Lateralization of tone processing in tonal language speakers

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5 May 2006

Introduction

The human brain has evolved to recruit neural tissue for specialized functions. Right-handed English speakers seem to have language comprehension and production lateralized into the Broca's and Wernicke's areas of the left hemisphere. On the other side of the brain, the right temporal lobe seems to handle the discrimination of aspects of music, including pitch, which leads to the understanding of tone or prosody (Liégeois-Chauvel et al., 1998). The interesting aspect of this kind of lateralization is that English is not the only language; there exist languages which depend upon tone for lexical decisions, such as Mandarin, Cantonese, Thai, and Vietnamese. What happens in the brains of people who natively speak tonal languages? Does the brain still lateralize tone processing to the right, does it move over to the left, or are there two separate sites for tone processing? This paper explores these questions and their ramifications.

In linguistics, "tone" refers to the use of pitch as a distinguishing feature between words (Yip, 2002). "Prosody" is a combination of sound features which include pitch. Most Indo-European languages make use of tone in the form of intonation, which is used to express emphasis or emotion. Tonal languages, however, make use of pitch within individual words to distinguish one word from another. The pitch changes are relative to the word and the rest of the sentence, so the overall pitch of one word can be higher or lower than the rest of the sentence if it is being emphasized, but the relative change in pitch within the word can be used to determine its tone and thus allow for lexical discrimination between words.

An important question going forward is whether studies which include bilinguals are as valid as those which test monolinguals. It is certainly possible that the bilingual brain is simply processing things differently. In a review of the history of the cerebral organization of bilinguals, Fabbro (2001) explains that early patient recovery studies indicated that bilinguals had a symmetric representation of language in both hemispheres. Later studies contradicted this finding, both due to the methodology and wider studies of aphasics with lesions to the right temporal lobe. Fabbro further describes that current patient and imaging studies indicate that the right hemisphere is used by bilinguals in the process of acquiring their second language, but once the language has been acquired the right hemisphere is just as active in monolinguals as it is bilinguals. This research indicates that the mere acquisition of a second language (even if it is tonal) does not change the necessity of the right hemisphere relative to monolinguals in that same language. Unfortunately Fabbro's review did not revolve around whether or not the right temporal lobes were required more for tonal languages.

Theories

Gandour (2000) identifies two major theories of prosody interpretation in the brain. One major theory argues that the neural components for sound processing are task- or domain-dependent, in that tone discrimination for speech would be a separate mechanism from tone discrimination for music. The other theory argues that the neural components are cue-dependent; different aspects of the acoustic signal are processed by different mechanisms regardless of whether the signal is speech or music. The task-dependent theory would predict that if linguistic tones are discriminated in the left hemisphere, it is still possible that musical tones could be discriminated in the right hemisphere. The cue-dependent theory would predict that tones would be discriminated in the same place regardless of whether they were a part of language or music.

Experiments

Many earlier studies of lateralization of linguistic processing focused around dichotic listening experiments. In these experiments participants would be presented stimuli to both ears simultaneously and report what they heard. The relationship between dichotic listening and temporal lobe processing is questionable, and imaging studies such as the fMRI performed by Jäncke and Shah (2002) show that dichotic listening causes much more activation in the frontal and temporal lobes than either single ear presentation, which indicates that it is possible dichotic listening is testing more than just normal temporal lobe processing. Given these results and the advent of imaging studies as a means of more directly observing activation, this paper does not focus on the results of dichotic listening studies.

Moen and Sundet (1996) contrasted two groups of hemisphere damaged speakers of East Norwegian, a two-tone tonal language with a ten-person control group. Patients were recruited from a pool of stroke patients, excluding those with neglect, global aphasia, or apraxia of speech. One group of four people was left-hemisphere-damaged, while the other group of four was right-hemisphere-damaged. Participants were shown written Norwegian words which differed only by tone and had to point to the word which was spoken. The control and right-hemisphere-damaged groups both performed well, while only one patient from the left-hemisphere-damaged group was able to identify all target words correctly. The other three left-hemisphere-damaged patients were 92%, 83%, and 50% accurate. Overall it seems that the left-hemisphere-damaged patients were more impaired than the right-hemisphere-damaged patients, consistent with the notion that linguistic tone processing is task-dependent and in the left hemisphere. This was, however, a very small study on brain damaged patients.

Klein, Zatorre, Milner, and Zhao (2001) performed a PET imaging study in which native Mandarin speakers (who did learn English, but only after the critical period) were contrasted with native English speakers on their ability to discriminate between Mandarin words which were phonetically the same except for tone. Both groups performed well (93% and 98% accurate), with the Mandarin group performing statistically better for obvious reasons. The interesting results came with the PET images: Mandarin speakers had higher cerebral blood flow (and thus assumed activation) in the left hemisphere and did not have more activation in their right temporal lobes over baseline. English speakers showed more activation in their right temporal lobes and right frontal lobes than baseline when performing the tone discrimination task. These results are perfectly in line with the task-dependent theory, in that English speakers cannot linguistically process words of a language they do not know, and therefore process the tones separate from language in their right temporal lobes. The hypothesis put forward by Klein et al. for the right frontal lobe activation is that it is part of a distributed process for retaining pitch or tone information in working memory.

Gandour, Wong, Hsieh, Weinzapfel, Van Lancker, and Hutchins (2000) performed a similar study earlier in which they had three groups of participants: Thai speakers, Chinese speakers (spoken dialect unspecified), and English speakers. They took tonal Thai words and presented them in a discrimination task similar to Klein et al.'s (2001), but they also presented the words after having filtered them with a low-pass filter. The idea is that the Thai words would become "blurred" and thus be processed by the components responsible for nonlinguistic acoustic processing. Only the Thai speakers showed more cerebral blood flow in the linguistic task than the nonlinguistic task, and the areas of activation were in the left hemisphere, again consistent with the task-dependent theory. The comparison of linguistic task to baseline showed cerebral blood flow in *both* the left and right temporal lobes as well as a lack of differential blood flow in the frontal lobes in *all* participant groups, which is contrary to the differentials found by Klein et al. (2001); the Thai speakers would not be expected to have differential activation in the right hemisphere over baseline. The explanation put forth by Klein et al. (2001) is that all task conditions were harder in Gandour et al.'s (2000) experiment. This is evidenced in the accuracy Gandour et al. (2000) report, which is significantly lower for all groups. The recruitment of the right temporal lobe, however, is still cause for thought and further research.

One of the assumptions being made is that right-handed Chinese speakers are equally as likely to be left hemisphere dominant as right-handed English speakers. Valaki, Maestu, Simos, Zhang, Fernandez, Amo, Ortiz, and Papanicolaou (2004) set out to determine whether this was the case by using MEG while right-handed Mandarin, Spanish, and English speakers (30, 20, and 42 participants, respectively) performed a spoken-word recognition task in their native languages. Spoken-word recognition tasks have traditionally been used in combination with the Wada technique to determine hemisphere dominance. Valaki et al. (2004) used a cutoff value of activation which previously had been tied to hemispheric dominance when compared with the Wada technique to determine that 100% of their Spanish-speaking population, 80% of their English-speaking population, and only 14% of their Mandarin-speaking population were left hemisphere dominant. Of particular importance was that the asymmetry was not merely present in peak activation; the asymmetries present for Spanish and English speakers were also asymmetries in the time course of activation at the resolution afforded by MEG. Concordantly, the Mandarin speakers were symmetrical in the time course of activation bilaterally. However, having seen the results of both Klein et al. (2001) and Gandour et al. (2000), Valaki et al. (2004) emphasized that the spoken-word recognition task does not specifically engage the question of which hemispheres are necessary for lexical decisions. Their results do not point to whether the recruitment of the right hemisphere is *necessary* or merely *redundant* for spoken-word recognition in Mandarin, but Valaki et al. (2004) do believe that their results point to a fundamental difference in the organization of the brain mechanisms for spoken-word recognition in Mandarin speakers.

Future Work

Despite the results from Valaki et al. (2004), neuroimaging studies such as Klein et al.'s (2001) and Gandour et al.'s (2000) seem to indicate that the tonal processing necessary for lexical decision tasks in tonal language speakers happens in the left hemisphere. This does not completely answer the question of whether tone processing is cue-dependent or task-dependent. It is entirely possible that *all* tone processing is recruited over to the left hemisphere for tonal language speakers. Apparently there have not been very many neuroimaging studies involving music to begin with (Peretz & Zatorre, 2005), let alone studies concerning music processing in the brains of tonal language speakers.

While not a neuroimaging study, Bent, Bradlow, and Wright (2006) found results which do speak to the aforementioned issue. They ran native Mandarin and English listeners through a variety of speech and sound discrimination tasks, including a pure tone contour identification task in which the participants had to indicate whether a computer-generated tone was flat, rising, or falling in pitch. The English listeners were actually more accurate than the Mandarin listeners in this task. The differences between groups seemed to be systematic, in that the Mandarin listeners made identification errors consistent with what would be expected if the tones were linguistic in nature; they were more willing to accept certain kinds of errors as fitting within a particular category than English listeners due to expectations from the Mandarin pitch contours. This indicates that there may be at least some form of shared tone processing between things perceived as speech and nonspeech.

Further research needs to be done to determine whether or not there truly is a separation between tone processing for language and tone processing for music (or other forms of nonspeech). If there is a separation, where is it? In a tonal language speaker, is the tone discrimination for music happening in the left hemisphere? Is this information then traveling over the corpus callosum to mix with the other acoustic feature processing in the right temporal lobe, or is tone discrimination equally able to happen in the left hemisphere for language and the right hemisphere for music? Unfortunately these questions do not seem to have been answered yet.

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