Learning Swedish Predictive Tones Correlates with Grey and White Matter Reorganization

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Introduction

- In Swedish, different tone patterns (accent 1 or accent 2) are associated with specific inflectional suffixes: *fisk*$_{accent1}$*-en* 'fish-sg' vs. *fisk*$_{accent2}$*-ar* 'fish-pl' (Bruce, 1977; Riad, 2012). Of these, accent 1 is associated with many fewer suffixes, *i.e.* accent 1 is a much better suffix predictor (Söderström, Horne, Frid, & Roll, 2016). Word accents are thus used as cues for inflectional suffixes (Roll, Söderström, & Horne, 2013; Roll et al., 2015).
- Accent 1 elicits significantly greater BOLD effects than accent 2 for Swedish native speakers in bilateral superior temporal gyrus, left Heschl's gyrus, temporal pole, inferior frontal gyrus and insular cortex (Roll et al., 2015).
- Invalid accent-suffix combinations elicit significantly greater BOLD effects than valid in the left inferior parietal lobe (IPL), right middle frontal gyrus and bilateral superior frontal gyrus (Roll et al., 2015).
- Cortical thickness in left planum temporale correlates with impact of invalid accent-suffix associations (Schremm et al., 2018).
- This study used T1- and diffusion-weighted magnetic resonance imaging (MRI) to study the neuroanatomical correlates of learning Swedish accent-suffix associations from a non-tonal L1 (German) using a smartphone game for 4 weeks.

Methods

- Participants: 23 Swedish native speakers. 36 German native speakers evenly distributed into either a melody (word accent) or morphology training group.
- Stimuli: 30 sentences of type form *'Kurt fick TARGET till jul'*, 'Kurt got TARGET for Christmas, where TARGET was a noun in singular or plural form with either matched or mismatched accent-suffix combination. In total 120 sentences (Fig. 1).
- Task: Respond whether target words were in singular or plural form. Task accuracies and response times were recorded.
- Scanning: Subjects were scanned before and after training with game (see Fig. 2 for morphology version)
- MRI scanner: 7T Philips Achieva with a 32-channel dual transmit head coil (Nova medical) and dielectric pads to mitigate B1-field inhomogeneities. T1-weighted images were acuired from an MP2RAGE sequence at 0.8 mm isotropic resolution. Diffusion-weighted images were acquired at 2 mm isotropic resolution in 56 directions and diffusion encoding strengths of b=[0 2000].
- T1-weighted data was analysed using Freesurfer's longitudinal stream and all statistical analyses were performed in QDEC. Statistical parameter maps underwent Monte Carlo simulation based multiple comparison correction using a cluster-wise threshold of p<0.05.
- Probabilistic tractography was performed using MRtrix3 after motion, eddy current and susceptibility .. Seed and stop regions for tract selections were taken from the Harvard-Oxford Cortical Structure Atlas.

Results

- Most of the participants in the melody group learned the accent-suffix associations as shown by game progression and by the subjects showing above-chance accuracy (>0.6) at the second scan being significantly impaired by invalid combinations (M_{diff}=0.0515, t(10)= 2.60,p = 0.0263). This was not true for the morphology group (M_{diff}=0.0104, t(10)= 0.450,p = 0.666). No effects were found for response times.

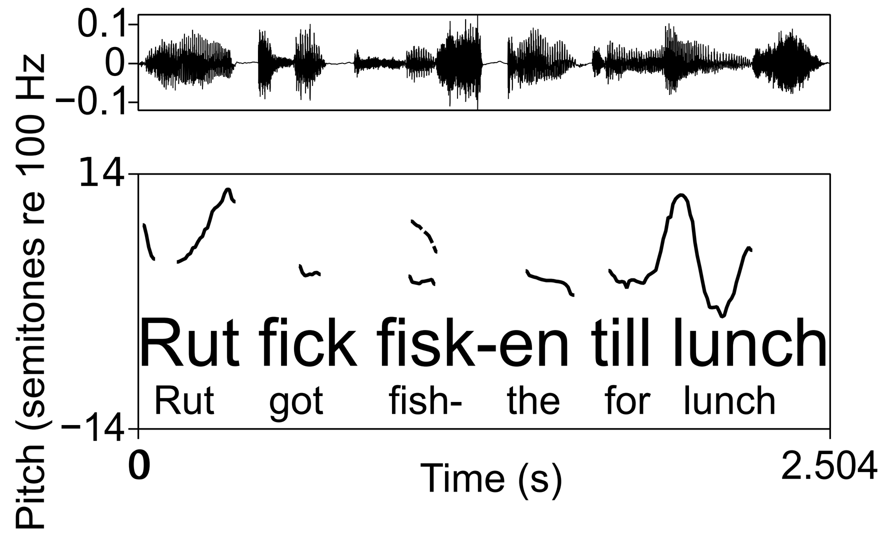

Fig. 1. Example of a stimulus sentence. Dashed pitch curve on the word-stem *fisk* 'fish' shows the high accent 2 tone compared to the low accent 1 tone (solid line).

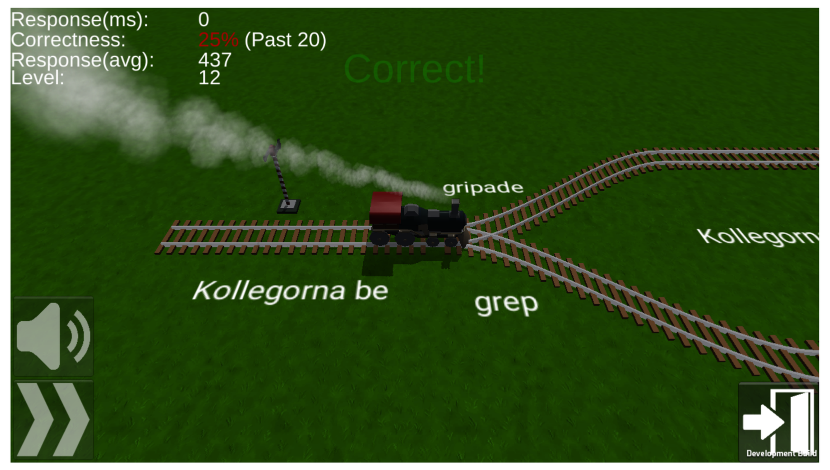

Fig. 2. Adult Germans learning Swedish were trained with for 4 weeks with a smartphone game focusing either on word accents or Swedish morphology. Screenshot from morphology version.

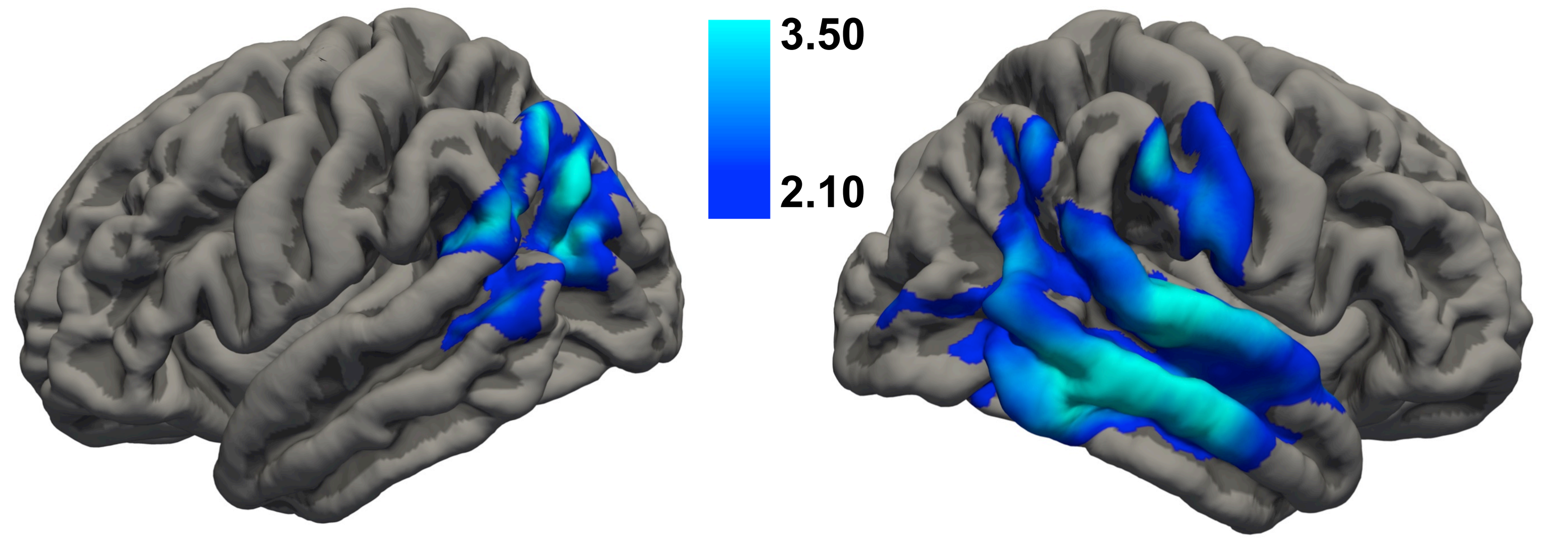

Fig. 3. German native speakers trained on accent-suffix combinations (melody group) had significantly more apparent cortical thinning than those trained in Swedish morphology. Apparent cortical thinning either indicates actual thinning or increase in cortical myelin.
Left IPL: t(23=-3.20, M_{Melody}=-0.0141mm/week, $M_{Morphology}$=0.0139 mm/week, cwp=0.001.
Right temporal lobe: t(23)=-4.22 ,M_{Melody}=-0.0293 mm/week, $M_{Morphology}$=0.0418 mm/week, cwp=0.001.
Right IPL: t(23)=-3.25, M_{Melody}=-0.0177mm/week, $M_{Morphology}$=0.0173 mm/week, cwp=0.0319

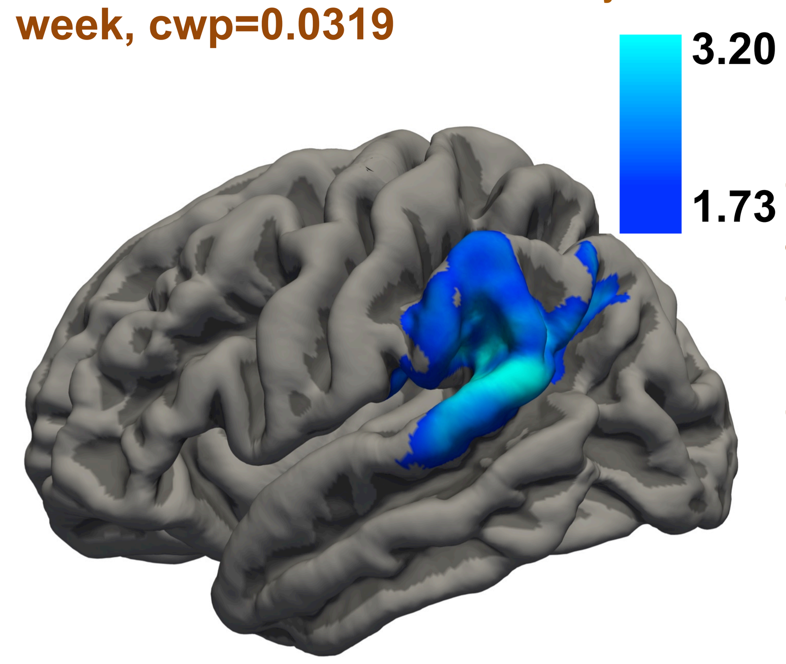

Fig. 4 Apparent cortical thinning correlated with impact on task accuracy from invalid accent-suffix combinations in the melody group (r=-0.765, t(14)=-3.25, cluster-wise corrected p (cwp)=0.0001).

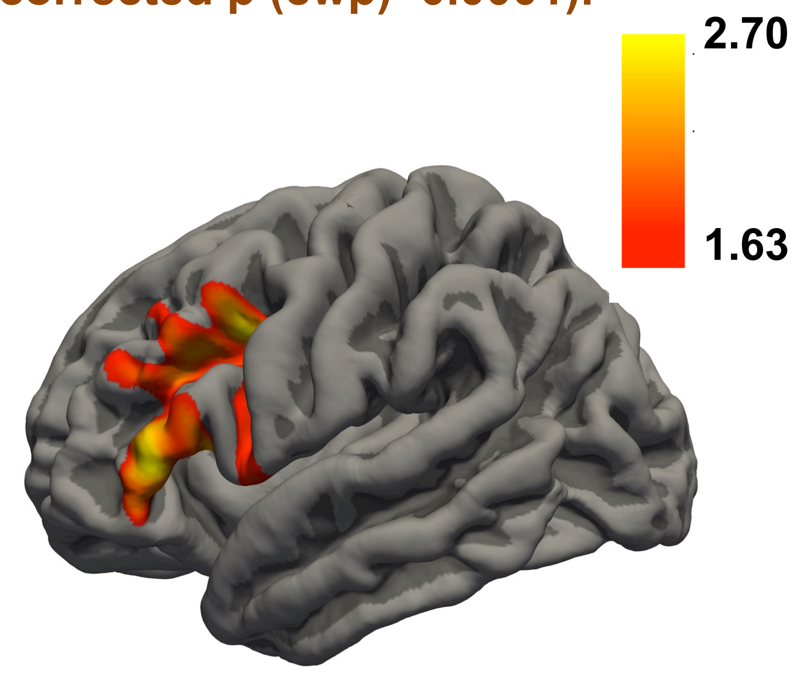

Fig. 5. Rate of apparent cortical thickening correlates with accuracy increase in the melody group (r=0.527, t(14)=2.16, cluster-wise corrected p (cwp)=0.0001).

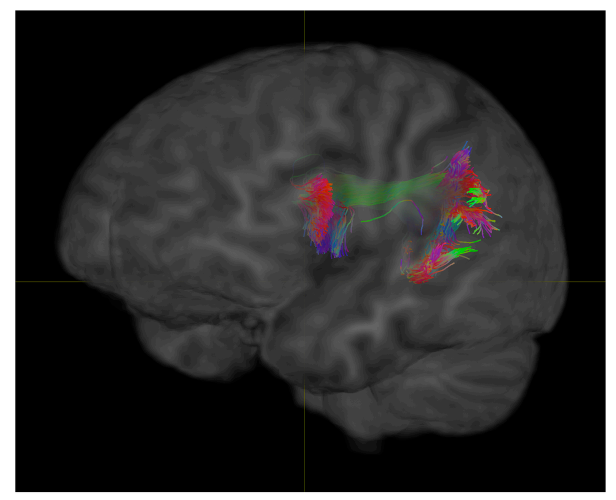

Fig. 6. Example of tractography results between left inferior frontal gyrus pars opercularis and planum temporale. Fractional anisotropy correlated with accuracy increase in the melody group (r= -0.710, t(10)= - 3.19, p= 0.00963).

Discussion

- Differences within the melody group in learning accent-suffix associations could reflect a difference in aptitude for becoming perceptive to accents' phonological cues.
- More apparent cortical thinning in perisylvian areas in the melody than morphology group possibly indicates a cortical reorganization as an effect of learning. Left IPL shows BOLD effects for invalid over valid accent-suffix combinations in Swedish native speakers (Roll et al. 2015). (Fig. 3)
- Apparent cortical thinning in the IPL and posterior STG correlated with impact on task accuracy from invalid accent-suffix associations. This could indicate that these areas are involved in learners' sensitization to word accents as phonological cues. (Fig. 4, 5)
- Apparent cortical thinning could either mean actual cortical thinning or increase in myelin content (Natu et al. 2019). Future studies on word accent learning with more imaging modalities are needed to discern the cause of cortical change.
- The negative correlation between fractional anisotropy and learning outcome could be due to an oligodendrocyte precursor proliferation step in white matter reorganization due to learning reflecting a stage in myelination. Future studies on learning accent-suffix associations should include more timepoints to capture the white-matter reorganization dynamics. (Fig. 6)

Conclusions

- Learning Swedish word accents as phonological cues to suffixes changes cortical morphology in bilateral IPL and right temporal areas.
- Reliance on learned phonological cues correlated with apparent cortical thinning in left IPL.
- Overall improvement in determining singular or plural form correlated with apparent cortical thickening in left IFG and decrease in fractional anisotropy in tracts between left IFG and planum temporale.

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