The role of the cochlea in Human speech recognition

Where is the speech information lurking?

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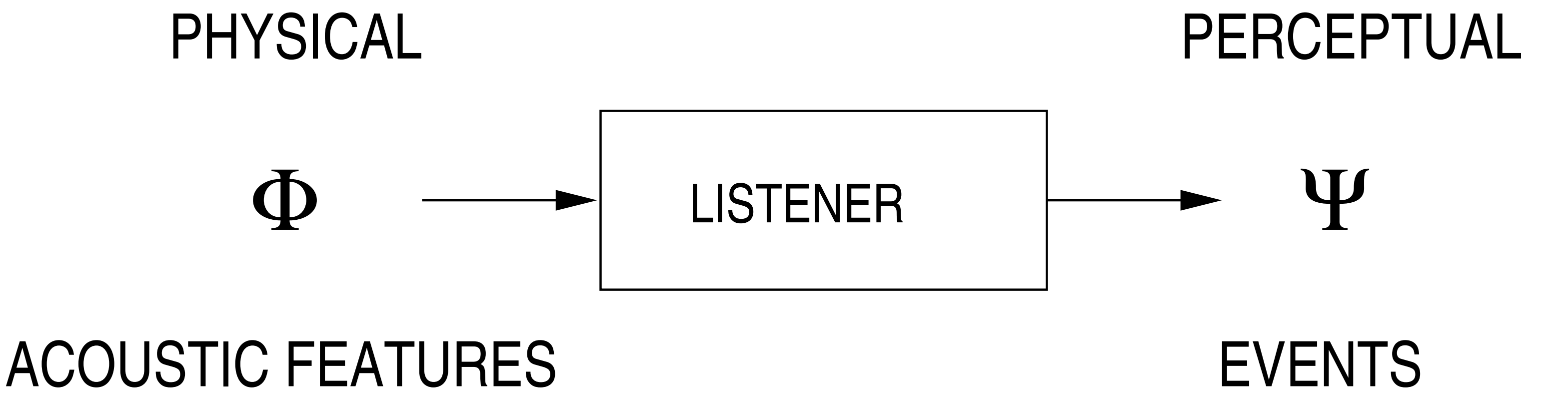
Objective



- Develop rigorous procedures for analyzing and modifying speech in noise, to:
  - identify perceptual features, denoted events
  - Develop a theory of human speech recognition (HSR) based on two basic measures:
    1. AI-Gram (speech audibility measure)
    2. Confusion matrix (speech discrimination measure)
- Show that across-frequency timing cues are events

Human listeners as a Shannon Channel

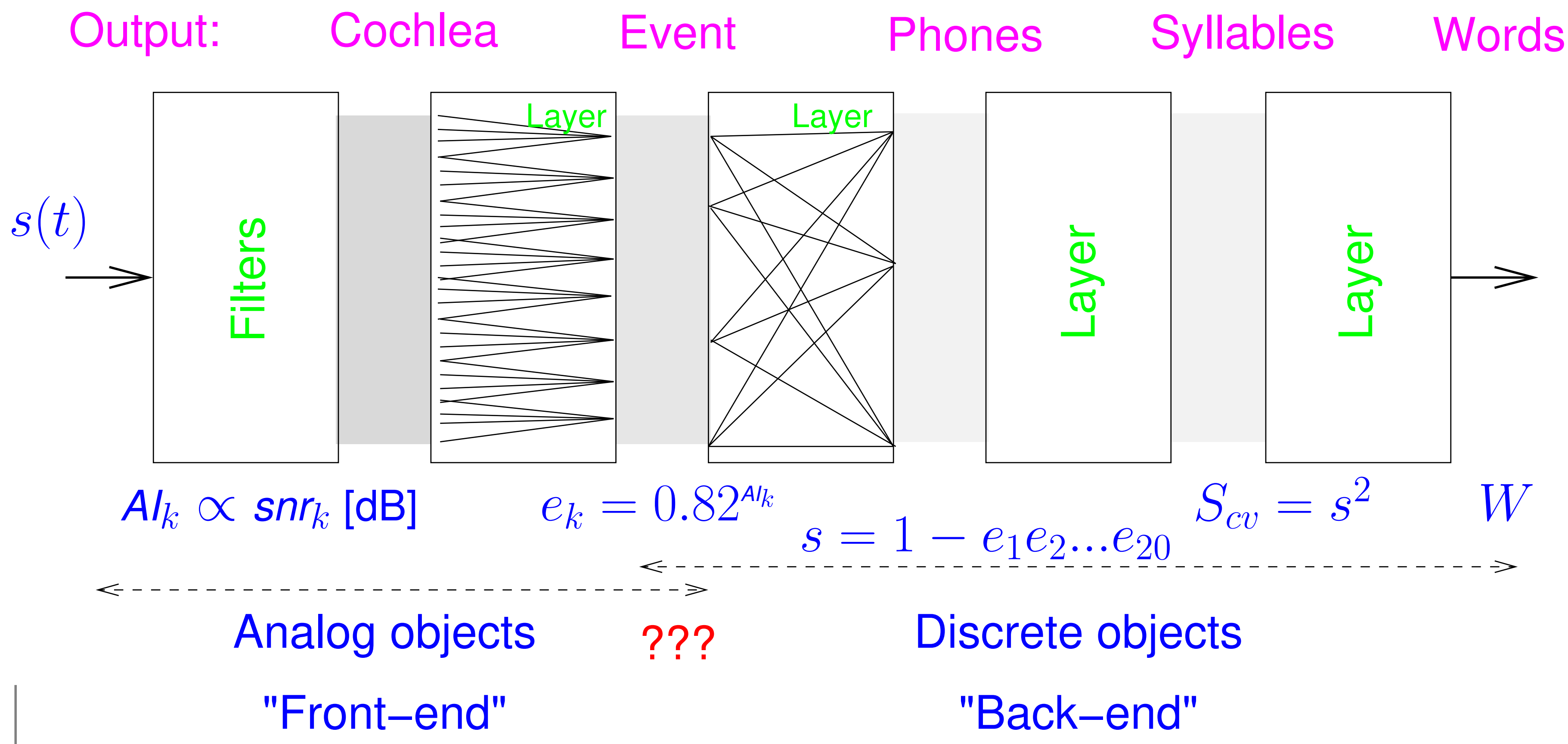
- My approach is inspired by information theory using a classic 3-pronged approach: Simplify, simplify, simplify
  1. The Channel capacity theorem gives the maximum information rate as:

$$\mathcal{C} \equiv \int \log_2 \left(1 + snr^2(f)\right) df \tag{1}$$

  2. The basic idea is to use a Maximum entropy (MaxEnt) speech source, and reduce the maximum information rate for by increasing the noise.
- Take full advantage of *Articulation Index* predictions of the average phone score $s = P_c(AI)$

Model of human speech recognition (HSR)

- The research goal is to identify *elemental HSR events*
  - An event is defined as a *perceptual feature*
  - Event errors are measured by band errors e_k



Articulation Matrices and *elemental events*

- Miller-Nicely's 1955 articulation matrix $\mathcal{A}$ measured at [-18, -12, -6 shown, 0, 6, 12] dB SNR

TABLE III. Confusion matrix for $S/N = -6$ db and frequency response of 200–6500 cps.

STIMULUS \ RESPONSE	*p*	*t*	*k*	*f*	*θ*	*s*	*ʃ*	*b*	*d*	*g*	*v*	*ð*	*z*	*ʒ*	*m*	*n*
p	80	43	64	17	14	6	2	1	1		1	1			2	
t	71	84	55	5	9	3	8	1				1	2		2	3
k	66	76	107	12	8	9	4					1			1	
f	18	12	9	175	48	11	1	7	2	1	2	2				
θ	19	17	16	104	64	32	7	5	4	5	6	4	5			
s	8	5	4	23	39	107	45	4	2	3	1	1	3	2		1
ʃ	1	6	3	4	6	29	195		3							1
b	1			5	4	4		136	10	9	47	16	6	1	5	4
d							8	5	80	45	11	20	20	26	1	
g					2			3	63	66	3	19	37	56		3
v				2		2		48	5	5	145	45	12		4	
ð					6			31	6	17	86	58	21	5	6	4
z					1	1	1	7	20	27	16	28	94	44		1
ʒ								1	26	18	3	8	45	129		2
m	1							4			4	1	3		177	46
n					4			1	5	2		7	1	6	47	163

STIMULUS

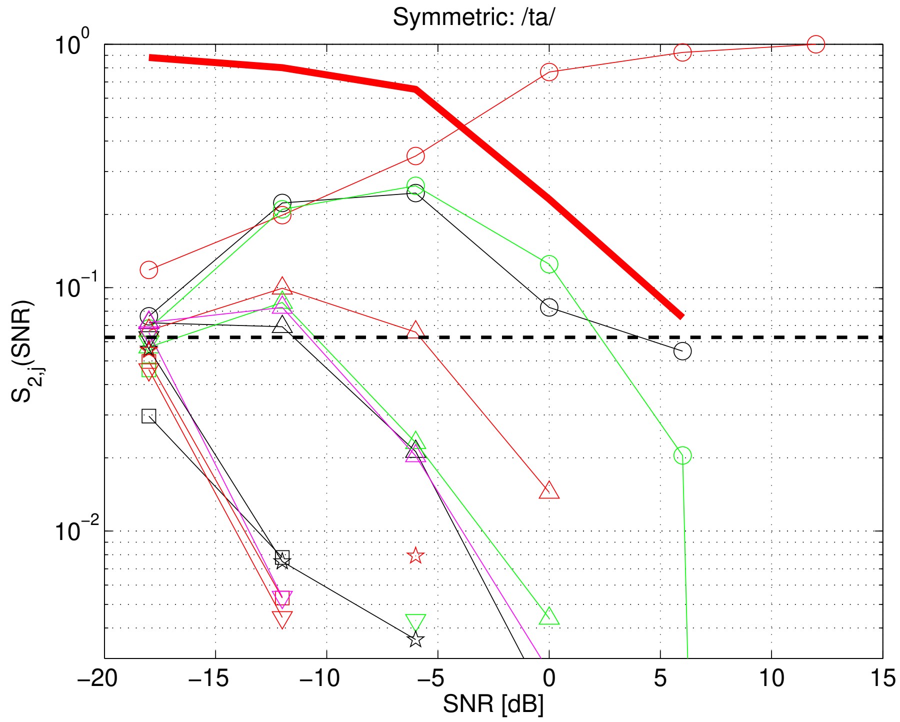
UNVOICED VOICED NASAL

RESPONSE

- Confusion groups imply underlying elemental events

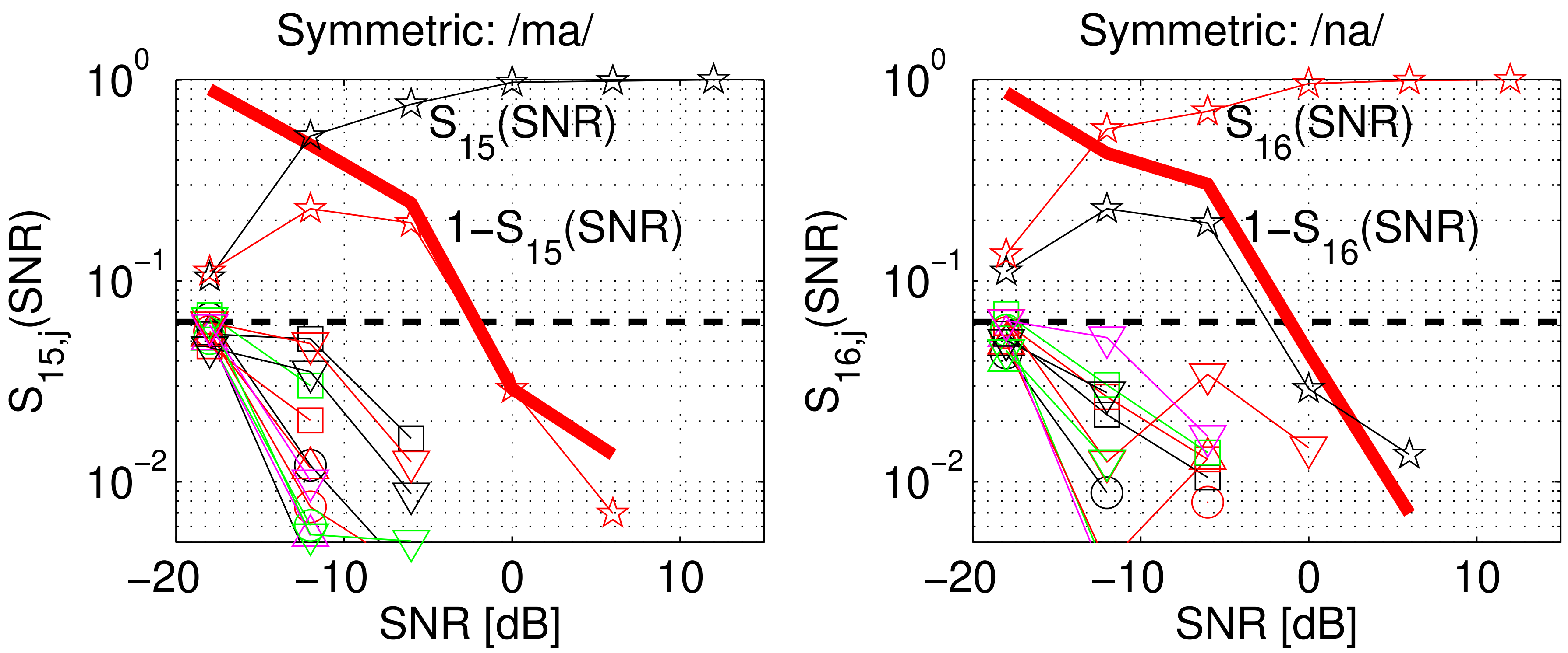
Case of /pa/, /ta/, /ka/ with /ta/ spoken

- Phone groups imply sub-phonemic units (i.e., events)



- How many events, and of what form?
- Plot of $\mathcal{A}_{i,j}(snr)$ for row i =2
- Solid red curve is total error $e_2 \equiv 1 - \mathcal{A}_{2,2} = \sum_{j\neq 2} \mathcal{A}_{2,j}$

The case of /ma/ vs. /na/

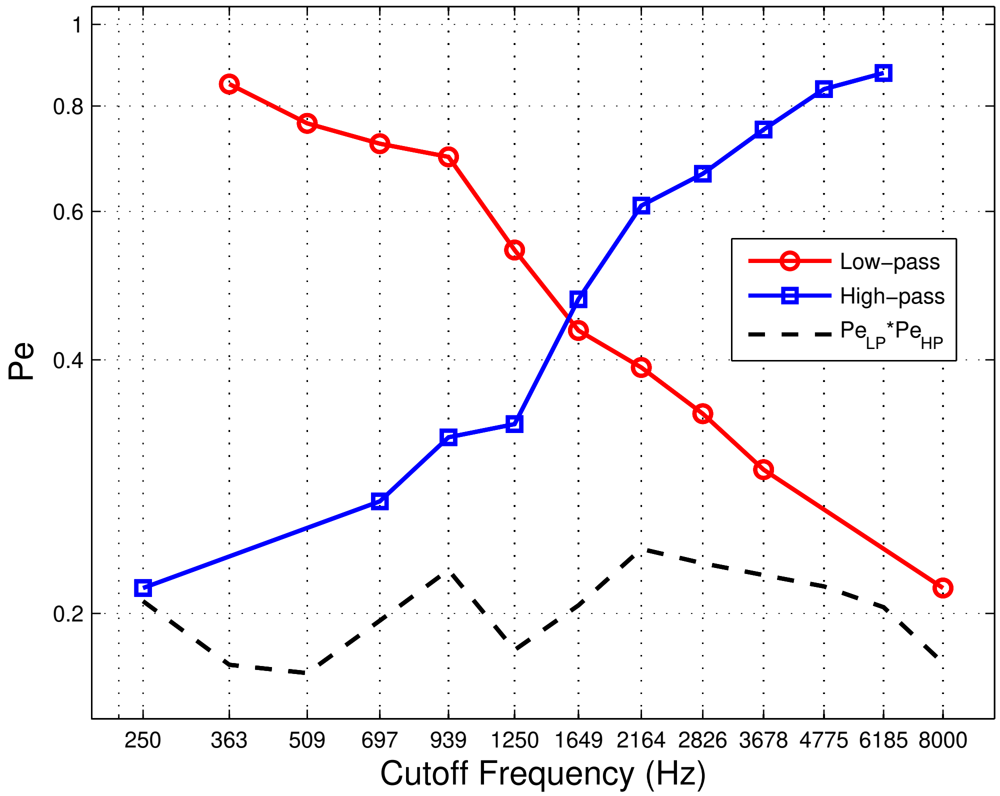


- This 2-group of sounds is closed since $\mathcal{A}_{/ma/,/ma/}(\mathit{SNR}) + \mathcal{A}_{/ma/,/na/}(\mathit{SNR}) \approx 1$
  - There can be only 1 event
  - Solid red curve is the total error: $e_i \equiv 1 - \mathcal{A}_{i,i} = \sum_{j \neq i} \mathcal{A}_{i,j}(\mathit{SNR})$

Fletcher's Lopass/Hipass result

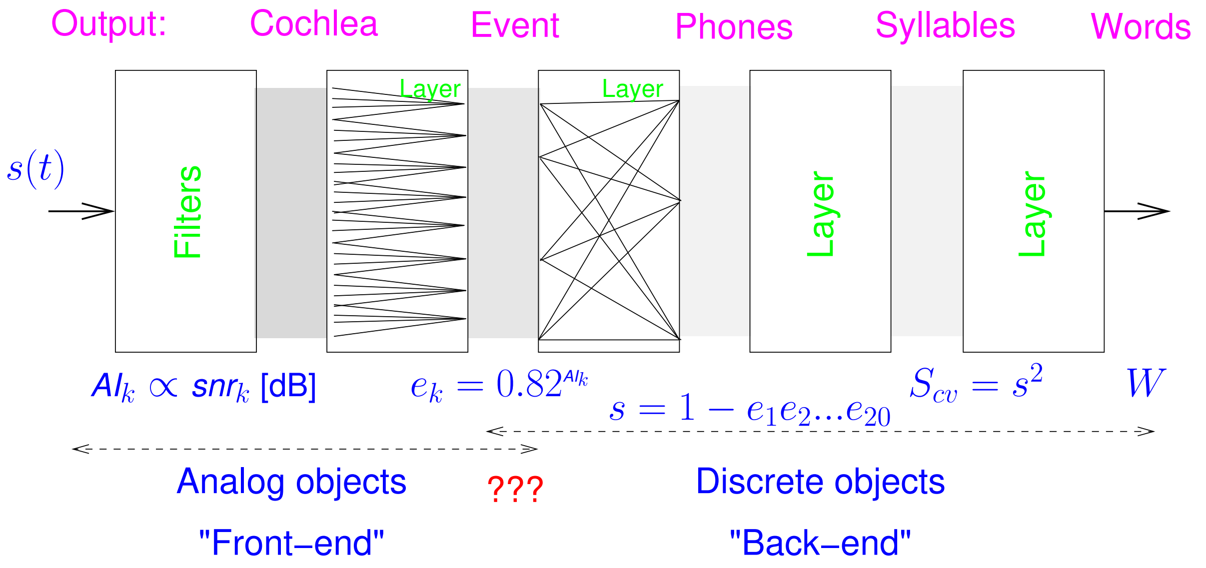
- The AI is based on the *band error product formula*

$$1 - P_c(SNR) \equiv e_{total}(SNR, f_c) = e_{lp}(SNR, f_c) e_{hp}(SNR, f_c) \quad (2)$$



Probabilistic measures of recognition

- k^{th} band articulation index: $AI_k = \frac{10}{30}\log(1 + c^2 snr_k^2)$
  - $c = 2$, $k = 1 \cdots K$ with $K = 20$
- Band (event) error: $e_k = e_{\min}^{AI_k/K} = \sqrt[20]{0.02}^{AI_k} = 0.822^{AI_k}$
- The $AI \equiv \frac{1}{K}\sum_k AI_k$, **?**
- MaxEnt phone score: $s = 1 - e_1 e_2 \ldots e_K = 1 - e_{\min}^{AI}$

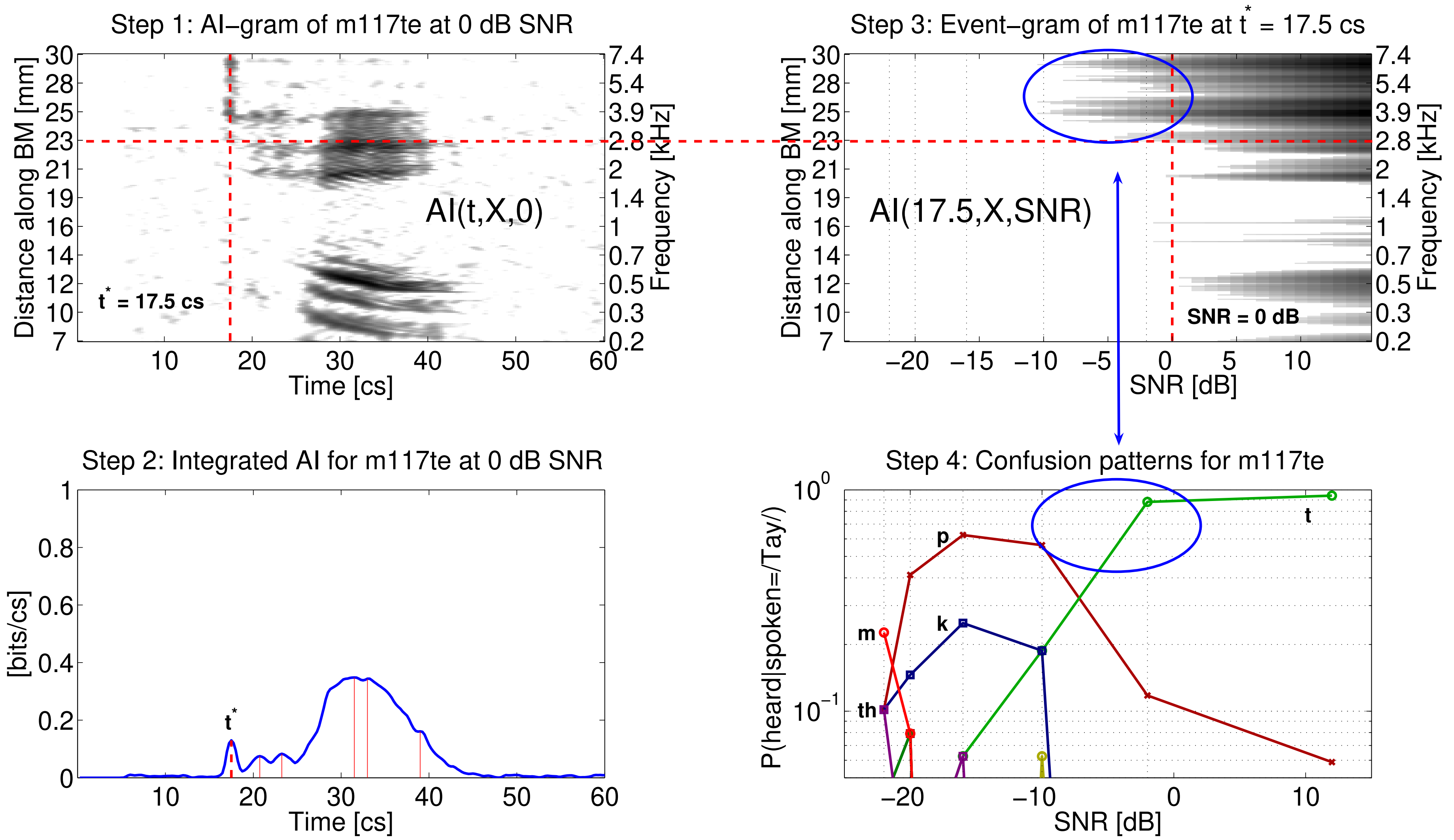


- MaxEnt syllable model score: $S_{cv} = s^2$, $S_{cvc} = s^3$

How can we find events?

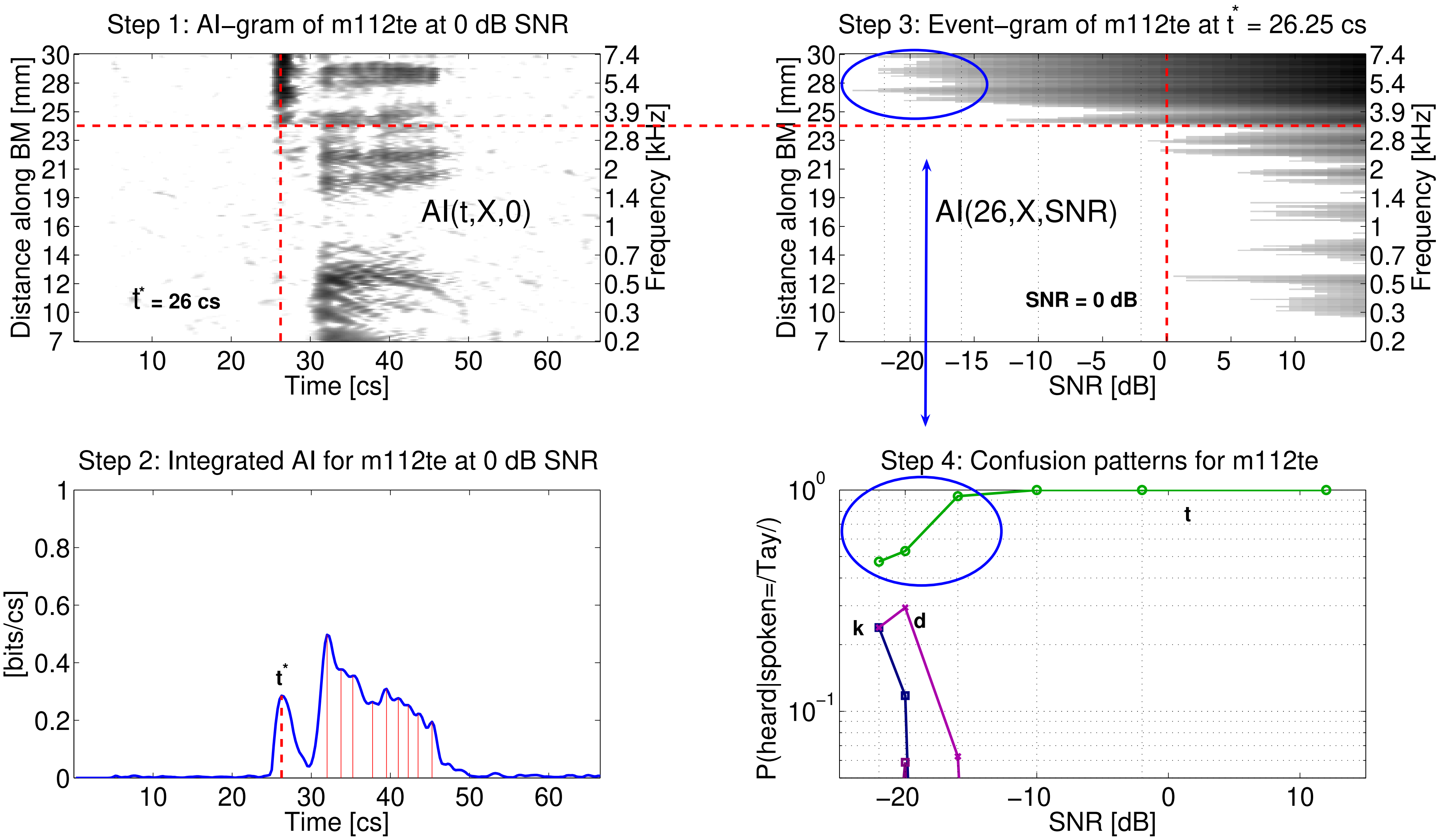
- A *4-Step analysis* relates confusions to an audibility measure (???):
- Modification of speech sounds
  - We developed a tool based on the Short-Time Fourier Transform (STFT) (?) that allows us to selectively:
  - Mask with noise specific time and frequency regions
    - so that this specific part of the speech becomes inaudible
    - selectively amplify specific regions
    - to increase intelligibility
    - We will present audio examples of original and modified sounds

m117/tɛ/ in speech-weighted noise



- /t/ confusion threshold at $P_c(SNR^* = -2) = 0.9$ correlated to Event-gram

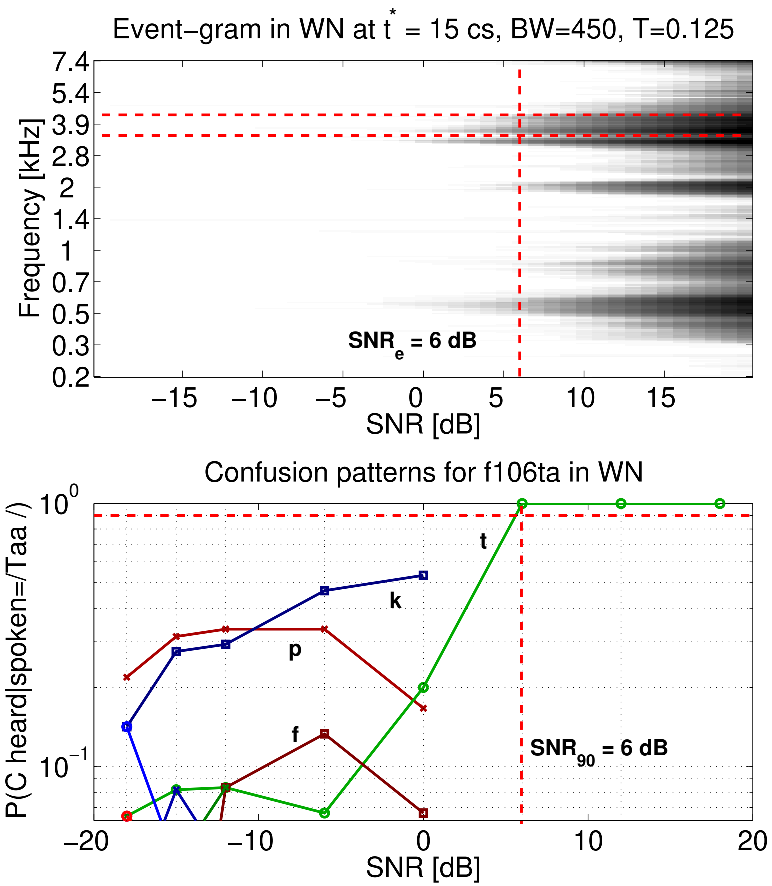
m112/tɛ/ in speech-weighted noise



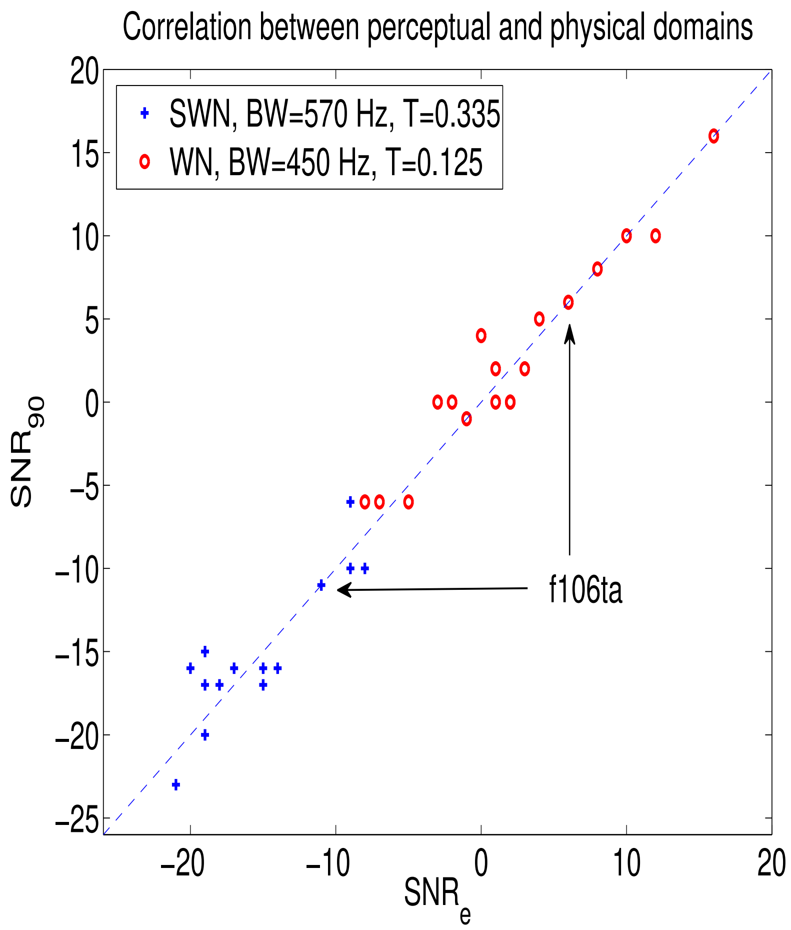
- /t/ confusion threshold at $P_c(\mathit{SNR}^* = -16) = 0.9$ correlated to Event-gram

Correlations of /t/ events

- High correlation across all /t/'s in the database

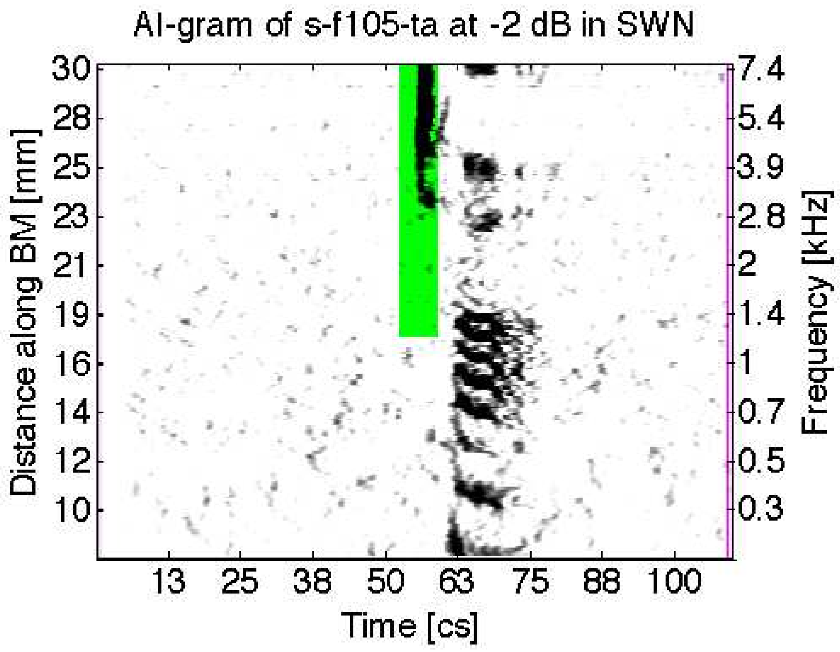


(a)

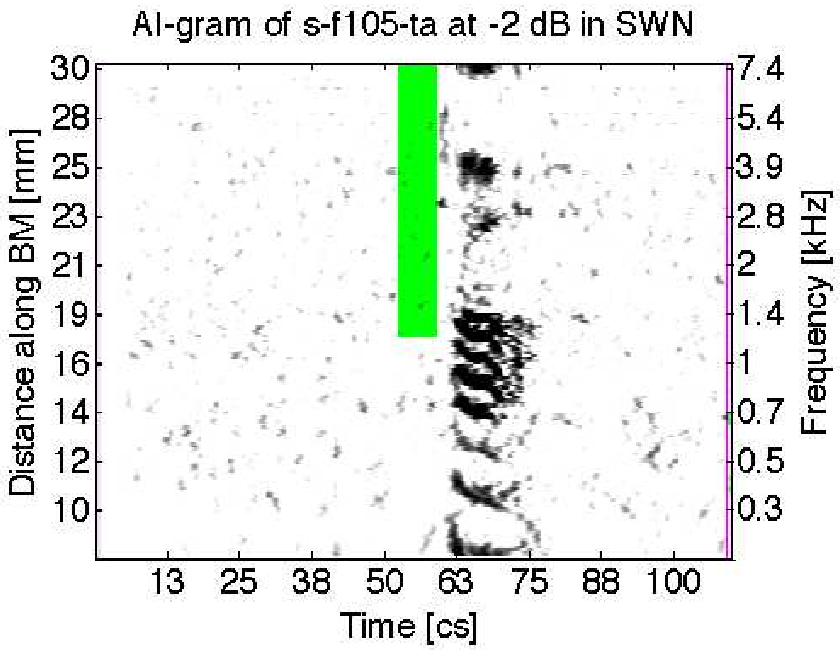


(b)

Masking of /tɑ/ timing cue



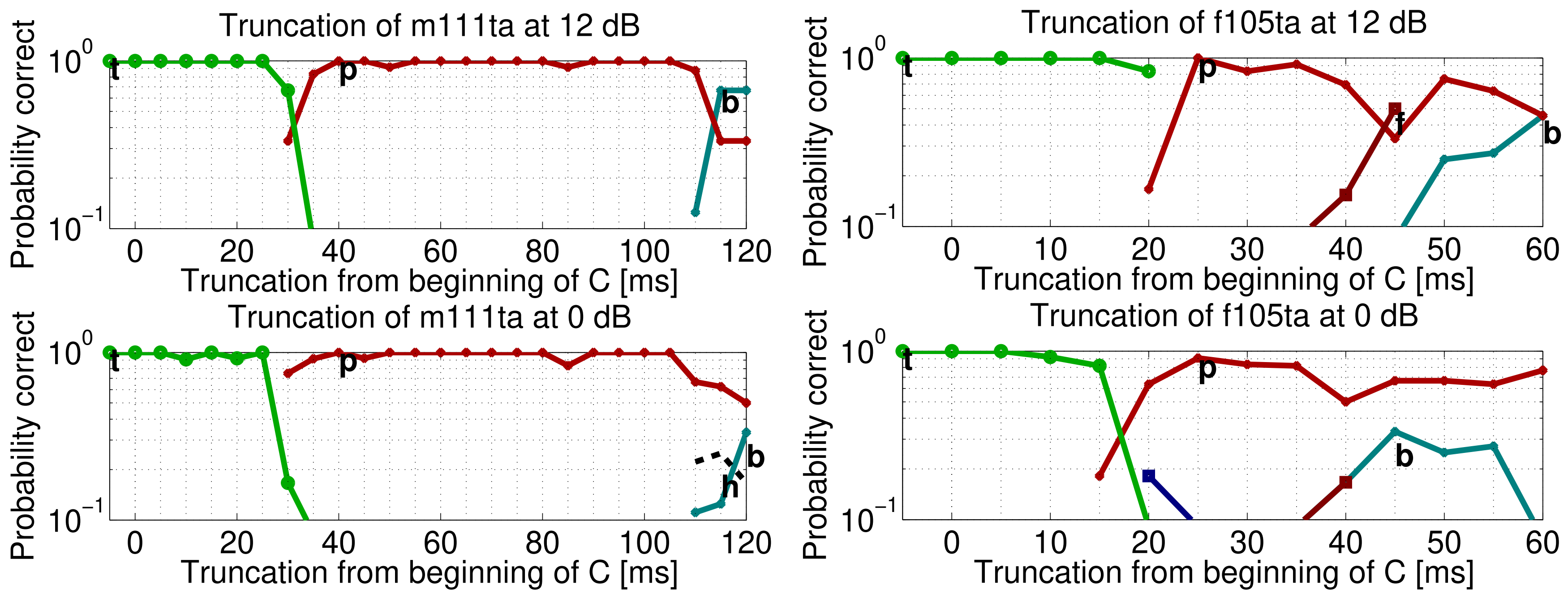
(c) Original /tɑ/



(d) Modified /tɑ/

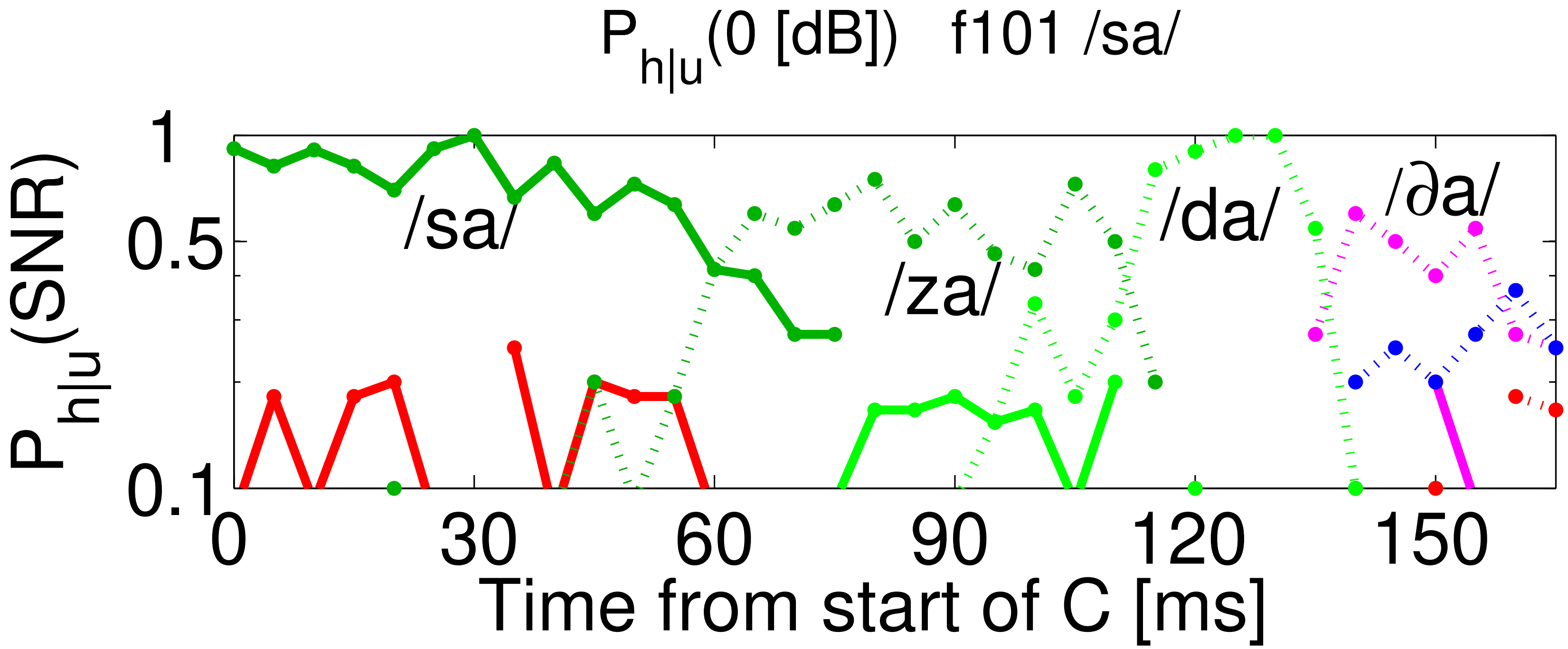
- When the /t/ burst is masked by noise, the perception morphs to /p/
- DEMO 4

Truncation of /tɑ/



- This represents the normal hearing responses to a truncated /tɑ/, from the start of the consonant
- Morphing from /tɑ/ to /pɑ/ to /bɑ/ at 0 and 12 dB SNR
- Similar to previous studies **?**, and our more extensive results

Truncation of f101 /sa/

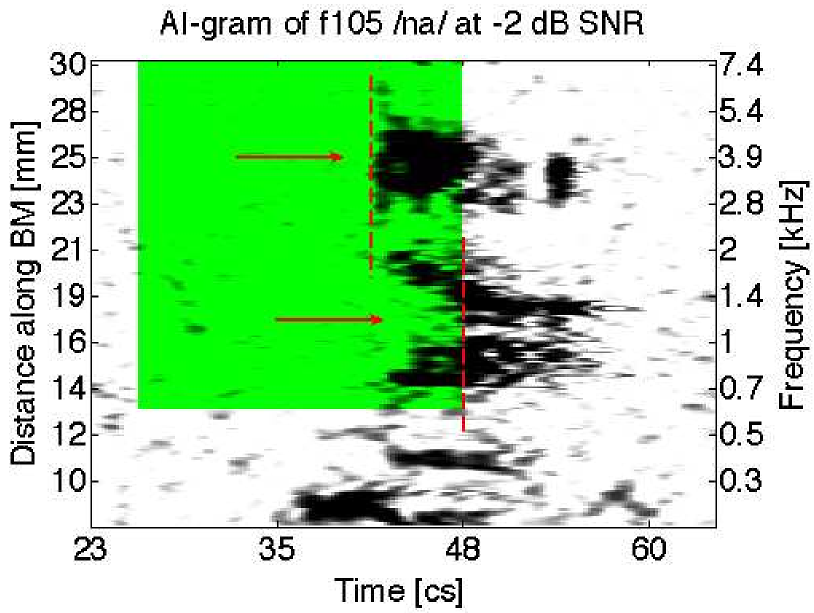


- This represents the normal hearing responses to a truncated /sɑ/, from the start of the consonant
- Morphing from /sɑ/ to /zɑ/ to /dɑ/ to /ðɑ/
- Duration seems to be a fricatives event

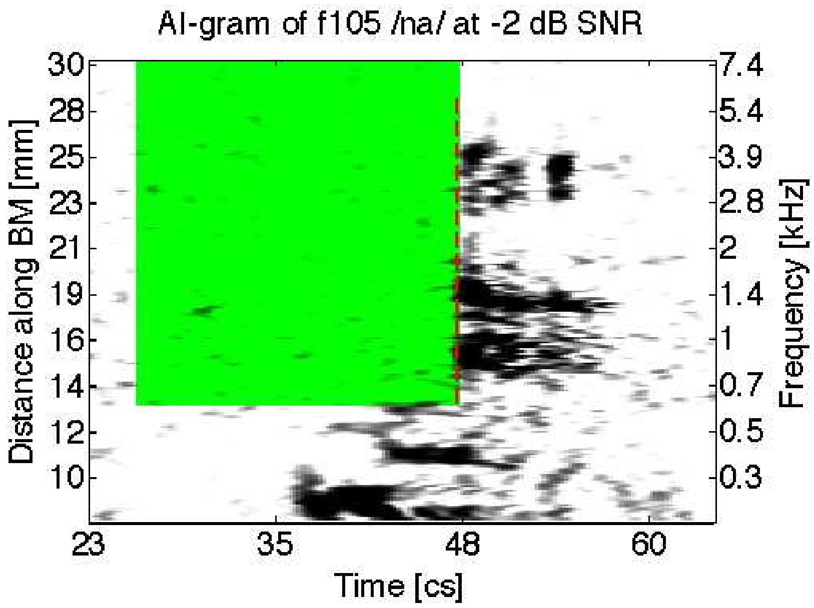
/mɑ/- /nɑ/ discrimination

- /nɑ/ recognition from /mɑ/ relies on a ≈ 50 ms delay formed from the F_1 and F_2 collision
- When we edit the speech so that the onset is simultaneous above 0.6 kHz, the /nɑ/ is robustly and naturally heard as /mɑ/
- METHODS: 9 listeners evaluated these sounds in open response random trial experiment.

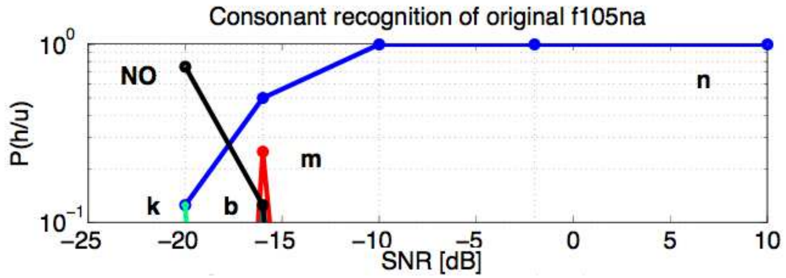
Deletion of /nɑ/ timing cue

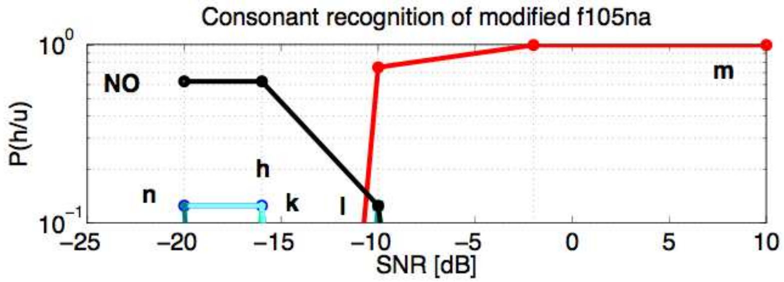


(e) Original /nɑ/



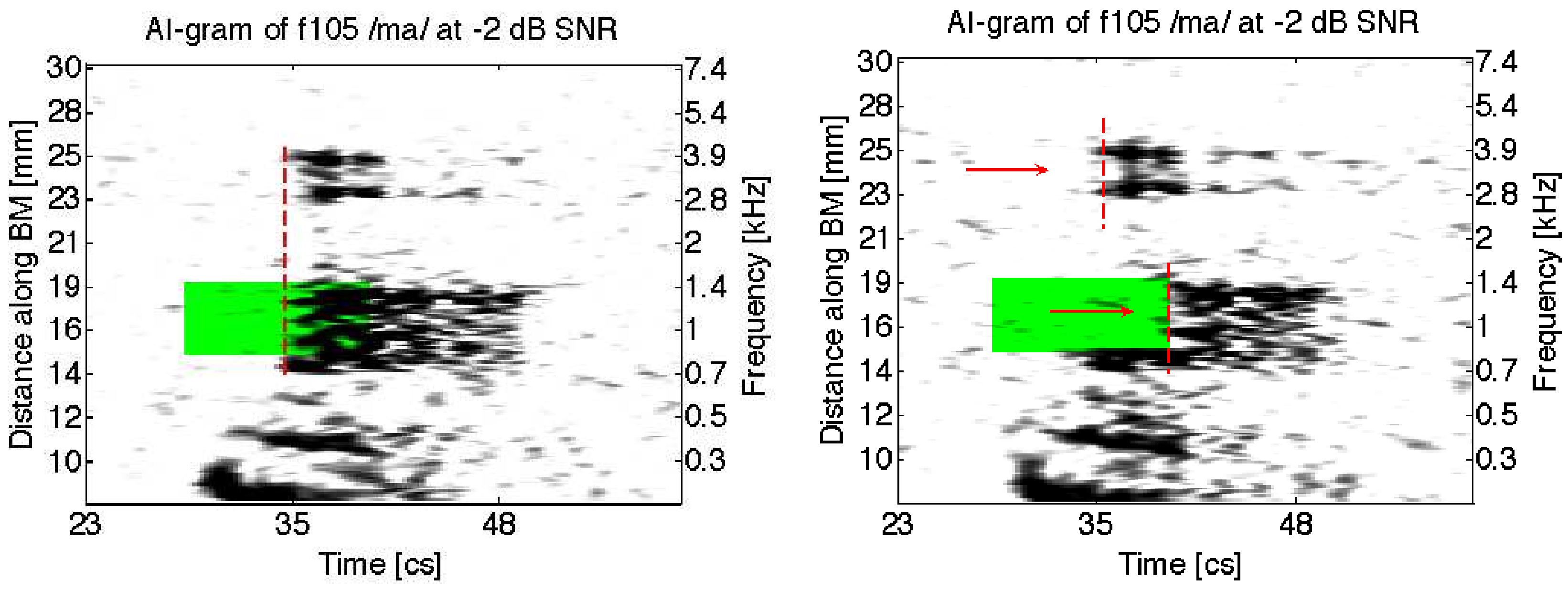
(f) Modified /nɑ/



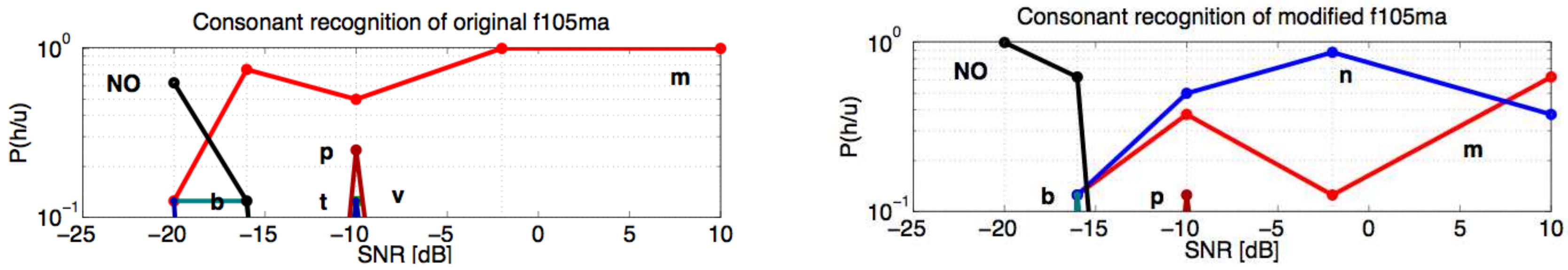


- DEMO

Creation of /nɑ/ timing cue

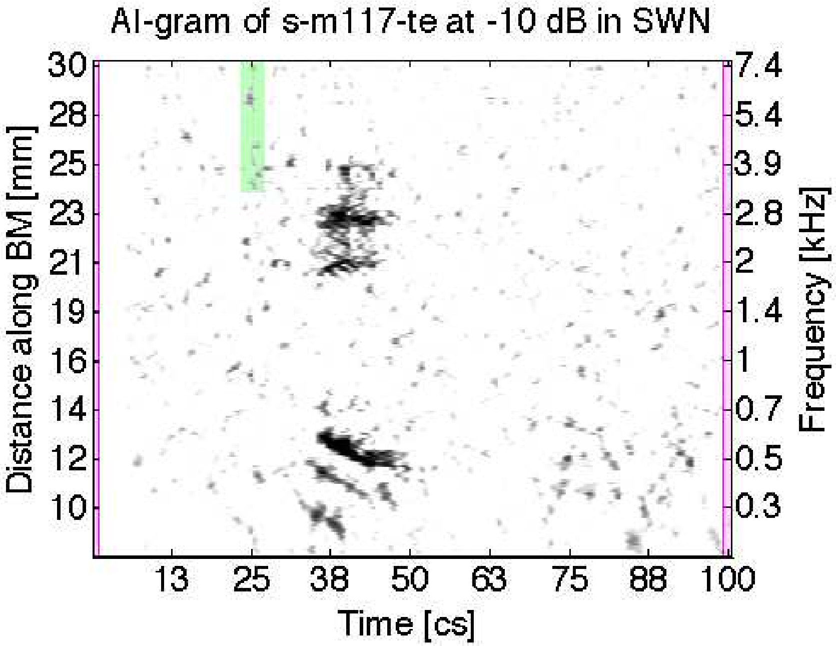


(g) Original /mɑ/ (h) Modified /mɑ/

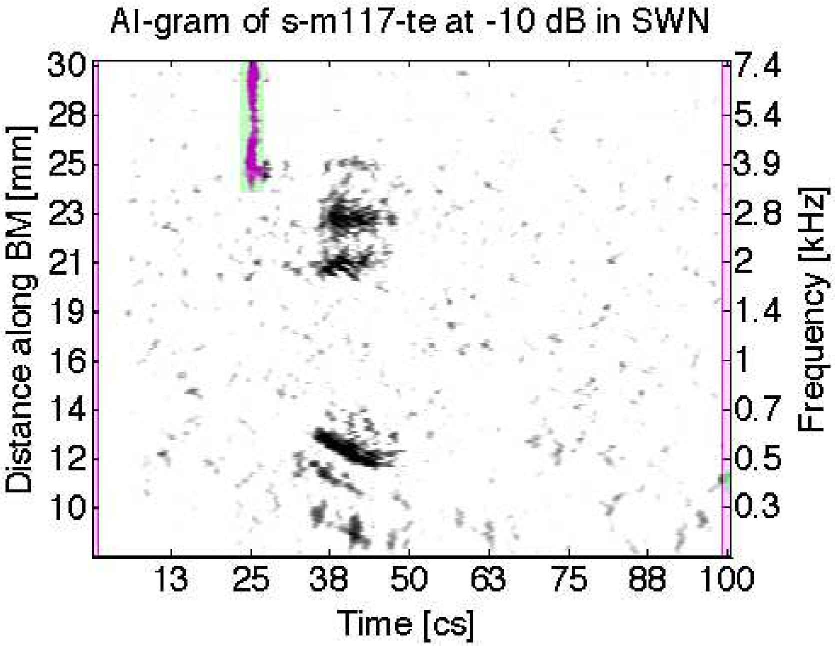


- DEMO

Enhancement of /tɛ/ event



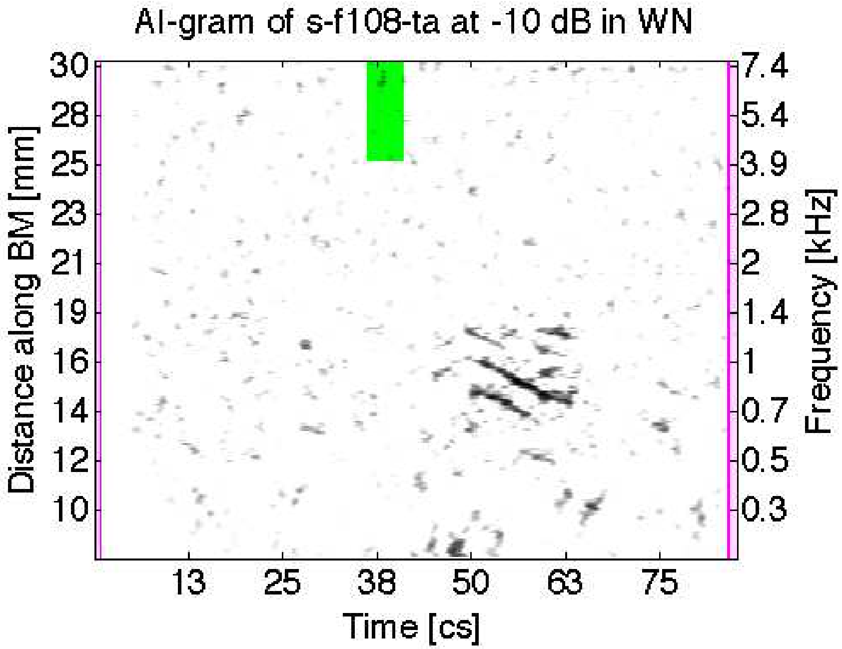
(i) Original /tɛ/



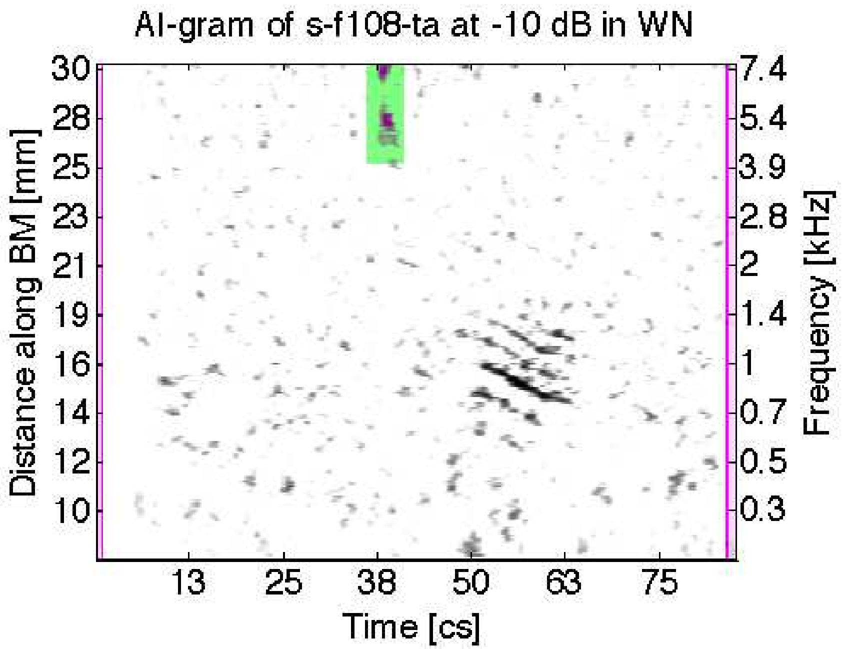
(j) Modified /tɛ/

- The sound is heard as /t/ again, we suppressed the morph (see confusion patterns of slide 4)
- METHODS: The /t/ burst is enhanced (14 dB) on the quiet sound, then noise is added
- DEMO

Enhancement of /tɑ/ event



(k) Original /tɑ/



(l) Modified /tɑ/

- The sound is heard as /t/ again, we increase /t/ recognition
- METHODS: The /t/ burst is enhanced (14 dB) on the quiet sound, then noise is added
- DEMO

Conclusion

- We have shown that normal listeners use *across-frequency timing coincidences* to discriminate consonants in noise
- We have developed a tool to modify speech sounds
  - Morph sounds. Ex: /mɑ/ - /nɑ/
  - Decrease or increase intelligibility. Ex: /tɑ/, /tɛ/
- This could well lead to the design of new hearing aids