681.06: Automatic cortical labeling system for neuroimaging studies of normal and disordered speech

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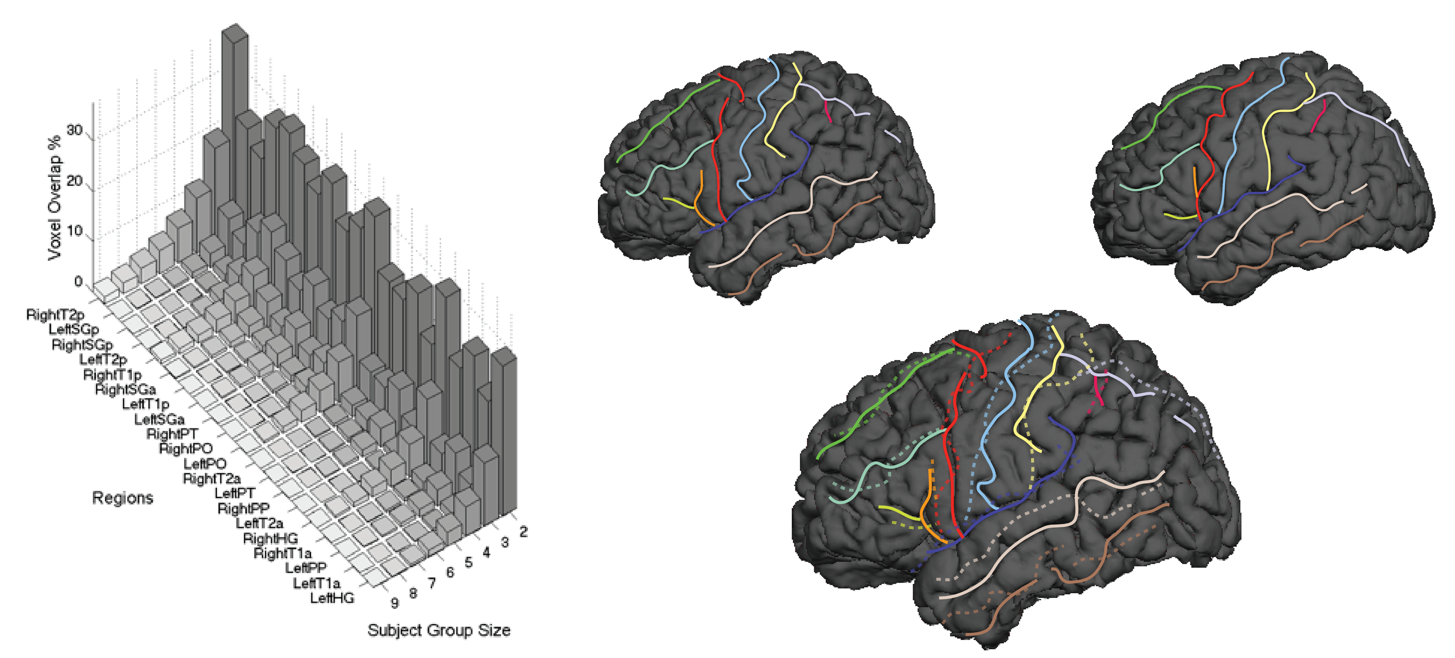
Background

Volume-based inter-subject averaging methods fail to account for cortical variability, resulting co-registration of functionally distinct regions and a loss of statistical power. This is particularly problematic for neuroimaging studies of speech because functionally distinct regions in the peri-Sylvian region that are distant along cortical surface are proximal in the volume. Individual region of interest (ROI)-based analysis analysis of cortical responses significantly improves statistical power (Nieto-Castanon et al., 2003) but requires lengthy, tedious labeling by an expert.



Anatomical variability after volume-based normalization and co-registration. *Left*: Mean voxel overlap of superior temporal ROIs at various group sizes. Little of no overlap is seen with groups of 9 subjects. *Right*: The alignment of major sulci. Sulci were drawn on 2 individual surfaces (top) and then overlaid on the same surface (bottom), aligned to the Sylvian fissure.

Freesurfer's (http://surfer.nmr.mgh.harvard.edu/) individual cortical surface-based inter-subject averaging (Fischl et al., 1999) improves upon volume-based methods (eg., Ghosh et al, 2010) but packaged cortical labeling atlases fail to distinguish putative functionally distinct areas that underlie speech processes. Here, we describe a cortical labeling system tailored for neuroimaging studies of speech that was used to generate a Freesurfer-based labeling atlas. We applied the atlas to T1 volumes of 18 fluent speakers and 20 persons who stutter to assess the performance of the automatic atlas.

Methods

SpeechLabel System: Each hemisphere is divided into 63 cortical regions based on individual anatomical landmarks. ***Superior temporal, inferior frontal, precentral regions are divided into multiple gyral and sulcal components.***

SLaparc Atlas Generation: Image segmentation, cortical surface reconstruction, surface-based co-registration, and initial surface labeling was performed on T1 MRI volumes from **17 neurologically normal subjects** (9 Female, Age: 20-43, Mean: 29) using Freesurfer v5.0. T1 data acquisition: Siemens TIM Trio 3T scanner, MPRAGE sequence, 1mm³ voxel size.

Surface labels were edited to conform to the SpeechLabel system (editing was overseen by a trained neuroanatomical expert). The labeled surfaces were used as a training set to generate the SLaparc atlas using standard Freesurfer tools (Fischl et al. 2004).

Atlas Application: The atlas was used to automatically label **18 additional fluent speakers** (PFS; 4 Female, Age 19-35, Age Range: 19-35) and **20 matched persons who stutter** (PWS; 5 Female, Age: 18-47, Mean: 27; SSI-4: 13-43, Median: 26). [See POSTER 681.12 for further analysis of these data]

To assess the performance of the automatic atlas, labels were corrected by a trained expert to conform to the SpeechLabel system and the automatic and manually corrected labels were compared in terms of percent overlap. Cortical regions were mapped to the each subjects T1 volume for these comparisons.

Region % overlap, PO, given by Dice coefficent: $PO = \frac{2\,|X \cap Y|}{|X|+|Y|}$

Labeled fsaverage: The Freesurfer fsaverage surface template was labeled by SLaparc and manually edited as needed.

Acknowledgments

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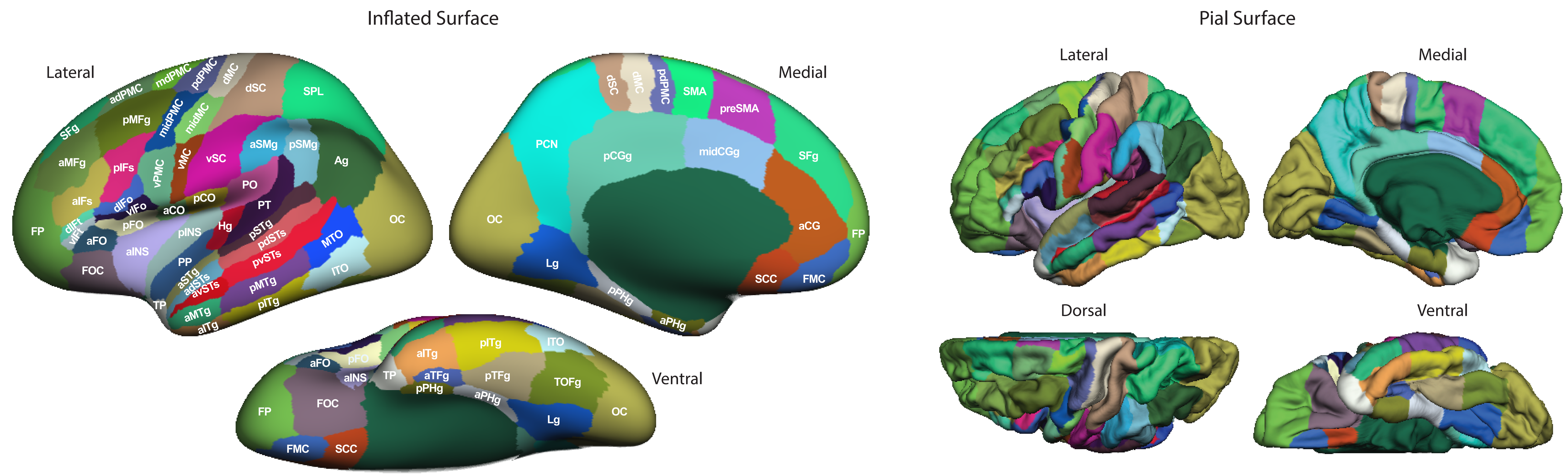
The SpeechLabel Cortical Labeling System

Regions are plotted on the Freesurfer fsaverage surface template for the left hemisphere. Each cortical hemisphere is divided into 63 regions of interest based on individual anatomical landmarks. Superior temporal, inferior frontal, precentral, and medial frontal regions are divided into functionally meaningful subunits for neuroimaging studies of speech. See table 1 for region abbreviation key.



Anatomical landmarks

Bounding sulci are shown on the mean surface curvature of the inflated fsaverage surface template for the left hemisphere. Red (positive curvature) indicates a sulcal region; green (negative curvature) indicates a gyral regions. Additional dividing landmarks include sulcal intersections and the anterior commissures . White stars indicate landmarks that are note easily viewed on the average template. See Table 2 for landmark abbreviation key.

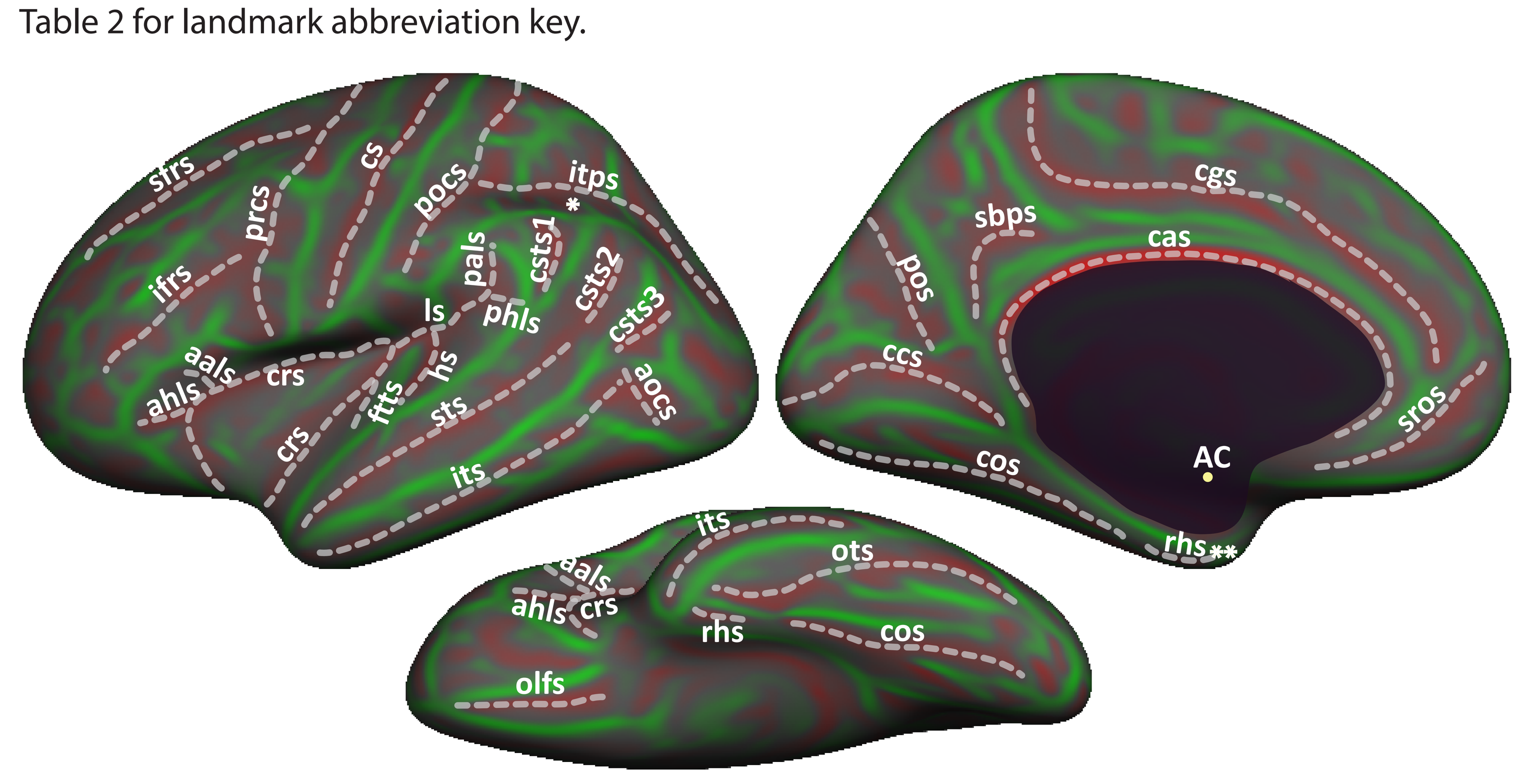


Table 1: Regions

aCGg	anterior cingulate gyrus	pCGg	posterior cingulate gyrus
aCO	anterior central operculum	PCN	precuneus cortex
adPMC	anterior dorsal premotor cortex	pCO	posterior central operculum
adSTs	anterior dorsal superior temporal sulcus	pdPMC	posterior dorsal premotor cortex
aFO	anterior frontal operculum	pdSTs	posterior dorsal superior temporal sulcu
Ag	angular gyrus	pFO	posterior frontal operculum
aIFs	anterior inferior frontal sulcus	pIFs	posterior inferior frontal sulcus
aINS	anterior insula	pINS	posterior insula
aITg	anterior inferior temporal gyrus	pITg	posterior inferior temporal gyrus
aMFg	anterior middle frontal gyrus	pMFg	posterior middle frontal gyrus
aMTg	anterior middle temporal gyrus	pMTg	posterior middle temporal gyrus
aPHg	anterior parahippocampal gyrus	PO	parietal operculum
aSMg	anterior supramarginal gyrus	PP	planum polare
aSTg	anterior superior temporal gyrus	pPHg	posterior parahippocampal gyrus
aTFg	anterior temporal fusiform	preSMA	presupplementary motor area
avSTs	anterior ventral superior temporal sulcus	pSMg	posterior supramarginal gyrus
dIFo	dorsal inferior frontal gyrus, *pars opercularis*	pSTg	posterior superior temporal gyrus
dIFt	dorsal inferior frontal gyrus, *pars triangularis*	PT	planum temporale
dMC	dorsal motor cortex	pTFg	posterior temporal fusiform
dSC	dorsal somatosensory cortex	pvSTs	superior temporal sulcu
FMC	frontal medial cortex	SCC	subcallosal cortex
FOC	frontal orbital cortex	SFg	superior frontal gyrus
FP	frontal pole	SMA	supplementary motor area
Hg	Heschl's gyrus	SPL	superior parietal lobule
ITOg	inferior temporal occipital gyrus	TOFg	temporal occipital fusiform gyrus
Lg	lingual gyrus	TP	temporal pole
mdPMC	middle dorsal premotor cortex	vIFo	ventral inferior frontal gyrus, *pars opercularis*
midCG	middle cingulate gyrus	vIFt	ventral inferior frontal gyrus, *pars triangularis*
midMC	middle motor cortex	vMC	ventral motor cortex
midPMC	middle premotor cortex	vPMC	ventral premotor cortex
MTOg	middle temporal occipital gyrus	vSC	ventral somatosensory cortex

Table 2: Landmarks

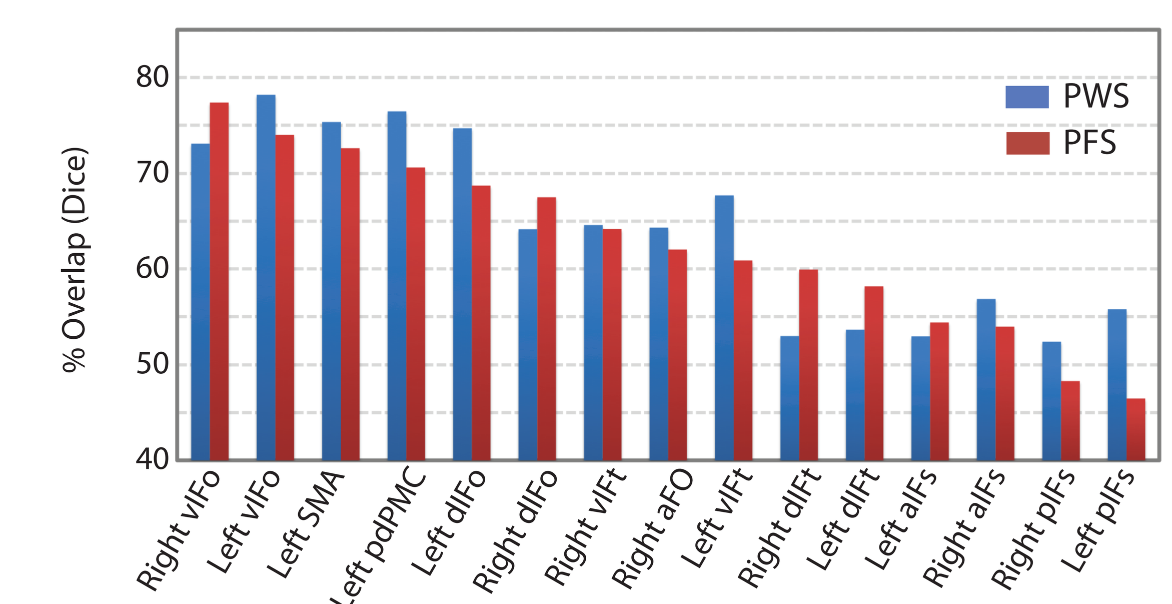
aals	anterior ascending ramus of the lateral sulcus
ahls	anterior horizontal ramus of the lateral sulcus
aocs	anterior occipital sulcus
cas	callosal sulcus
ccs	calcarine sulcus
cgs	cingulate sulcus
cos	collateral sulcus
crs	circular insular sulcus
cs	central sulcus
csts1	caudal superior temporal sulcus, first segment
csts2	caudal superior temporal sulcus, second segment
csts3	caudal superior temporal sulcus, third segment
ftts	first transverse temporal sulcus
hs	Heschl's sulcus
ifrs	inferior frontal sulcus
ihs	interhemispheric sulcus
itps	intraparietal sulcus
its	inferior temporal sulcus
locs	lateral occipital sulcus
ls	lateral sulcus
olfs	olfactory sulcus
ots	occipitotemporal sulcus
pals	posterior ascending ramus of the lateral sulcus
pcs	paracentral sulcus
phls	posterior horizontal ramus of the lateral sulcus
pis	primary intermediate sulcus
pocs	postcentral sulcus
pos	parietooccipital sulcus
prcs	precentral sulcus
rhs	rhinal sulcus
sbps	subparietal sulcus
sfrs	superior frontal sulcus
sros	superior rostral sulcus
sts	superior temporal sulcus
ti	temporal incisure

Overlap of automatic and manually edited labels

PFS: Mean PO: 88% +/- 10%, Range: 46-100; **PWS:** Mean PO: 88% +/- 9%, Range: 52-100

Good overall overlap b/w auto and edited labels and no difference b/w groups (2-tailed paired t-test of mean overlaps for each region: $p > .41$). But are specific regions of low overlap, especially **subdivisions of the inferior frontal gyrus region** (see plot below).

PO of speech regions with PO < 75% in one of the groups subject groups.



Conclusions

The SpeechLabel system divides the cortex into regions that are tailored for neuroimaging studies of speech production.

The SLaparc Freesurfer atlas automatically applies the system to T1 MRI volumes with relatively little user input/anatomical expertise, providing cortical ROIs at a huge time savings:

Fully manual operator editing time:	8-16 hours/brain
Fully automatic operator editing time:	.5-1 hours/brain
Auto+manual cleanup time:	1-2 hours/brain

Freesurfer tools provide an easy means to create surface and volume-based cortical *AND* white matter regions of interest .

2 Useful applications for neuroimaging research:

i. individually derived ROIs for group comparative analyses, e.g., morphometric analyses, functional analysis, diffusion tensor analyses, that is not dependent upon inter-subject image volume averaging [See POSTER 681.12 and POSTER for examples]

ii. provides a common substrate for localizing effects within a surface-based template

But, accuracy of automatic classifier needs improvement in some key speech processing regions, including medial and inferior frontal areas. *Why?* Bounding landmarks in these areas are highly variable and boundaries are not well captured by surface curvature (only affects Application (i)!).

As we continue to refine and expand the labeling system, need to develop piece-wise labeling templates based on better understanding of region/sulcal variability.