

Effects of Tissue-Specific Spatial and Intensity Smoothing Approaches on Parametric Inference in Quantitative MRI

A. Jacquemin¹, C. Phillips¹

¹ GIGA-CRC Human Imaging, University of Liège, Liège, Belgium

a.jacquemin@uliege.be

Introduction

Quantitative MRI (qMRI) provides interpretable maps of the brain's physical properties. However, when standard Gaussian kernel smoothing is applied, the interpretability of these maps can be compromised by **partial volume effects**, particularly at the boundaries between tissue classes such as grey matter (GM) and white matter (WM). To mitigate this issue, several tissue-specific smoothing approaches have been proposed.

In qMRI, Draganski et al. introduced a linear, tissue-weighted, Gaussian and compensated smoothing approach known as *Tissue-Weighted Smoothing* (TWS) (Eq. 1).¹ In diffusion tensor imaging, Lee et al. proposed a WM-specific, non-linear, tissue-masked, Gaussian and compensated smoothing approach called *Tissue-Specific smOOthing compeNsated* (TSPOON).² For functional MRI, Smith et al. developed a non-linear, tissue-masked, intensity-weighted smoothing approach using the *Smallest Univalue Segment Assimilating Nucleus* (SUSAN) (Eq. 3).³

Objective #1: Generalization of TSPOON (gTSPOON) to GM & WM

Objective #2: Comparison of the effects of TWS, gTSPOON and SUSAN on qMRI data.

Eq. 1 $TWS(x) = \frac{g * (w.s(\phi))}{g * w}$; $TPM > 0.05$ & $g * w > 0.05$

Eq. 2 $GTSPON(x) = \frac{g * (M_{TC}.s(\phi))}{g * M_{TC}}$; $g * M_{TC} > 0.05$

Eq. 3 $TSUSAN_{TC}(x) = susan * (M_{TC}.s(\phi))$

Where:

- $s(\phi)$ = quantitative map warped into standard space
- w = modulated tissue weights
- M_{TC} = "winner-takes-all" tissue mask
- $g*$ = Gaussian isotropic smoothing operator
- $susan*$ = SUSAN smoothing operator

Methods

TSPOON's Generalization: The TSPOON approach was generalized to all tissue classes (Eq. 2), using both GM and WM tissue-specific masks. These masks are generated using the "winner-takes-all and greater than 20%" criterion.¹

Comparison Strategies: TWS, gTSPOON and SUSAN were used to reproduce results from Callaghan et al.'s aging study⁴ involving 138 participants (19-75y), allowing a quantitative comparison of the two smoothing approaches. The statistical parametric maps (SPMs) derived from TWS, gTSPOON and SUSAN are compared using statistical approaches. Additionally, the differences induced by the three smoothing approaches were systematically investigated.

References & Toolboxes

- ¹ Draganski et al., *NeuroImage* (2011) ; ² Lee et al., *NeuroImage* (2009) ;
³ Smith et al., *NeuroImage* (2004) ; ⁴ Callaghan et al., *Neurobiology of Aging* (2014) ; hMRI-toolbox – Open Source Imaging ; SPM12 Software - Statistical Parametric Mapping ; FSL - FMRIB Software Library

Results

The statistically significant regions identified using TWS were larger and more numerous than those identified using gTSPOON (Figure 1). The FWER statistical thresholds were generally higher with gTSPOON compared to TWS, whereas the effective smoothing was larger with TWS than with gTSPOON.

Despite their differences, the results of TWS and gTSPOON remain similar compared to those obtained via SUSAN. Indeed, the latter exhibits far fewer statistically significant voxels and clusters. The SUSAN approach also shows lower effective smoothing, while its FWER statistical thresholds are higher. These findings were consistent across all quantitative parameters.

Additionally, large brain regions were significantly affected by the choice of smoothing approach, particularly at the tissue boundaries.

TWS	gTSPOON	SUSAN
#voxels: 41k / 21k	#voxels: 34k / 19k	#voxels: 9.4k / 3.7k
#clusters: 659 / 311	#clusters: 512 / 285	#clusters: 316 / 199
FWHM: 6.1 / 8.1 mm	FWHM: 6 / 8 mm	FWHM: 2.7 / 4 mm
T-value: 5.3 / 5	T-value: 5.3 / 5	T-value: 5.7 / 5.4

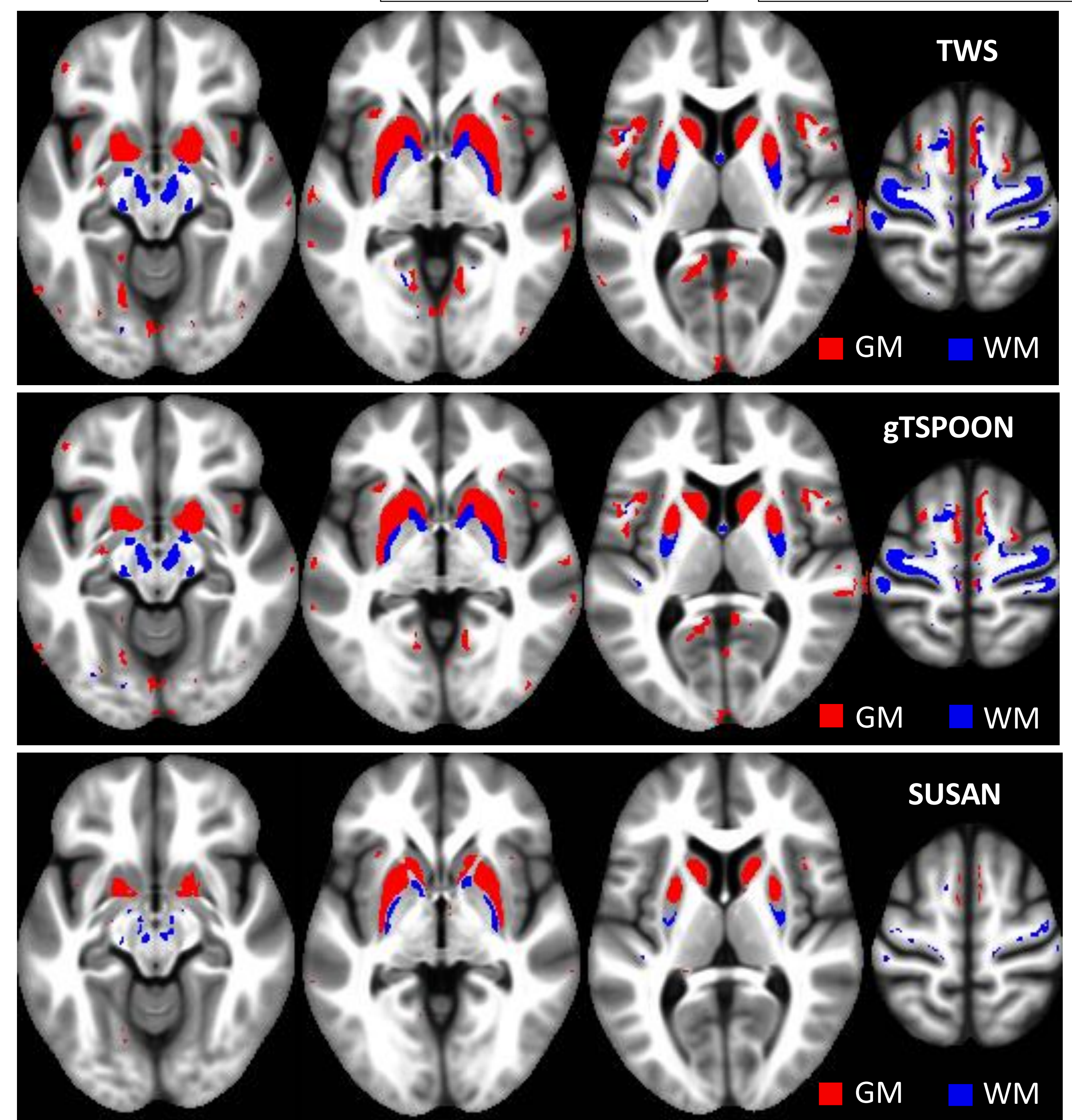


Figure 1: SPMs identifying regions in which $R2^*$ significantly increased with age, at the $p < 0.05$ FWE corrected level and the corresponding numbers of significant voxels and clusters.

Discussion

These findings underscore the critical impact of smoothing on statistical outcomes in qMRI studies. Although TWS is the most sensitive approach, both TWS and gTSPOON offer advantages for exploratory or population-based studies. SUSAN stands out as the most conservative of the three approaches. SUSAN's strengths may lie in applications where preserving the integrity of fine-grained spatial features is prioritized over broad statistical power, such as in high-resolution or highly localized analyses (confirmatory studies).