

# Passive learning of speech sounds associated with microstructure of fronto-temporo-parietal but not fronto-striatal white matter tracts

## Possible implications for implicit language learning tasks

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### Introduction

Language learning involves implicitly acquiring a sensitivity for novel speech sounds and phonological structure [1]. Implicit learning skill differs between individuals [2] and this individual difference could potentially be reflected in the quality of white matter tracts relevant for speech perception and production [3] or for implicit sequence learning [4]. Implicit learning of speech has been suggested to draw from either corticostriatal circuits or from cortico-cortical associations with Broca's area [5]. Most previous studies on neuroanatomical correlates of implicit learning have used tasks such as the serial reaction time task or artificial grammar tasks that lack phonologically relevant stimuli [4] which severely limits interpretation of their results with regards to language learning. To address this, we have used the implicit phonetic memory subtest (LLAMA D) of the LLAMA language learning aptitude tests [6], [7] and diffusion-weighted magnetic resonance imaging (dMRI) to investigate possible associations between implicit learning of speech sounds and white matter microstructure important for speech perception and implicit learning. Findings from speech processing-related tracts presented here have been published [8] but possible associations between phonetic memory and quality of striato-frontal tracts important for implicit learning have not been investigated before. Such associations could indicate that the sensitivity to implicitly remember new speech sounds could shape or be shaped by the quality of the white matter pathways between language- and implicit learning-related brain areas.

### Method

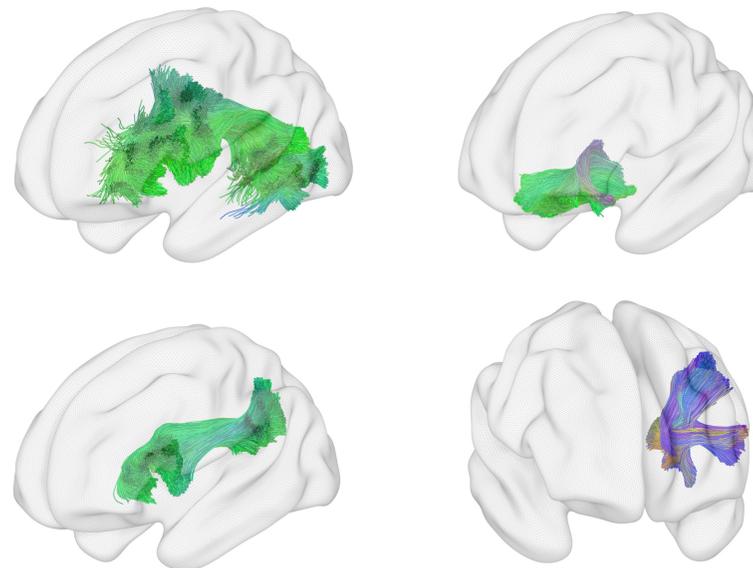
**Participants:** Fifty-seven right-handed university students, 15 male and 42 female, 22-27 years old.

**LLAMA D:** Participants were told to listen to a speech stream that, unknown to them, consisted of 10 words in a British Columbian native language foreign to all participants. Thereafter, participants listened to 20 words, 10 old and 10 new, in a random order and asked to state if the word was new or heard before.

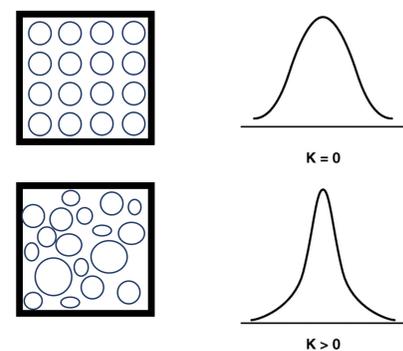
**MRI acquisition:** An actively shielded 7T scanner (Achieva, Philips, Best, Netherlands) equipped with a (Nova) headcoil with 2 transmit and 32 receive channels. B1 field inhomogeneities were reduced by using dielectric pads [9]. Two diffusion-weighted sequences, one single shell (TR=9600ms, TE=73ms, FA=90°, SENSE=1.5, part. Fourier=0.642, 2mm isotropic resolution, 56 directions, b=[0, 2000]s/mm<sup>2</sup>) for tractography and one multi-shelled (TR=6.500ms, TE=88ms, FA=90°, SENSE=2, part. Fourier=0.75, 2x2x4mm<sup>3</sup> voxels, [1, 6, 6, 12, 16] directions, b=[0, 100, 700, 1400, 2000]s/mm<sup>2</sup>) for DKI parameter estimation. Additionally, one b=0 scan with flipped phase encoding direction was acquired for correcting susceptibility-induced distortions.

**dMRI processing:** All volumes were corrected for susceptibility-induced errors [10], eddy currents, motion [11], and aligned to MNI space. Segmentation of bilateral arcuate fasciculus (AF), superior longitudinal fasciculus part III (SLF III), striato-fronto-orbital (ST\_FO), and striato-premotor (ST\_PREM) were segmented using the openly available TractSeg tool [12] (figure 1). Diffusion kurtosis parameters were estimated using the freely available DESIGNER tool [13]. Higher diffusion kurtosis means larger tissue complexity (figure 2).

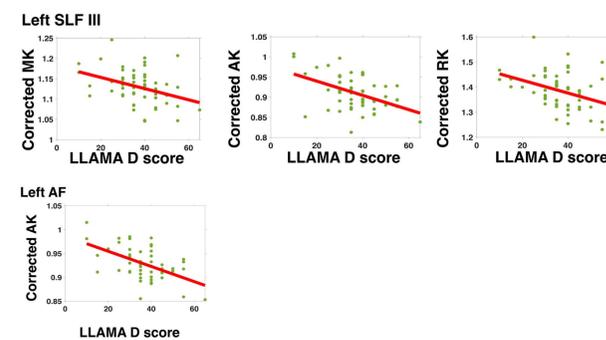
**Statistical analysis:** Correlations between mean diffusion parameter values from each tract and LLAMA D scores were assessed using R [14]. Age and gender were added as covariates of no interest in all analyses.



**Figure 1:** Left white matter tracts segmented for investigation in this study. Right homologues were also studied but are not shown here. *Top left:* Arcuate fasciculus (AF) connecting the inferior and middle frontal with the temporal cortex. *Bottom left:* Superior longitudinal fasciculus III (SLF III) connecting the inferior frontal gyrus and the supramarginal gyrus. *Top right:* Striato-fronto-orbital (ST\_FO) connecting the striatum with the orbitofrontal gyrus. *Bottom right:* Striato-premotor (ST\_PREM) connecting the striatum with the premotor cortex.



**Figure 2:** Homogenous tissue within an image element (top) means low diffusion kurtosis while more complex tissue (bottom) due to e.g. different cell types or twisting axons lead to higher diffusion kurtosis.



**Figure 3:** Significant correlations between implicit phonetic memory (LLAMA D) score and kurtosis parameters, given age and gender as covariates of no interest [8]. Mean kurtosis (MK) is the average kurtosis along all diffusion encoding directions while axial (AK) and radial (RK) kurtosis is the kurtosis along and across the principal diffusion direction, respectively.

### Results

LLAMA D score correlates negatively with axial kurtosis of the left AF ( $r=-0.58$ ,  $p=8.53e-05$ ) and left SLF III ( $r=-0.440$ ,  $p=0.0011$ ; figure 3). Moreover, LLAMA D scores correlates with mean ( $r=-0.356$ ,  $p=0.0095$ ) and radial ( $r=0.0058$ ,  $p=0.0058$ ) kurtosis in left SLF III (figure 3). No significant (all  $p>0.17$ ) correlations with any diffusion parameters were found in the ST\_FO or ST\_PREM tracts. No other correlations were found for the remaining diffusion parameters in the left AF and SLF III.

### Discussion

Implicit phonetic memory capacity is negatively correlated with kurtosis parameters in the left AF and SLF III but not in fronto-striatal tracts. Lower kurtosis parameter values indicate a more coherent and homogenous white matter tract [15]. Left AF and SLF III connect speech perception and production areas and stronger connections between them could indicate a more sensitive passive speech sound learning system. No correlations were found for any fronto-striatal tracts previously implied as connecting areas important for implicit learning though especially for sequence learning [4]. This could potentially indicate that the influence of basal ganglia is of low importance for individual differences in passive learning of speech sounds. Important to note is that there is no sequence learning in the LLAMA D test, in contrast to widely used implicit learning tasks such as artificial grammar learning or serial reaction time task. A possible direction for future research is to develop an implicit learning test battery that probe more linguistically relevant aspects of implicit learning.

### Conclusions

Capacity for passive learning of speech sounds is associated with parameters relating to more coherent and homogenous white matter-tracts in the left AF and SLF III but not fronto-striatal tracts. Left AF and SLF III could form the basis for a passive speech learning system that is differently active for different individuals. The lack of correlation with parameters in fronto-striatal tracts potentially indicate that there is room for a battery of implicit learning tests that could shed light on the neural bases for implicit components of language learning.

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