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Surface-based Smoothing of Brain Imaging Data in Voxel Space

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Introduction

Spatial smoothing of brain imaging data is mostly applied in voxel-space to increase signal-to-noise ratio (SNR) and enable group statistics.
Although computationally inexpensive, volumetric smoothing methods do not account for cortical gyrification and mix signals across tissue borders (see Fig. 1), resulting in inflated, shifted activation patterns and consequently in false positives.
In contrast, surface-based methods only include gray matter and thus, show high spatial specificity. Here, a novel approach is introduced combining advantages of volumetric and surface-based analyses.

Figure 1: a) Schematic section of an anatomical, T1-weighted slice: CSF: black, gray matter (GM): gray, white matter: white; an active voxel (seed) within the GM is marked in green **b)** distances of voxels with high GM-probability from the seed using quasi-Euclidean geodesic distances and **c)** Euclidean distances (GM outlined).

Patients and Methods

Blood oxygen level dependent fMRI data of 18 healthy subjects performing a finger-tapping task were spatially smoothed with the novel procedure using 3D masks and geodesic (anatomy-constrained), quasi-Euclidean distances (gQED) therein as weights.
Statistics and activation patterns were compared to those of isotropic smoothing in voxel-space (SPM) and purely surface-based analysis (FreeSurfer Functional Analysis Stream: FS-FAST).

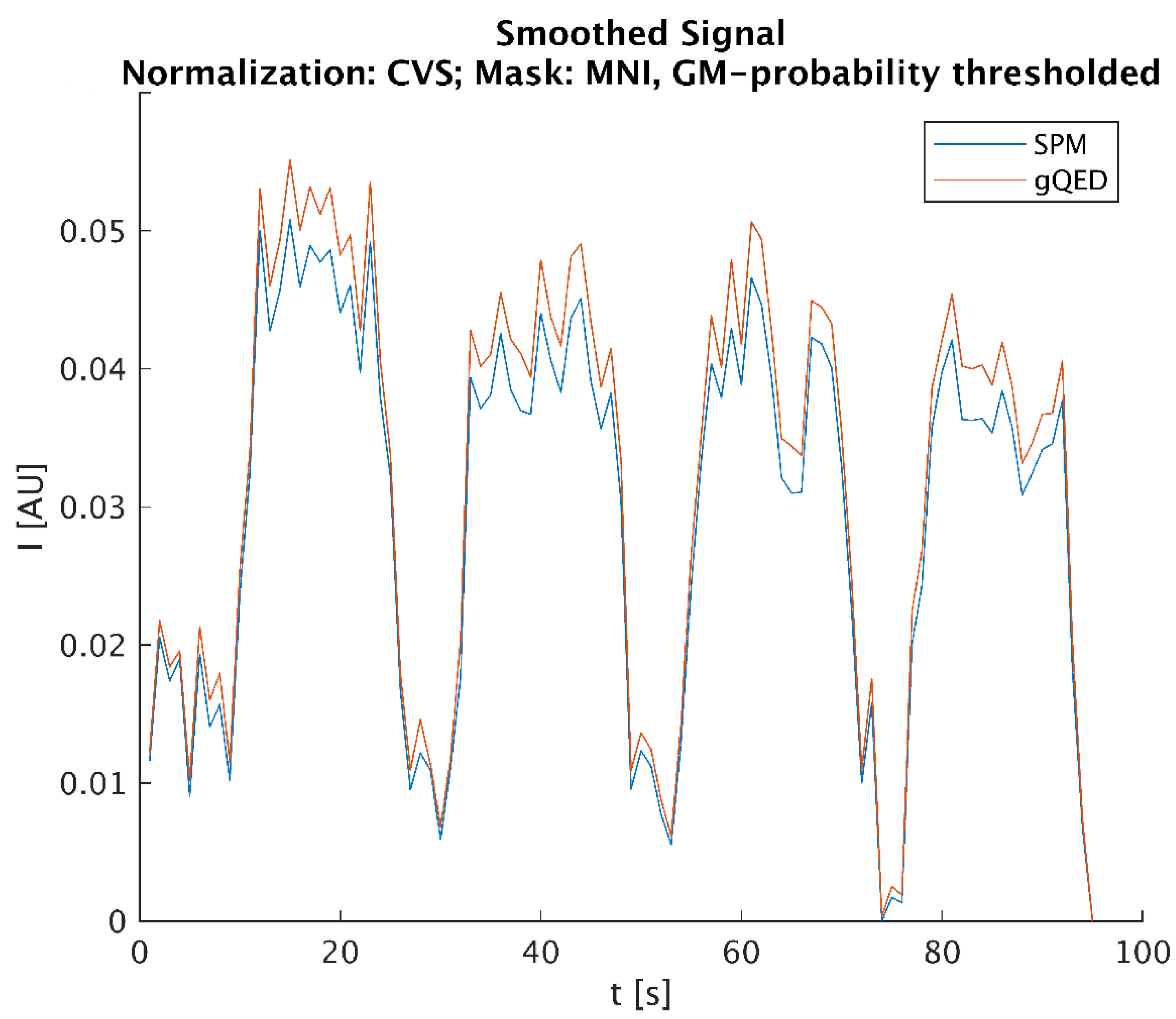

Figure 2: Time courses of a single representative subject's BOLD-signal at the statistically most relevant voxel in the left motor cortex (MNI-coordinates: [-40 -24 58]) after slice-time correction, realignment, coregistration to anatomical scan (T1), spatial normalization (combined surface and volume morph) and smoothing with either SPM (FWHM = 8 mm, implicit masking) or gQED (FWHM = 8 mm). Note the higher effect strength (signal variation between rest and task) for gQED. tSNR is reduced for gQED, though.

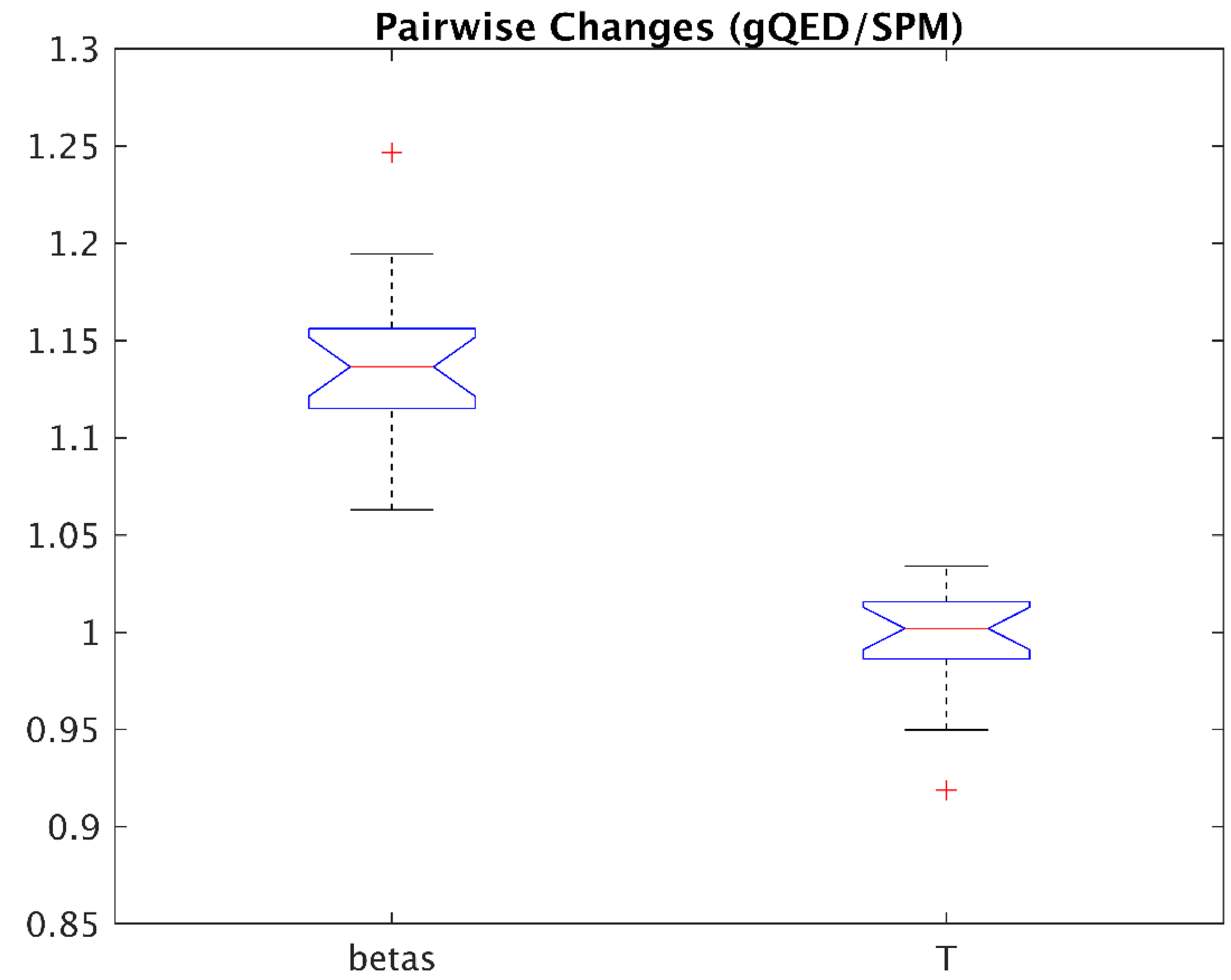

Figure 3: Ratio of subject-level beta-values (beta(gQED)/beta(SPM)) and T-statistics (T(gQED)/T(SPM)) at the most significant voxel within the left motor cortex: While increases of more than 10% in beta values for the gQED-analysis-pipeline were observed, T-statistics remained on average approximately the same.

Results

gQED delivered results similar to SPM with regard to temporal SNR as well as single-subject and group statistics (see Fig. 2 & 3).
Using conservative gray matter masks, higher spatial sensitivity was obtained with gQED due to reduced signal spill between hemispheres and neighboring gyri as compared to SPM (see Fig. 4).
Volumetric group statistics were significantly larger (range T-value +42% - +69%) than those derived with FS-FAST.

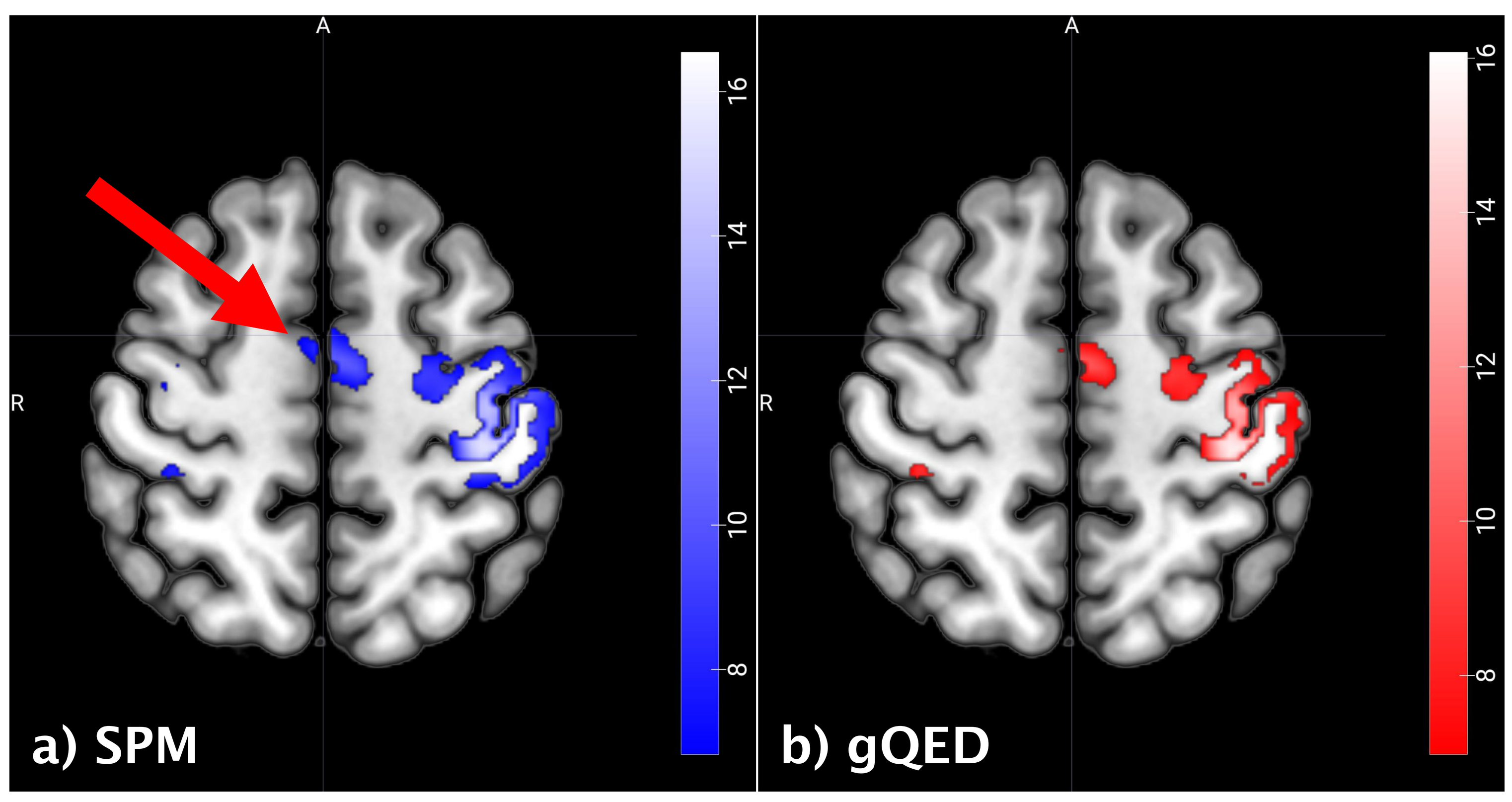

Figure 4: Group-level T-statistics overlaid on MNI-152 template: **a)** smoothing performed with SPM and implicit masking **b)** smoothing performed with gQED. Note the signal spill from the left hemisphere to the right hemisphere at the supplementary motor area for SPM

Conclusion

Spatial smoothing of functional data may introduce severe limitations if applied independent of the underlying anatomy. Most methods including brain anatomy are either entirely surface-based or only applicable for single-subject analyses.
With gQED, smoothing is performed only within the gray matter as part of a volumetric analysis and higher spatial sensitivity can be achieved, given sufficient spatial normalization. Furthermore, the proposed approach is not limited to fMRI but applicable to numerous brain imaging modalities.