Effects of Tissue-Specific Smoothing Approaches on Statistical Analysis in Quantitative MRI

Poster #37

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Introduction

Quantitative MRI (qMRI) provides interpretable maps of the brain's physical properties. However, when smoothed with a standard Gaussian kernel, their interpretability is affected by **partial volume effect** at the border of tissue classes, e.g. grey and white matter (GM and WM). To address this issue, tissue-specific smoothing approaches, such as "**Tissue-Weighted Smoothing**" (TWS) [1] (Eq. 1) and "**Tissue-SPecific smOOthing compeNsated**" (TSPOON) [2] have been proposed, designed respectively for qMRI in GM/WM and diffusion tensor imaging in WM only. TWS and TSPOON rely on GM/WM tissue segmentation, resp. using the continuous tissue density values, i.e. probability maps, or a binarized version, i.e. tissue-specific masks.

Objective #1: Generalizaton of TSPOON (GTSPOON) to GM & WM

Objective #2: Comparison of the effects of TWS vs. generalized TSPOON on qMRI data

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

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

Where:

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

Comparison Strategies: TWS and GTSPOON were used to reproduce results from Callaghan et al.'s aging study [3] involving 138 participants (19-75y), allowing a quantitative comparison of the two smoothing approaches. The "statistical parametric maps" (SPMs) derived from TWS and GTSPOON are compared using statistical approaches. Additionally, the differences induced by the two smoothing approaches were systematically investigated.

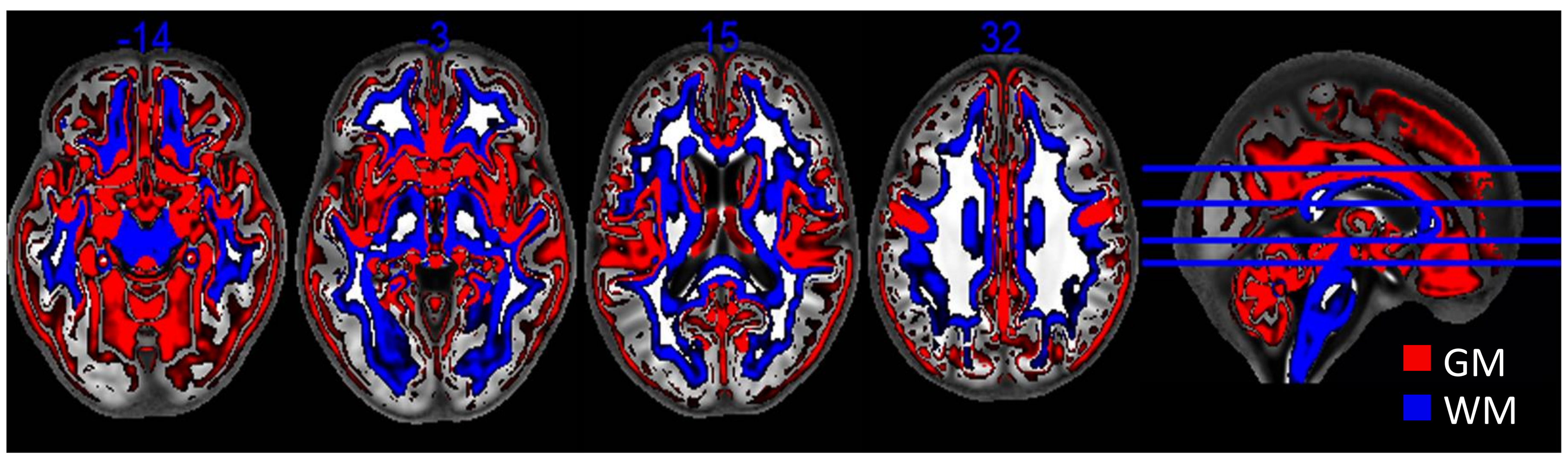

Figure 1: SPMs of significant differences, at the $p < 0.05$ FWE corrected voxel-wise level, between Mtsat maps smoothed with TWS and GTSPOON, for the GM (in red) and WM (in blue).

Results

Large brain regions were significantly affected by the choice of smoothing approach, particularly at the boundaries between GM and WM (Figure 1). The statistically significant regions identified using TWS were larger and more numerous than those identified using GTSPOON (Figure 2). The FWER statistical thresholds applied were generally higher with GTSPOON compared to TWS, whereas the effective smoothing was larger with TWS than with GTSPOON. These findings were consistent across all quantitative parameters (Mtsat, PD, R1 and R2*).

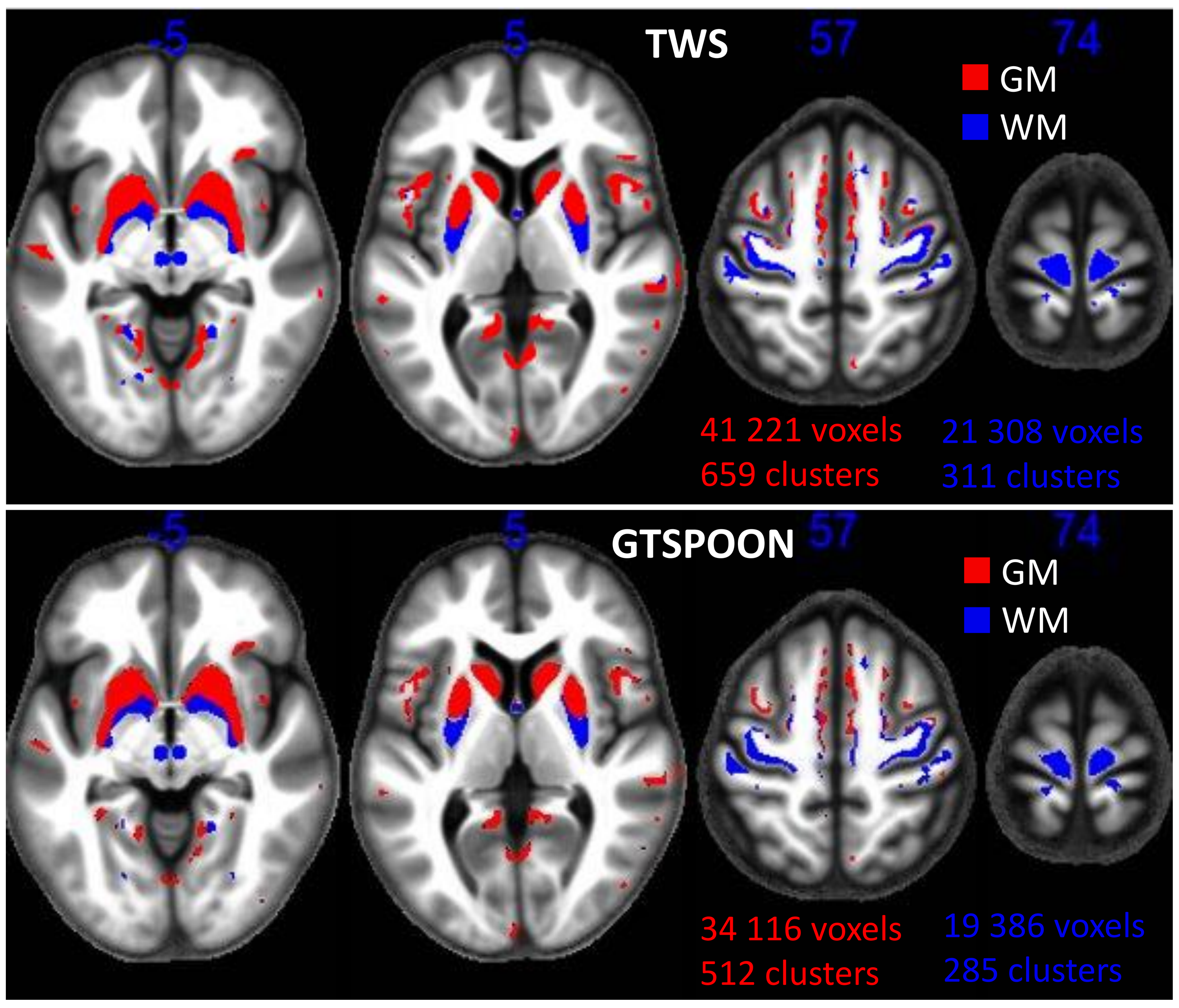

Figure 2: SPMs identifying regions in which R2* significantly increased with age, at the $p < 0.05$ FWE corrected level and the corresponding numbers of significant voxels and clusters.

Discussion

These findings underscore the critical impact of smoothing on statistical outcomes in qMRI studies. The TWS approach is overall more sensitive, whereas GTSPOON is more specific and leads to more robust smoothing. The choice of smoothing approach depends on the type of study being conducted (e.g., population-based or longitudinal studies favor TWS, while confirmatory studies favor GTSPOON).

Toolboxes & References

Toolboxes:

hMRI, hMRI-toolbox – Open Source Imaging &

SPM12 SPM12 Software - Statistical Parametric Mapping

References:

[1] Draganski B. et al. NeuroImage (2011) https://doi.org/10.1016/j.neuroimage.2011.01.052 ;

[2] Lee J. E. et al. NeuroImage (2009) https://doi.org/10.1016/j.neuroimage.2008.09.041 ;

[3] Callaghan M. F. et al,. Neurobiology of Aging (2014) https://doi.org/10.1016/j.neurobiolaging.2014.02.008