Analysis of timbral micro variations of noisy musical sounds using computational models of the auditory periphery and multidimensional scaling

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introduction

Neurophysiological and psychophysical findings on the auditory peripheral processing suggest that human perceptual system, from the early stages of processing, focuses on those components of the acoustic signal which are most likely to contain significant information-bearing elements.

perceiving categorically in vision

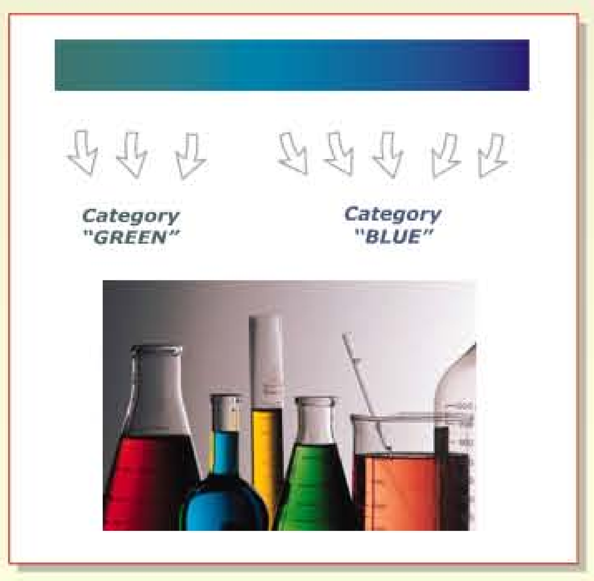

FIG. 1: The illustrated continuum of wave-lengths is perceived in the form of discrete color categories.

This characteristic trend is closely related to a fundamental function of human cognition, by which various sensory stimulations of continuous nature are transformed and represented in the form of discrete perceptual states, subsequently organized into different classes of experience (categories).

The psychophysical approach to categorical perception of sensory continua is elaborated through two basic experimental tasks: identification (labelling stimuli) & discrimination (telling stimuli apart).

Indications of categorical perception: "Equal-sized physical differences between stimuli are perceived as larger or smaller depending on whether the stimuli are in the same category or in different ones" (Harnad, 1997).

Experimental research on the categorical perception of various sensory continua showed that discrimination acuity is expected to be worse within categories than at boundary regions.

objective

The present investigation is focused on the hypothesis whether there is an indication of categorical perception characteristics within the primary or peripheral auditory processing (pre-categorical stages of processing) for musical timbre - related continua.
Our primary concern was to quantify computationally the variation of "discrimination sensitivity" in the post-synaptic auditory nerve, using as stimuli a series of timbral micro variations, which form a transition in physically equal steps, between two discrete timbral categories: a clear flute tone (category A) and a flute-plus-noise one (category B).

method - stimuli

The timbral transition was constructed applying a systematic variation to a timbre related physical parameter of the flute tone – i e the proportion of tonal to noise spectral components – by equal amounts, according to the following procedure:

STEP 1: A generative signal *f(t)* of a steady-state flute tone (A5-880 Hz), 100 msec in duration, was synthesized at a sampling rate of 44100 Hz.

STEP 2: A noisy signal *n(t)*, the prototype of category B, was produced from *f(t)* by cutting off narrow bands around the distinct tonal components of the spectral envelop (FIG. 3a).

STEP 3: A tonal signal *sf(t)=f(t)-n(t)*, the prototype of category A, was resulted from *f(t)* by removing all non-tonal ("noisy") spectral components (FIG. 3f).

STEP 4: The whole set of variations was produced by adding signals *sf(t)* and *n(t)* according to the formula: $x_{mean}(t)$: $x(t)=a\cdot sf(t)+b\cdot n(t)$, where $a,b>0$. Then *a* and *b* were varied successively by a step of 2.5% and in each case a+b was equal to 100%.

VAR 1: 0%max(P_{tonal}) & 100%max(P_{noise}) – FIG. 3a
VAR 2: 2.5%max(P_{tonal}) & 97,5%max(P_{noise})
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VAR 40: 97.5%max(P_{tonal}) & 2,5%max(P_{noise})
VAR 41: 100%max(P_{tonal}) & 0%max(P_{noise}) – FIG. 3f

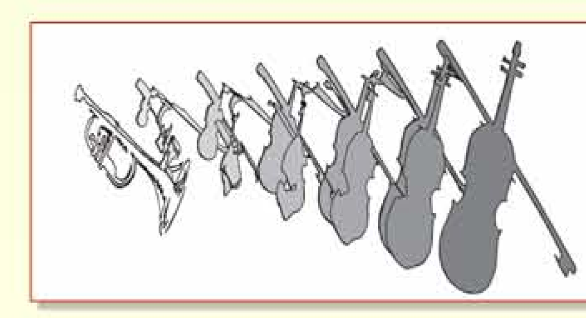

***FIG. 2:** Graphical analogue of a timbral transition (Kretz, 2002, Journal of New Music Research)*

Mean power spectra for variations no. 1, 9, 17, 25, 33 and 41 are illustrated in figures 3a -3f (see below).

Pitch, loudness and total duration were kept constant.

method - analysis

3D graphs of the corresponding Neural Activity Patterns (NAPs) in the post-synaptic auditory nerve were plotted for all micro variations using Paterson, Allerhand and Giguere's computational model of the auditory periphery (Paterson et al., 1995). NAPs that correspond to variations no. 1, 9, 17, 25, 33 and 41 are illustrated in figures 4a -4f (see below).

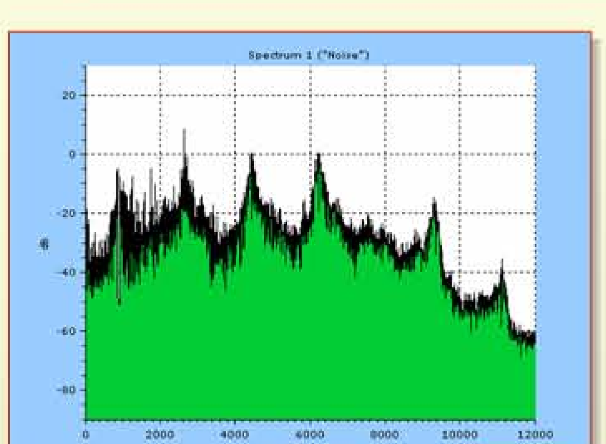

FIG. 3a

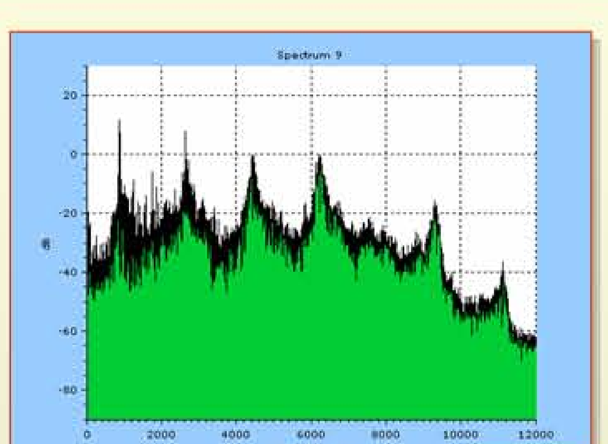

FIG. 3b

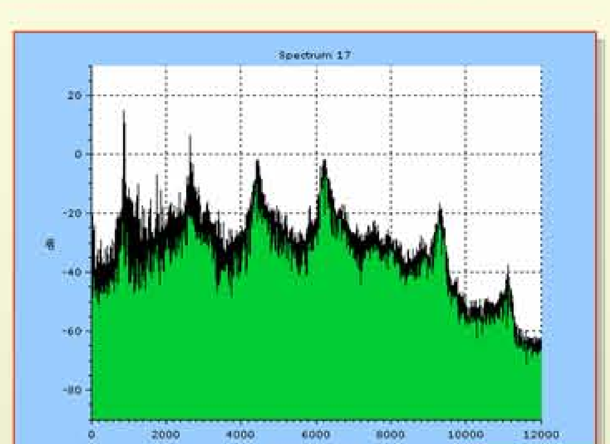

FIG. 3c

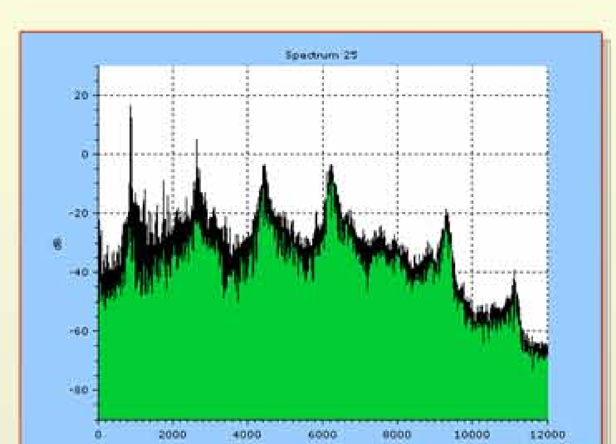

FIG. 3d

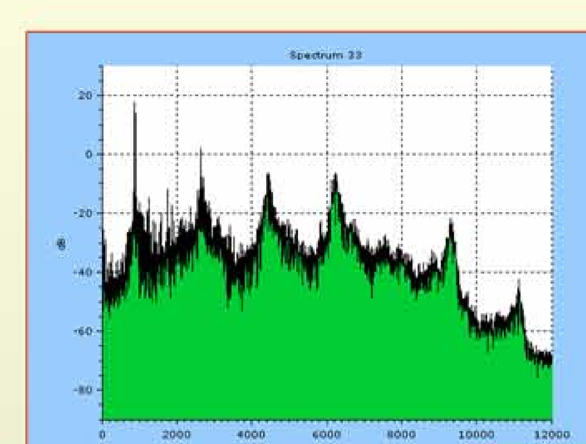

FIG. 3e

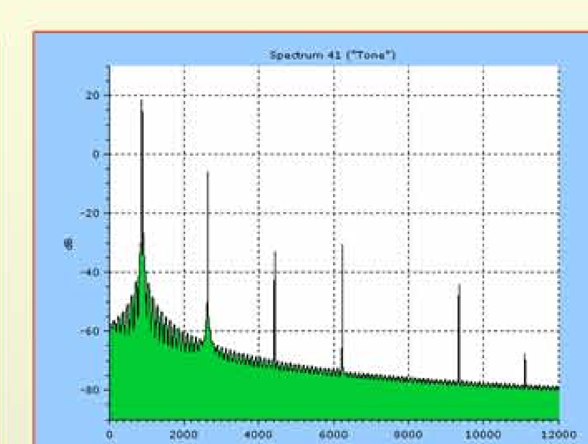

FIG. 3f

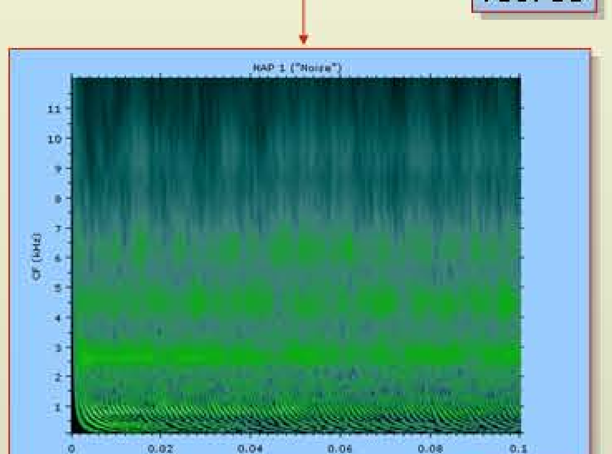

FIG. 4a

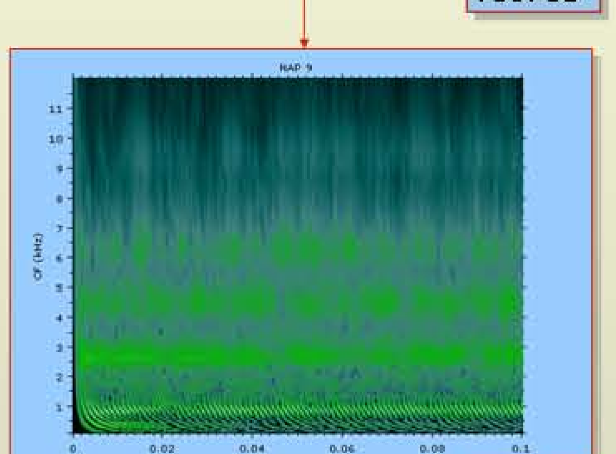

FIG. 4b

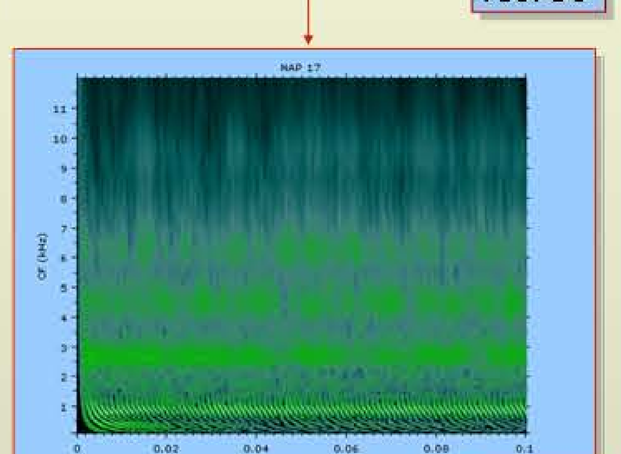

FIG. 4c

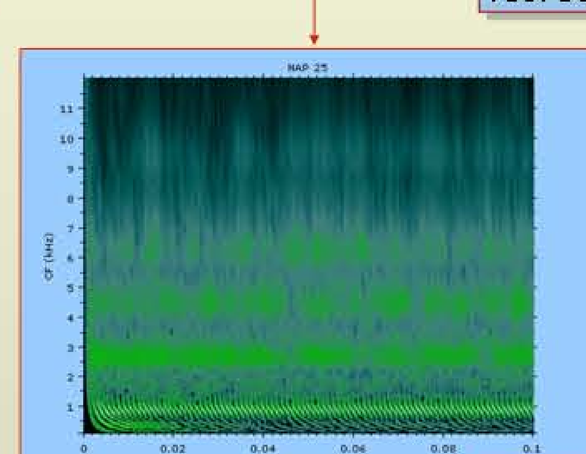

FIG. 4d

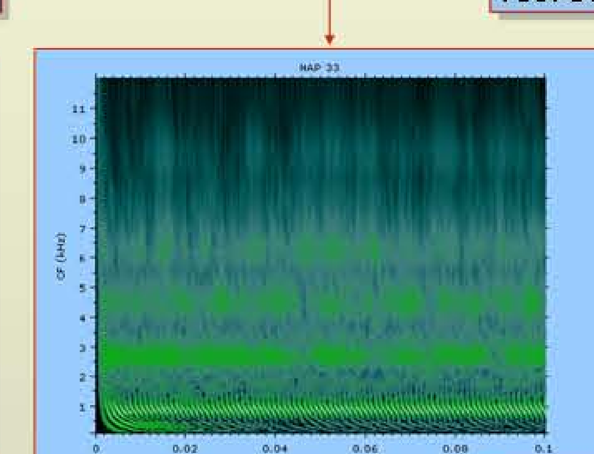

FIG. 4e

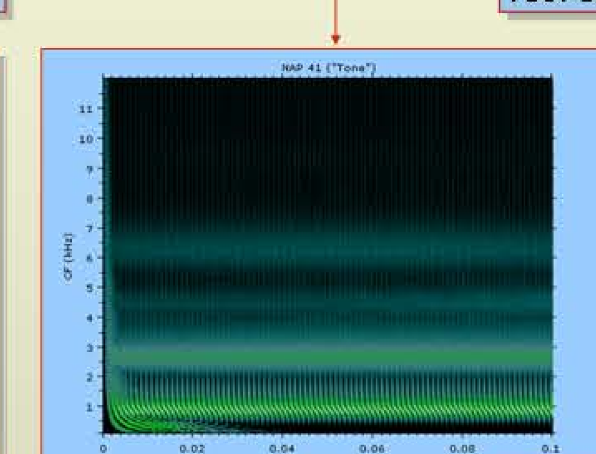

FIG. 4f

results & discussion

Distances for all adjacent NAPs were used as a metaphor for the psychophysical notion of "discrimination sensitivity" at that level of processing, and they were calculated adopting Euclidean distance metrics by the formula:

$$d_{f_k}(i,j)=\frac{1}{N_\tau}\sum_{\tau}\left|NAP_{\mu_i}(f_k,\tau)-NAP_{\mu_j}(f_k,\tau)\right|$$

Distance calculations and subsequent MDS analyses were performed for neural activation distributions both within each cochlear frequency channel (FIG. 5a) and across all channels (FIG. 5b).

Equal-sized physical differences along the continuum are distorted (FIG. 5b) and the characteristic one-dimensional distribution of points for the mean neural activity reveals a reverse "discrimination function" (i e reduced "discriminability" towards boundary regions and increased "discriminability" near the best exemplars within each category), in comparison to the classical categorical perception paradigm.

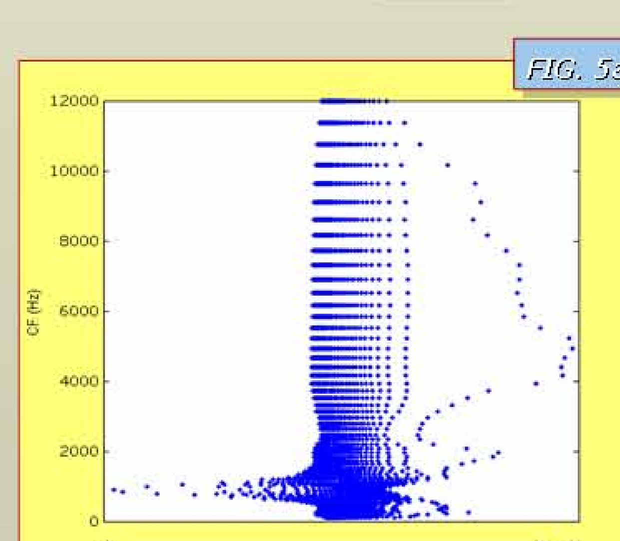

FIG. 5a

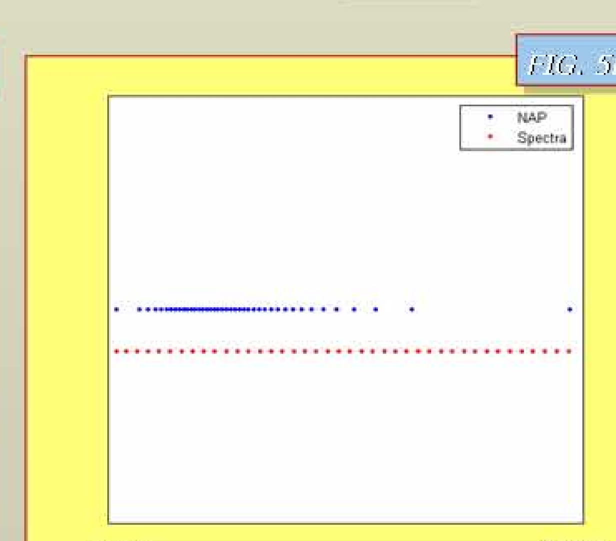

FIG. 5b

CONTACT INFO:

further research

An extension of the present research which is currently running, aims at a mapping of the same timbral continuum at the output of the whole perceptual process, through an elaboration of discrimination psychoacoustical tests, by presenting pairs drawn from the same set of stimuli, to real listeners.