Cognitive Control and Cortical Thickness: New Perspectives on Bilingualism

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Abstract

In 2014, Benjamin Katz and colleagues from the University of California, Irvine investigated the effects of various motivational factors (such as awarding points and prizes) on monolingual children's performance on the N-Back task, a well-known test of cognitive control. Contrary to expectation, it was found that increasing motivation either had no effect on performance or, in some variable conditions, actually hindered response time and accuracy, presumably by distracting the participants.

This summer, while working in Dr. Arturo Hernandez's University of Houston (UH) Laboratory for the Neural Bases of Bilingualism, I, with the guidance of PhD candidate Brandin Munson, designed, coded, and piloted an experiment based on the Katz paper. We tested Spanish-English bilingual and English monolingual participants using an improved and expanded experimental paradigm than that from 2014, looking specifically for between-group differences in baseline cognitive control and changes in proficiency resulting from a variety of motivational factors. The task was also designed to demonstrate individual differences between motivational factors and between different groupings of motivational factors.

While results are still pending, the design and method of this experiment, as well as details of other lab work I was involved in this summer at UH with Dr. Pilar Archila-Suerte, are discussed below.

Design/Methods

The results of the 2014 Katz paper (Differential effect of motivational features on training improvements in school-based cognitive training, *Frontiers in Human Neuroscience* 8) run contrary to the idea that more motivation necessarily leads to better performance. One aspect lacking in the design, however, was that motivational factors were not tested in isolation, therefore making it difficult to directly compare the effects across factors and, since the factors were presented in combinations, may have had an inhibiting effect on reaction time simply due to an overabundance of feedback. Additionally, the group tested consisted solely of young, monolingual children, making it difficult to extrapolate from the results to the general population. Finally, could it be that the nature of the task itself in the original paper affected the ability of the participants to integrate the motivational feedback?

To address these issues above, I designed and coded a two new tasks using a Python-based, open source, psychological and cognitive science experimental library called Expyriment (http://docs.expyriment.org/index.html). This provided a direct way to program – and later modify if needed – the tasks and also automatically compute accuracy and reaction times for analysis.

All of the following design decisions were incorporated into two versions of the task, one modeled off the original Katz N-Back test paradigm (which has the additional feature of allowing for the task to get more difficult or easier depending on previous responses i.e. 4 correct reactions changes it from a 2-Back task to a 3-Back task) and one a simple Simon task. The control condition is a simple series of iterations of the task. The variable conditions will be identical with the insertion of 1-second feedback slides (correct or incorrect) after each response with 5 different motivational factors being presented in isolation: verbal, nonverbal (pictures of thumbs up/down), points (incrementing and decrementing), lives remaining, and Spanish (as appropriate).

While only getting IRB approval and pilot testing (n=4), from which it was impossible to find any differential effects of feedback or between groups, was accomplished during this summer, the eventual target group of participants will consist of both monolingual and Spanish/English bilingual university students. ANOVAs will distinguish if there is an effect on reaction time and/or accuracy (measures of cognitive control) for either task as caused by the various motivational factors compared to the control, and, if so, whether these effects on cognitive control are seen more or less strongly in either the monolingual or bilingual group. The hypotheses will lie in the direction of finding, as a replication, an inhibiting effect of at least some motivational factors on performance in the N-Back version and that the bilingual group will show less of this negative effect on their cognitive control.

Additional Work: MRI Analysis

Aside from the coding and design described above, most of my time in the lab was spent helping various other lab members with scripting and post-doctoral fellow Dr. Pilar Archila-Suerte with the following. Thanks to her for help with the following write-up.

In the past year, Dr. Hernandez's lab conducted a magnetic resonance imaging (MRI) experiment studying the brains of Spanish-English bilingual and monolingual children. Independent of the results of this experiment, preliminary analysis also indicated concordance with some previous work which correlated cortical thickness (thinning) in the superior temporal gyrus (STG) and language proficiency. Interest in this question led to this secondary project with the same imaging data. Here, we examined differences in cortical thickness between bilingual children who were highly proficient in two languages (i.e., English and Spanish) and bilingual children who were only proficient in one of the languages (i.e., Spanish). We hypothesized that children who were highly proficient in both languages would show more thinning in several cortical regions than children who were only proficient in one.

All children (N=38) learned Spanish as the native language at home and English as the second language at school at around 5 years of age. Expressive and receptive abilities in both languages were assessed through the standardized Woodcock Language Proficiency Battery. Five-minute anatomical scans were acquired using a 3-Tesla magnetom TIM Trio scanner and a 12-channel head coil. A Magnetization Prepared Rapid Gradient Echo (MPRAGE) sequence was implemented (TR= 1.2s, 256 X 224 matrix, 1 mm^3 voxel size). During statistical analysis, the sample of children was split into 2 groups: **balanced bilinguals** and **unbalanced bilinguals**. The degree of discrepancy between L1 and L2 proficiency scores was used to classify the children (Mean discrepancy = 11.27, SD = 8.14). Sixteen children were classified as balanced (smaller discrepancy) and 14 children were classified as unbalanced (larger discrepancy). The groups did not significantly differ in age, SES, total number of years of education, years of education in L2, or Spanish proficiency. They only significantly differed in the proficiency of English. Cortical thickness values from the bilateral STG, middle frontal gyrus (MFG), inferior frontal gyrus (IFG), and inferior parietal lobule (IPL) were extracted from FreeSurfer and entered into SPSS. These brain regions were selected because of their known involvement in language processing.

Surface-based morphometry

FreeSurfer 5.3.0 software (http://surfer.nmr. mgh.harvard.edu/, Center for Biomedical Imaging, Charlestown, MA) was used to measure cortical thickness of high spatial resolution 3D T1-weighted images from anatomical scans. FreeSurfer corrects for motion and strips the skull of each T1-weighted image, transforms images into Talairach space, and segments tissue into cerebrospinal fluid (CSF), gray matter, or white matter based on intensity gradients. The cortex is displayed as a surface model with a mesh of triangles (i.e., vertices). After cortical reconstruction, deformable procedures such as surface inflation are smoothed with a full-width-half-maximum Gaussian kernel of 30 mm and averaged across participants using a non-rigid high-dimensional spherical averaging method to align cortical folding patterns. This is followed by the parcellation of the cerebral cortex into respective gyral and sulcal structure, along with the generation of curvature and sulcal maps.

After automatic surface reconstruction, participants' brain images were visually checked (by me) in 2D using Freeview 1.0. Each of the volume's slices was scrolled through on the coronal, sagittal, and horizontal planes to ensure correct surface extraction and labeling of the white matter and pial surface. In case of defective labels, images were manually corrected and examined after a second surface reconstruction. Two participants were dropped before data analysis due to excessive banding in the images produced by head motion.

Statistical analyses

Preliminary whole-brain between-subject analyses were conducted through a FreeSurfer toolbox called *Qdec*. *Qdec* provides a pre-specified statistical design that only permits the examination of simple group comparisons or bivariate correlations using one covariate and one nuisance factor. A separate statistical package was needed to inspect the data in-depth including additional covariates. Intracranial volume (ICV) along with gyral and sulcal cortical thickness values obtained from the Destrieux atlas in FreeSurfer were imported into the statistical package SPSS 22 (http://www.spss.com) to conduct a complex MANCOVA model. In SPSS, we examined the cortical thickness of the area that survived threshold in the whole brain analysis conducted in Qdec; namely, the bilateral STG. This area was subdivided into smaller regions: 1) transversal, 2) lateral, 3) polar, and 4) planum temporale. A multivariate analysis of co-variance (MANCOVA) evaluated whether cortical thickness in each of these sub-regions was significantly different between monolingual and bilingual children, adjusting for differences in age, L2 proficiency, SES and ICV.

Results

Results showed that balanced bilinguals have significantly thinner **MFG** and **IFG** bilaterally as well as thinner **IPL** in the left hemisphere relative to unbalanced bilinguals. Therefore, children who are learning two languages and have equal proficiency in both have decreased cortical thickness in regions associated with working memory, attention, and speech production. These results suggests one of two potential scenarios: 1) through experience, balanced bilinguals show thinning of the MFG, IFG, and IPL more than unbalanced bilinguals, or 2) these regions in balanced bilinguals were initially thinner and this anatomical characteristic propelled their learning in both languages. Similar to the studies of brain anatomy and intelligence, it is possible that the trajectory of cortical thinning in the prefrontal cortex is dynamic and both experience and genetic predispositions influence the outcome of first and second language acquisition.