing fibers than traditional magnitude data as evaluated by the number of secondary fiber direction identified.

**Discussion:** Our results reveal that real valued diffusion method enables unbiased signal averaging and model fitting in dMRI. Diffusion MRI, with its intrinsically low SNR, suffers from non-Gaussian noise distributions which introduces visible bias to the data, particularly at high resolution and/or diffusion weighting. The use of phase-corrected, real-valued data for dMRI eliminates such noise bias and will, therefore, help to clear the way for more detailed and accurate studies of white matter microstructure and structural connectivity at a finer scale.




**(C)** Real valued data eliminate the effect of piling up noise for low SNR dMRI. Especially in central brain areas with high noise, averaged real data show increased contrast (both images are on the same scale) **(D)** FA values calculated from low SNR magnitude data resemble SNR maps of coil arrays. Highly anisotropic brain areas such as the corticospinal tracts appear with low FA (white boxes). FA maps based on real valued data with low SNR do not show such bias. FA distributions reveals, that 50% higher contrast for FA maps was achieved using real valued data. **(E)** Bootstrapping shows an increased ability to resolve secondary fiber directions for real valued dMRI.

**References:** (1)Jones.et.al. MRM(2004) (2)Bammer.et.al. Diffusion MRI (2010) (3)Holdsworth.et.al. JMRI(2012) (4)Setsompop.et.al. NeuroImage(2012) (5)Cohen-Adad.et.al. JMRI(2011) (6)Descoteaux.et.al. MRM(2007)