Two Time Scales in Speech Processing

Maria Chait*, Steven Greenberg, Takayuki Arai***, Jonathan Z. Simon**** and David Poeppel***

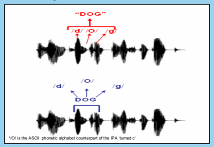
**Neuroscience and Cognitive Science Program, Cognitive Neuroscience of Language Lab, Department of Linguistics, University of Maryland College Park*
*** Centre for Applied Hearing Research, Technical University of Denmark, Kgs. Lyngby, Denmark*
****Department of Electrical and Electronic Engineering, Sophia University, Tokyo*
*****Departments of Biology and Electrical & Computer Engineering, University of Maryland College Park*

INTRODUCTION

The basic units into which the acoustic speech signal is perceptually segmented is an issue of central importance for speech research. A growing body of research points to the perceptual importance of both the phonetic segment and the syllable during the course of speech processing. These, often contradictory, findings have led to two kinds of popular models of speech segmentation. In one, the speech stream is initially segmented into phonemic segments which are later combined to create supra-segmental units. The second model assumes that the syllable is the basic unit of speech perception, with the phone serving as a secondary unit of analysis (Figure 1). The first model accounts for fast subjects' reaction time data in phoneme-detection tasks[1] while the latter one accounts for the results obtained using the structural induction paradigm (see [2][3][4][5]). At the same time it is clear that neither model alone can accommodate the full spectrum of experimental results.

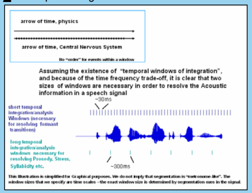
Here we propose a different model (Figure 3) - one that attempts to reconcile these seemingly contradictory findings and suggest a new method of systematically examining the extraction and subsequent combination of the informational constituents of the speech signal.

1 Existing models



*/O/ is the ASCII phonetic alphabet counterpart of the IPA 'turned c'

2 Temporal Integration Windows

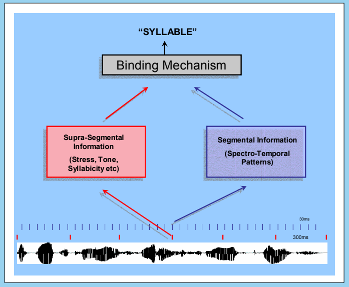


arrow of time, physics
arrow of time, Central Nervous System
No "order" for events within a window
short temporal integration/analysis Windows (necessary for resolving formant transitions)
~30ms
long temporal integration/analysis windows necessary for resolving Prosody, Stress, Syllabicity etc.
~300ms

Assuming the existence of "temporal windows of integration", and because of the time frequency trade-off, it is clear that two sizes of windows are necessary in order to resolve the Acoustic information in a speech signal

This illustration is simplified for Graphical purposes. We do not imply that segmentation is "metronome-like". The window sizes that we specify are time scales – the exact window size is determined by segmentation cues in the signal.

3 Suggested model



"SYLLABLE"
Binding Mechanism
Supra-Segmental Information (Stress, Tone, Syllabicity etc)
Segmental Information (Spectro-Temporal Patterns)
30ms
300ms

MULTI-RESOLUTION ANALYSIS MODEL

The MRA model is based on the notion of **Temporal Integration Windows** (Figure 2). According to this view, the CNS treats time not as a continuous stream but as a series of temporally quantized windows and extracts data from each window[6].

We believe that segmental and supra-segmental information are extracted separately but simultaneously from the input stream from "short" (~30ms) and "long" (~300ms) windows of integration. These streams are then bound together to create a stable representation (we refer to it as the "SYLLABLE") that constitutes the input for higher-order processing associated with lexical access. According to this model, syllable-sized units, as well as phoneme-sized units, are **equally fundamental**. The precise type of information extracted from these temporal-integration windows depends on phonological and prosodic constraints specific to the listener's native language.

MODEL PREDICTIONS

1. Both low frequency (supra-segmental) and high frequency (segmental) information are necessary for successful speech processing.
2. The two streams are initially analyzed separately.
3. The binding of the two streams occurs with a delay of approximately 200-300 ms.
4. Once the stable representation has been created, we expect segmental and supra-segmental information to be perceptually integral (interference effects are symmetric)[7] [8] [9]

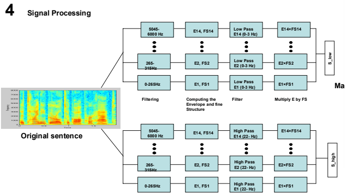
METHODS

Our signal processing technique (Figure 4) is an extension of Drullman's [10] analysis-resynthesis scheme (developed for experiments in [11]) and is based on overwhelming evidence as to the significance of the temporal envelope of the acoustic signal for successful speech processing ([12] [13] [14]).

The original wide band speech signal is split into 14 frequency bands with an FIR filter bank spanning the range 0-6kHz spaced in 1/3 octave steps across the acoustic spectrum. The amplitude envelope from each band is computed by means of a Hilbert transform and then either low (0-3Hz) or high (22-40Hz) band passed before being combined again with the original carrier signal.

The result for each original signal (S) is S_low and S_high, containing only low or high modulation frequencies, which correspond to the extraction of supra segmental and segmental units (Figure 5) .

4 Signal Processing



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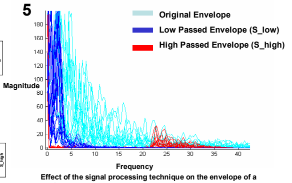


Effect of the signal processing technique on the envelope of a sentence

PROCEDURE

Experiment 1 (N=36)

Stimuli: 53 sentences from the IEEE corpus.
All stimuli were processed under 3 conditions:

0-3 Hz Low Pass	(presented Diotically)
22-40 Hz Band Pass	(presented Diotically)
0-3 and 22-40 Hz	(presented Dichotically)

Procedure:
Stimuli were delivered via Sennheiser HD580 head-phones. The presentation was counter-balanced to eliminate ear effects.
Each subject heard all 53 sentences but only one condition per sentence.
A practice block of 26 sentences preceded the experiment.

Task: subjects were asked to write down what they heard as precisely as possible.

Experiment 2 (N=150)

Stimuli: 36 sentences from Experiment 1.
All stimuli were 0-3 and 22-40 presented dichotically. Experimental conditions:

onset asynchrony (0-350ms)
low leading/high leading
ear of presentation

Procedure and Task was the same as Experiment 1

Responses in both experiments were scored by counting the number of correct syllables in all words.

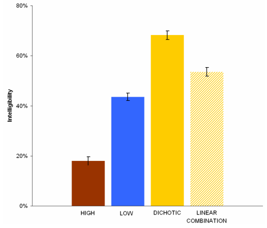
EXPERIMENT 1:

Mean (S.E)

The values on the y axis reflect intelligibility scores (max=1)

The derived variable 'predicted' is computed as $1-[(1-High)\times(1-Low)]$ and reflects the expected performance in the 'dichotic' condition if 'high' and 'low' are added linearly.

All differences are highly significant at p<0.001



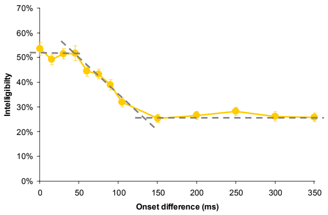
This finding suggests a non-linear interaction between the performance on 'dichotic' and the performance on 'high' and 'low.

* Presented here is the grand average analysis the same results are found in the analysis by items

EXPERIMENT 2: INTRODUCING A TIME-SHIFT BETWEEN 'LOW' and 'HIGH'

we introduce a time-shift in the onset of S_low relative to S_high to investigate the temporal properties associated with the binding mechanism.

No differences were found between high-leading/low-leading conditions. Asynchronies less than 45 ms have no effect on intelligibility; performance declines sharply between 30-150 ms, remaining constant beyond that interval.



This evidence suggests that segmental and supra-segmental information are extracted separately but simultaneously from the input stream and then bound together to create a stable representation

SUMMARY AND CONCLUSIONS

- Performance on the 'low' condition alone is relatively high, consistent with previous findings[10].
- Speech intelligibility is significantly increased when both low and high frequency modulation information is available to the listener. This finding is inconsistent with claims that only low frequency modulations contribute to speech understanding.
- Performance on the 'dichotic' condition is significantly higher than the sum of the performances on 'high' and 'low' conditions. This finding suggests the existence of a binding process in which the two information streams are joined together to create a composite representation that is more than the sum of its parts.

FUTURE WORK:

- In Experiment 3 we will investigate electrophysiological (MEG) correlates of multi-time-resolution binding.

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