Brain Responses to Pitch Perception: Is there a specific function of the right hemisphere?

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Introduction

To date there is still an ongoing debate concering the role of the right hemisphere (RH) in speech processing. Interestingly, recent brain imaging studies observed RH involvement, particularly in the supratemporal plane, whenever human subjects were engaged in various aspects of pitch processing [1,2].

In intonational languages like English and German, pitch is one of most important prosodic parameters. Pitch/F0 modulations in spoken utterances help speakers and listeners to mark differences at the sentence-level, e.g. distinguishing questions from statements. By contrast, surprisingly little is known about the question of how the human brain processes selective prosodic parameters comprised in the speech signal such as pitch/F0 modulations or the role of pitch level in the perception of voice.

Thus, we combined several functional brain mapping methods to identify selective brain regions which are associated with the processing of pitch information.

Experiment 1

In an MEG-experiment the magnetic mismatch negativity (MMNm) of pitch manipulated signals in comparison to a natural voice was measured. 10 native german subjects (4 male) listened to the stimuli, consisted of the German word "Dach" (roof). The standard was produced by a male voice. Deviant 1 (natural stimulus) was produced by a female speaker. Deviant 2 stimuli (pitch-shifted) were generated by lowering the pitch of Deviant 1 stimuli to that of Standard stimuli (~78 Hz). Pitch-adapted stimuli sounded fairly natural, like the voice of an elderly woman. As it is typical for a nonattentive oddball-paradigm subjects were asked to watch a film without sound thereby ignoring all auditory input.

The MMNm elicited by the natural stimulus differed weakly from the standard, whereas the pitch-manipulated signal elicited an increase in overall current density, particularly at about 150-250 ms after word onset (cf. Figure 1). This increase is attributed to the unusualness of the low pitch female voice. The data strongly suggest that the RH regions mediate the processing of pitch-altered speech voices (cf. Figure 2).

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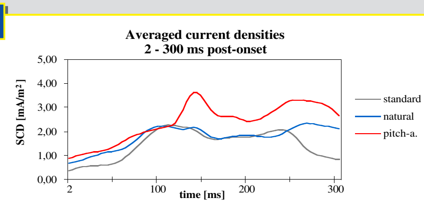

Average brain responses to the standard stimulus (natural male voice), deviant1 (natural female voice) and deviant2 (pitch-altered signal) from 2-300 ms post onset, measured as Surface Current Density [mA/m²].

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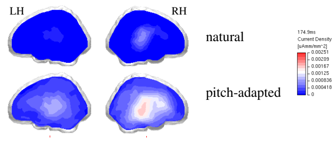

Average SCD maps of the brain responses to deviant1 (natural female voice)(top row) and deviant2 (pitch-altered signal) (bottom row).

Experiment 2

A further MEG-experiment was performed to investigate the brain responses to normal and manipulated pitch information at the sentence-level. Analogous to previous ERP-studies [3] syntactically correct ("*The child was lost.*") and incorrect ("*The child was in the lost*") sentences were presentend auditorily whereby processing the latter normally elicits an early left anterior negativity (ELAN). In particular, this study tested the hypothesis that the degree of lateralization of this early syntax-related negativity depends on the reliance on prosodic cues available in the auditory sentence input. Therefore, the pitch of sentences was flattened by artificial resynthesis. Magnetic field density maps (cf. Figure 3) illustrates that syntactic violations evoked early bilateral responses. Brain responses to pitch flattened sentences were lateralized to the right hemisphere.

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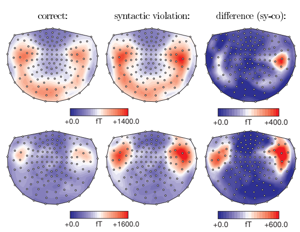

Topographical maps of the surface derivative of correct and incorrect sentences as well as the difference (incorrect - correct) for pitch-flattened sentences (top row) and regular sentences (bottom row). Brain responses to syntactically incorrect sentences between 120-200 ms are lateralized to the right hemisphere for the pitch-flattened condition (top right). Sentences with regular pitch information yield a symmetrical response (bottom right).

Experiment 3

This ERP-study investigated the processing of prosodic information in spoken dialogues. Subjects listened to sentences varying the position of sentence accent realized by pitch modulation. Sentences were preceded by wh-questions requiring narrowly focused constituents in the answers. Answers were given in four conditions: correct or incorrect prosodic patterns either with normal pitch information or a flattened pitch contour. The ERP data show an increased frontal negativity for the pitch-flattened sentences in contrast to normal sentences (cf. Figure 4). Analogous to Experiment 2, the right lateralized topography of this negativity points to an essential role of right hemisphere areas whenever sentences lacking pitch variations have to be processed. Presumably, this increased negativity corresponds to an increased effort for extracting missing pitch modulations from monotonous sounding sentences.

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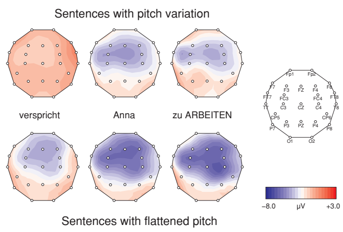

Exemplary activation maps of the fragments from appropriate verb-focussed sentences illustrate an increased frontal negativity during the perception of pitch flattened sentences.

Experiment 4

By means of fMRI measurements the present study aimed to identify the particular brain regions associated with processing pitch manipulated sentences (cf. Figure 5). Subjects listened to syntactically and lexically correct sentences comprising either a natural or unnatural pitch contour. Comparing the brain responses to natural vs. flattened sentences reveals that no brain regions subserve more strongly in processing natural speech whereas several cortical areas, particularly in the right frontal and right posterior temporal cortex responded more clearly to flattened sentences (cf. Figure 6). Analogous to the aforementioned EEG- and MEG-experiments the brain allocates more effort when missing prosodic information has to be substituted.

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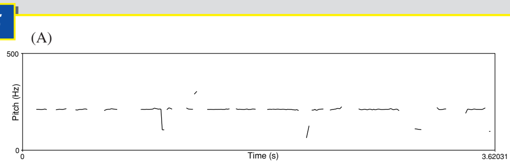

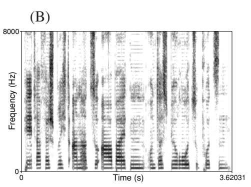

(A) Pitch tracking of pitch-flattened speech signals demonstrates missing sentence melody, whereas the narrow-band spectrogram (B) reveals a broad range of spectral frequencies (0-8 KHz). In linguistic terms it means that syntactic and lexical information is still present.

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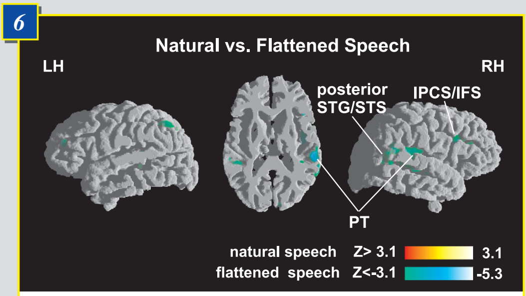

Intersubject-averaged brain responses (N=14) for natural and pitch-flattened speech are superimposed onto a 3D normalized and white matter segmented reference brain.

Discussion

We performed a series of auditory studies based on Event Related Brain Potentials (ERPs), on data obtained from MEG and on hemodynamic responses using event-related fMRI. Our aim was to analyze the brain's reaction to correct and manipulated pitch presentation in spoken German utterances, and in single words. The pitch manipulations were conducted using speech resynthesis techniques resulting in speech signals containing either flattened pitch or low pitch voices. The ERPs of one study investigating sentences elicited a significant sustaining right frontal component which was more negative for specific pitch mismatch as compared to pitch match conditions. To compensate the parsimonious spatial resolution of ERP surface data, source modeling of analogous MEG data was performed. The Surface Current Density maps gained from two MEG-studies indicated significantly stronger involvement of the right frontal and temporal cortex when subjects listened to sentences and single words lacking natural pitch information. Finally, an event-related fMRI study also investigating normal and manipulated pitch information observed stronger brain activation in right posterior temporal as well as right inferior frontal areas when subjects listened to sentences with flattened as compared to natural pitch contour.

Conclusion

Given the data at hand, it can not be concluded that a particular brain region is selectively responding to pitch modulations, but the combined pattern of results suggest that several cortices in the right perisylvian region are obviously more strongly recruited when anomalous pitch information has to be processed. However, it is not yet clarified how the right hemisphere contributes to the processing of pitch manipulated material precisely. Whether the stronger responses to pitch manipulated material might be attributed to the mismatch between spectral properties and F0 and/or to repair/re-analysis functions will be subject to further discussion.

References

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[2] Klein, D. et al. (2001). *NeuroImage* 13. 646-653.

[3] Hahne, A. & Friederici, A.D. (1999). *J Cog Neurosci* 11. 194-205.