

A sensitivity analysis of MRI scanner and model parameters for measuring relaxation times

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Sensitivity analysis exploring how an MRI measurement is affected by the scan set up and curve fitting methods

Quantitative magnetic resonance imaging (qMRI) allows the estimation of a physical measurement from magnetic resonance imaging (MRI). Unlike in qualitative MRI, which relies on relative measures between regions in an MR image, signal intensities may be intrinsically linked to a property of the object being scanned.

Sensitivity analyses such as analysis of variance (ANOVA)^[1] can be used to explore a system's response to change in influential factors^[2]. For example, how sensitive a measurement of a qMRI parameter is to the fitting methods applied. This can be useful in identifying sources of uncertainty or in optimizing an analysis procedure.

The transverse relaxation time, T_2 , characterizes decay of excited transverse magnetization. T_2 can be estimated by fitting an exponential decay curve to T_2 -weighted MR images.

The specific pulse sequence chosen, as well as the various parameters which may be set during the MRI scan set-up, may all have an impact on the output measurement of T_2 . Longer MRI scan times may allow more precise measurements of T_2 but are more difficult to transfer into the clinic. In practice, there is a compromise between accuracy (bias) and precision (variance) driven by signal-to-noise considerations. Knowing what compromises can be made without impacting strongly on the output T_2 estimate is useful for moving from research into clinical MRI.

Here we perform a sensitivity analysis of T_2 with respect to scan set up and curve fitting parameters using an MRI simulator and digital phantom.

Methods

We used a digital phantom of 12 cylindrical vials with known T_2 values to generate synthetic MR images (Figure 1). The images are produced by simulating the entirety of the MRI process^[3], as described by the Bloch equations^[4]. We selected regions of interest (ROIs) centered on each vial and performed a fitting analysis to determine the output T_2 values for each vial.

We performed two full factorial experiments to estimate T_2 : firstly, changing factors (fitting parameters) in the curve fitting methods used to calculate T_2 , and secondly changing factors (acquisition parameters) within the simulation set up. The levels taken by all factors for the fitting experiment and the simulation experiment may be found in Table 1 and Table 2, respectively. Each experiment had a balanced design, i.e., we used an equal number of observations for every combination of factors and levels^[2].

We run two-way second order ANOVA and calculated the relative sensitivity of our measurement to the changes in the factors investigated.

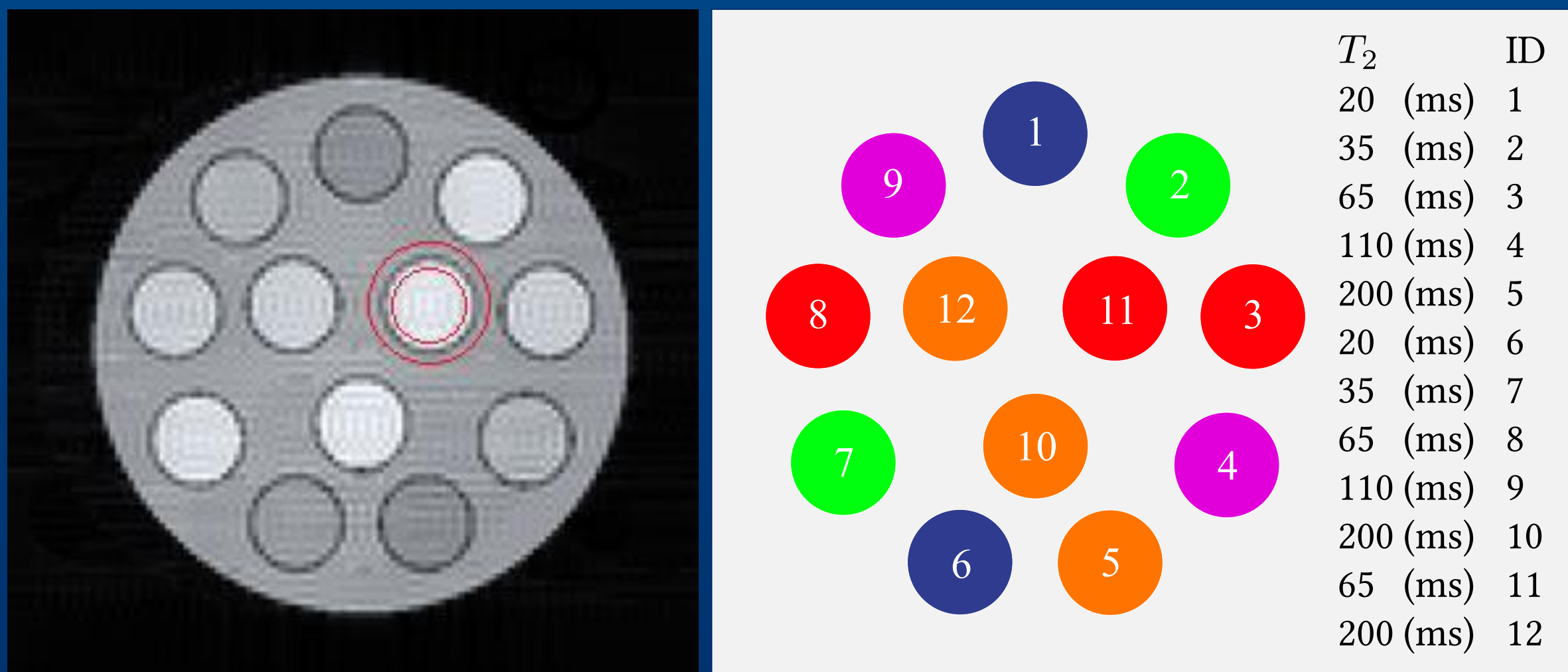


Figure 1: Left: Simulated MR image of the digital phantom. Two illustrative ROIs are shown by the red circles: one which extends beyond the vial edges (positive radius values) and one which is entirely within the vial (negative radius values). Right: Arrangement of vials in the simulated phantom with their simulated T_2 values.

Table 1: List of factors examined during experimentation with the fitting methods and their levels.

Factor	Levels
Model	Mono-exponential, Bessel functions
Fitting method	Voxel-wise, ROI
Radius of ROI relative to vial (voxels)*	+4,+3,+2,+1,0,-2
Offset from centre of ROI (voxels)	0,1,2,3,4

*Positive values indicate the ROI extends N voxels outside of the vial of interest, negative values indicate the ROI is N voxels within the vial.

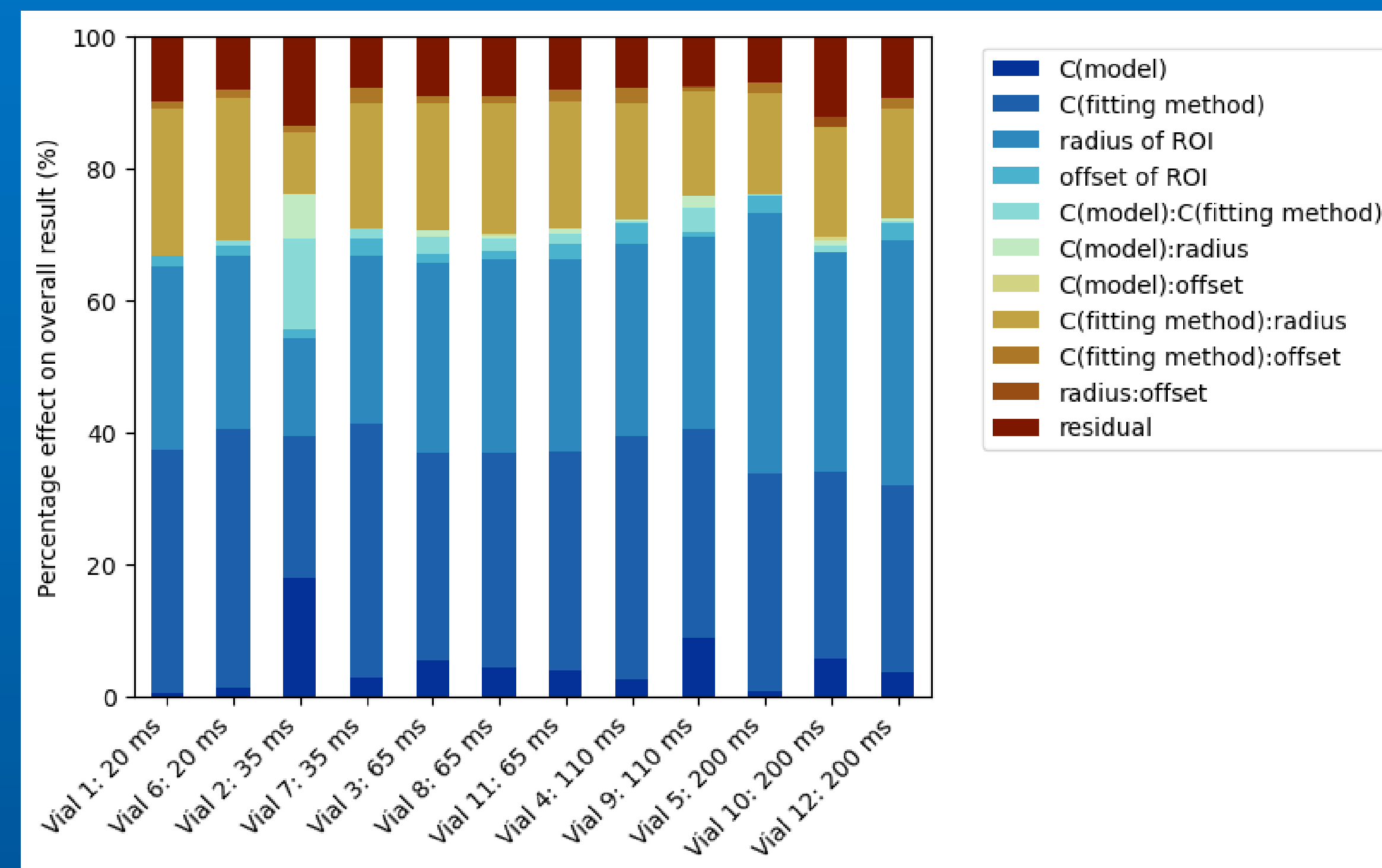


Figure 2: Relative sensitivities (in percent) of the T_2 calculation for each fitting parameter investigated. "C" depicts categorical variables, ":" denotes a cross-term. The 'residual' term encapsulates errors from higher order interactions and the approximation of linearity in the ANOVA.

Chosen fitting method and ROI size affect measurement of T_2

Figure 2 shows the results from the curve fitting ANOVA for the factors and their cross-terms. The factor to which the fitting is most sensitive for $T_2 < 200$ ms is the fitting method.

For vials with $T_2 = 200$ ms, the factor with the highest sensitivity is the radius of the ROI. There is no apparent trend in the sensitivities with T_2 .

From our ANOVA examining the effect of the chosen fitting parameters on the output T_2 relaxation time, we find that the factors with the greatest impact are the fitting method and size of the chosen ROI.

Future work using curve fitting to measure T_2 should take care when adjusting these factors as small changes may have a large impact on the output measurement result.

Table 2: List of factors examined during experimentation with the simulation and their levels. The ranges selected are representative of clinical set up values.

Factor	Levels
Repetition time, T_R (ms)	2500, 5000
Frequency and phase encoding steps	64x64, 128x128
Slice thickness, dz (mm)	1.05, 2.5, 5, 7.5, 10
Flip angle (°)	85, 87, 90

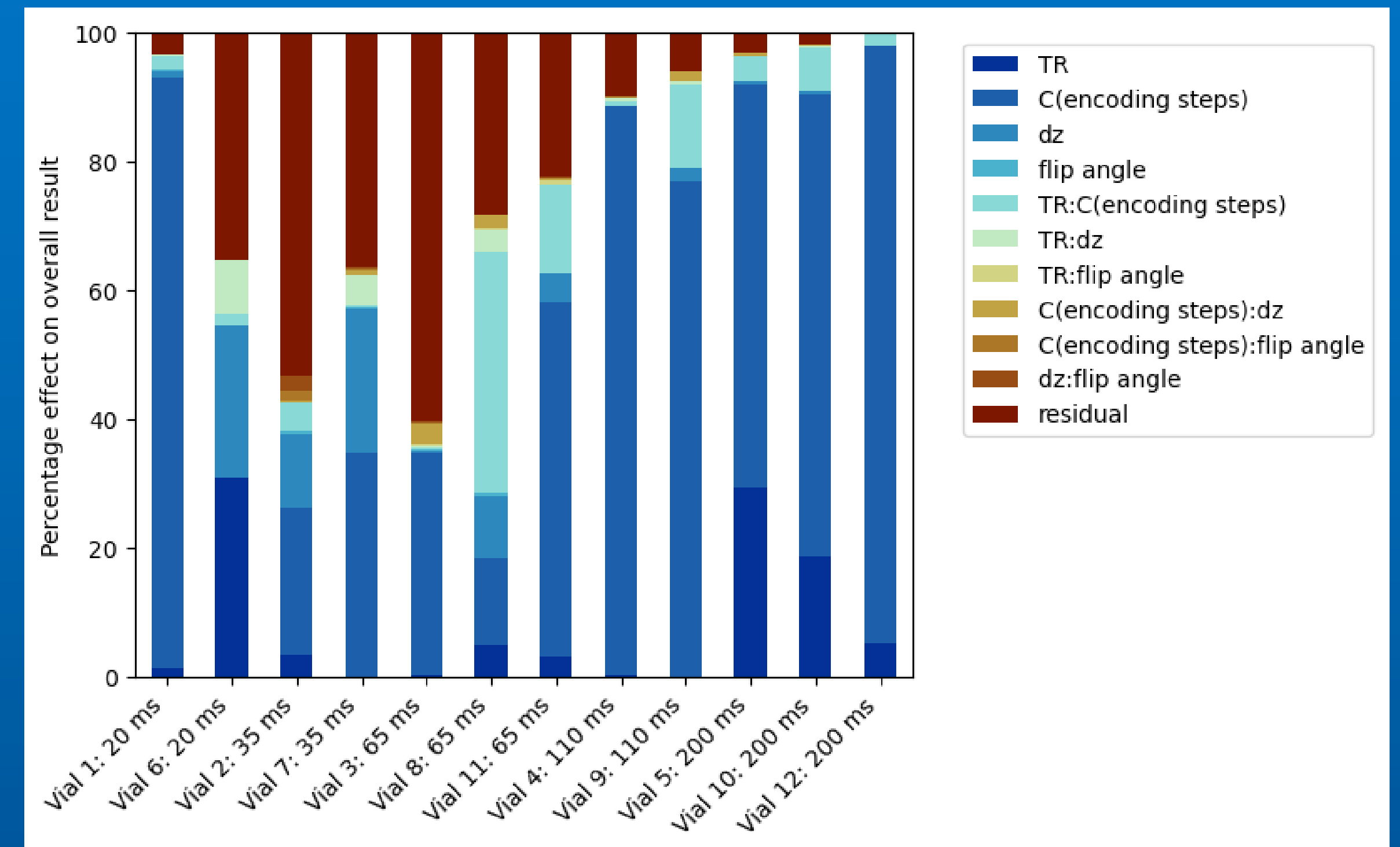


Figure 3: Relative sensitivities (in percent) of the measured T_2 for the simulated MRI scan set-up parameters. As in Figure 2, 'C' depicts categorical variables, ":" denotes a cross-term, and the 'residual' term encapsulates errors from higher order interactions and the approximation of linearity in the ANOVA.

Resolution of the output image important when measuring T_2

Figure 3 shows the results from the ANOVA of the simulation acquisition factors. For most vials, we find the most important factor in the simulation is the number of frequency and phase encoding steps (the total image resolution).

The second most important factor is either repetition time or slice thickness, although these effects are much smaller than those of the frequency and phase encodings, are not consistent, and show no trend with T_2 .

Increasing the frequency and phase encoding used in obtaining the k-space and output MR image increases the output image resolution by increasing the number of voxels in the same field of view, albeit at the expense of increased measurement times. Higher resolution is important, particularly at the edges of the ROI, because including background noise in the fitting gives poorer results for the output T_2 .

Our results suggest that care should be taken when selecting frequency and phase encodings as small changes in the encodings may have a large impact on the output result.

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