Where language pionieer Paul Broca and alien music meet

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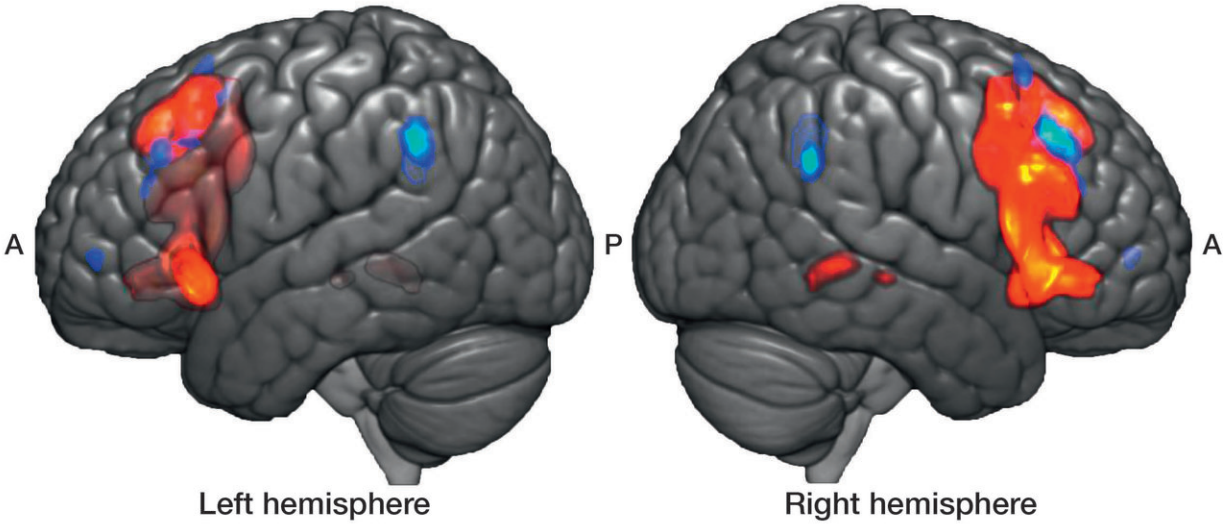

Broca's area, restricted to the left hemisphere, is centrally involved in language processing. The equivalent area, in the right hemisphere (red), plays a similar role but for the processing of music. More specifically, it's activated when we notice violations of musical grammar. The areas in blue are typically associated with working memory and show increased brain activity when the grammar gets longer and more complicated. Credit: *Nature Scientific Reports*

What might alien music sound like? Would it be structured hierarchically as our music is with verses and a chorus? Would we even be able to appreciate it? Vincent Cheung from Max Planck Institute for Human Cognitive and Brain Sciences, thinks the answer would be yes,

assuming it was predicated on local and non-local dependencies. His research published this week in *Scientific Reports* explains what exactly that means.

Vincent Cheung, along with Angela Friederici, has been investigating non-local dependencies in music and trying to determine how the human brain processes them. In language and music, dependencies are conceptual threads that bind two things together. Non-local dependencies bind non-adjacent items. For example, in pop music, the second instance of a verse, following a chorus, would have a non-local dependency with the first instance of the verse. Experientially, it is clear to us that we are hearing a sequence that we have heard before. According to Cheung, composers use such devices to build up our expectations and elicit strong emotional responses to the music. But how does the brain recognize these patterns and what does this have to do with Paul Broca?

Paul Broca was a famous French physician and anatomist whose work with aphasic patients in the 1800s led to the discovery of Broca's area; a small patch of the cerebral cortex just above the temple, specifically on the left side of the brain. Broca's area is critical for speech production and for the processing of, you guessed it, dependencies in language. For example, Broca's area is active when we detect violations to our well-learned grammatical rules. Surprisingly, despite Broca's area being one of the most studied human brain regions, neuroscientists are still not exactly sure what the same region does, on the other side of the brain.

Theory suggests the right hemisphere equivalent, or homologue, of Broca's area plays a similar role but for the processing of music instead of language. However, researchers have had difficulty demonstrating this, partly due to an inability to tease apart contributions of local and non-local dependencies to the structural hierarchy of the music. Enter Vincent Cheung's alien music.

Of course, Mr. Cheung doesn't really have authentic music from a distant world but that is how he referred to the music he developed for his study. He created a novel 'genre' of music described as, "randomly generated combinations of tone-triplets that were combined in a palindrome-like manner". While that may not sound very pleasant, the short stimuli were actually quite pleasing to the ear. Vincent's stimuli allowed the team to overcome the confounding hurtle of local dependencies. Importantly, there were sequences that conformed to a fabricated musical grammar as well as sequences that did not. This opened the door to determining where in the brain musical, non-local, dependencies are processed.

Musicians of varying expertise were invited to the laboratory to listen to Cheung's short compositions. Their task was to guess whether individual sequences were grammatical, or not, and through their correct and incorrect responses, determine the underlying grammatical rule. Once the rule was learned participants were invited to perform the task in an MRI scanner, allowing the researchers to see which brain areas were recruited. The researchers hypothesized bilateral activation of the inferior frontal gyrus, the anatomical structure housing Broca's area, during ungrammatical sequences compared to grammatical sequences. A clever manipulation also allowed them to dissociate between the processing of the non-local dependencies and the sheer demand on working memory. The complexity of the sequences was systematically varied such that more information would need to be held in memory in certain conditions.

The results, published in *Scientific Reports* this week, were consistent with their predictions, plus one surprise. The so-called Inferior frontal gyrus (IFG) was activated more during sequences which were ungrammatical than grammatical, although brain activity was more weighted towards the right hemisphere. That is, the brain became more active in the IFG during grammatical violations of the learned rule, but

that tended to be more on the right than in Broca's area on the left. Frontal and parietal regions with known roles in working memory were also found to underlie the complexity dimension of the task. Interestingly, the researchers found that the degree of functional connectivity, between brain regions involved in detecting grammatical violations and those related to working memory, predicted the performance accuracy of the participants in determining whether a sequence was grammatical or not. This suggests the task is accomplished through the integration of information in memory with some form of neural computation of the musical grammar in the right homologue of Broca's area.

Vincent Cheung, first author of the underlying study, suggests the importance of the work lies in demonstrating that neurons capable of encoding non-local dependencies are not 'supra-modal'. Rather, subpopulations seem to be geared for different stimulus types, now including music.

More information: Vincent K. M. Cheung et al, The right inferior frontal gyrus processes nested non-local dependencies in music, *Scientific Reports* (2018). DOI: 10.1038/s41598-018-22144-9

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