Differences in Resting-State Functional Connectivity Between Early and Late Bilinguals

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Introduction

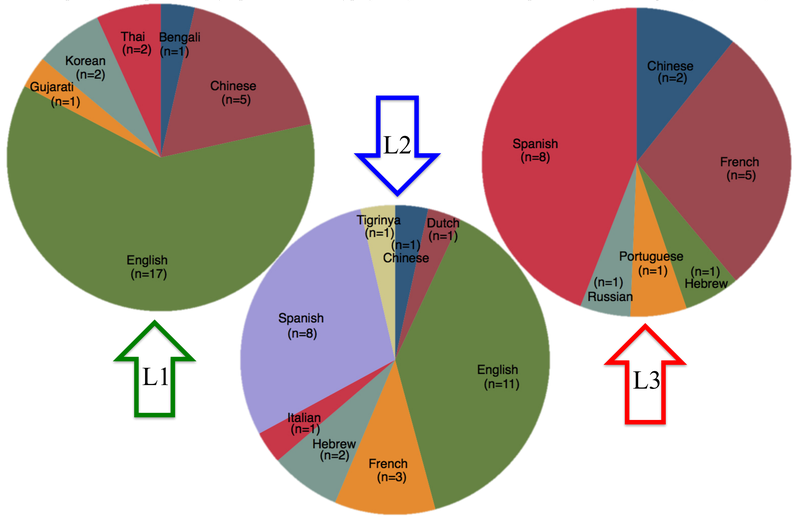
- Previous studies have found that bilinguals demonstrate stronger intrinsic connectivity in the frontoparietal control network at rest than monolinguals (Grady et al., 2015) as well as greater fractional anisotropy (FA), a measure thought to reflect white matter integrity, than monolinguals in association tracts in the left hemisphere (e.g., Luk et al., 2011; Mohades et al., 2012; Pliatsikas et al., 2014).
- Few studies have explored whether such differences in resting-state functional connectivity (rsFC) and white matter structure exist between early (i.e., simultaneous) vs. late (i.e., sequential) bilinguals.
  - Berken et al. (2016) found evidence of stronger rsFC between the left inferior frontal gyrus (IFG) and regions associated with language control in simultaneous vs. sequential bilinguals. Kousaie et al. (2017) report greater anticorrelation between the default mode network (DMN) and task-positive attention network in simultaneous vs. sequential bilinguals.
  - Kuhl et al. (2016) found that duration of speaking in an L2 was positively associated with FA in the left arcuate fasciculus (AF) and corpus callosum. Similarly, Hämäläinen et al. (2017) found that early bilinguals had greater FA in the left AF and lower MD in the right AF than late bilinguals.
- Even so, due to methodological constraints, previous studies have been limited to solely investigating differences in resting state functional connectivity using a handful of seed regions.
- **Objective**: To replicate previous findings regarding differences in rsFC and white matter structure between early vs. late bilinguals and extend this work by (1) using a comprehensive set of seed to whole brain analyses and (2) integrating functional and structural methods.

Methods

***Participants (N=28,** 5 male)*

	Early Bilinguals (n=12)	Late Bilinguals (n=16)
Age (years)	M=26.66 (SD=3.62)	M=24.30 (SD=3.72)
Age of L2 speech onset (years)* **	M=4.50 (SD=1.24) range=2-6	M=10.06 (SD=2.98) range=7-15
Age of L3 speech onset (years)**	M=9.90 (SD=4.56), *n*=10	M=16.43 (SD=3.69), *n*=8
Self-reported L1 language proficiency (max=7)	M=5.67 (SD=1.78)	M=6.63 (SD=1.50)
Self-reported L2 language proficiency (max=7)	M=4.58 (SD=2.15)	M=4.44 (SD=2.03)
Self-reported L3 language proficiency (max=7)	M=1.70 (SD=1.25), *n*=10	M=2.63 (SD=2.00), *n*=8
KBIT-2 Nonverbal Reasoning (standard score)	M=105.42 (SD=13.28)	M=111.13 (SD=15.64)
KBIT-2 Verbal Reasoning in English (standard score)	M=105.93 (SD=12.15)	M=113.27 (SD=23.13)
% daily speaking in non-English language	M=11.08% (SD=5.97)	M=16.62% (SD=4.80)
Dominant home language (for the last 5 years)	50% English, 50% non-English	68% English, 32% non-English
Not born in the U.S.	*n*=5	*n*=5
Reports basic knowledge of an L4	*n*=3	*n*=3

*Note: **=p<0.01, ***=p<0.001; Self-reported measures of proficiency were rated on an 7-point scale from 1 (Beginner) to 7 (Native)*

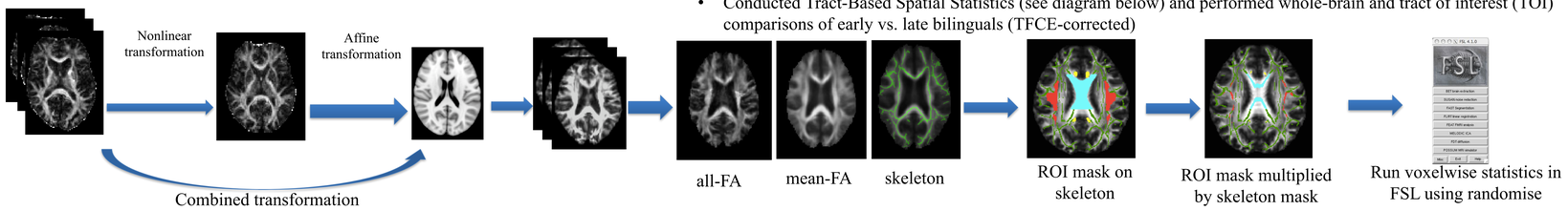


Methods (continued)

Data Acquisition

- Language and Social Background Questionnaire (adapted from Luk & Bialystok, 2013)
- Behavioral Assessment Battery:
  - Kaufman Brief Intelligence Test (KBIT-2)
- Resting-state fMRI and DTI acquired using Siemens 3T Magnetom Prisma Fit w/ 32-channel head coil:
  - 6-min resting-state scan, 64 slices, 2.3x2.3x2.3mm, whole brain coverage, TR/TE=650/34.80 ms
  - 81 DTI slices, 1.8x1.8x1.8mm, whole brain coverage, TR/TE=3700/83 ms, A >> P phase encoding direction, T > C-25 orientation

Tract-Based Spatial Statistics



Data Analysis

<u>Resting-state Functional Connectivity</u>

- Analyzed using AFNI_16.3.13 (Cox, 1996)
- Preprocessing: despiked, slice-time corrected, aligned to the anatomical scan, motion-corrected, transformed to Tailarach space, ventricle and local white matter regression performed using subject-specific anatomical masks generated in FreeSurfer (Dale et al., 1999), and spatially smoothed, all using afni_proc.py
- Used 3dGroupInCorr to perform two-sample unpaired t-tests comparing functional connectivity from a seed (3mm radius sphere, set "on-the-fly") to the whole brain for early vs. late bilinguals (FWE-corrected)

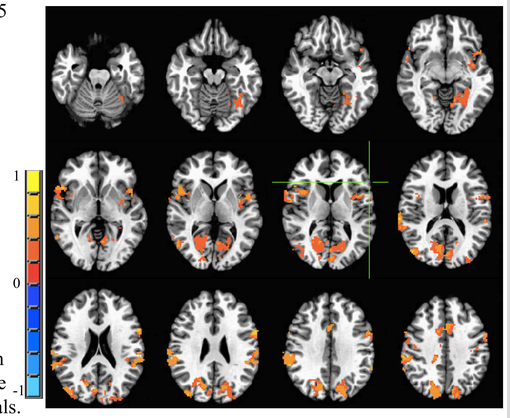
<u>Diffusion Tensor Imaging</u>

- Analyzed using FSL-5.0.4 (Smith et al., 2004)
- Preprocessing: Eddy current correction, brain extraction using BET, and diffusion tensor fitting to corrected data
- Conducted Tract-Based Spatial Statistics (see diagram below) and performed whole-brain and tract of interest (TOI) comparisons of early vs. late bilinguals (TFCE-corrected)

Results

Resting-State Functional Connectivity

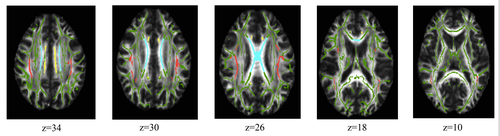
- No evidence of differences in resting-state connectivity between early and late bilinguals using the following seed regions: ventromedial prefrontal cortex (vmPFC-same coordinates as Kousaie et al., 2017), bilateral superior temporal gyri (STG), bilateral transverse temporal gyri (TTG), bilateral middle temporal gyri (MTG), among others.
- A left IFG seed (x=-58, y=27, z=5, MNI) yielded many significant regions, even when thresholded at $p<0.01$ with FWE-corrected $p<0.05$. This center of this seed located in BA 45 is labeled with green crosshairs in the figure on the right.
- For all of the resulting regions, early bilinguals exhibit stronger connectivity with the left IFG at rest than late bilinguals.
- These regions are the:
  - bilateral precunei (4265 vox, $p<0.001$)
  - bilateral middle frontal gyrus (1080 vox, $p<0.001$)
  - left precentral gyrus and insula (978 vox, $p<0.001$)
  - right precentral gyrus and insula (906 vox, $p<0.001$)
  - right inferior parietal lobule (580 vox, $p<0.001$)
  - left inferior parietal lobule (258 vox, $p=0.01$)
- Similar regions (although fewer in general) were also seen when using the right IFG (BA 45 or 46) as a seed, all more strongly correlated with the seed for early vs. late bilinguals.



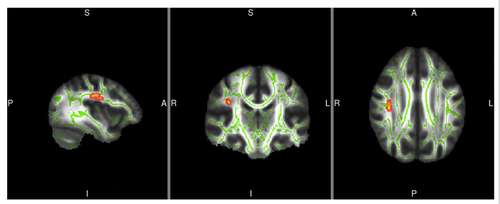
DTI

- No evidence of whole-brain group differences in FA between early vs. late bilinguals
- Analysis restricted to theory-driven tracts of interest
- **The targeted analysis revealed that early bilinguals have greater FA in the right SLF than late bilinguals, on average (TFCE-corrected $p<0.05$)**
- No evidence that late bilinguals have greater FA than early bilinguals, on average, in any tract

TOIs
- Corpus Callosum
- L & R Superior Longitudinal Fasciculus (SLF)
- L & R Cingulum



Early > Late Bilingual FA Comparison



Conclusions

- Early bilinguals exhibit stronger resting-state functional connectivity than late bilinguals between the left IFG and its right homolog as well as with other regions in the frontoparietal control network (e.g., bilateral inferior parietal lobules, bilateral precunei).
- No evidence that early and late bilinguals exhibit differences in functional connectivity among certain other regions associated with language (e.g., TTG, STG, MTG) and executive functions (e.g., vmPFC contrary to Kousaie et al.'s , 2017 finding)
- No evidence of whole-brain group differences in FA between those with early vs. late L2 AoAs
  - Consistent with Hämäläinen et al.'s (2017) claim that ROI-based analyses necessary to overcome TBSS whole brain biases
- Early bilinguals have higher levels of FA, and therefore potentially greater white matter integrity, in the right SLF, the right homolog of the region identified by Kuhl et al. (2016) and Hämäläinen et al. (2017); however, no evidence in the left SLF
- Limitations: Small sample not representative of the general U.S. adult population in terms of age or IQ; self-reported measures of language proficiency

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