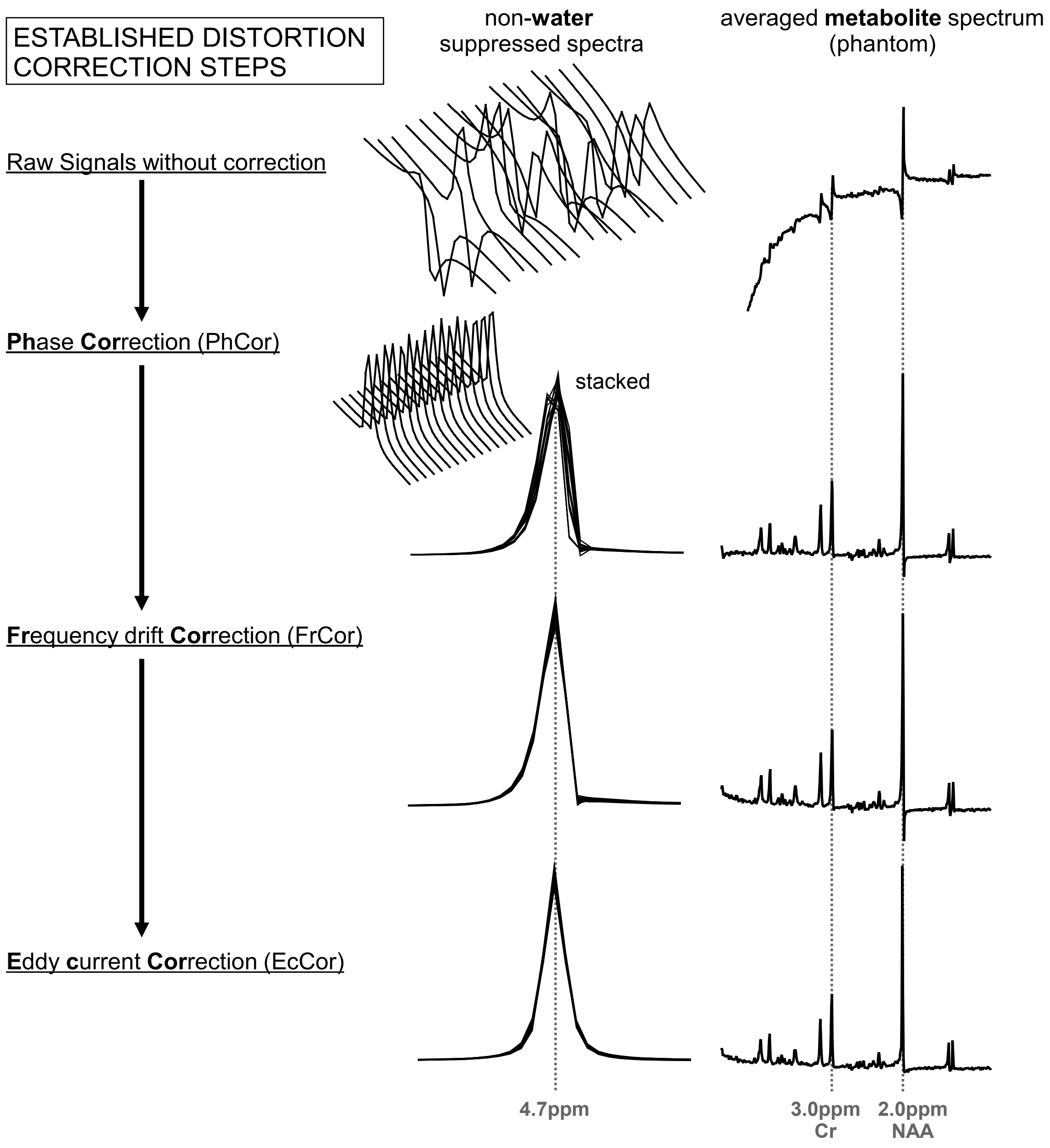

Figure S1: *Illustration of the established correction steps using unsuppressed water signals including Phase Correction (PhCor), Frequency drift Correction (FrCor) and Eddy current Correction (EcCor) are applied before motion compensation.*

Figure S2 shows the results for tests on the stationary phantom to define the ground truth (GT) ADCs. Fig. 2A documents the effect of signal phasing on the ADC estimation. Although no change on the water ADC is visible, the metabolite ADCs are affected non-negligibly by phase correction (PhCor). This is assigned to compensation of incoherencies in single acquisitions (e.g. due to table vibrations). The application of MoCom (reference level of 15%) merely leads to a lowering of ADCs within the CRLBs. Thus, GT in the stationary phantom is defined by ADCs derived after PhCor, but without MoCom. Fig. 2B reveals the mono-exponential decay of the water signal area in the stationary phantom, typical for unrestricted Gaussian diffusion.

A

ADC [$\cdot 10^{-4}$ mm²/s]

	water	Cho	Cr	Glu	Lac	mI	NAA
without correction (FrCor & EcCor applied by default)	24.80	10.88 ±0.06	9.40 ±0.04	8.10 ±0.16	10.52 ±0.09	7.65 ±0.14	7.65 ±0.02
PhCor ↓	**+0.05%**	**-2.02%**	**-1.70%**	**-7.65%**	**-2.19%**	**-5.75%**	**-2.48%**
PhCor **GROUND TRUTH**	24.81	10.66 ±0.06	9.24 ±0.03	7.48 ±0.14	10.29 ±0.08	7.21 ±0.11	7.46 ±0.02
MoCom ↓	**-0.03%**	**-0.39%**	**-0.35%**	**-1.08%**	**-0.30%**	**-0.64%**	**-0.51%**
PhCor + MoCom	24.80	10.62 ±0.06	9.20 ±0.03	7.40 ±0.13	10.26 ±0.08	7.16 ±0.11	7.42 ±0.02

B

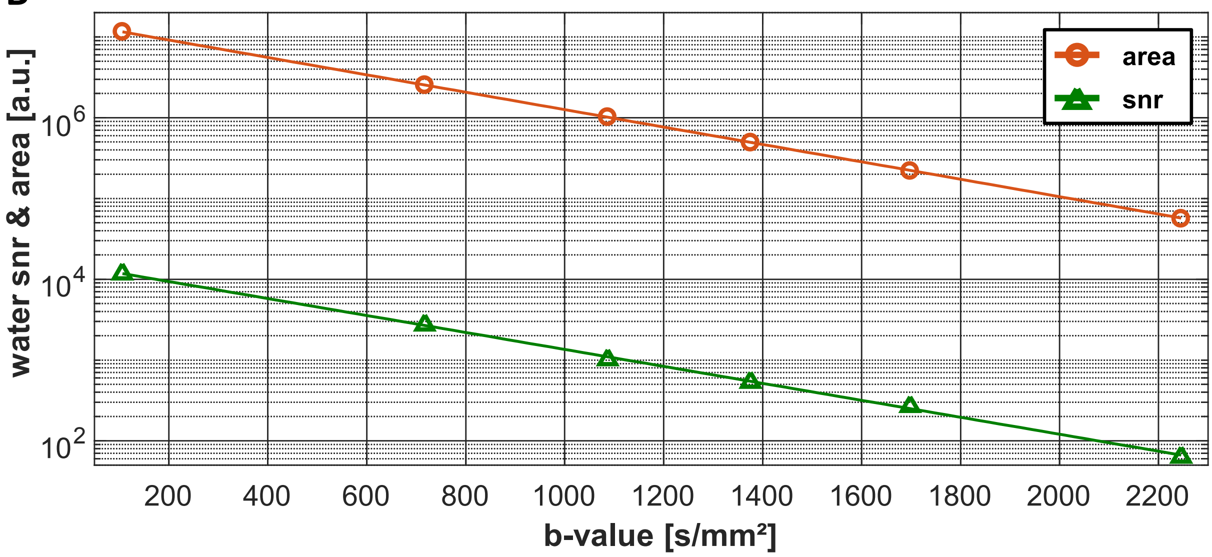

__Figure S2:__ Illustration of effects of the different signal processing steps on ADC estimation in the stationary phantom. A) includes the numerical data for metabolites and water signals. The water ADC stays almost constant during signal processing. In contrast, the ADCs of metabolites reduce markedly with phase correction (PhCor), whereas motion compensation (MoCom) has merely a marginal effect on the metabolite ADCs (not exceeding the range spanned by CRLBs). Thus, ground truth (GT) ADCs were defined by the PhCor results, before MoCom. B) shows the area and SNR decay of the GT water signal together with a mono-exponential fit.

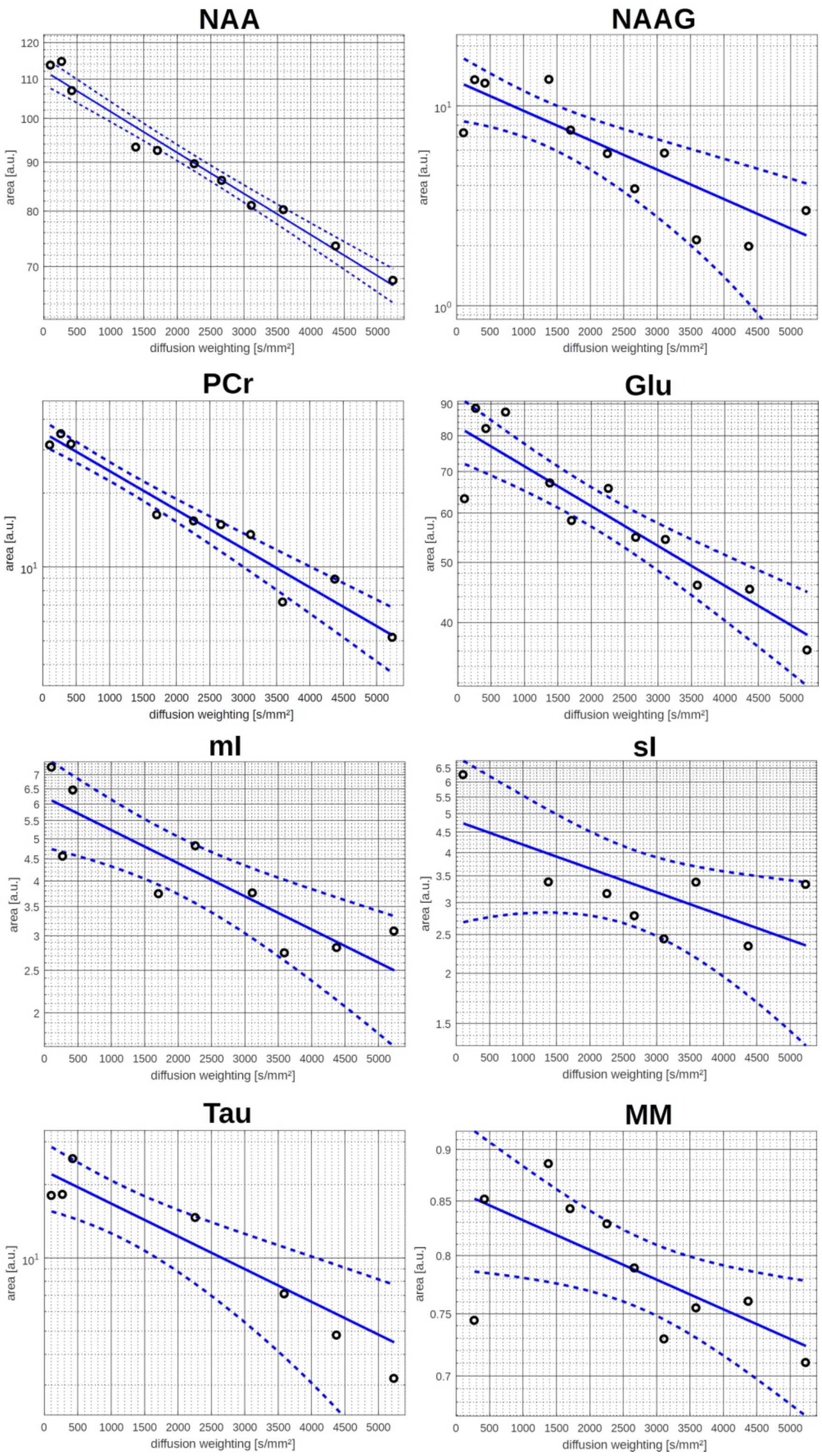

Figure S3: *Depiction of weighted mono-exponential fits for metabolite ADCs shown for an exemplary set of metabolites from the sequential fitting approach for a single subject (weighting factors derived from the area CRLBs; confidence interval (CI) visualized by dashed lines; measurement points outside the CI are considered as outliers and do not contribute to the final fit).*

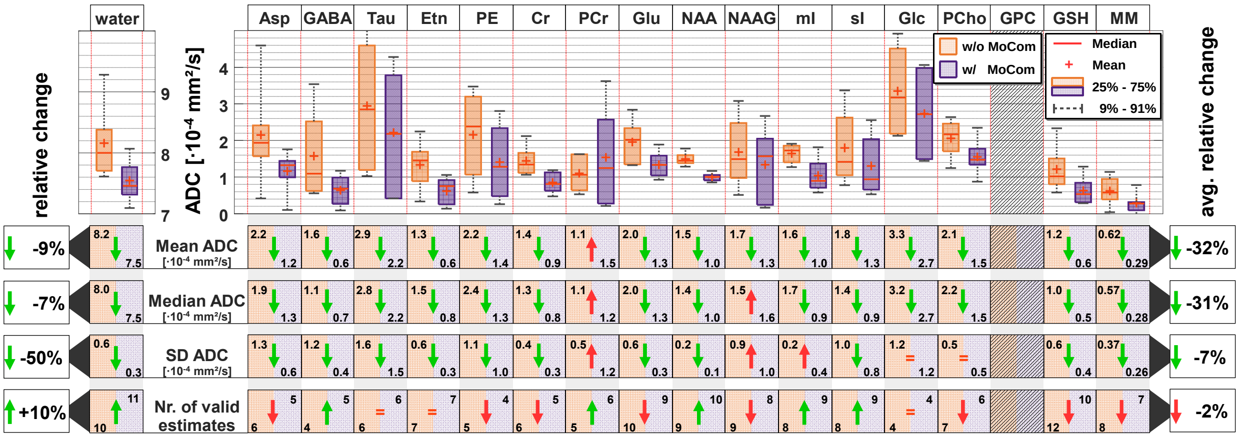

Figure S4: *Tabulated cohort ADCs as obtained by sequential fitting. They agree well with results obtained by simultaneous fitting. The reduced number of valid estimates in comparison to the simultaneous fit approach is attributed to the missing constraint in the second diffusion dimension reducing the fitting stability.*

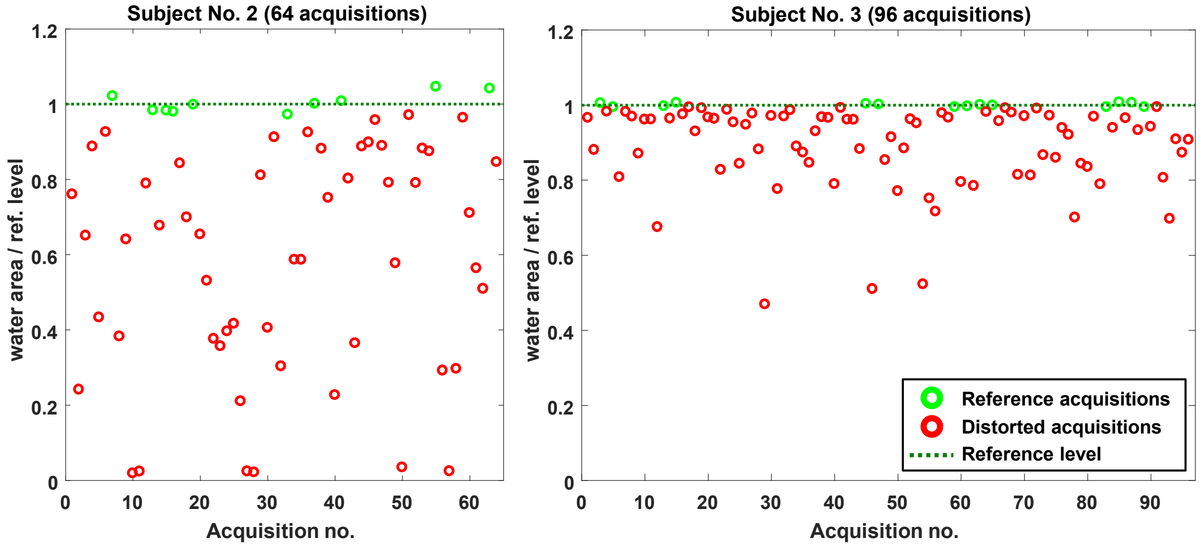

Figure S5: *Visualization of the definition of the reference level using the top 15th percentile for two subjects. Estimated areas of the water resonance in subsequent acquisitions are plotted for the maximum b-value used in two subjects. On the left, a large spread of signal amplitude represents a case where motion seems to have a large effect, while on the right most acquisitions yield signal levels near the maximum, while only a minor portion of acquisitions seems affected by motion. In both cases, the distribution of amplitudes is non Gaussian and the maximum attainable signal is visually well defined and well represented using the described percentile criterion. In both cases (and this is valid for the whole cohort) the standard deviation of acquisitions within the top 15th percentile is between 1 and 3%.*