Exploring the Relationship Between Prosodic Cue Production and Functional Connectivity in the Bilingual Brain

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Introduction

While many aspects of the neurobiology of language have become less elusive over the years, the neural bases of prosody remain controversial. Prosody refers to the melody and rhythm of speech, and includes acoustic cues such as fundamental frequency (F0) and duration [1]. Listeners use these prosodic cues to segment spoken language into words and sentences [2]. Different languages use the same prosodic cues following different segmentation patterns [2]. The current study aims to investigate how mastery of prosodic production across multiple languages in bilinguals is reflected in the brain at the network level.

While classical language areas, such as Broca's area in the inferior frontal gyrus (IFG) have been linked to language production, increasing evidence suggests that areas outside of the cortex may also be playing a key role [3]. The basal ganglia are thought to have a modulatory effect on the cortex for language processing, and have been linked to articulatory control in a second language [4]. A subcortico-cortico-cerebellar network for processing aspects of speech related to timing has also been proposed, specifying a potential link between the cerebellum, the basal ganglia and classical language regions of the cortex [5].

The current project aims to investigate whether mastery of prosody across two languages is associated with differences in the brain at the network level. We first used whole-brain Voxel-Based Morphometry (VBM) to investigate if gray matter volume (GMV) in the brain was associated with prosodic production in bilinguals. A dissociation was found where native-like F0 production was associated with GMV in the bilateral basal ganglia while native-like duration production was associated with GMV in the left cerebellum, across both languages (for all findings greater GMV was observed in English, while smaller GMV was observed in French). The current work builds on these initial findings, focusing on resting-state functional brain connectivity. We investigate the impact of bilingualism on functional connectivity and hypothesize that bilinguals with more native-like prosodic attainment in their languages will show increased functional connectivity between the brain regions previously identified in the VBM analyses (i.e., the bilateral basal ganglia and left cerebellum) and traditional language production regions in the cortex (i.e. left IFG).

Methodology

Fifteen English-French bilinguals (first language [L1] English) participated in the current study. Participants completed a behavioural prosodic (language) task, as well as a resting-state functional magnetic resonance imaging (rs-fMRI) scan. The prosodic task was used to characterize participants' ability (or lack of ability) to produce native-like prosodic cues in both English and French. Stimuli were 80 sentence pairs, with 40 sentence pairs per language. Target word(s) of a sentence pair shared the same phonology and were interpretable as either one bisyllabic or two monosyllabic words, depending on how they were segmented prosodically (e.g. 'kiwi' vs. 'key we'). This design forced participants to use prosodic cues to differentiate between the two possible segmentations and meanings of the target words, which were disambiguated by subsequent context. For example:

1. If you would like a **kiwi** I will buy one tomorrow.
2. If you would like a **key we** can duplicate one.

Participants were audio recorded while reading the sentences aloud. F0 and duration values for the target words were then extracted and difference ratios (comparing production of target words across stimuli pairs) were calculated to characterize participants on a continuum from native-like to non-native-like in both English and French. This continuum was based on previous work with a larger sample that included both English-dominant and French-dominant bilinguals [6].

For the resting-state fMRI scan, participants were asked to remain still, to clear their mind and to fixate on a cross that was presented in the center of the screen. Data were acquired on a 3T TrioTim Siemens scanner using a 32-channel head coil at the Montreal Neurological Institute. Data were preprocessed using SPM8 with standard preprocessing steps. Seed-to-voxel functional connectivity analyses were performed using the custom software CONN version 18.b [7]. Seed regions were created by generating a 6mm sphere around the peak of the clusters that were found to be related to prosodic production in the VBM analysis.

Results

Whole brain seed-to-voxel functional connectivity analyses were conducted, and all reported results were significant at a threshold of $p(FDR)<0.05$. In English, native-like F0 production was associated with increased functional connectivity between the left putamen seed and the right IFG (opercularis and triangularis) and the left supramarginal gyrus (SMG). Similarly, native-like duration production in English was associated with increased connectivity between the left cerebellum seed and the right SMG and angular gyrus. In French, native-like production of F0 was associated with increased connectivity between the right caudate seed and the bilateral cerebellum Crus II. Furthermore, native-like production of duration in French was associated with increased connectivity between the right caudate seed and the left SMG/angular gyrus.

Discussion

The connectivity observed between various seeds and the SMG and angular gyri did not directly follow from the hypothesis that increased connectivity would emerge between the basal ganglia, cerebellum and left IFG. Nonetheless, the findings support the more global hypothesis of increased functional connectivity between the pre-defined seeds and (other) cortical language regions. Notably, the SMG has been associated with language and prosodic perception in Mandarin-English bilinguals [8]. Furthermore, the finding of significant functional connectivity between the right caudate and the bilateral cerebellum (rather than cortical language regions) for the French F0 condition, although unexpected, supports previous work suggesting that a subcortico-cortico-cerebellar network may be working in tandem for speech processing [5]. Further work will include determining whether the increased functional connectivity observed between the caudate and the cerebellum is specific to the prosodic cue (F0), the language (French; L2) or both. The current study highlights the potential role of the basal ganglia and the cerebellum in prosody and language production more globally, as well as their potential modulatory effect on regions of the cortex, namely the SMG and the IFG. Ongoing work will further specify the role these networks play in articulatory control for prosodic production and whether comparable connectivity patterns emerge for prosodic perception.

References

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