Consonant confusions in normal and hearing impaired ears
Acoustic Feature Processing

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- This form of *paradoxical-contradictions* are known as Yogi-isms

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- Summary + Conclusions 6 mins $\Sigma 50$

- When You Come to a Fork in the Road,

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  Take It!

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   - Hypothesis: HI Consonant discrimination in noise is due to:

     $\Rightarrow$ Cochlear Dead regions?

     $\Rightarrow$ Poor acoustic time/freq edge detection?

     $\Rightarrow$ Auditory plasticity?

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- Context:
  - G.A. Miller 1951 *Language and communication*
  - G.A. Miller 1962 5-word Grammar $\equiv$ 4 dB of SNR
  - Boothroyd JASA 1968; Boothroyd & Nittrouer 1988
  - Bronkhorst et al. JASA 1993

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- Hearing Impaired studies
  - 2004-2011: Confusion matrices HSR@UIUC

Allen et. al HSR Experiments 2004-2011

Year	Experiment	Student &Allen	Details	Publication
2004	MN04(MN64)	Phatak	16C+4V SWN	JASA (2007)
2005	MN16R	Phatak, Lovitt	MN55R	JASA (2008)
	HIMCL05	Yoon, Phatak	10 HI ears	JASA (2009)
2006	HINALR05	Yoon *et al.*	10 HI ears	JSLR (2012)
	Verification	Regnier	/ta/	JASA (2008)
	CV06-s/w	Phatak/Regnier	8C+9V SWN/WN	
2007	CV06	Pan	CV06	–
	HL07	Li	Hi/Lo pass	JASA (2009)
2008	TR08	Li	Furui86	ASSP (2009)
2009	3DDS	Allen, Li	plosives	TASLP (2011)
	3DDS	Li	plosives	JASA (2010)
	Verification	Abhinauv	burst mods	JASA (2012)
	Verification	Cvengros	burst mods	Rewrite JASA
	MN64 NZE	Singh	PA07	JASA (2012)
2011	3DDS	Li,Trevino	Fricatives	JASA (2012)
	HINAL11-IV	Han	17 HI ears w NALR	Thesis Ch. 3
2010	HIMCL10-I,II,III	Trevino	17 HI ears @MCL	JASA (2013)

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  You Mean Now?

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Methods: The count (confusion) matrix

- Miller-Nicely's 1955 articulation matrix $P_{h|s}(SNR)$, 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	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
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UNVOICED VOICED NASAL

RESPONSE

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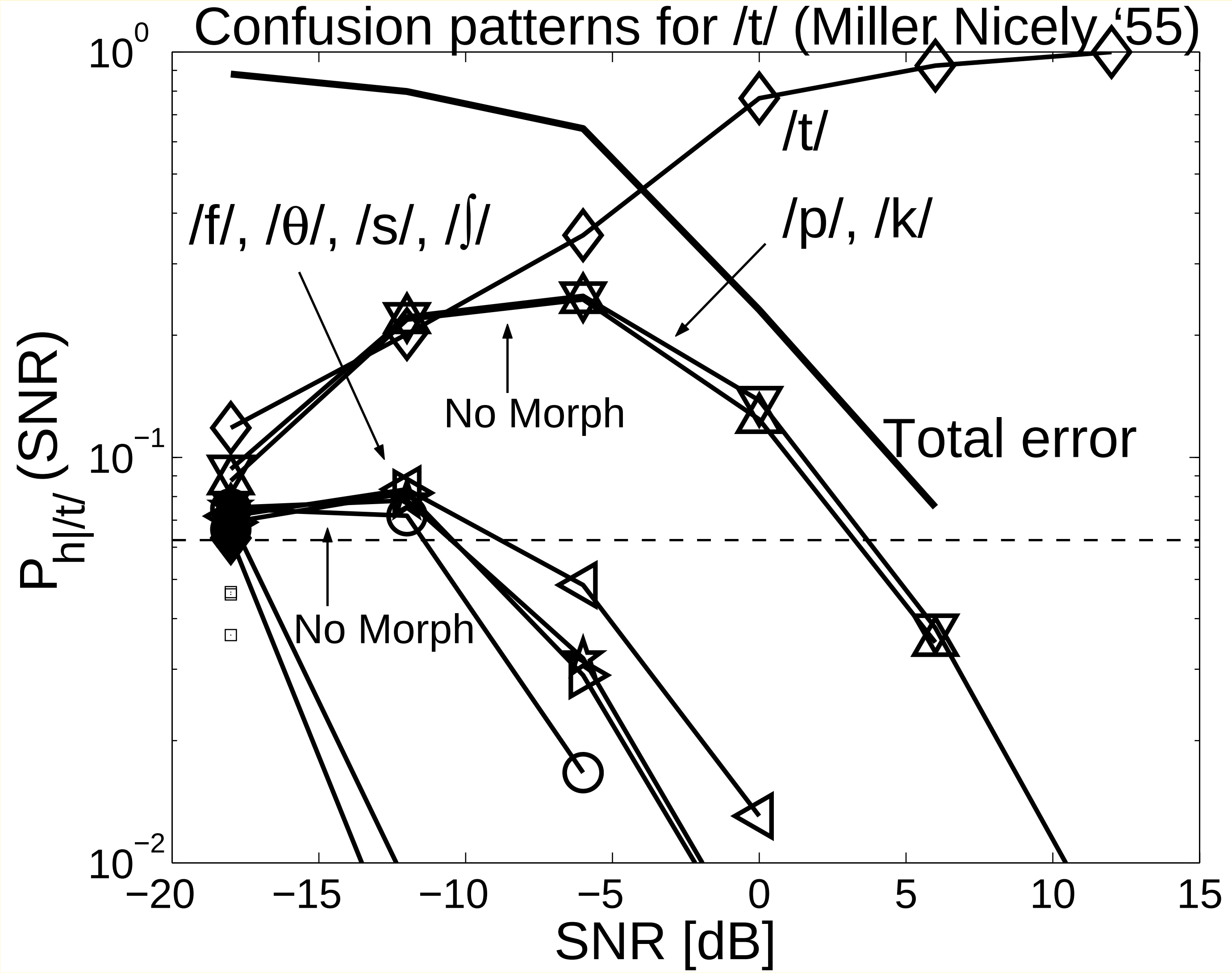
RESPONSE

- Confusion groups $\equiv$ *inhomogeneous confusions*

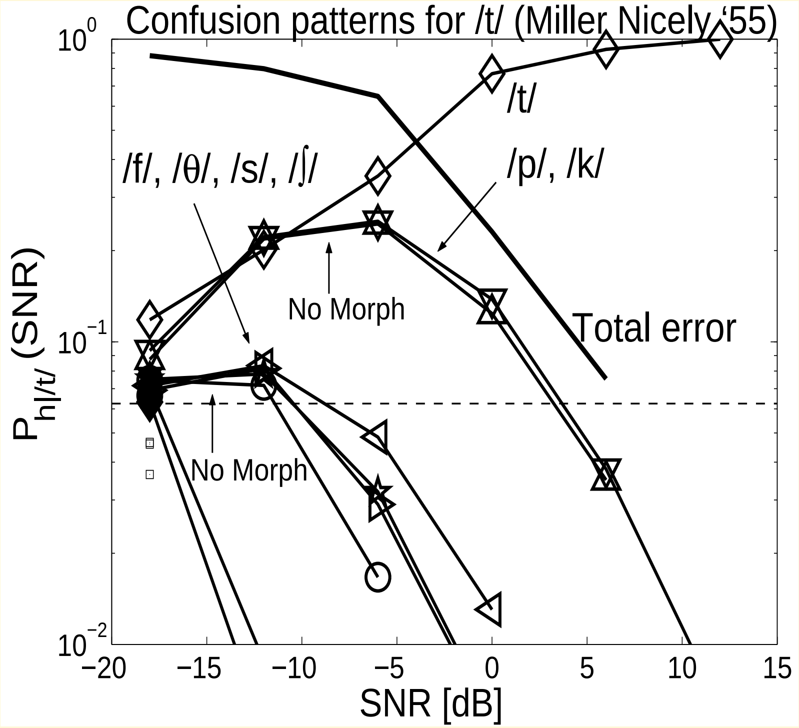
Row of confusion matrix (CM) $P_{h|/t/}$

- This *confusion pattern* characterizes the /t/ row vs SNR



Row of confusion matrix (CM) $P_{h|/t/}$

- The SIN_t of averaging across tokens:
  - Token confusions are strongly heterogeneous!
  - Averaging obscures per-token confusions



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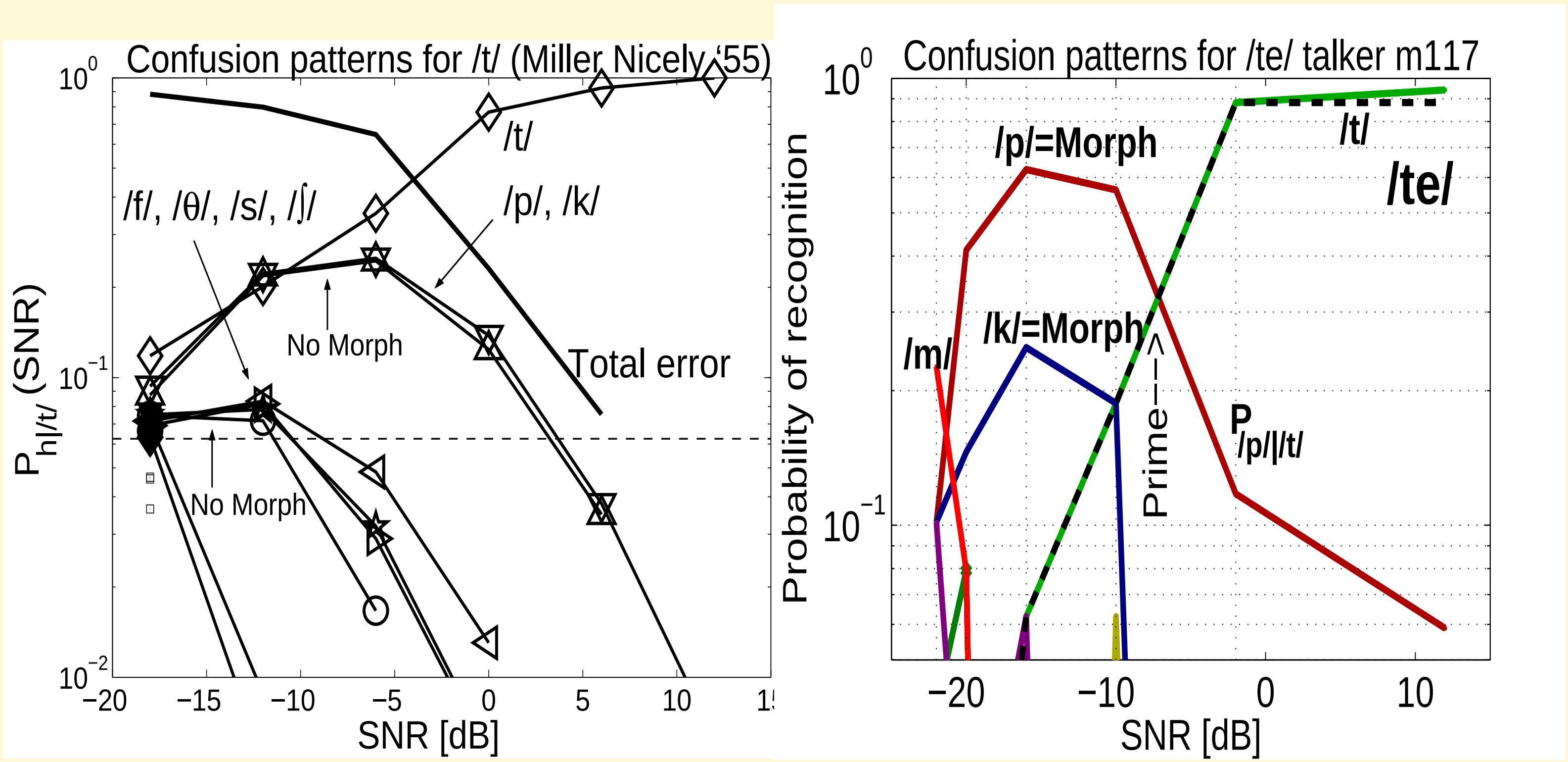

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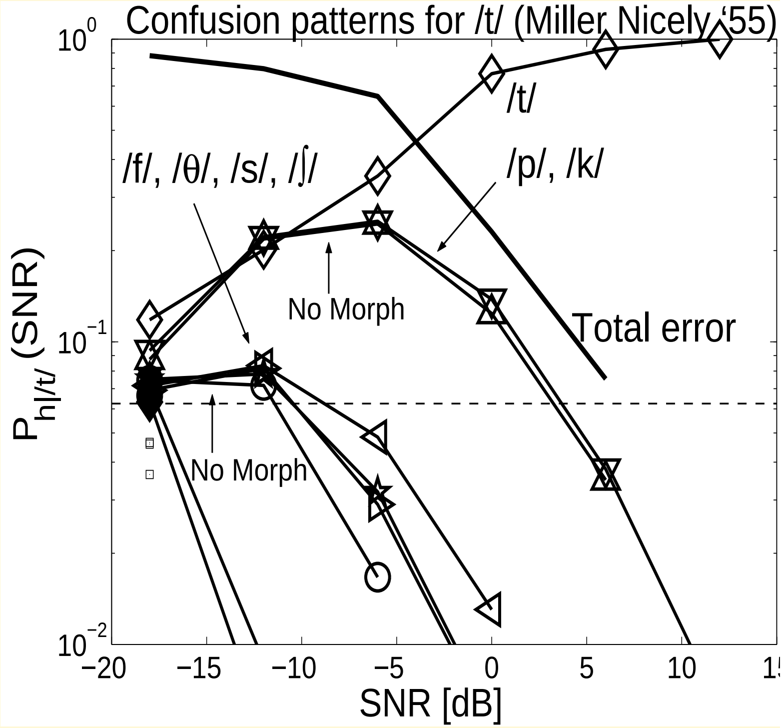

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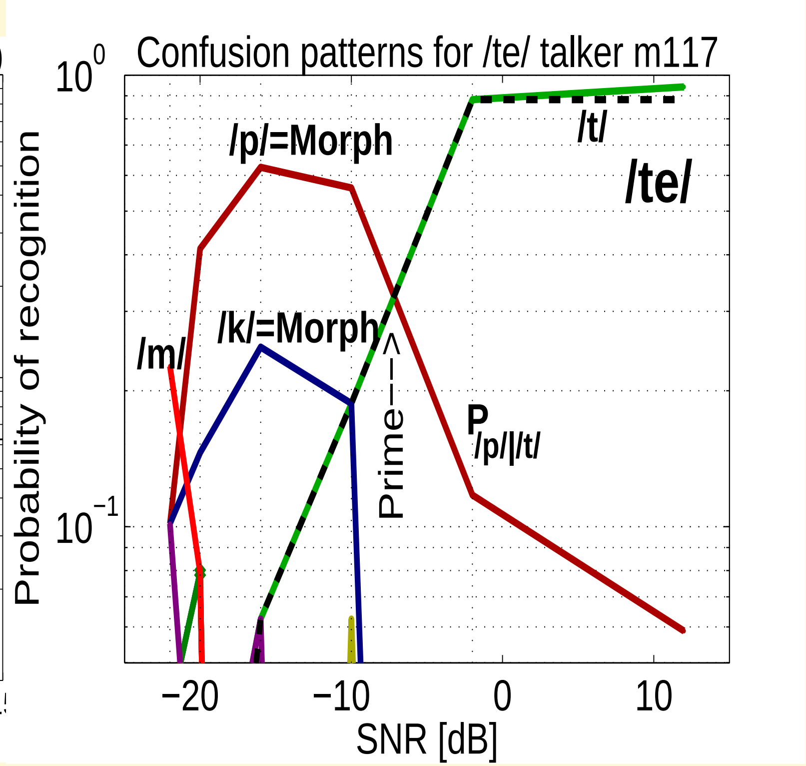

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- Methods: Cochlear models & signal processing
  - AIgram Régnier & Allen 2008; Li & Allen 2009,10,11

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  Do acoustic speech features exist?
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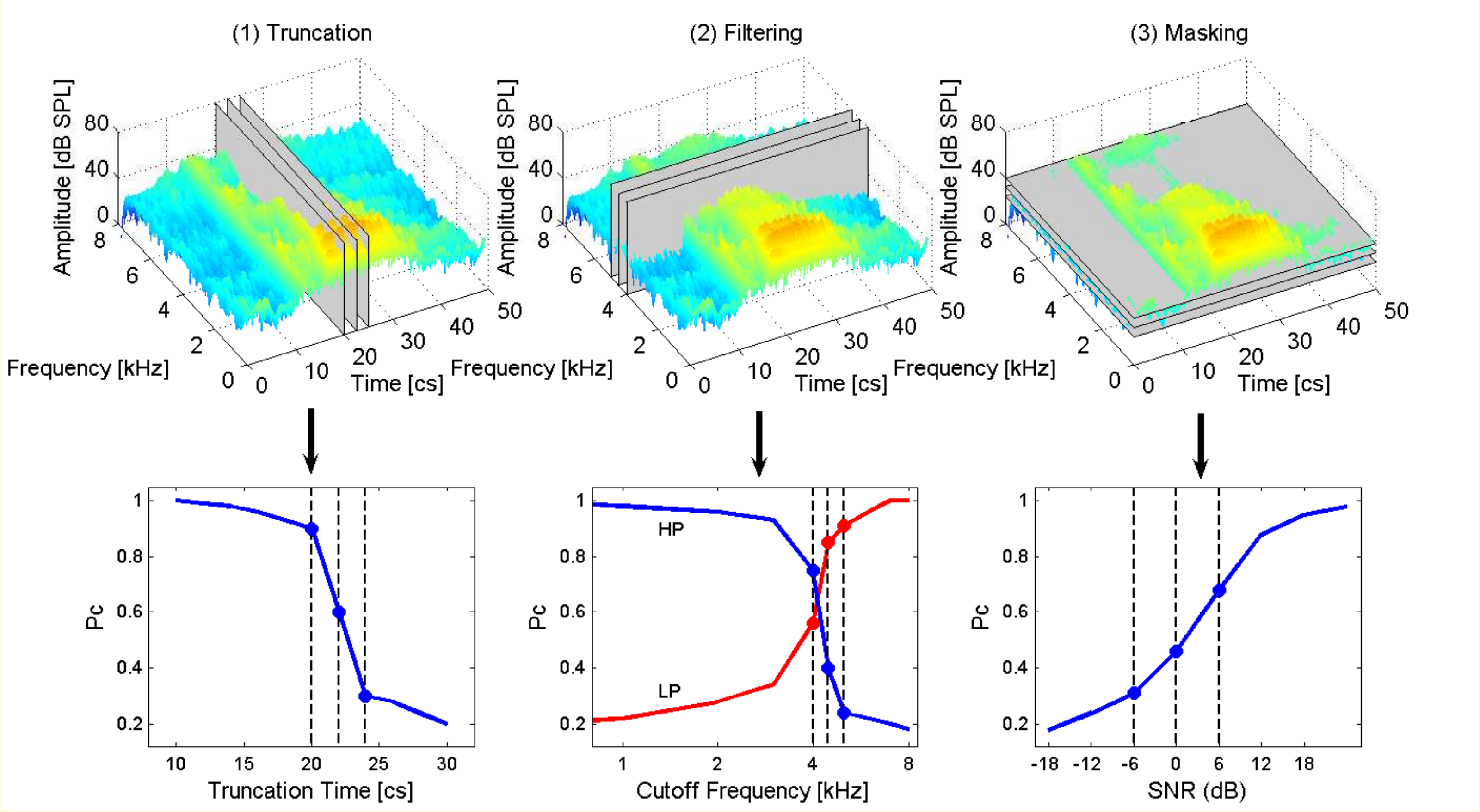
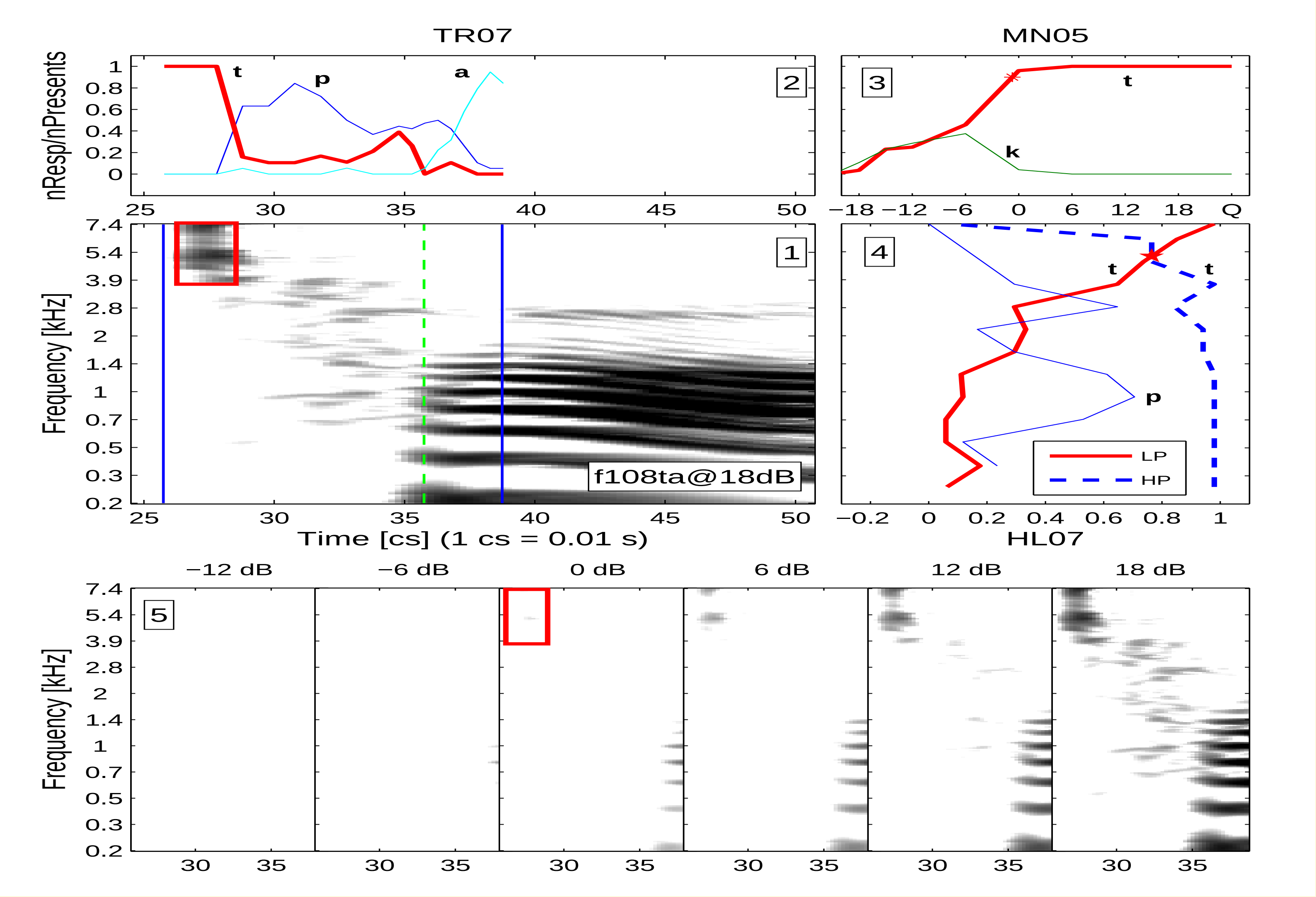


- Algram: Truncation in Time, Intensity and Frequency



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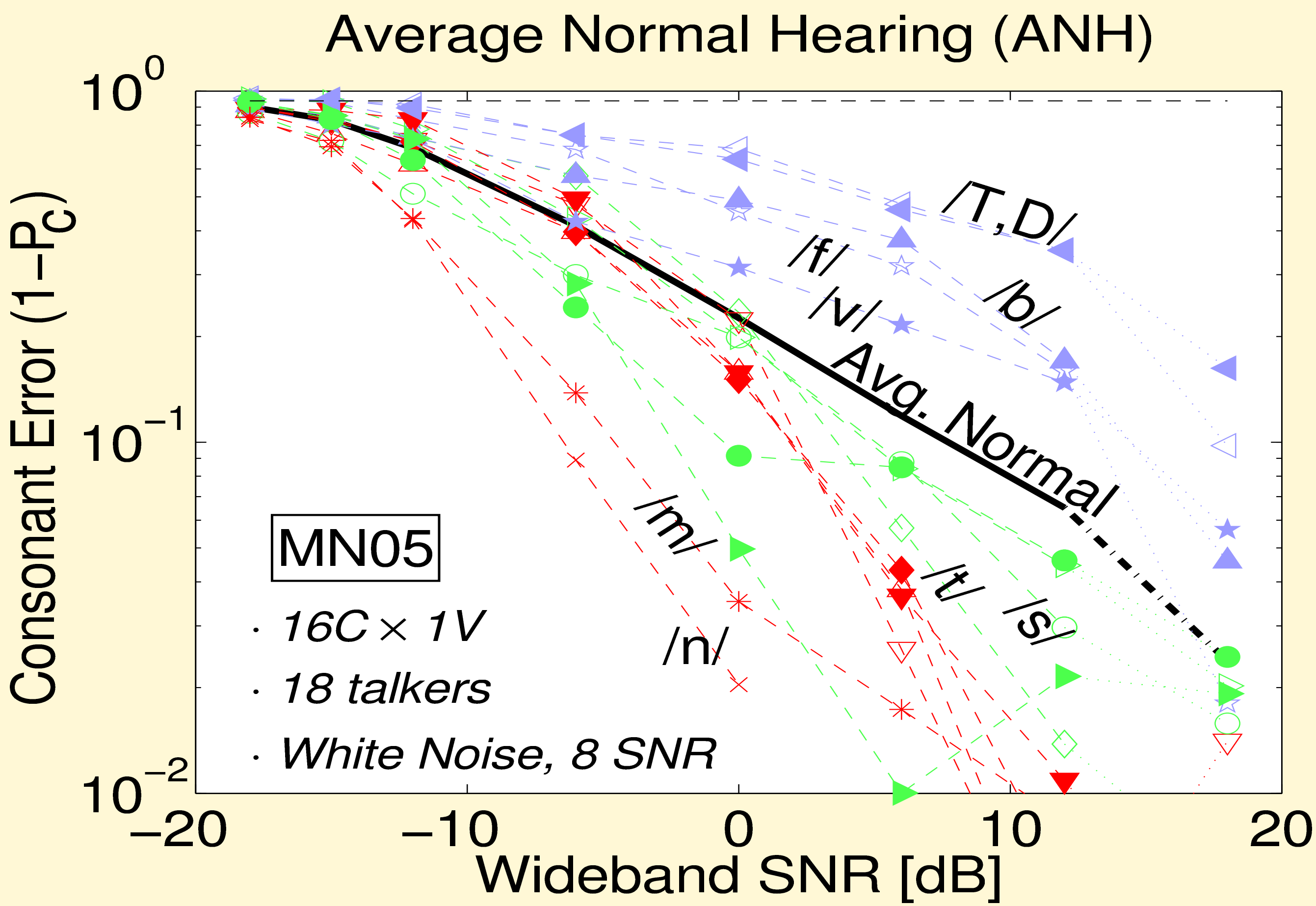

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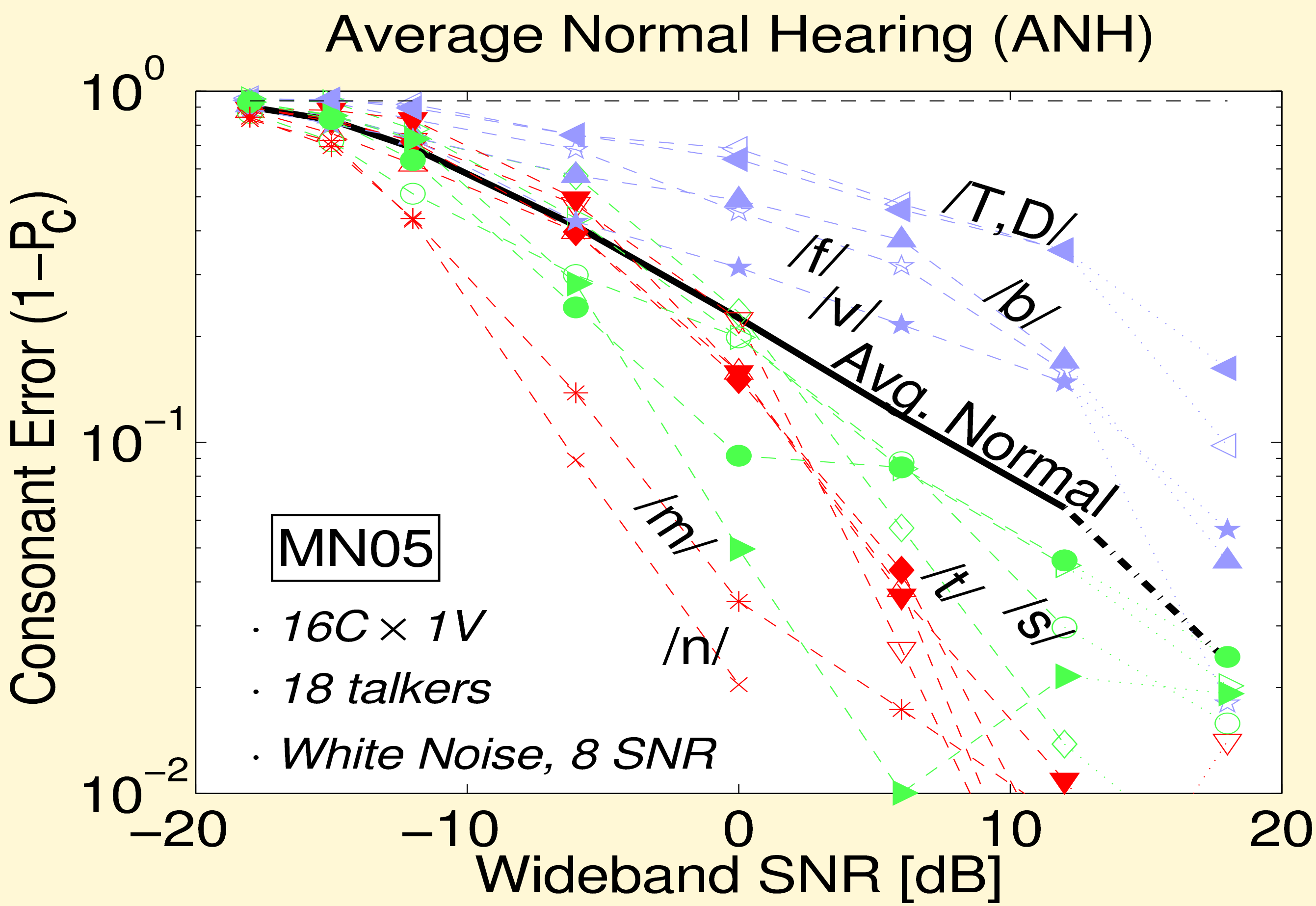
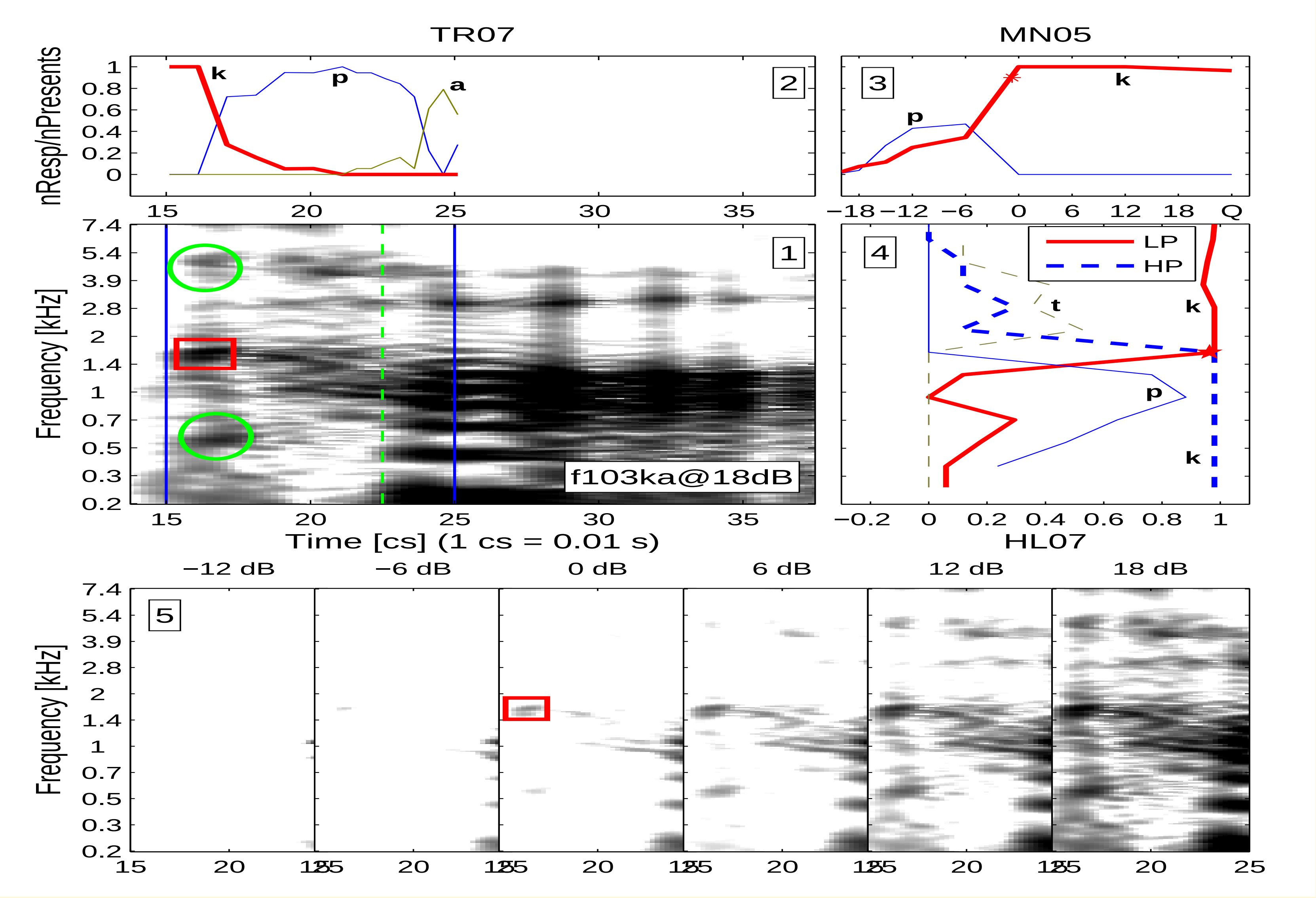
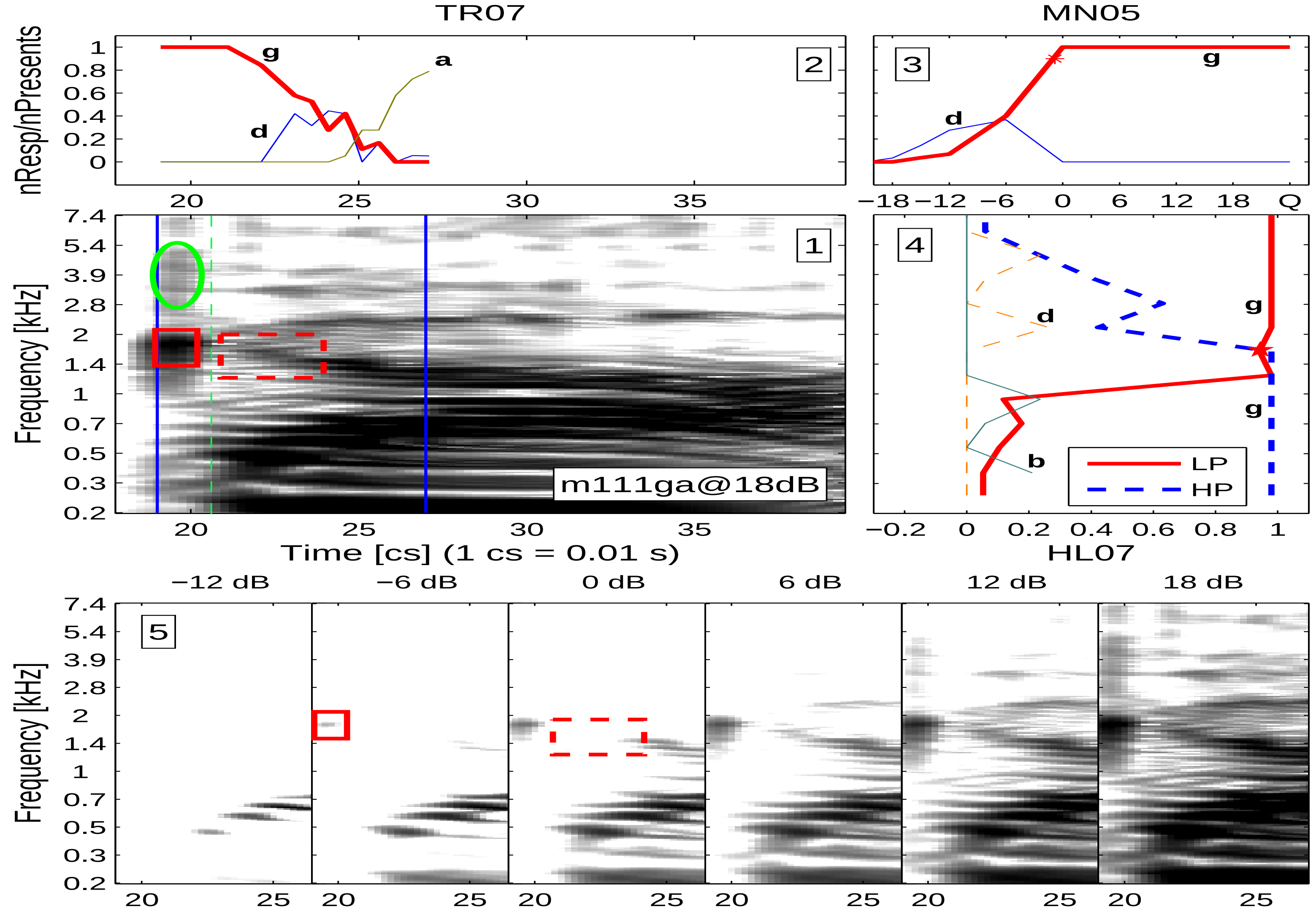


- Averaging obscures the multimodal consonant error distribution



TR07
MN05
nResp/nPresents
k
p
a
2
3
1
4
5
Frequency [kHz]
f103ka@18dB
Time [cs] (1 cs = 0.01 s)
HL07
LP
HP
t
Q
−12 dB
−6 dB
0 dB
6 dB
12 dB
18 dB

3DDS Method /ga/



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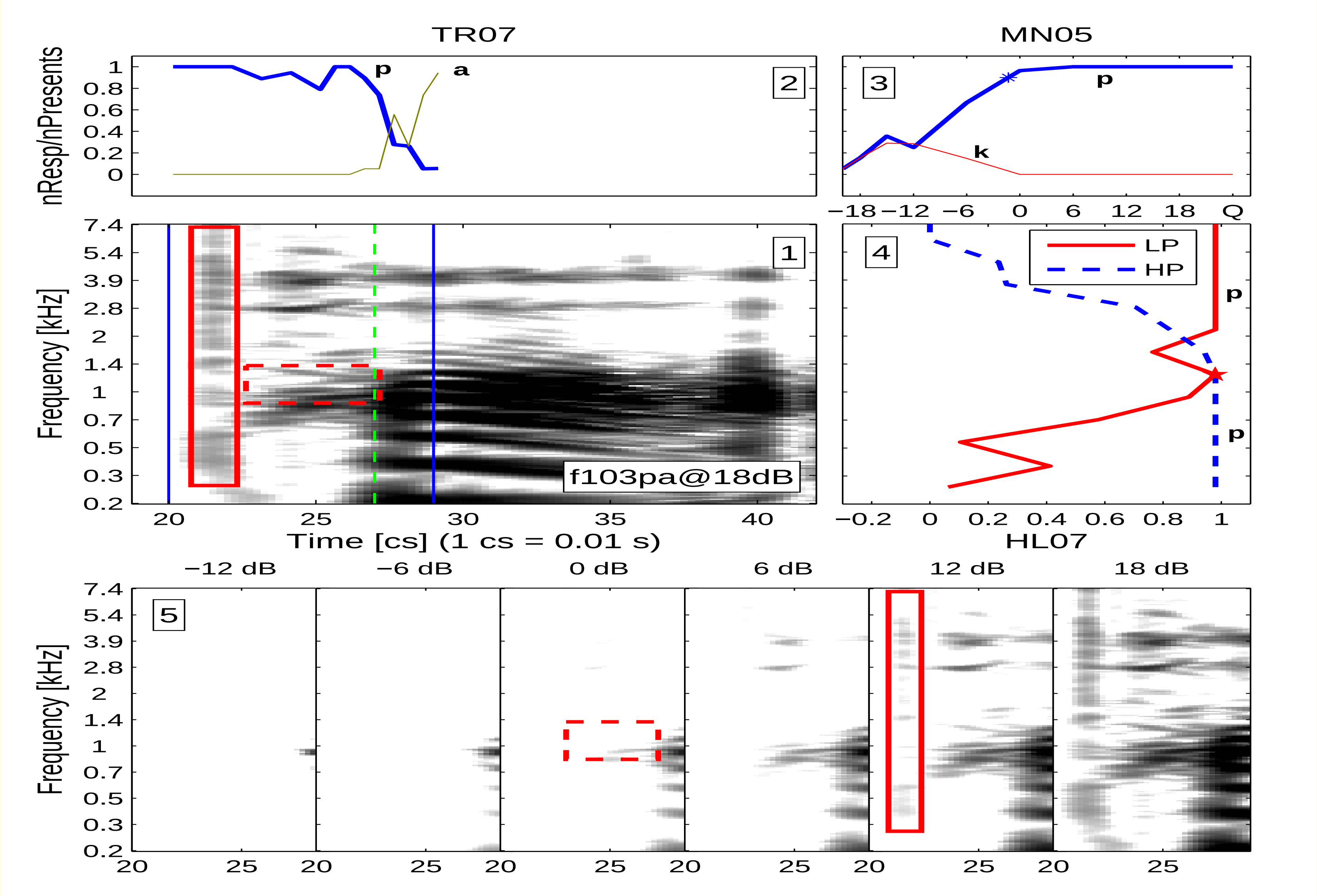
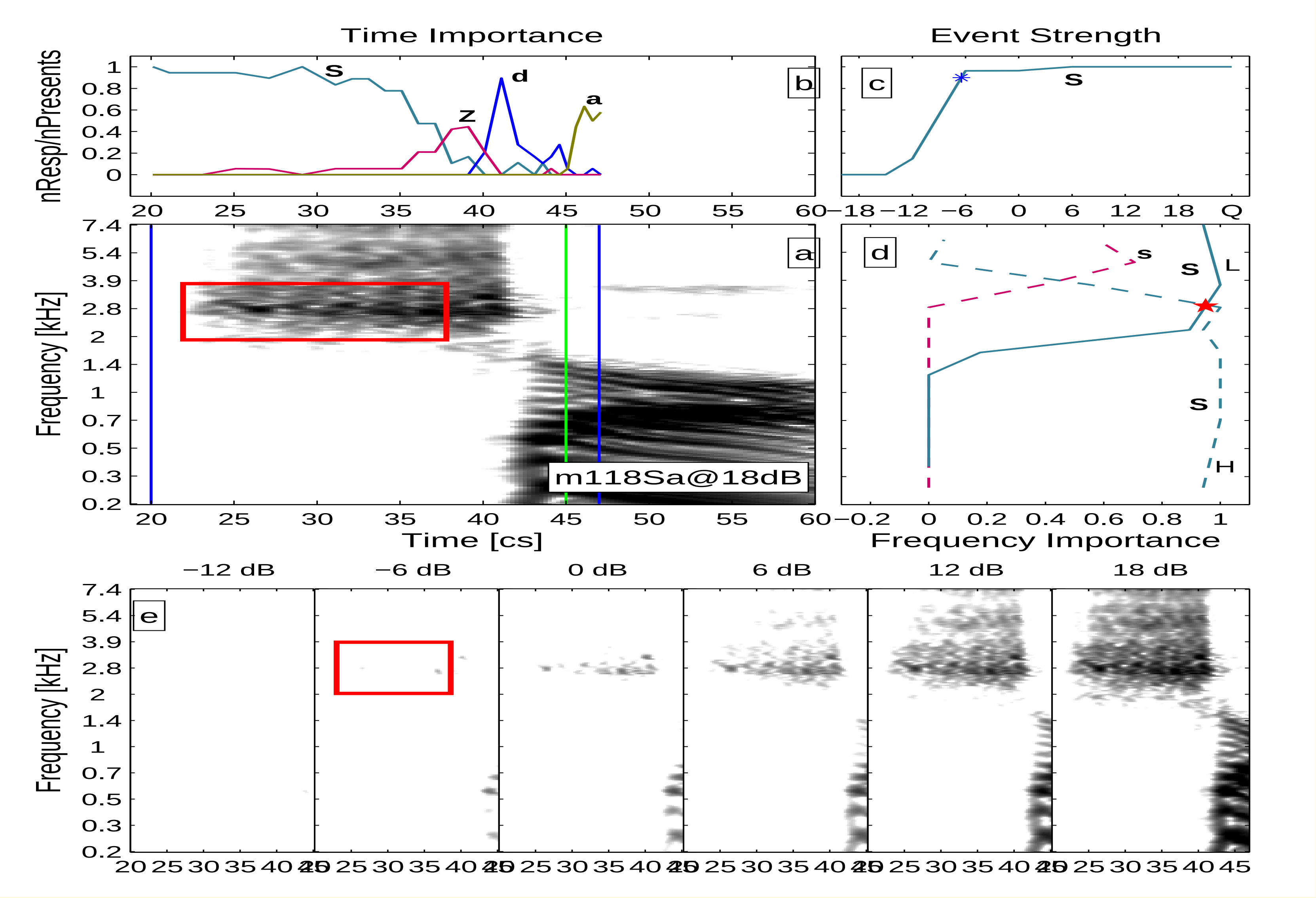


3^d-DS Method /ʃa/



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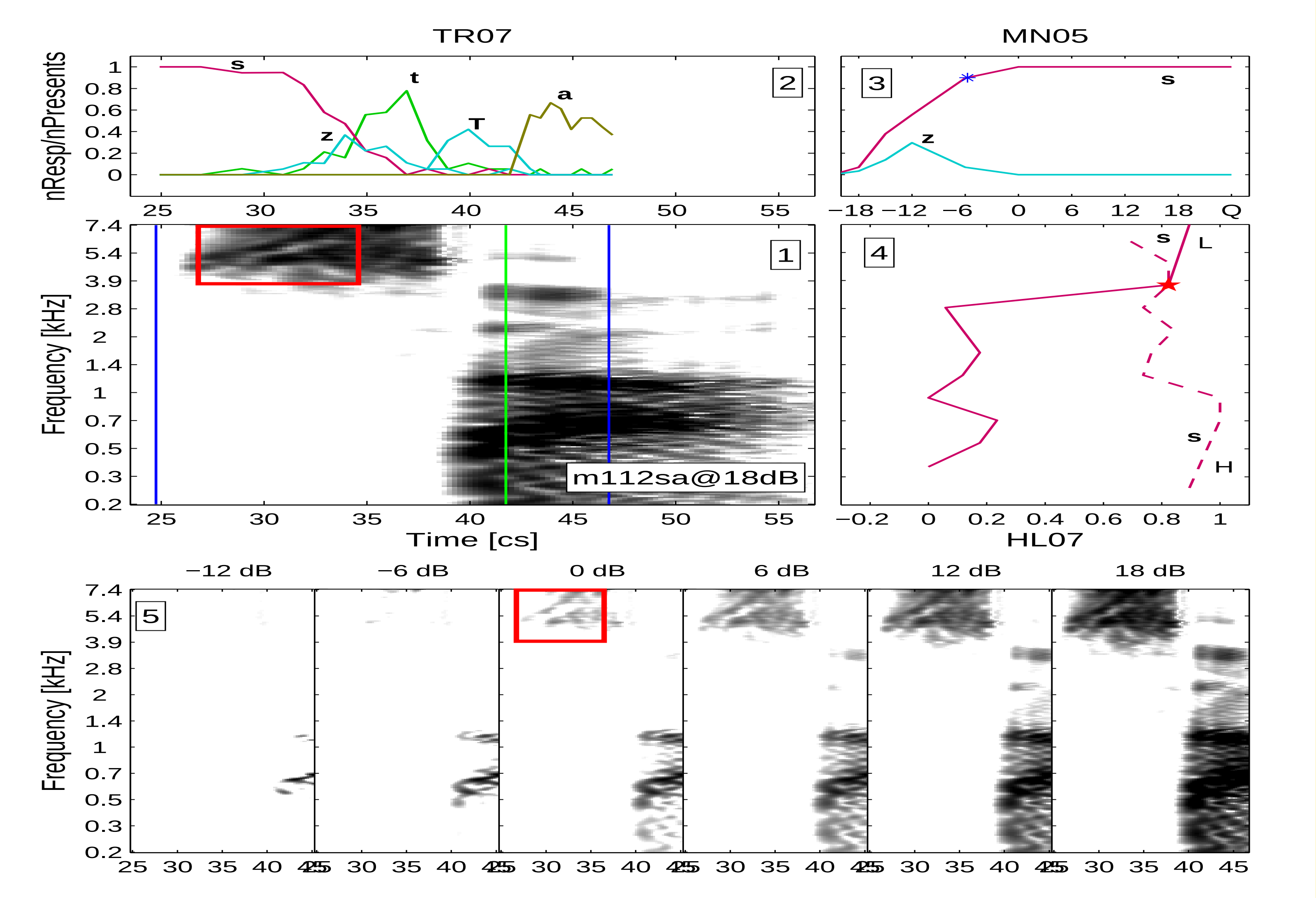
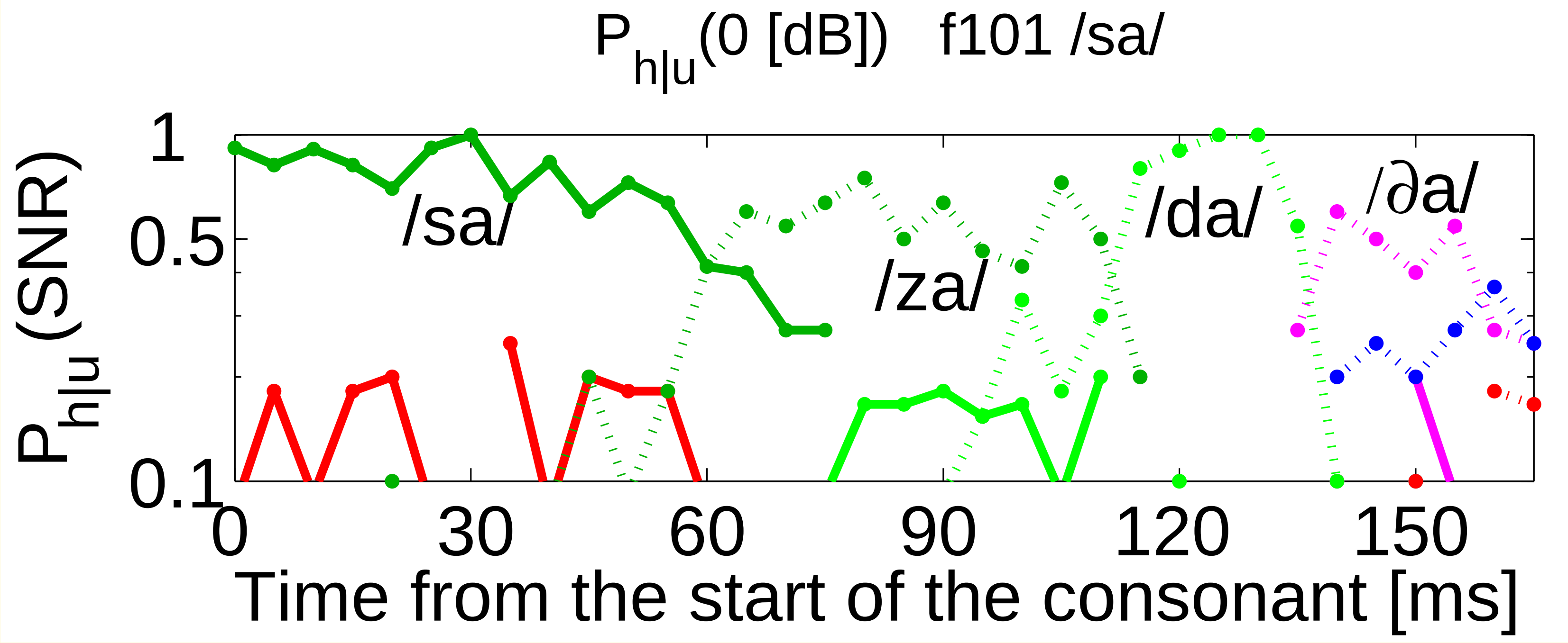
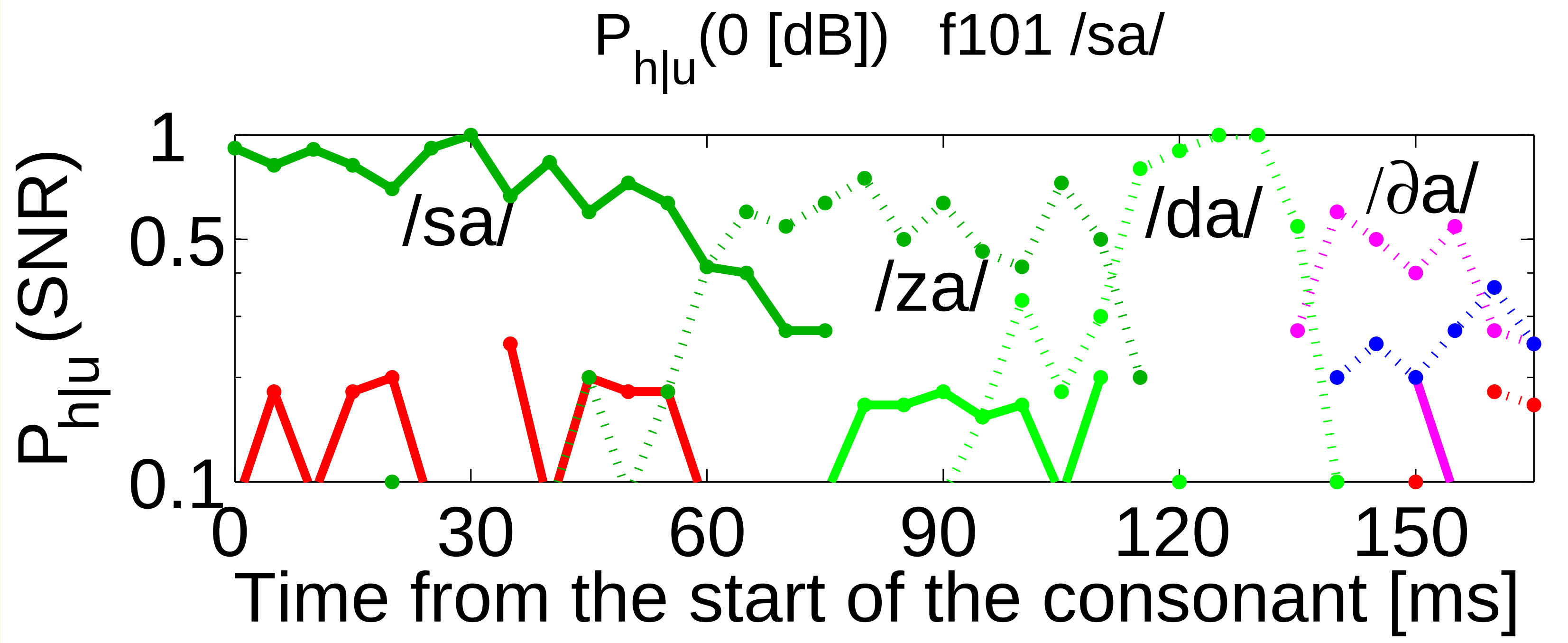
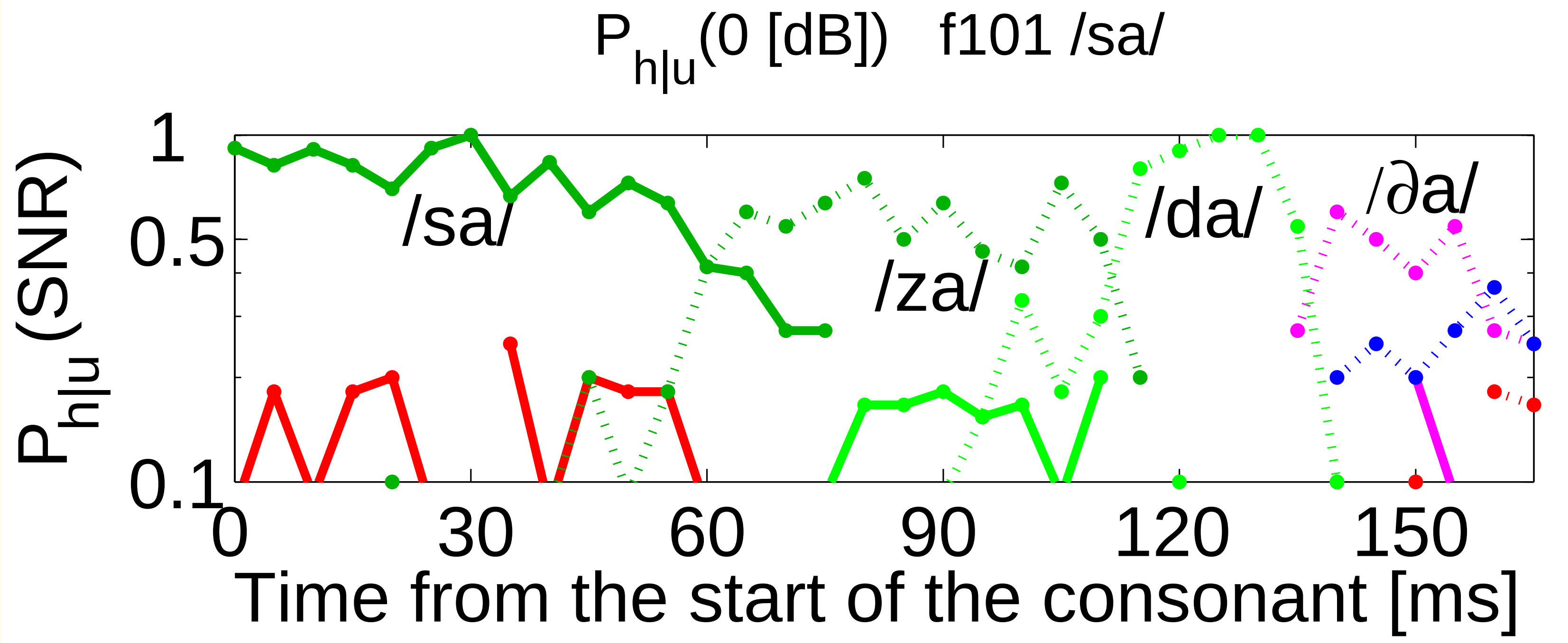



$P_{h|u}$(0 [dB]) f101 /sa/
$P_{h|u}$(SNR)
1
0.5
0.1
0
30
60
90
120
150
Time from the start of the consonant [ms]
/sa/
/za/
/da/
/∂a/



- NH responses to onset truncation /sɑ/



- NH responses to onset truncation /sɑ/
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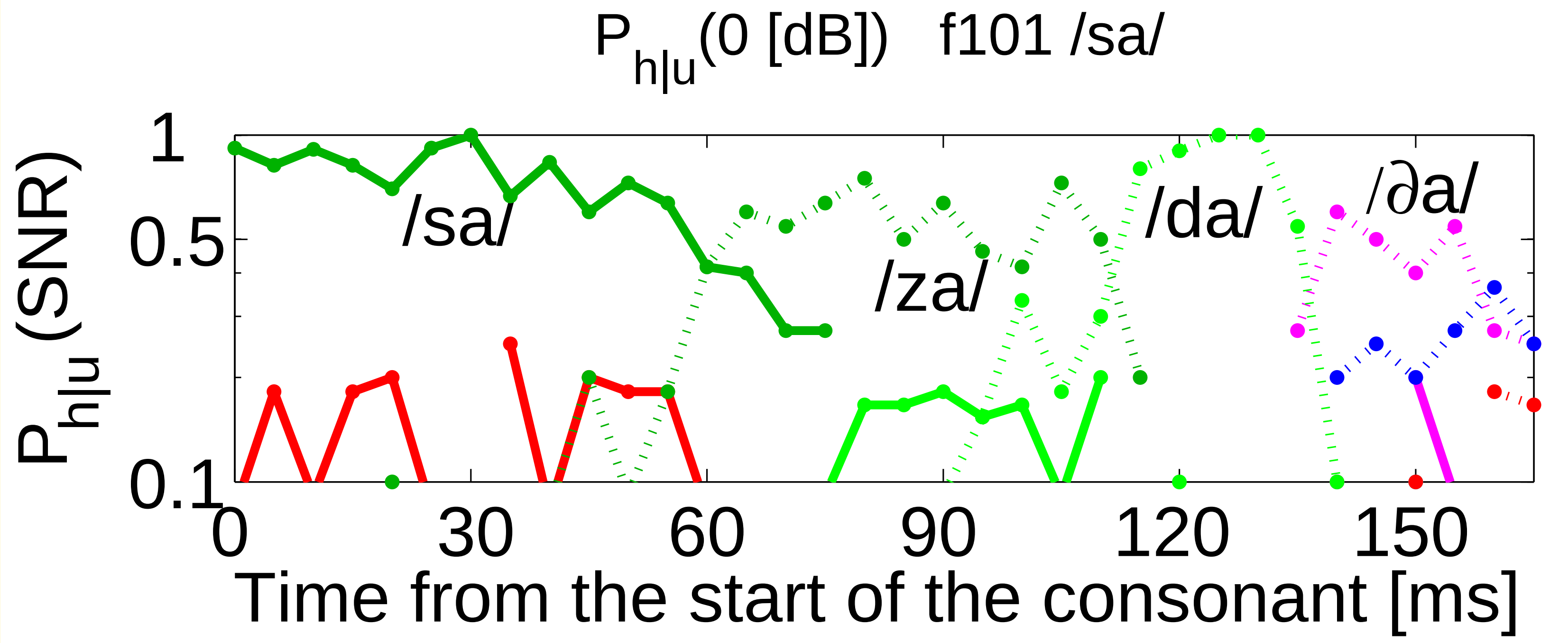

- NH responses to onset truncation /sɑ/
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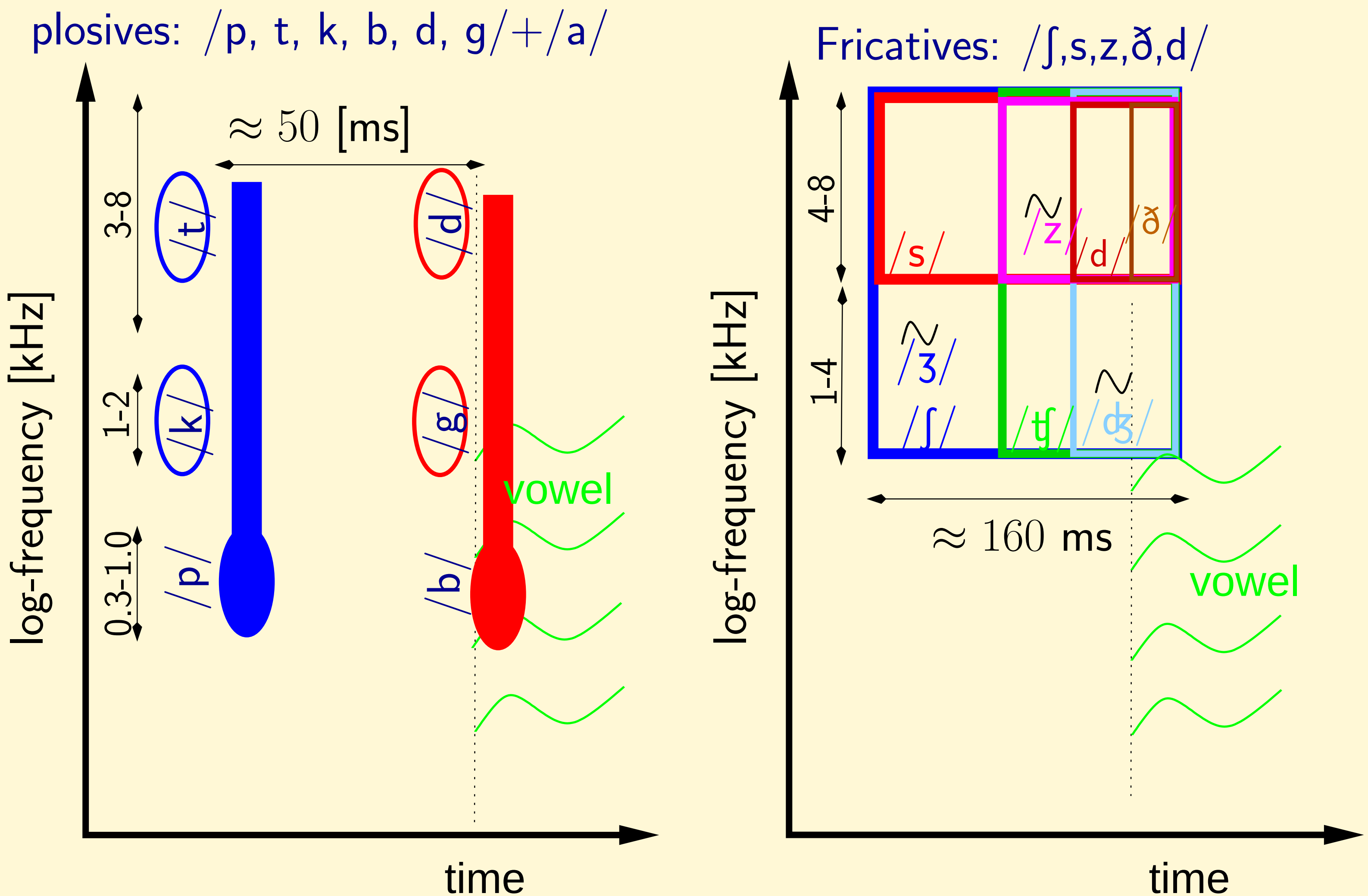
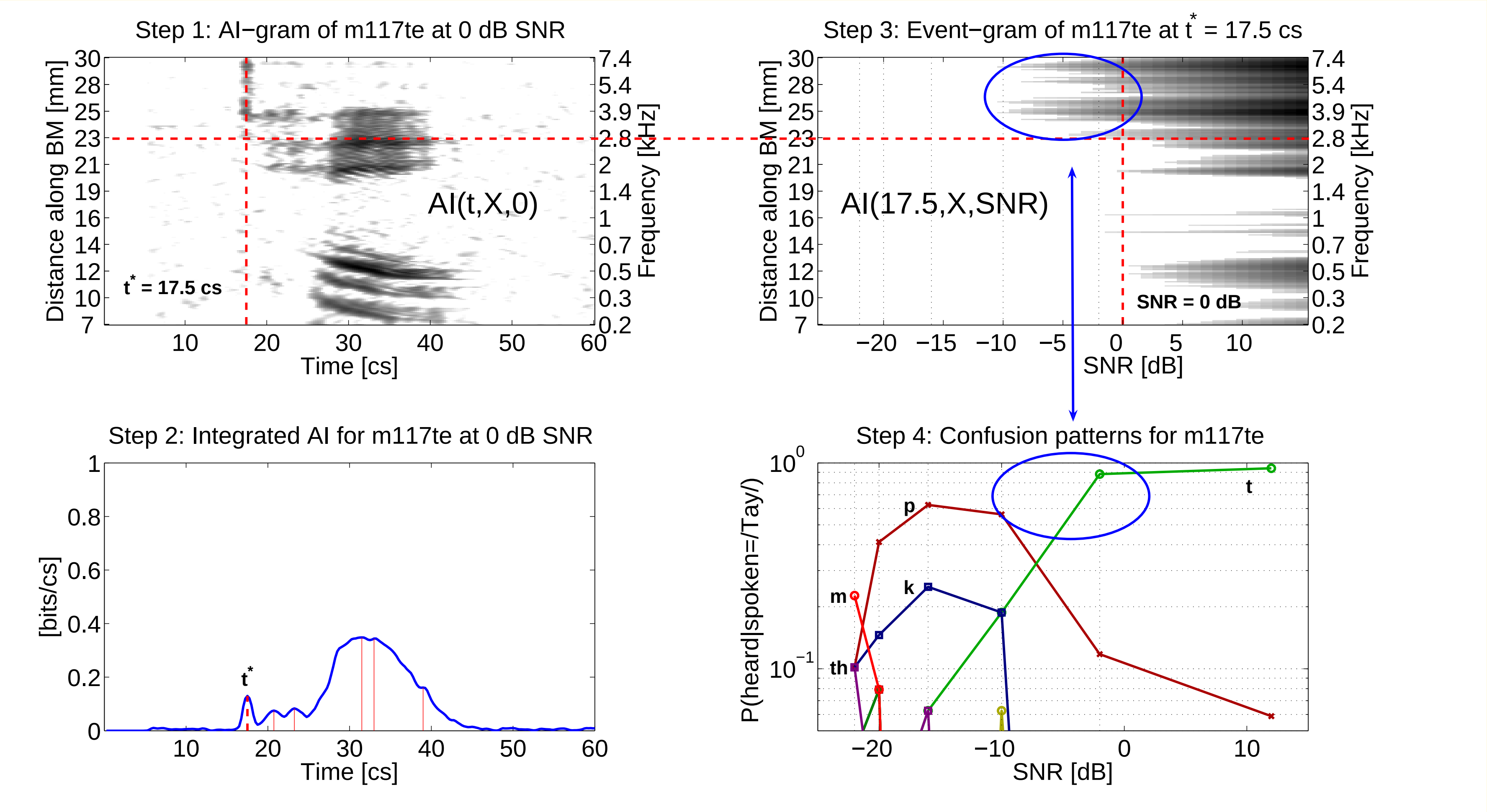
- Duration, low-frequency edge and F_0 modulations define a fricative cue

Summary of Consonant structure

- Time-frequency structure of plosives and fricatives



m117/te/ in speech-weighted noise



- /t/ confusion threshold at $P_c(SNR^*_{90} = -2)$ dB at 90% correct

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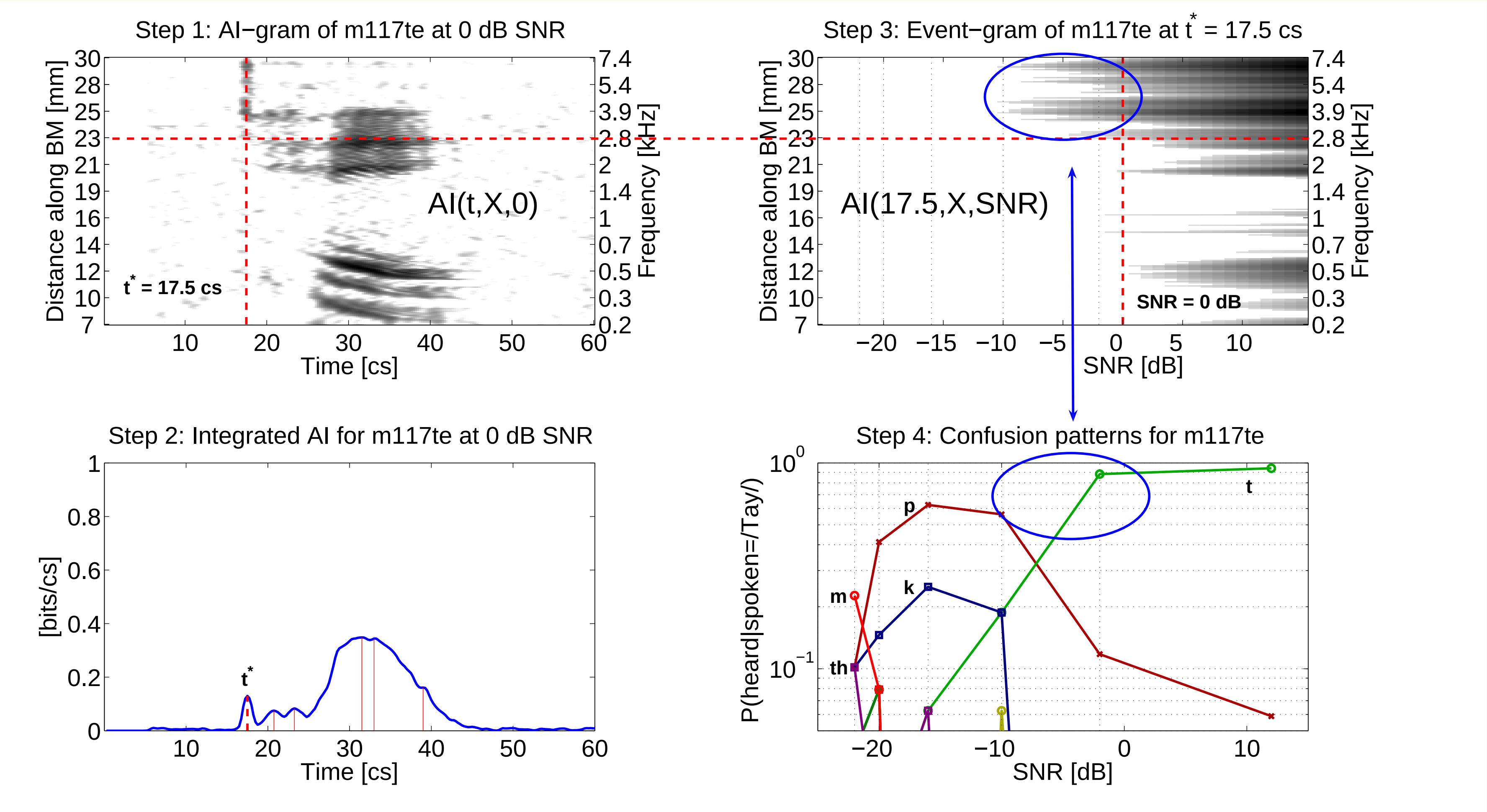

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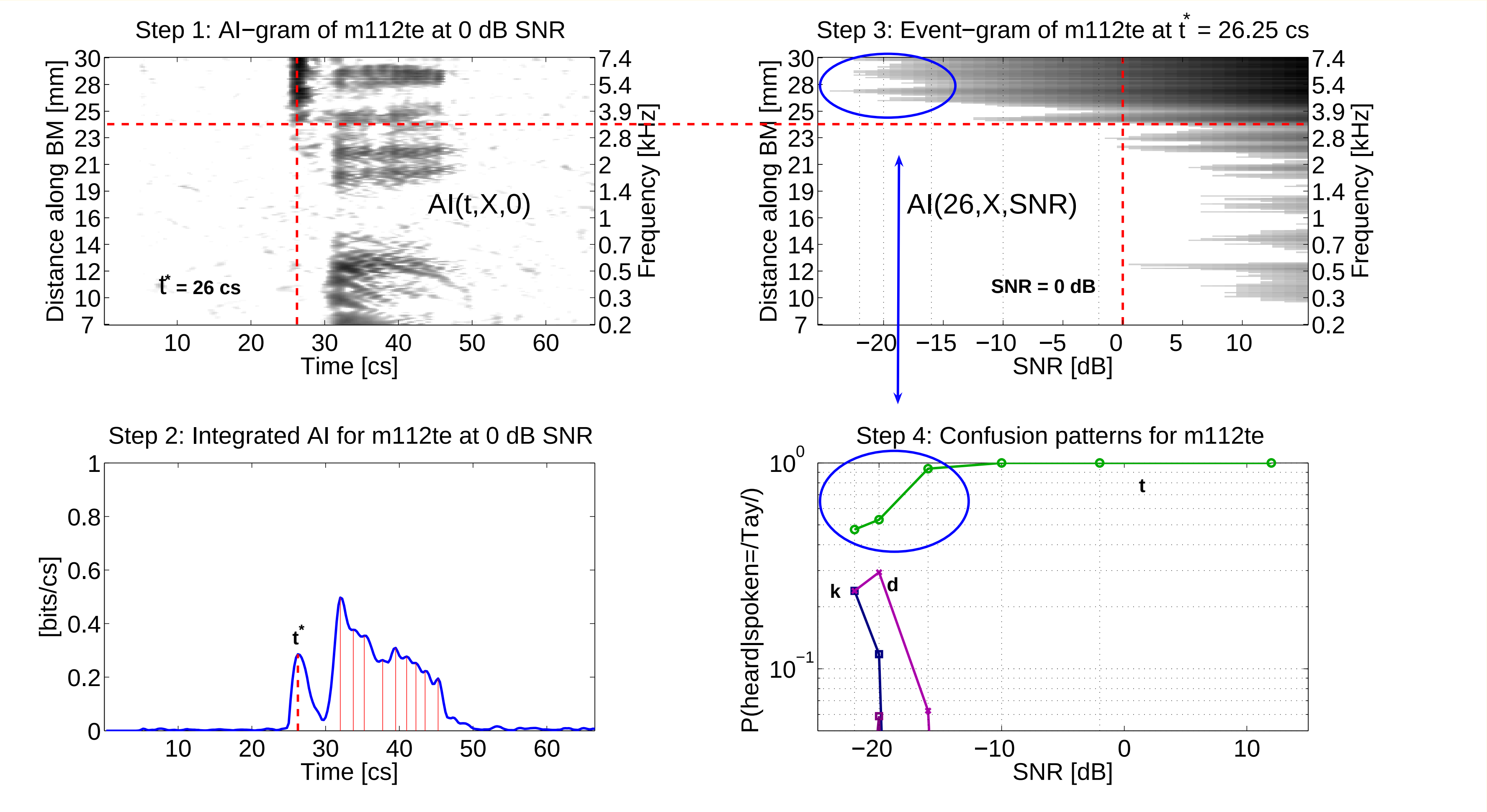
- This is an example of a high-error /te/

m112/te/ in speech-weighted noise



- /t/ confusion threshold at $P_c(SNR^*_{90} = -16)$ dB at 90% correct

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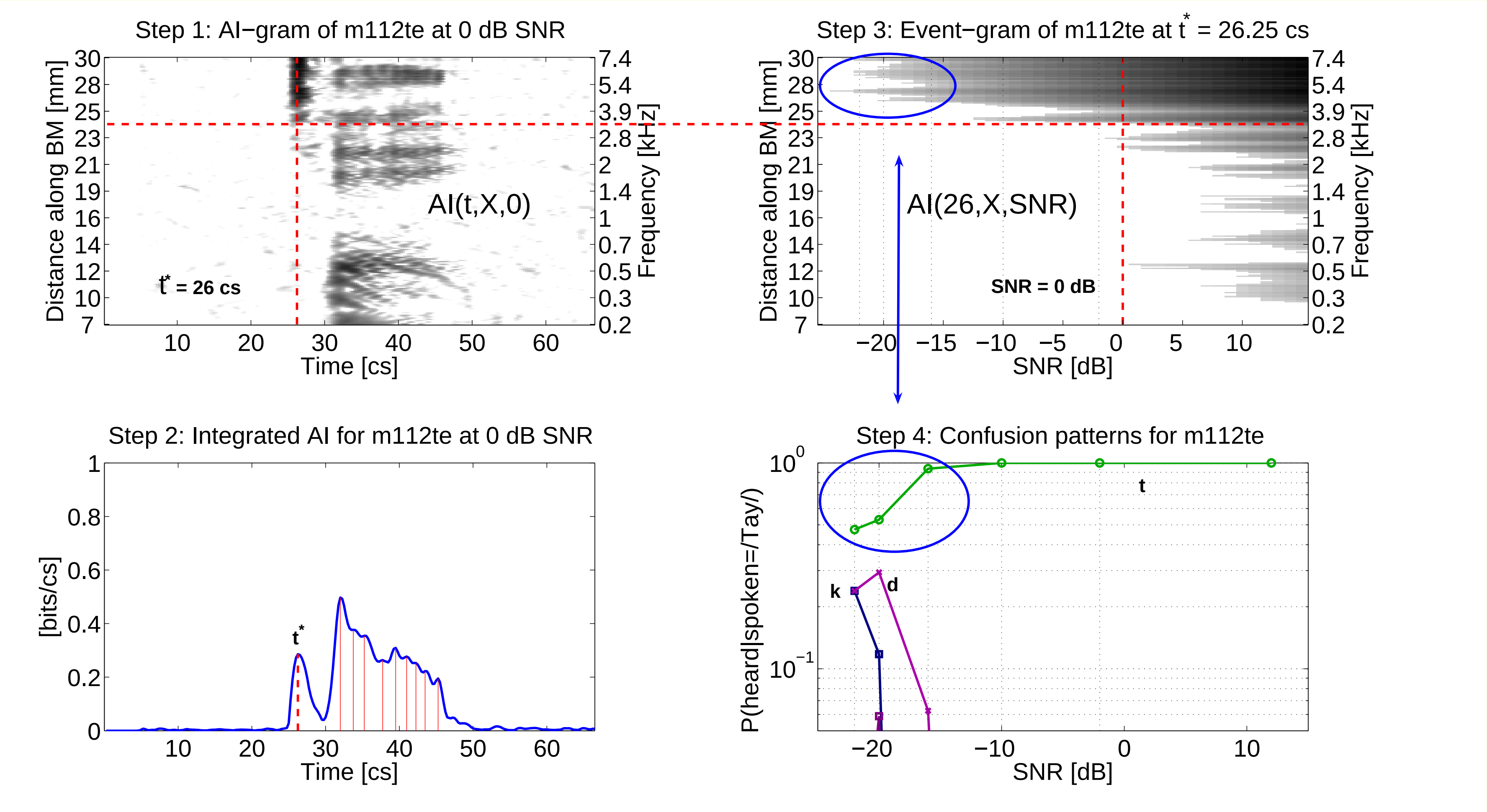
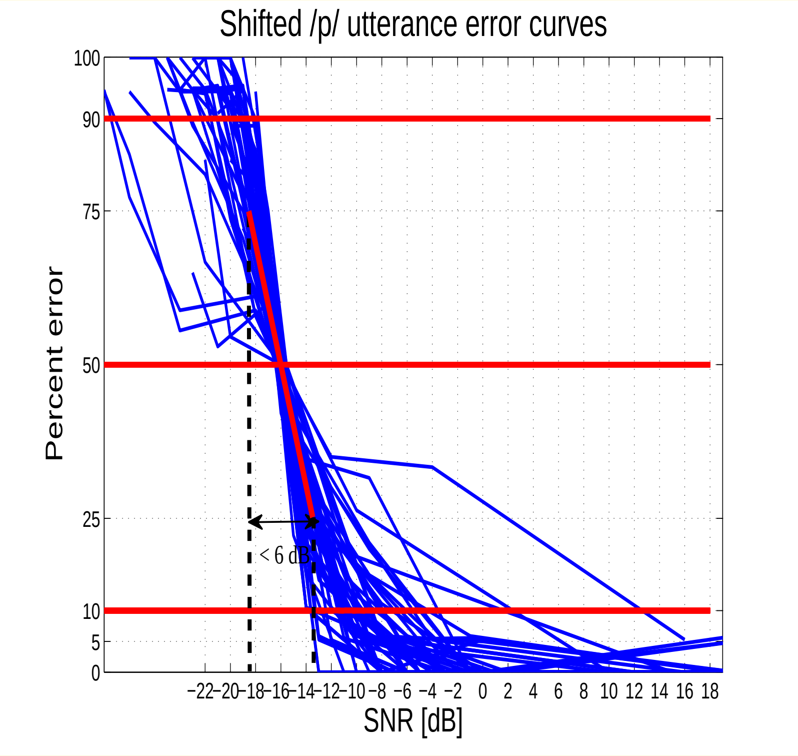


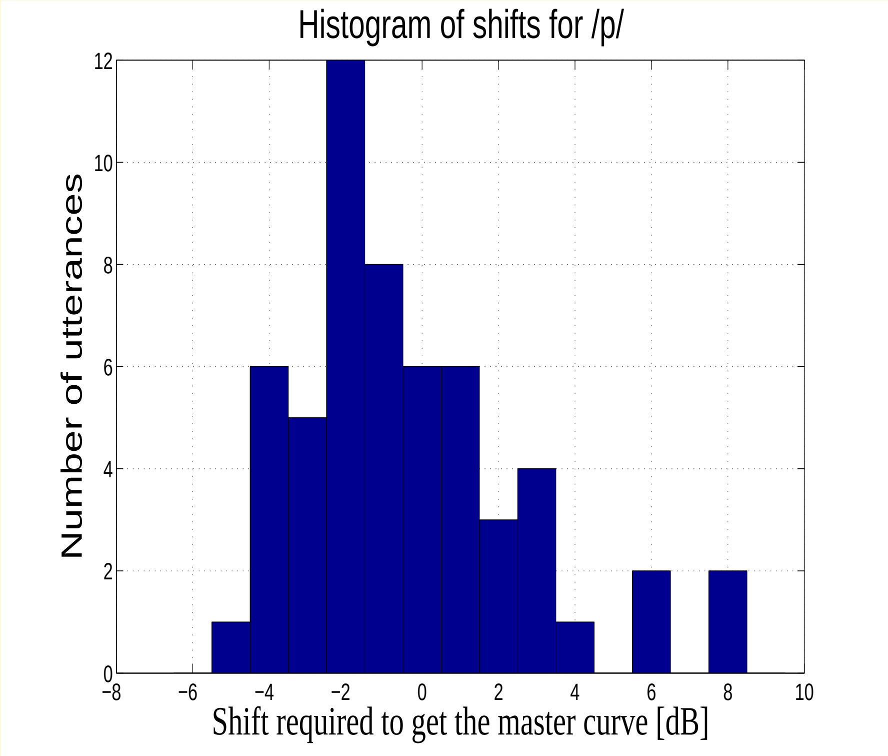
- /t/ confusion threshold at $P_c(SNR^*_{90} = -16)$ dB at 90% correct
- This is an example of a low-error /te/

Properties of $P_e(SNR)$ for /p/

- Error vs. SNR shifted to 50% threshold SNR^*_{50} (LEFT)
- Histogram of 50% error thresholds (RIGHT)
  - Sharp transition ⇒ Binary Plosive identification!



(a) $P_e(SNR - SNR^*_{50})$



(b) Distribution of SNR^*_{50}

- The average score is quantified by the articulation index

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  - The AI has a *huge* variance ($\Rightarrow$ low utility)

Conclusion NH ears

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- I have not yet discussed the HI token dependence

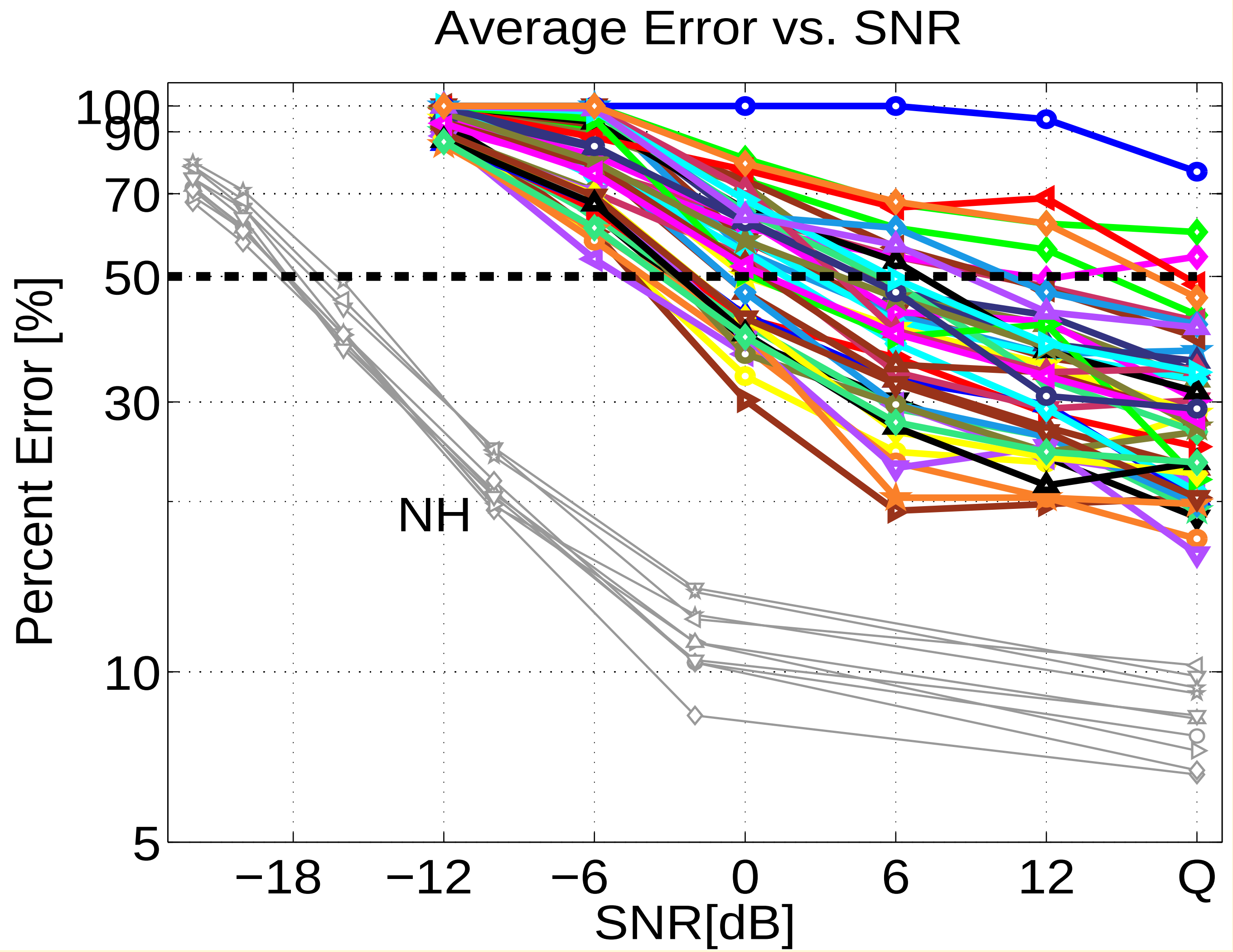
Outline

1. Intro + Objectives 2 mins
   - Research objectives
2. Historical overview 4 mins $\Sigma 6$
   - AG Bell (1860), Rayleigh (1910) to Shannon (1948)
   - Speech-feature studies ($>$1950)
3. Methods 8 mins $\Sigma 14$
   - Channel capacity and the Articulation Index
   - Psychophysics of speech/AIgram/3DDS
4. Results with NH ears 10 mins $\Sigma 24$
   - Binary features; Confusions; Primes and Morphs;
5. Results with HI ears 20 mins $\Sigma 44$
   - Individual differences of consonant confusions
6. Summary + Conclusions 6 mins $\Sigma 50$

Yogi Berra Quote:

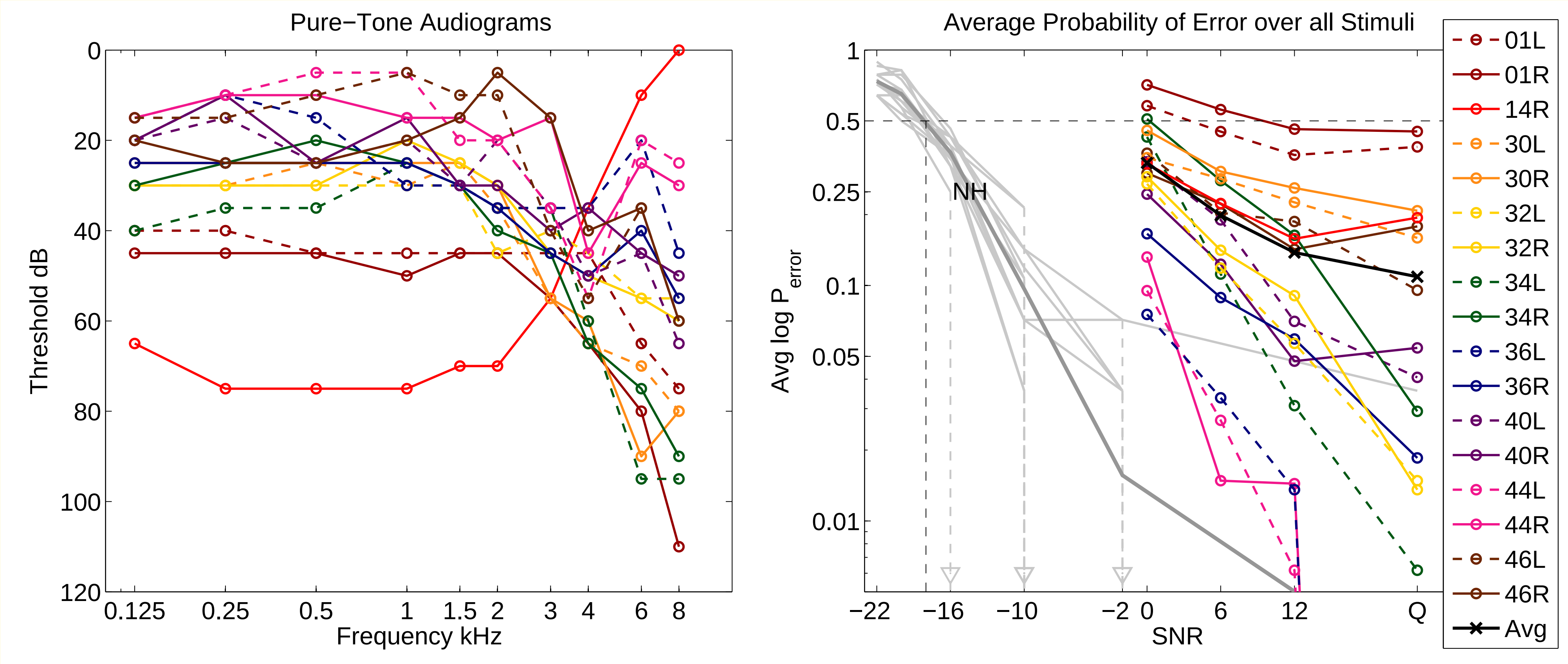
- "You can observe a lot by watching."

- Very large spread of error vs. SNR



PTA & Average CV error over 17 HI ears

- 14 Miller-Nicely *zero-error* CV tokens:
  /p,t,k, b,d,g, f,s,ʃ, v,z,ʒ, m,n/+/a/



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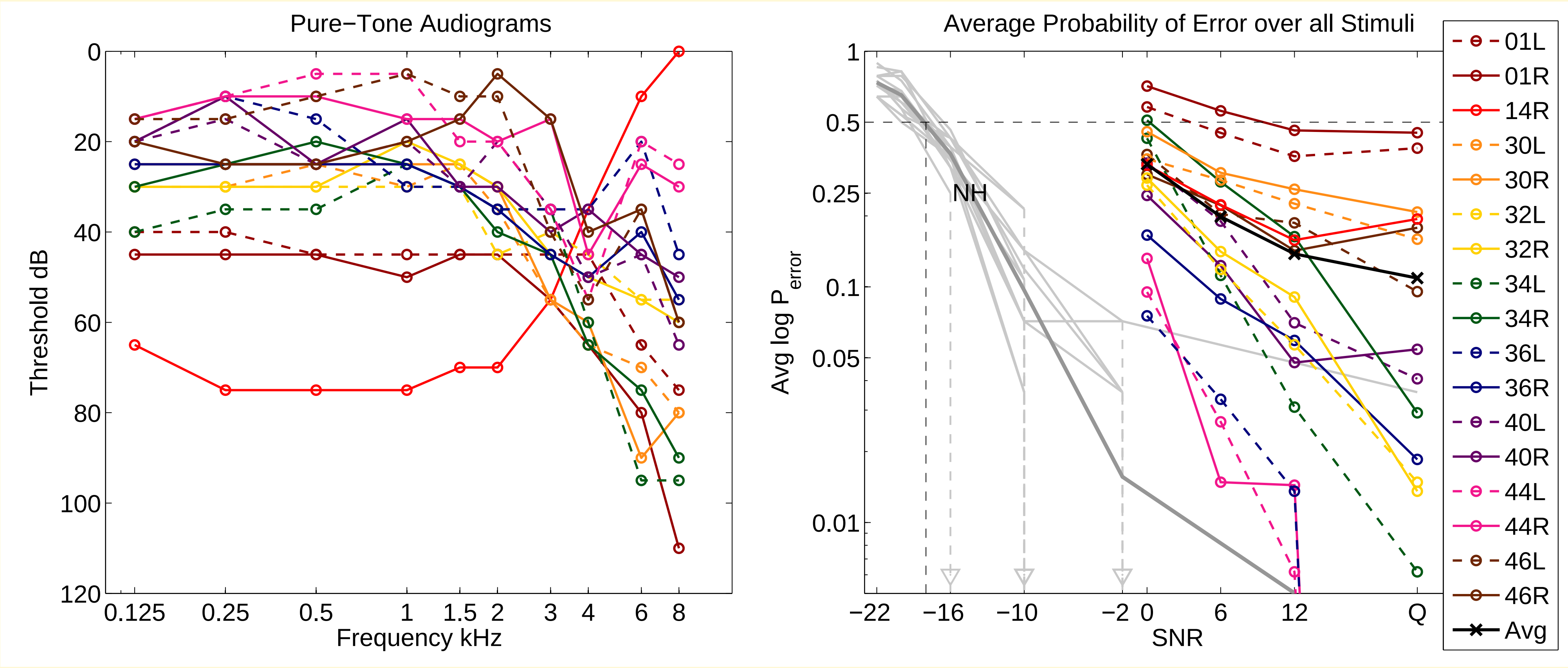
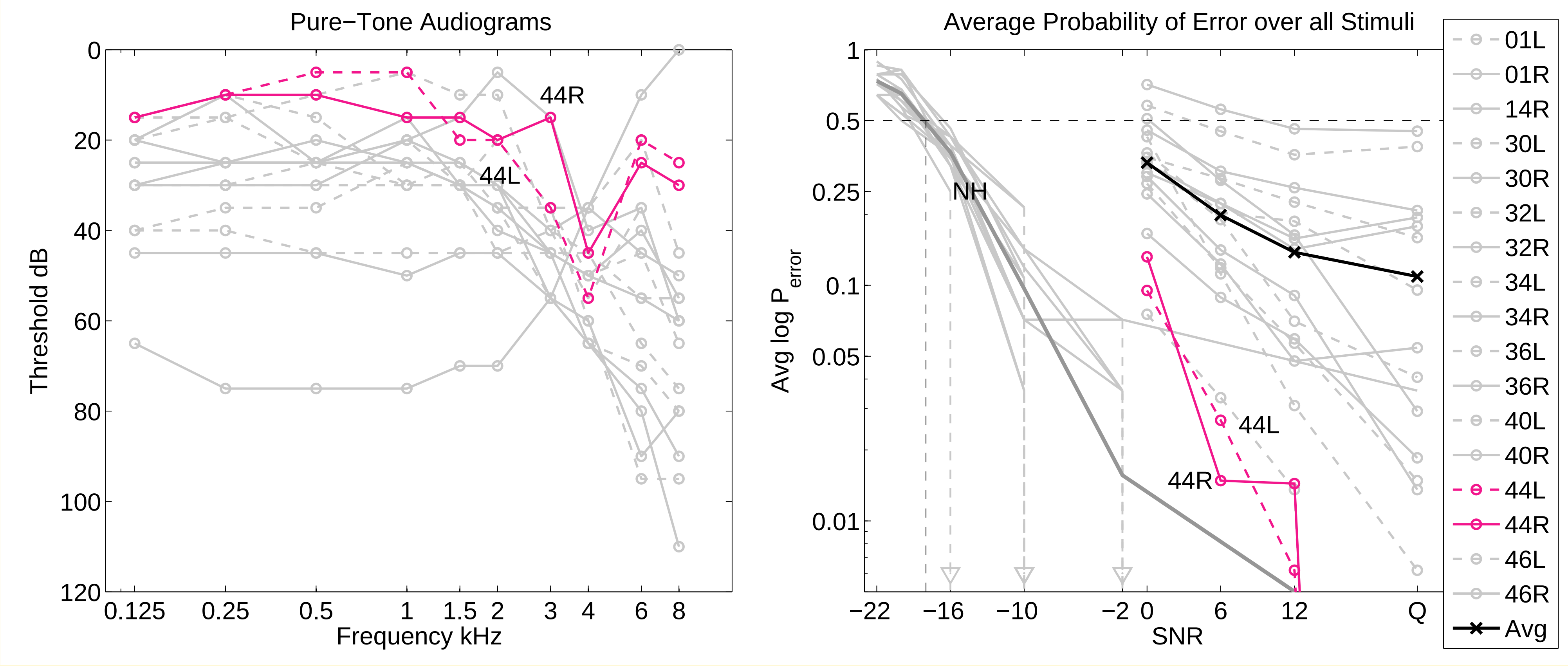


- 2 tokens for each CV (1-male & 1-female)

PTA & Average CV error – 44-L/R

- Subject 44-L/R (Left/Right) is our "best" listener!



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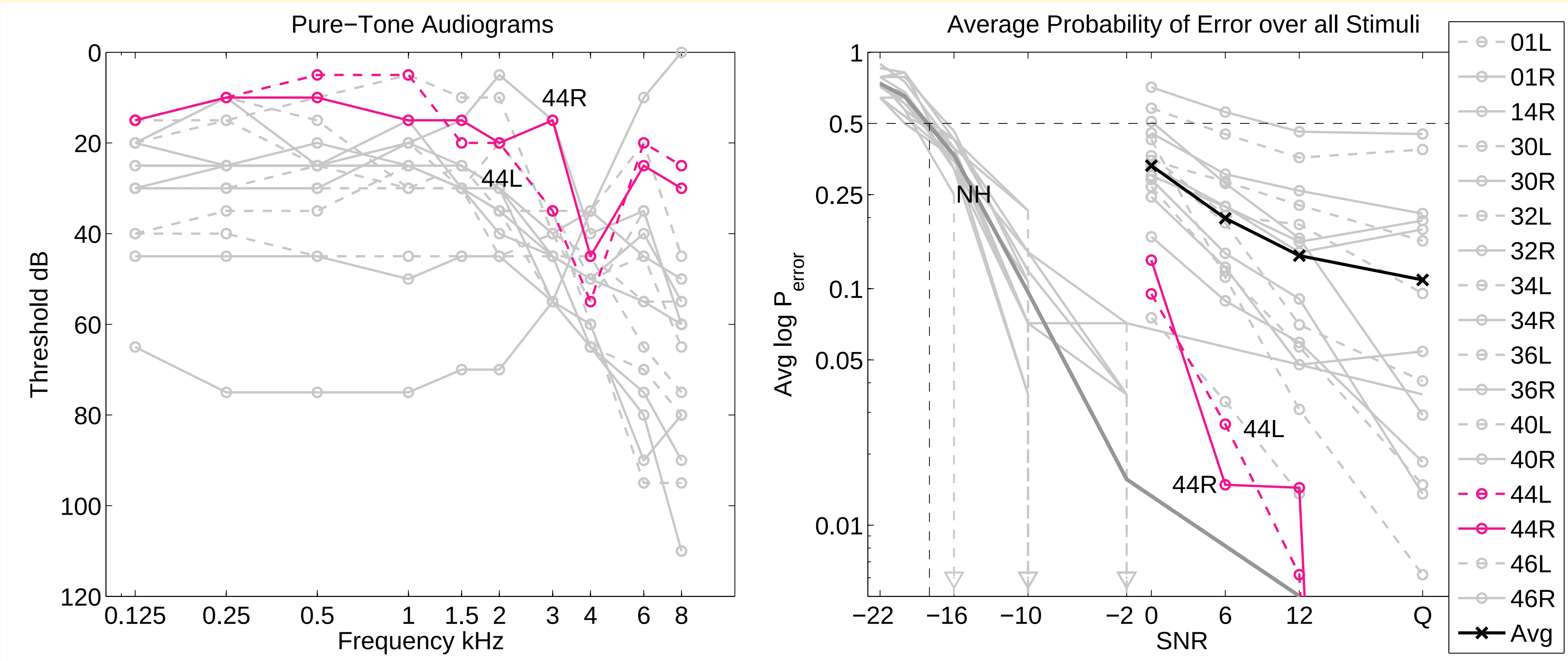
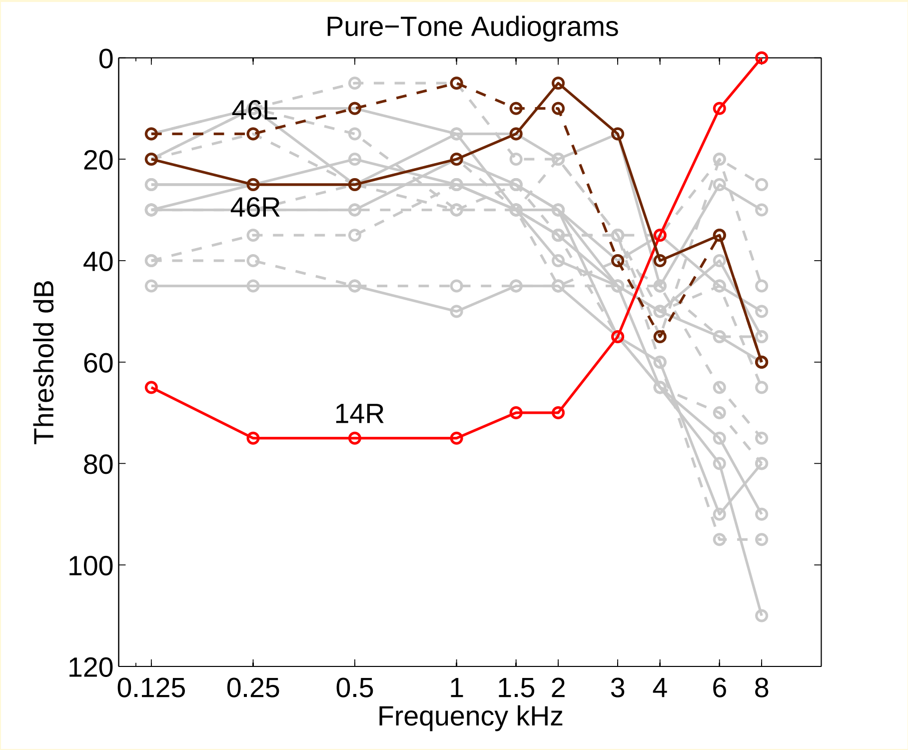
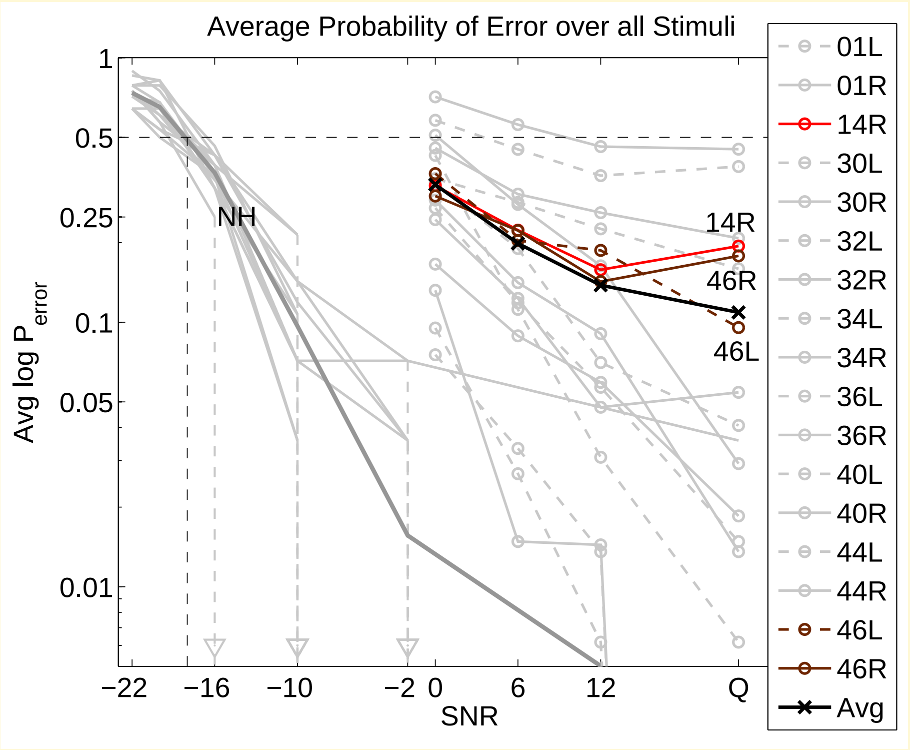


If only life were always this simple!

- Very different HL with nearly identical average speech scores





  - Average speech scores show no correlation with hearing-level,

PTA & Average CV error: 14R, 46L/R

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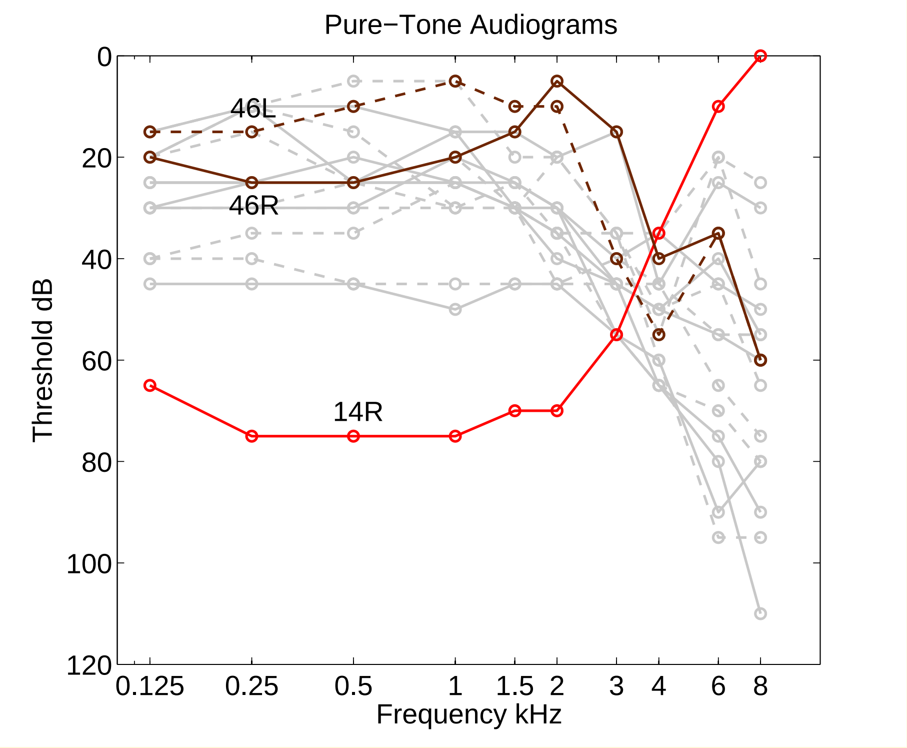

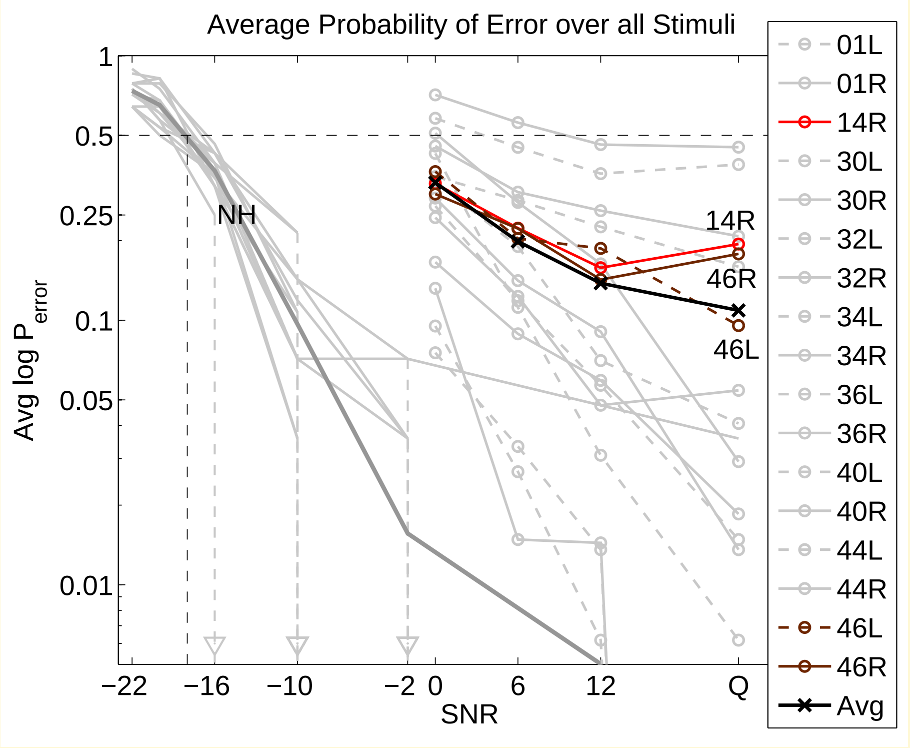

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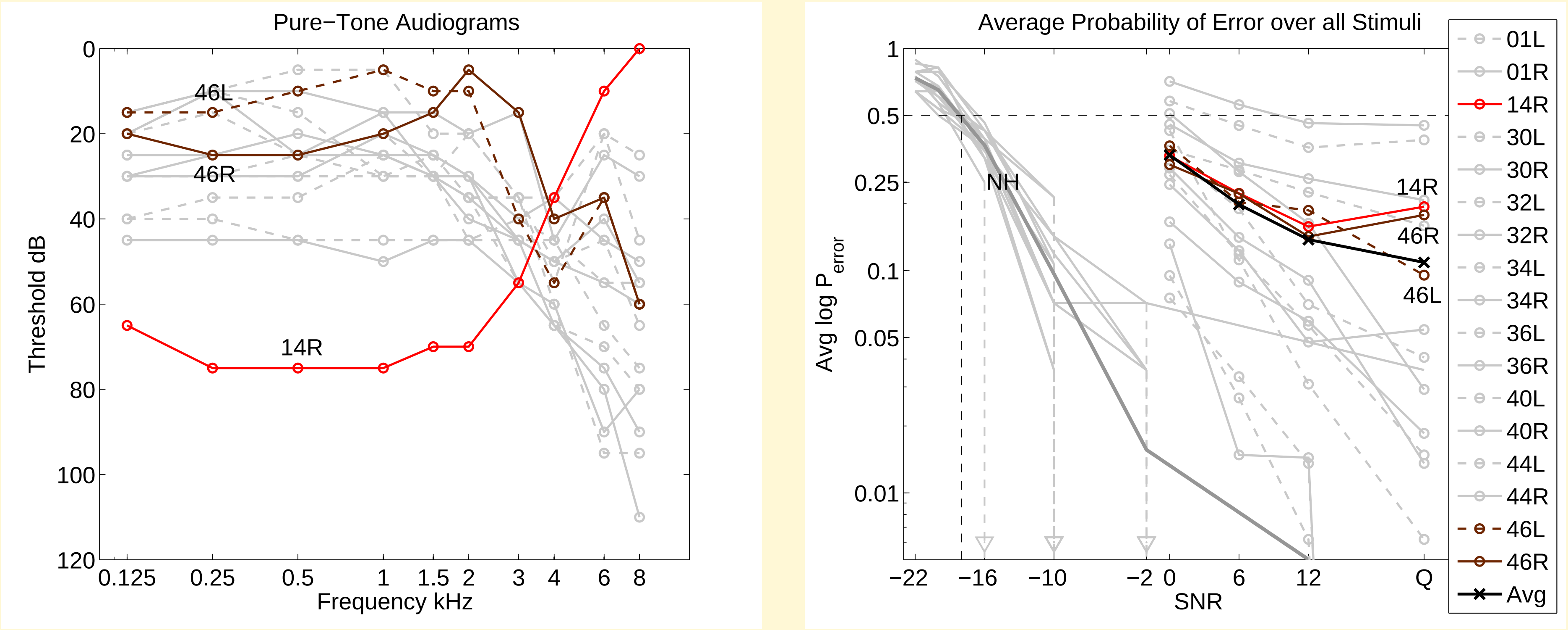

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- Why? . . .

PTA & Average CV error: 14R, 46L/R

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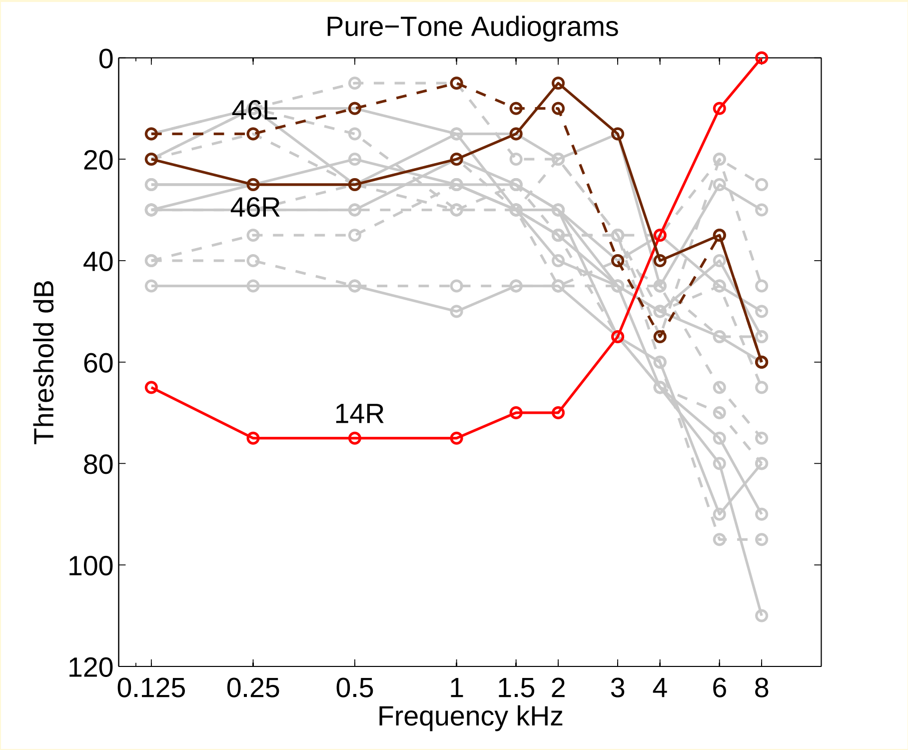
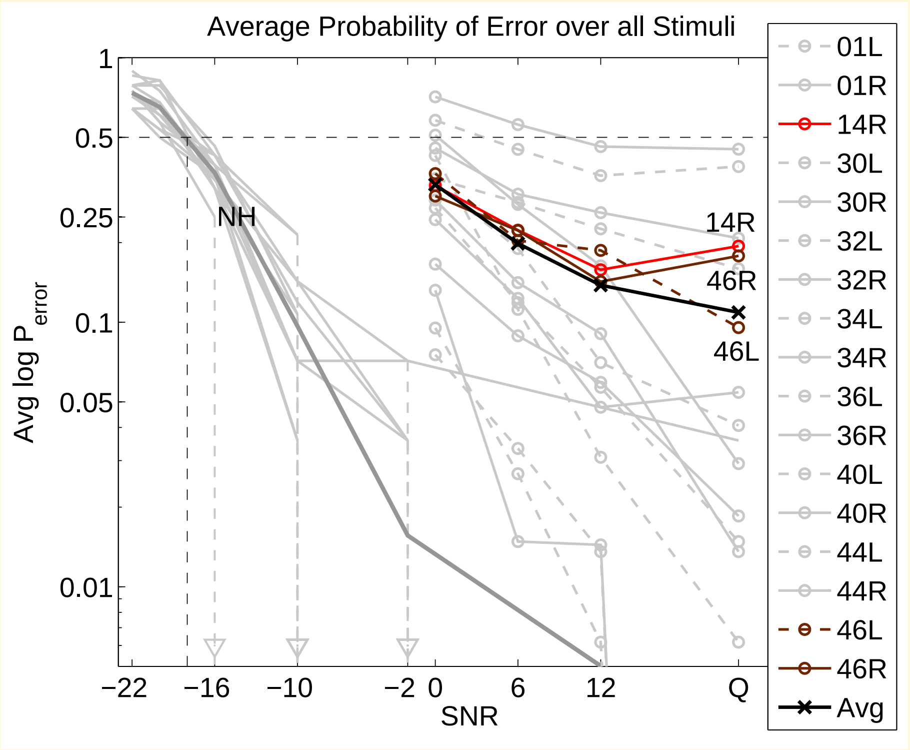


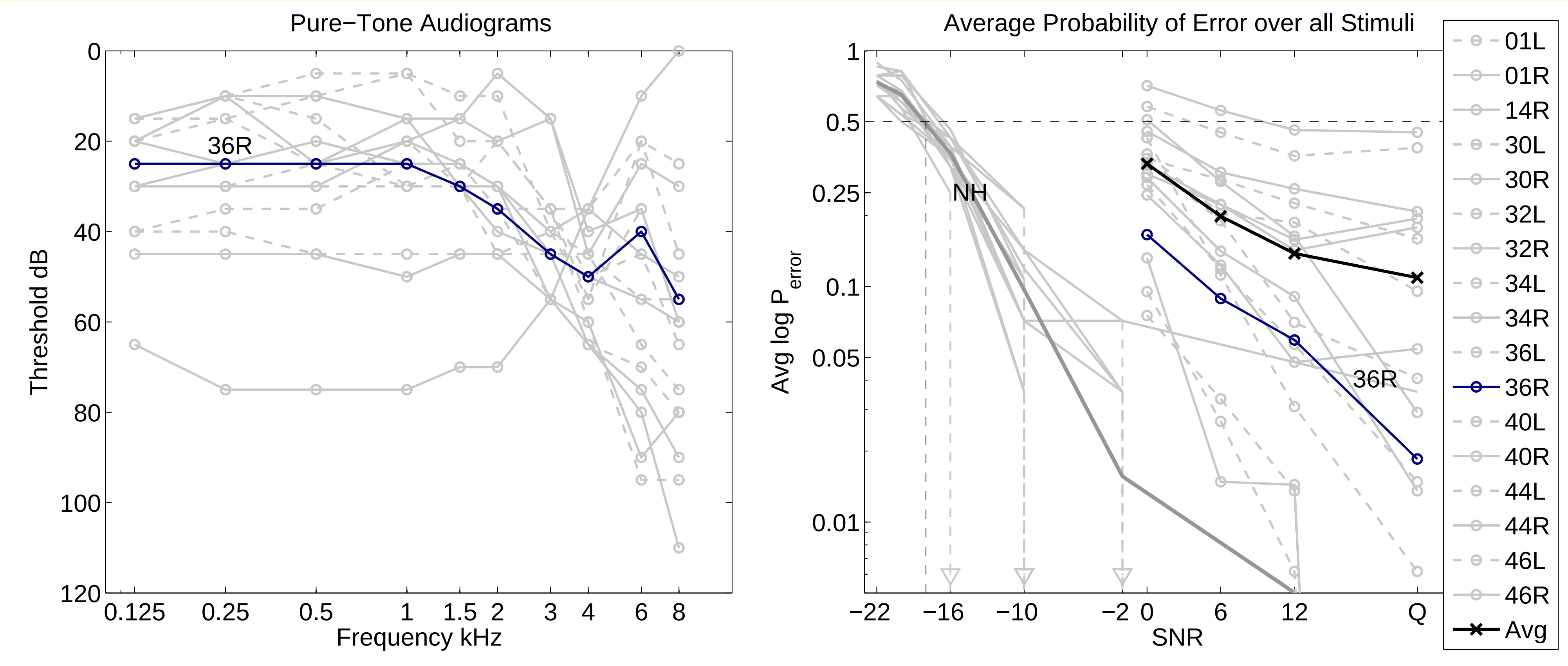


  - Average speech scores show no correlation with hearing-level, with massively different audiograms!

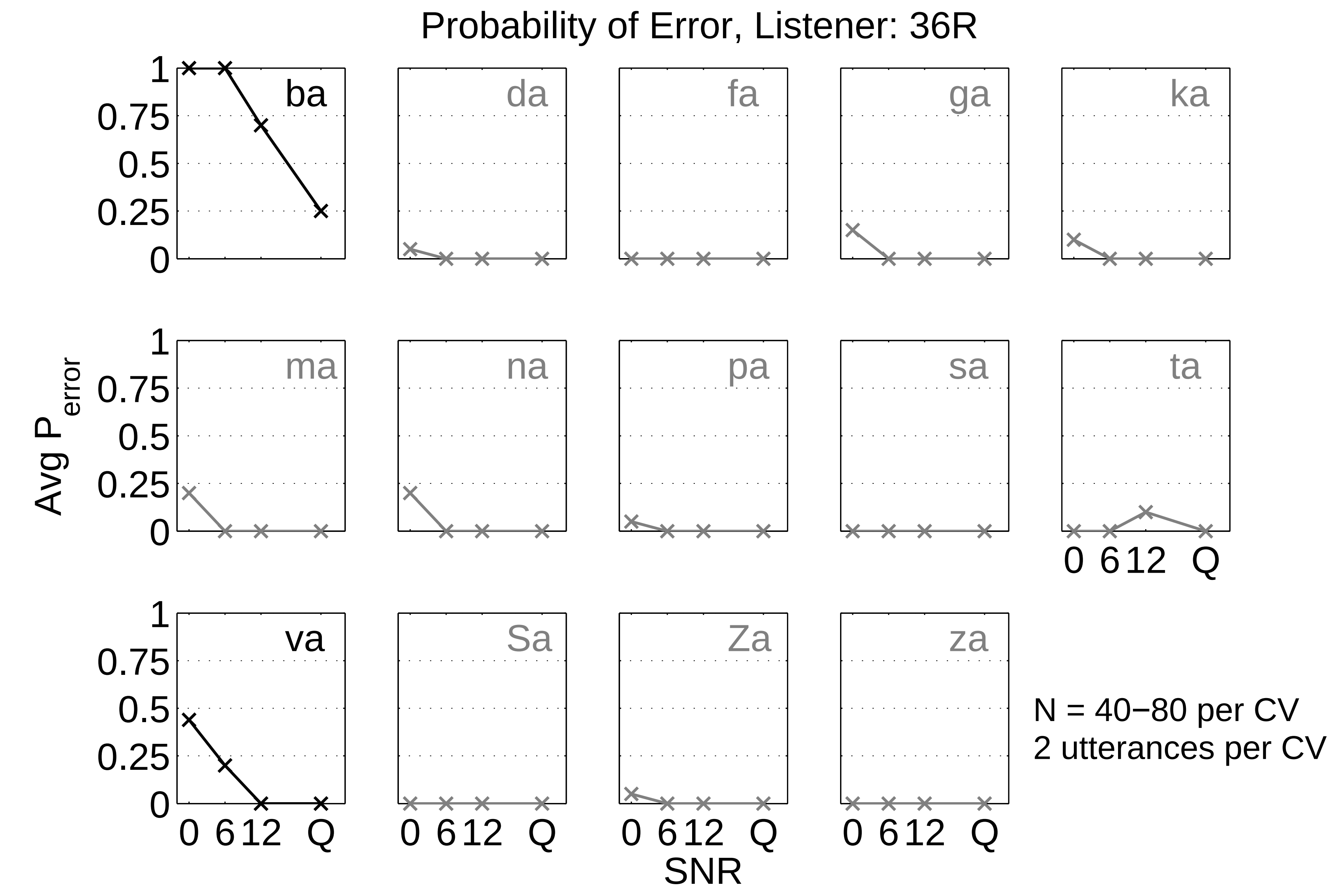
- Why? . . . Too much averaging!

PTA & Average CV error: 36R

- Case study for 36-R



For Subj 36R: only /ba, va/ have errors!



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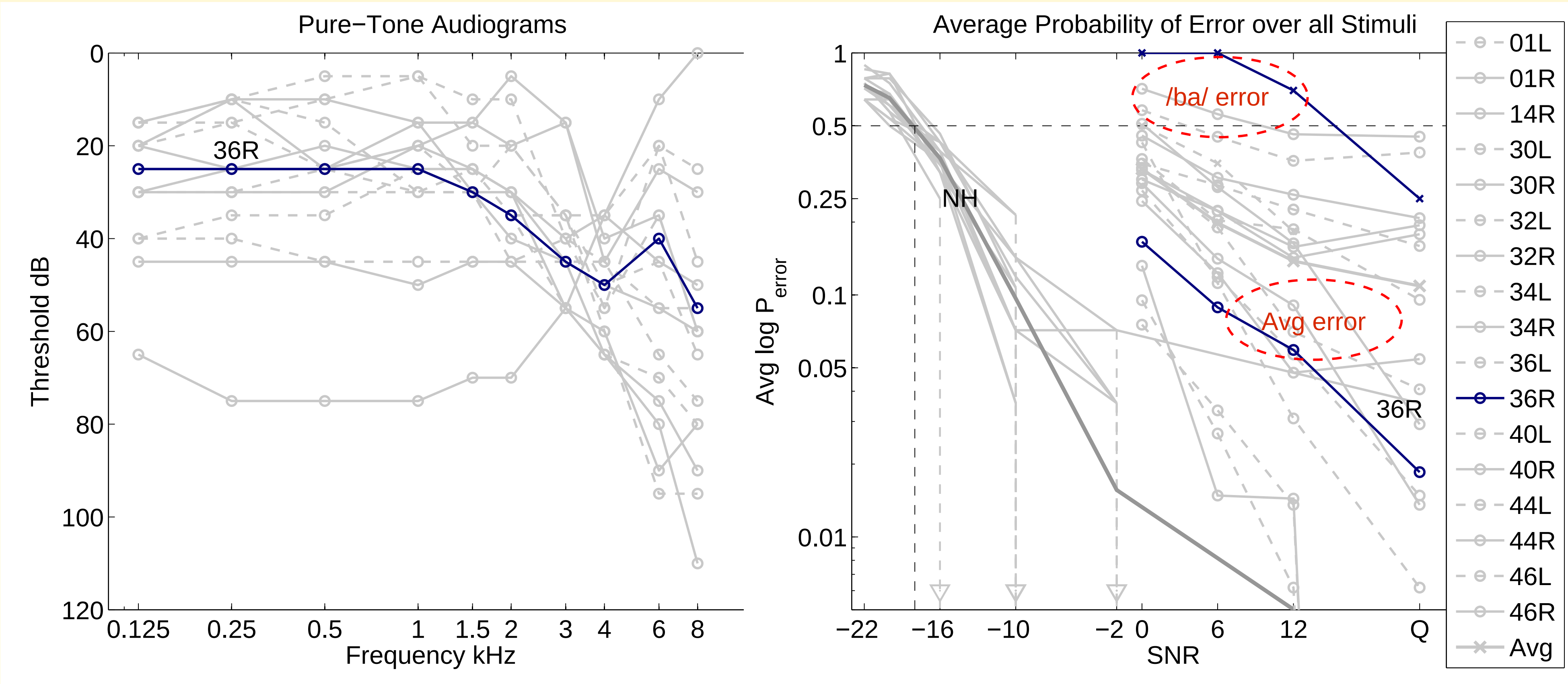
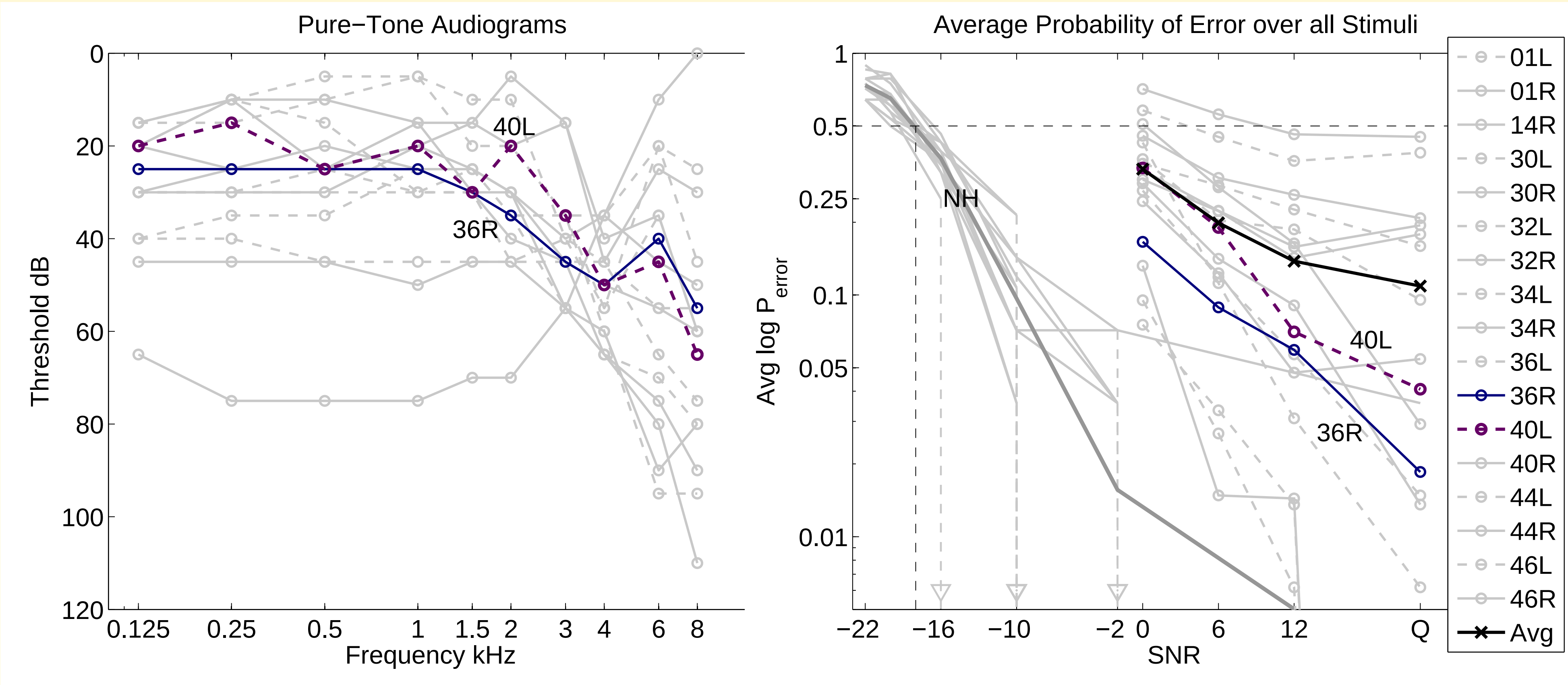


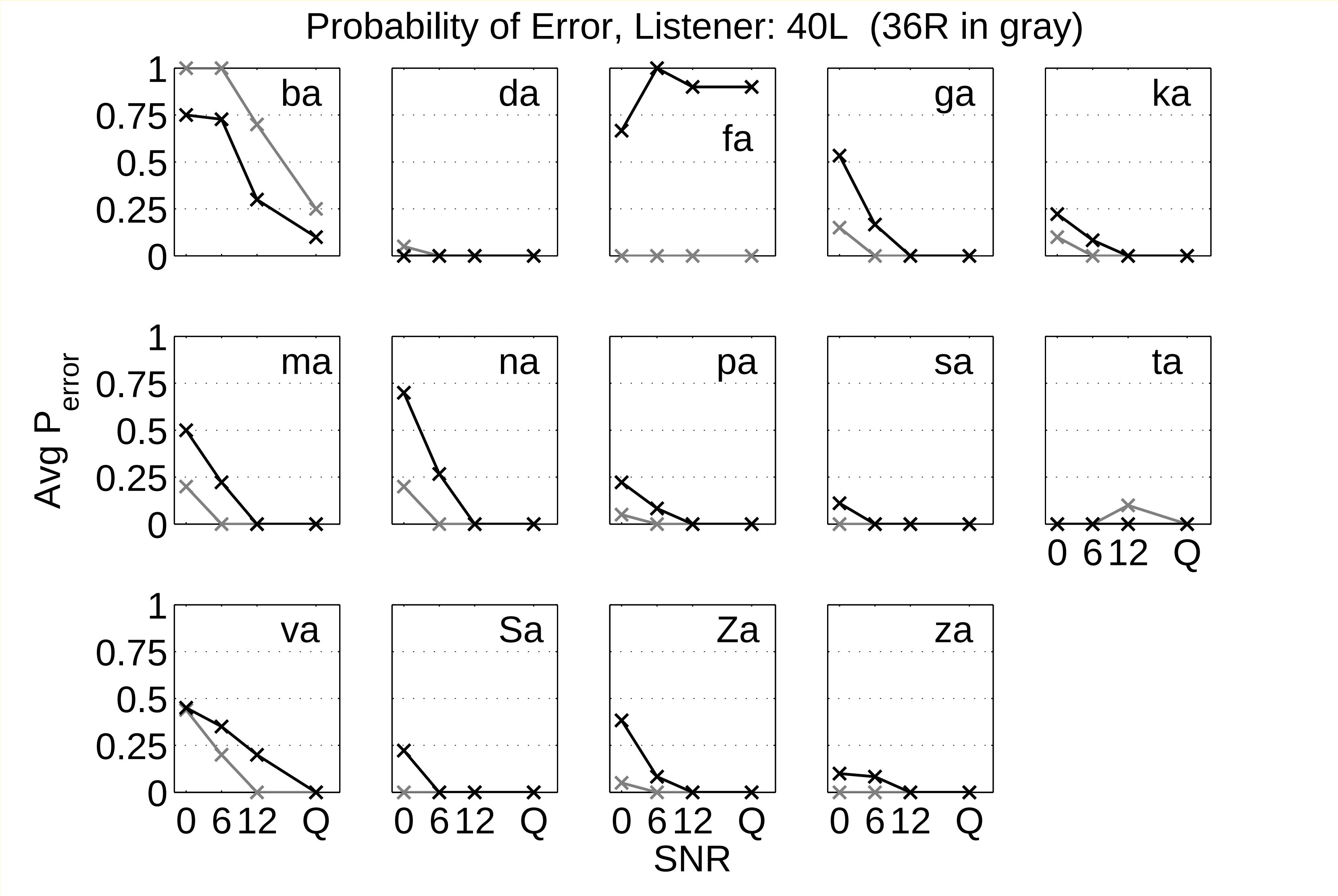
PTA & Average CV error: 40L vs 36R

- Case study for 40L

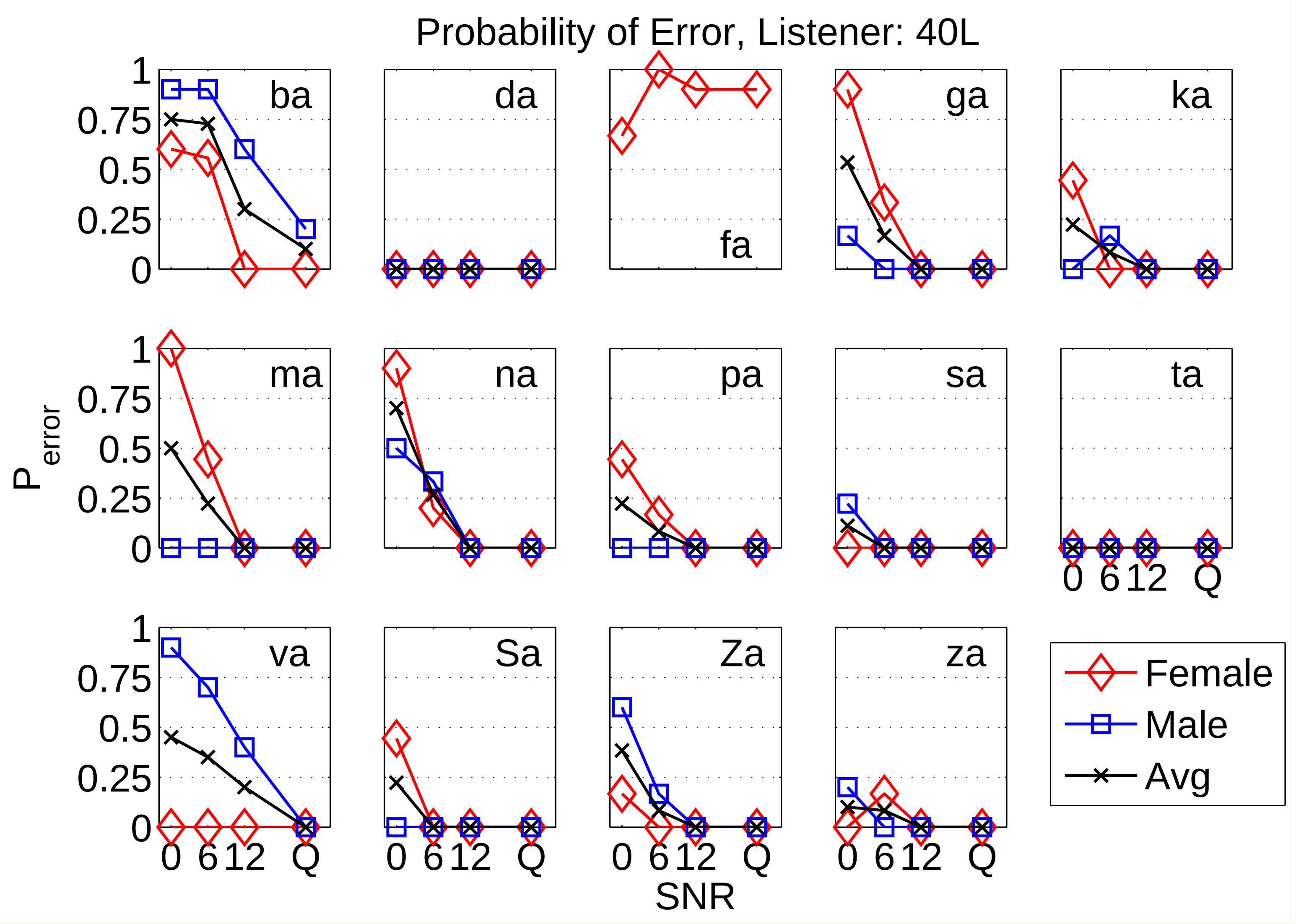


Subject 40L error > 36R

- Errors for 40L re 36R: /ba, fa, ga, ka, ma, na, pa, va, ʒa/

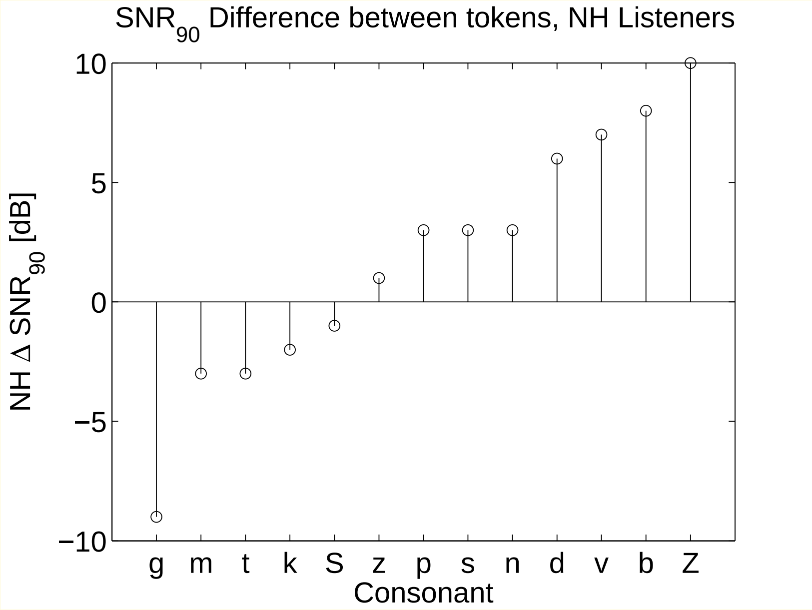


- The token (i.e., talker) errors across CVs are asymmetric



NH vs. HI Utterance differences

- Rank order of consonants by SNR_{90}



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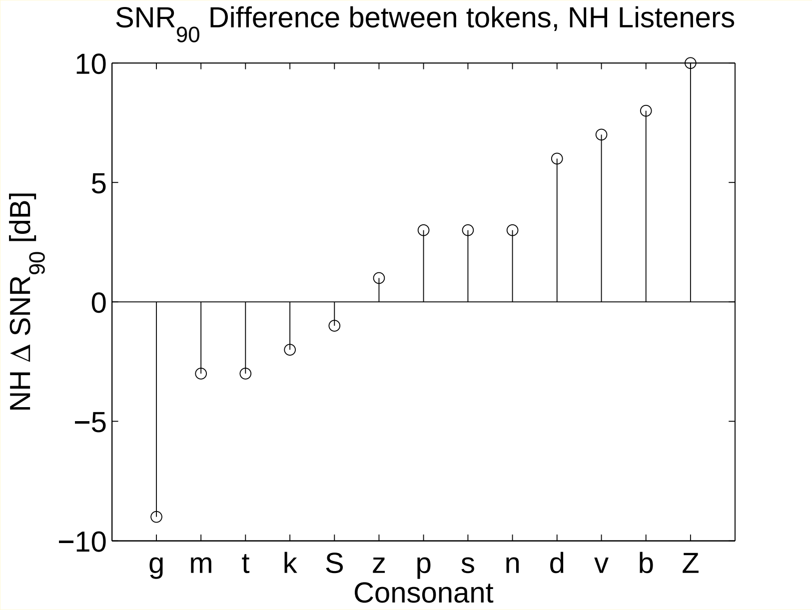

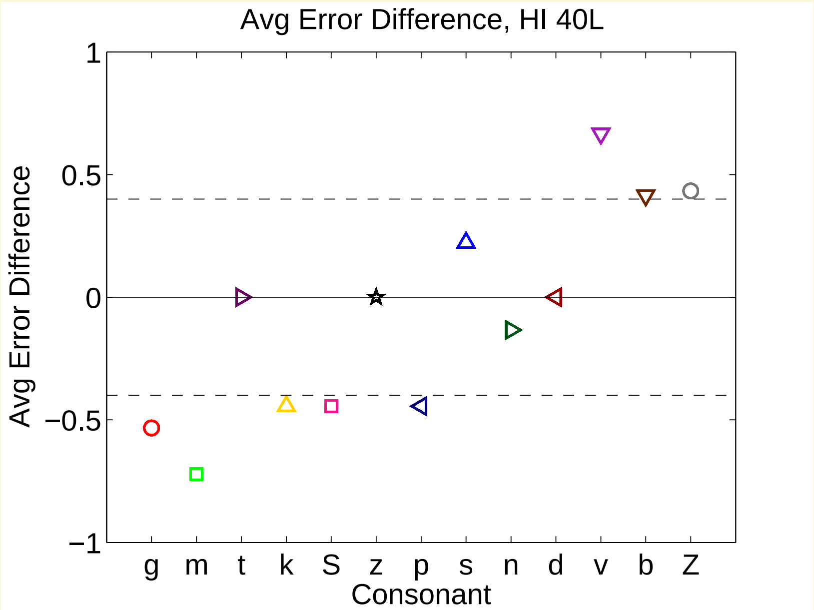

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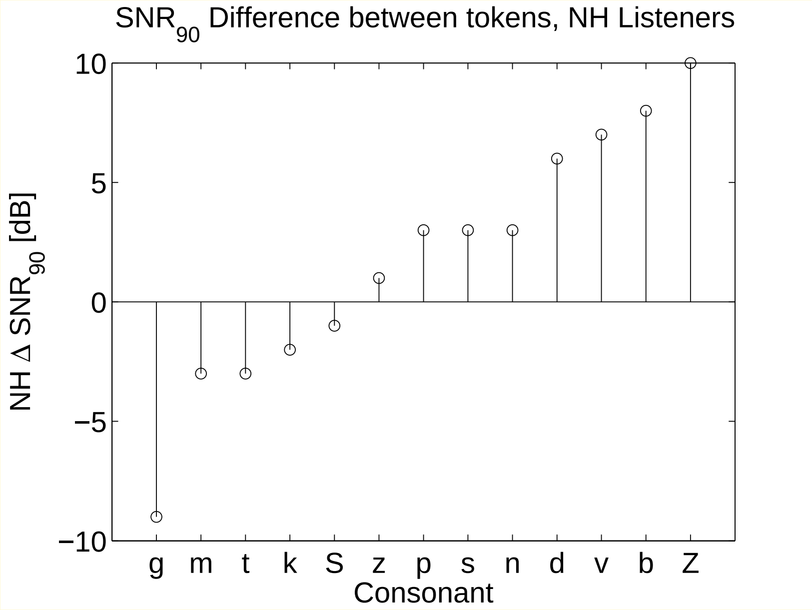

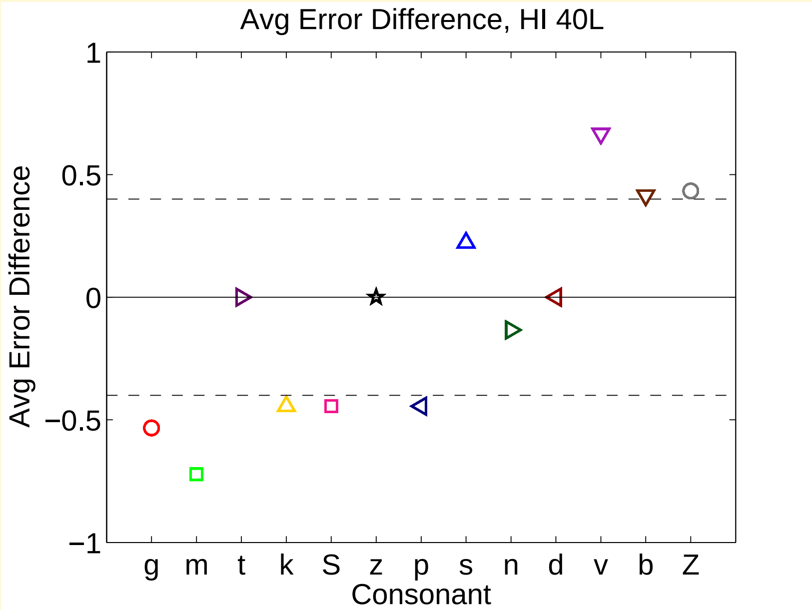

- Note tight relationship in the error difference for NH ears (left) and subject 40L (right)

NH vs. HI Utterance differences

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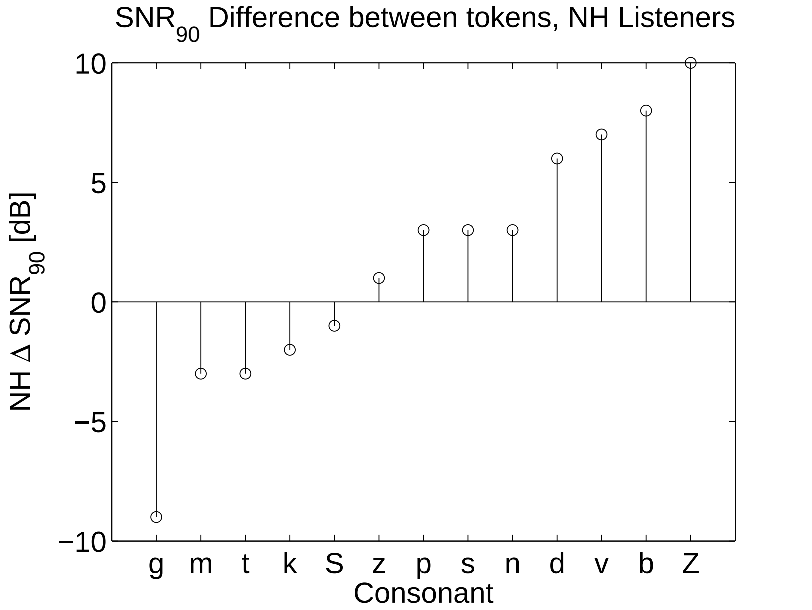

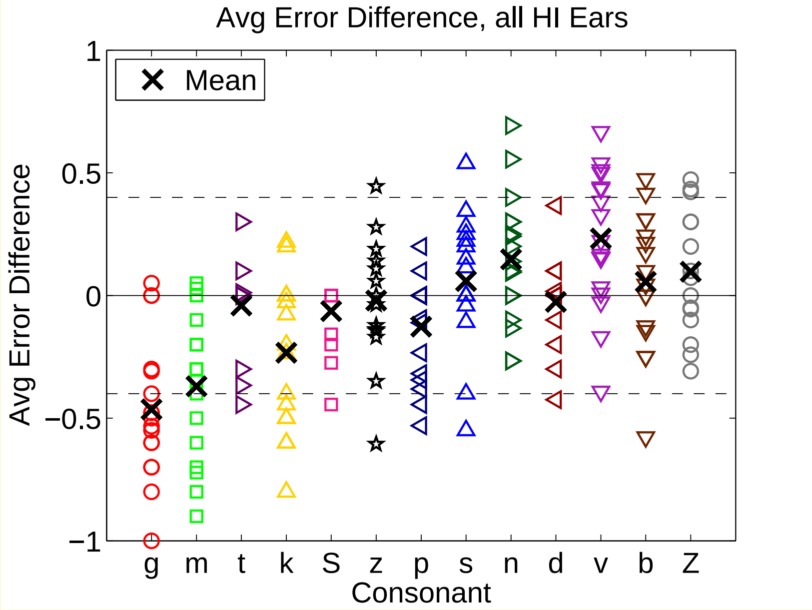

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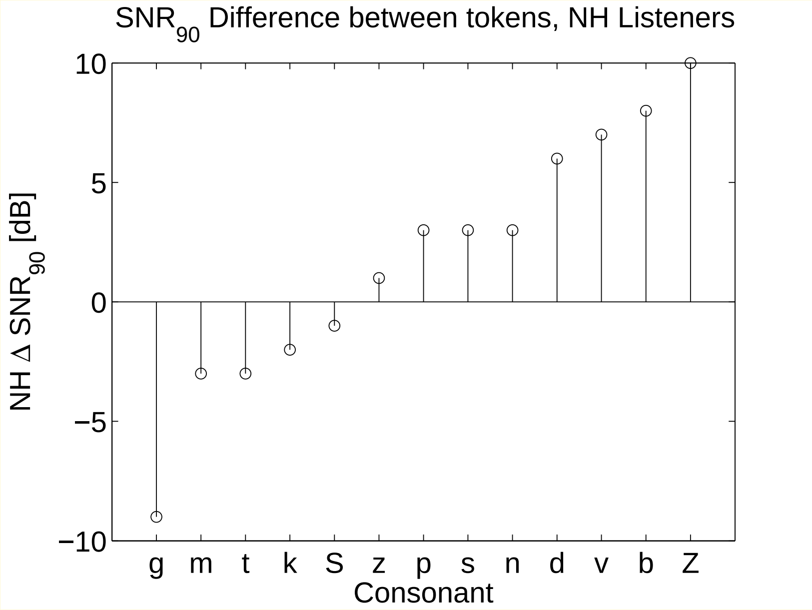

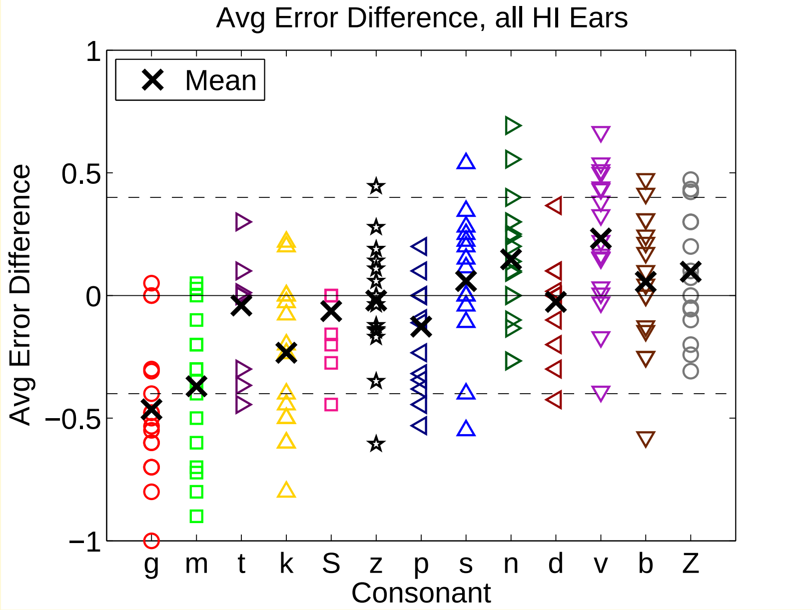

- Note the order correlation between NH and HI listeners ($\rho = 0.81$, p< 0.001)

Yogi Berra Quote:

- We made too many wrong mistakes.

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Conclusion on HI errors

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Conclusion on HI errors

- The Audiogram and Average Consonant errors have low correlation
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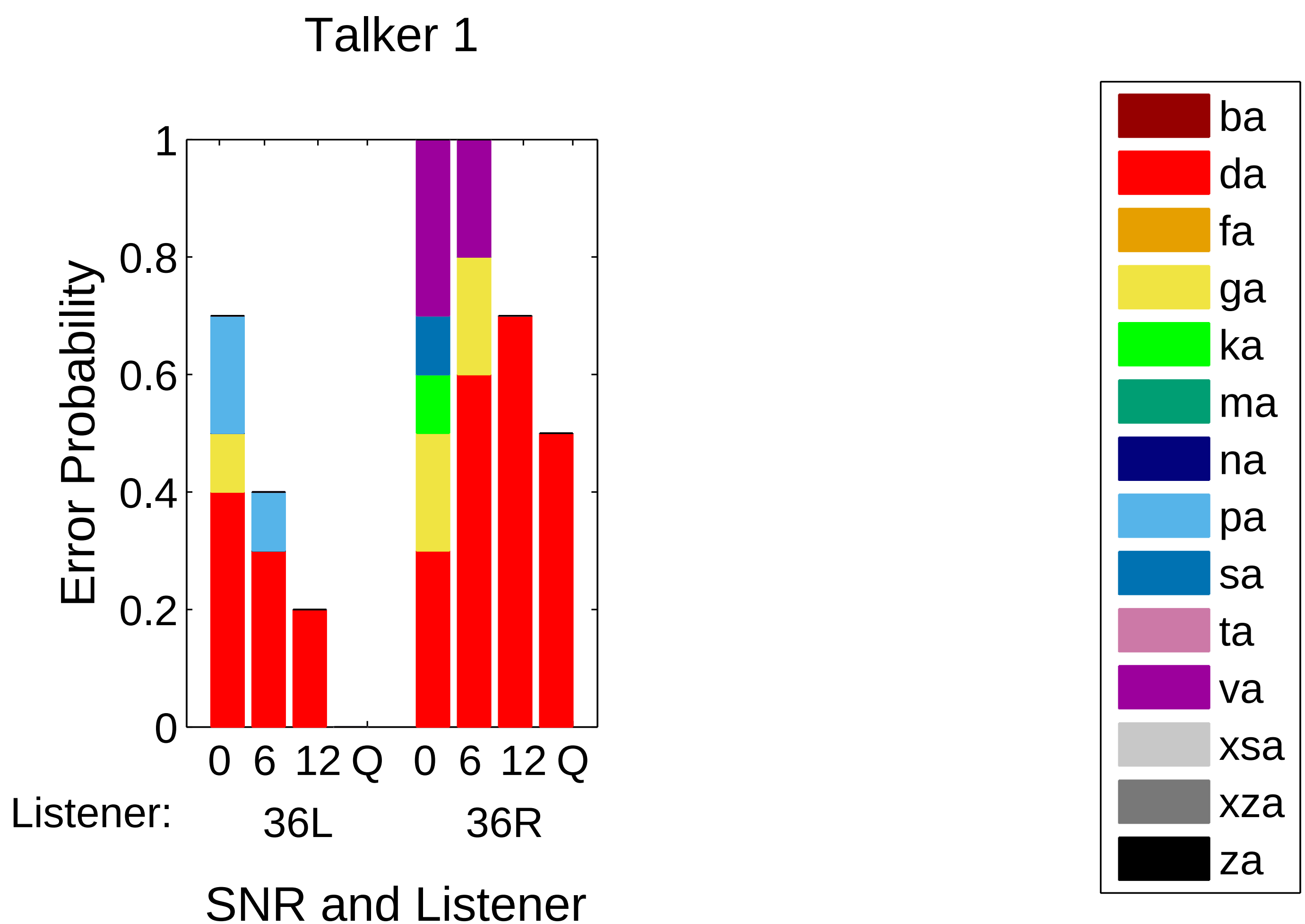
  - Errors
  - Confusions
- Averaging destroys important HI subject information
  - Making the HI subject *appear* as inconsistent
- The 3 deadly SINs of averaging:
  1. Across *HI subjects:* SIN_s
  2. Across *consonants:* SIN_c
  3. Across *tokens:* SIN_t

Confusions for Talker 1 of /ba/

- Colors label the confusions



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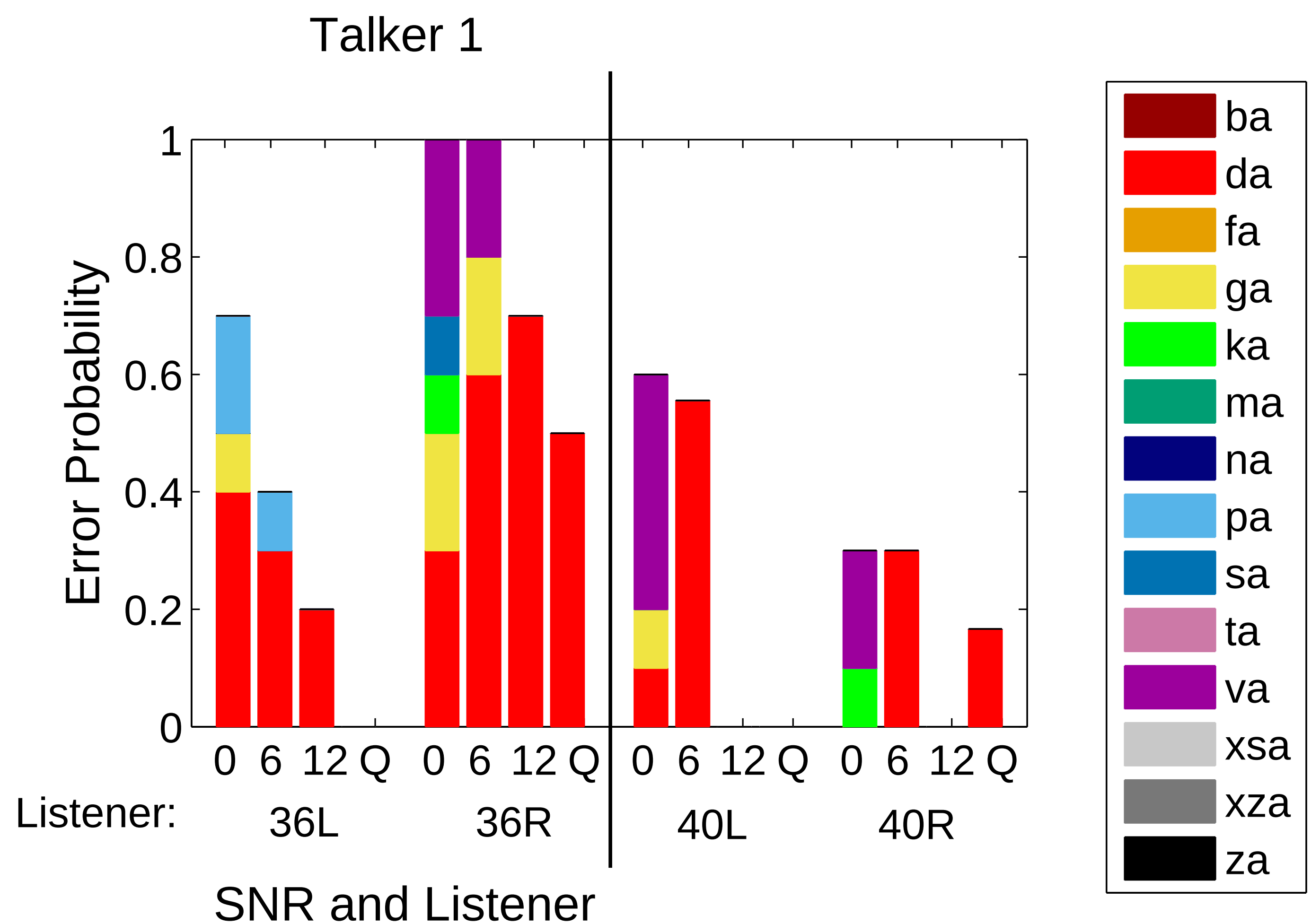

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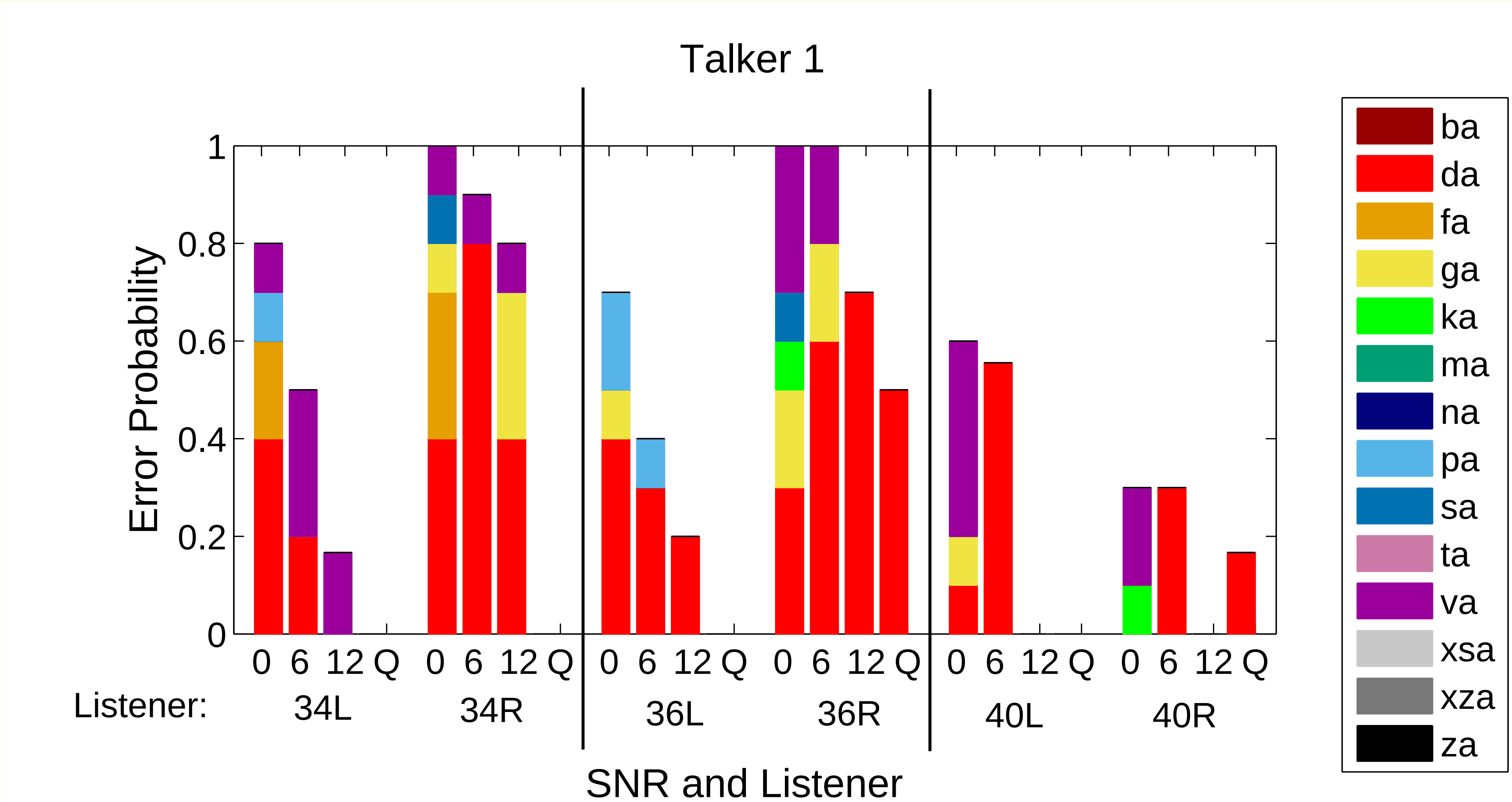

Confusions for Talker 2 of /ba/

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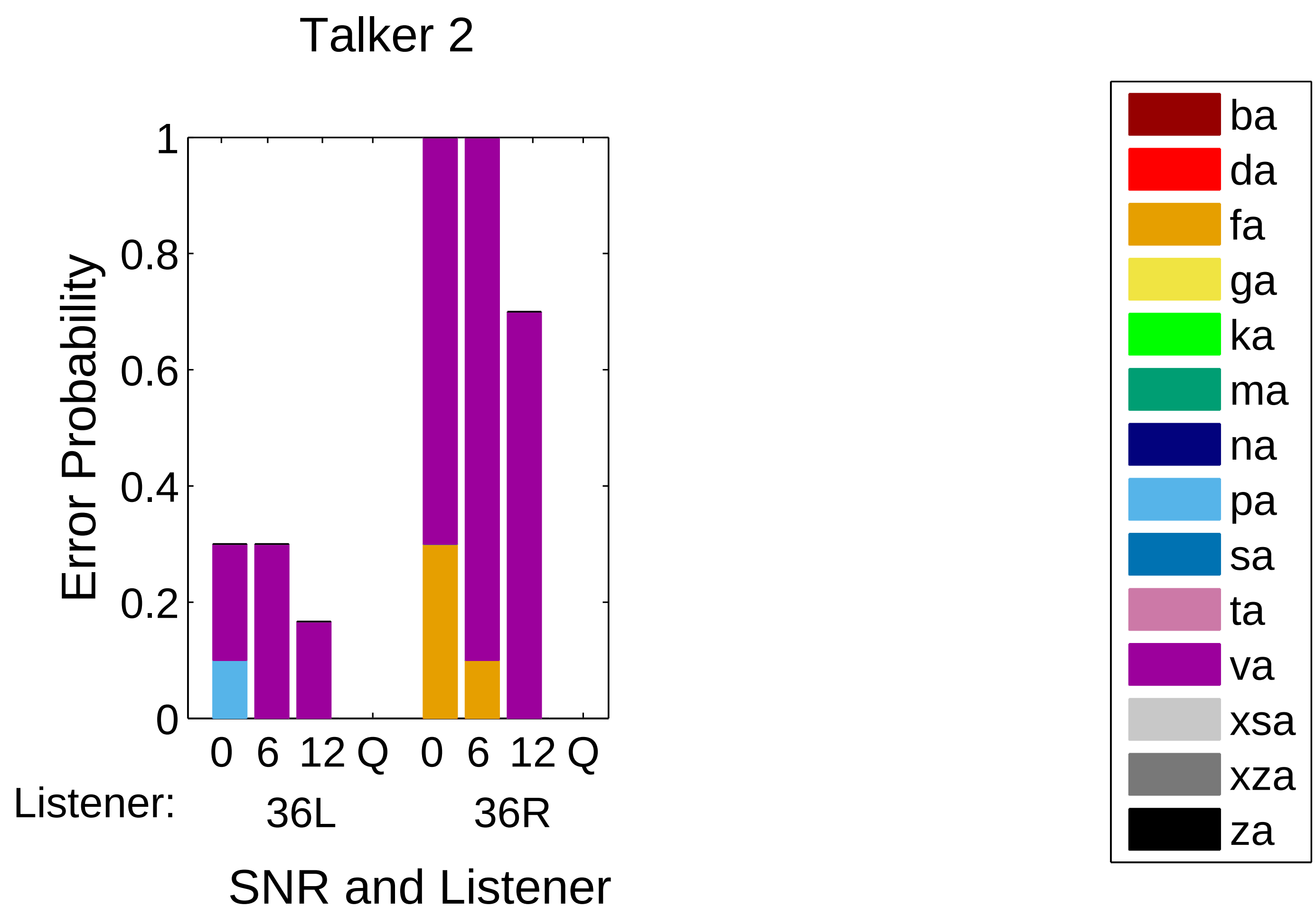

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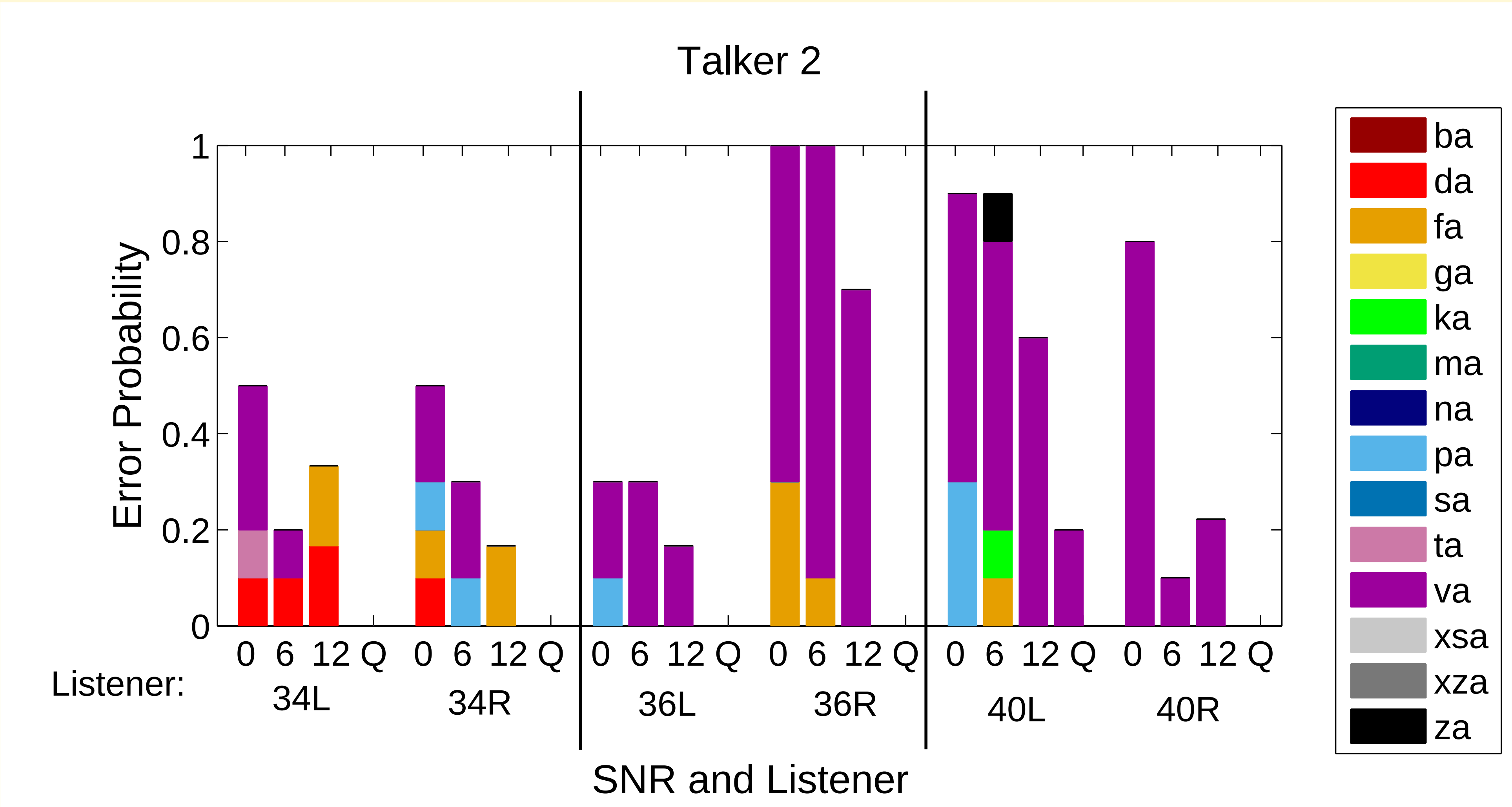
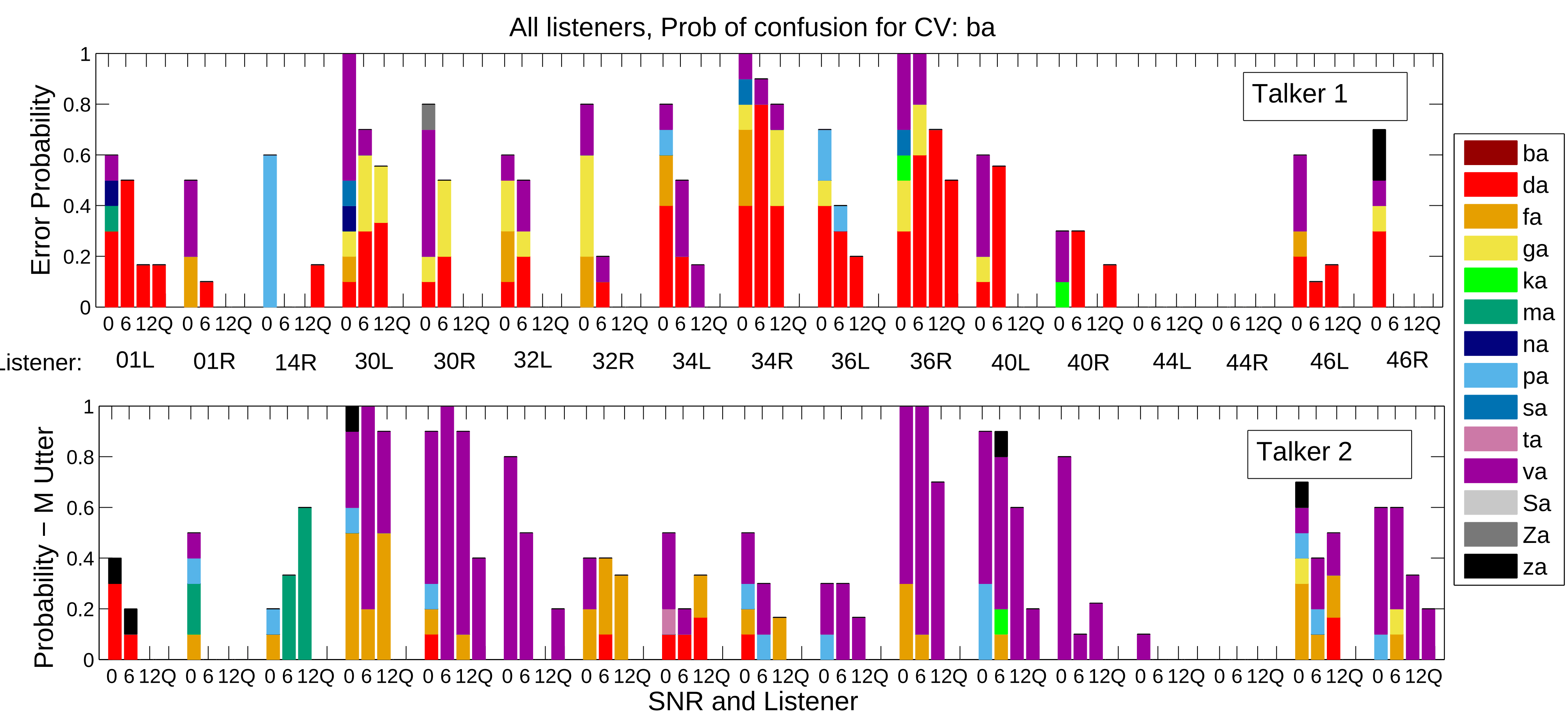


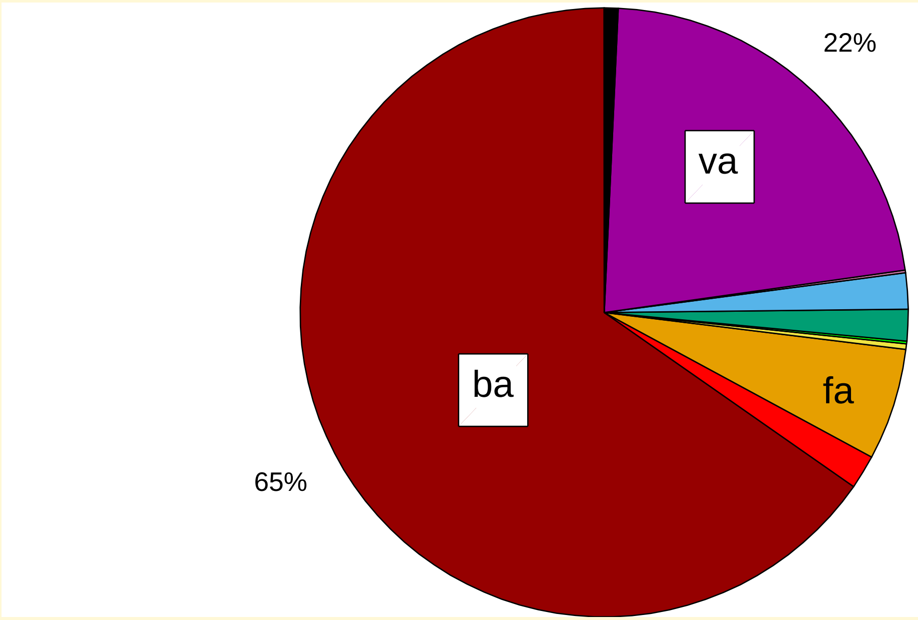
Confusions for two tokens of /ba/

- Colors label the confusions
  - Talker 1 /ba/ → /da/
  - Talker 2 /ba/ → /va/



Confusions for two tokens of /ba/

- Average confusions for /ba/
  - Do NOT average across tokens: SIN$_t$ #3 !



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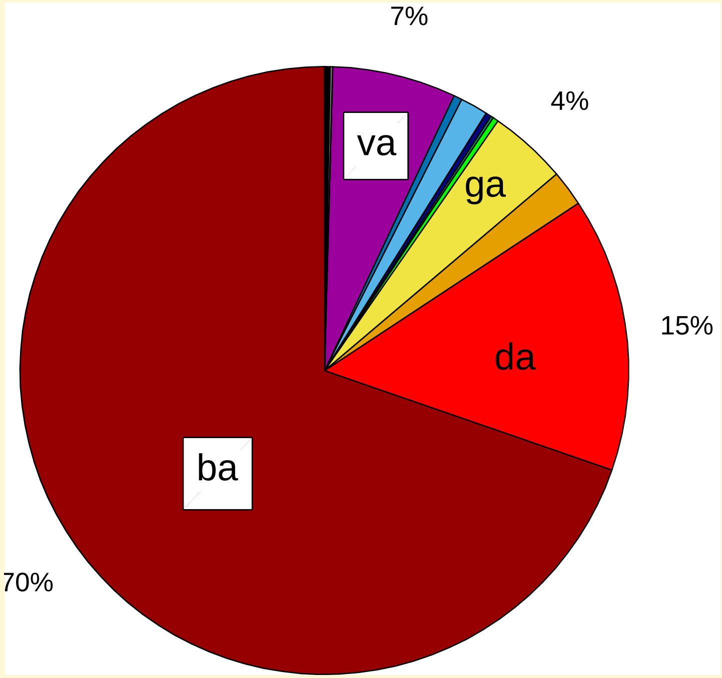

(b) Talker 2

Confusions for two tokens of /va/

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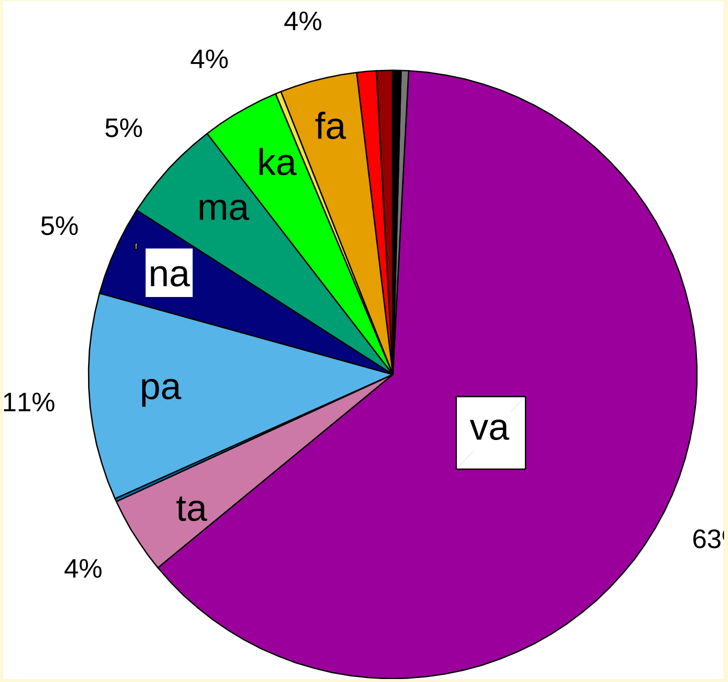

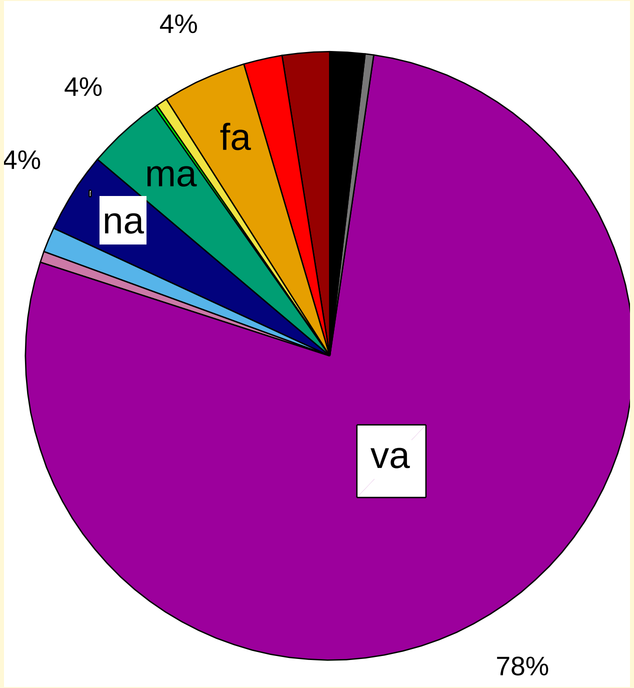

Confusions for two tokens of /ga/

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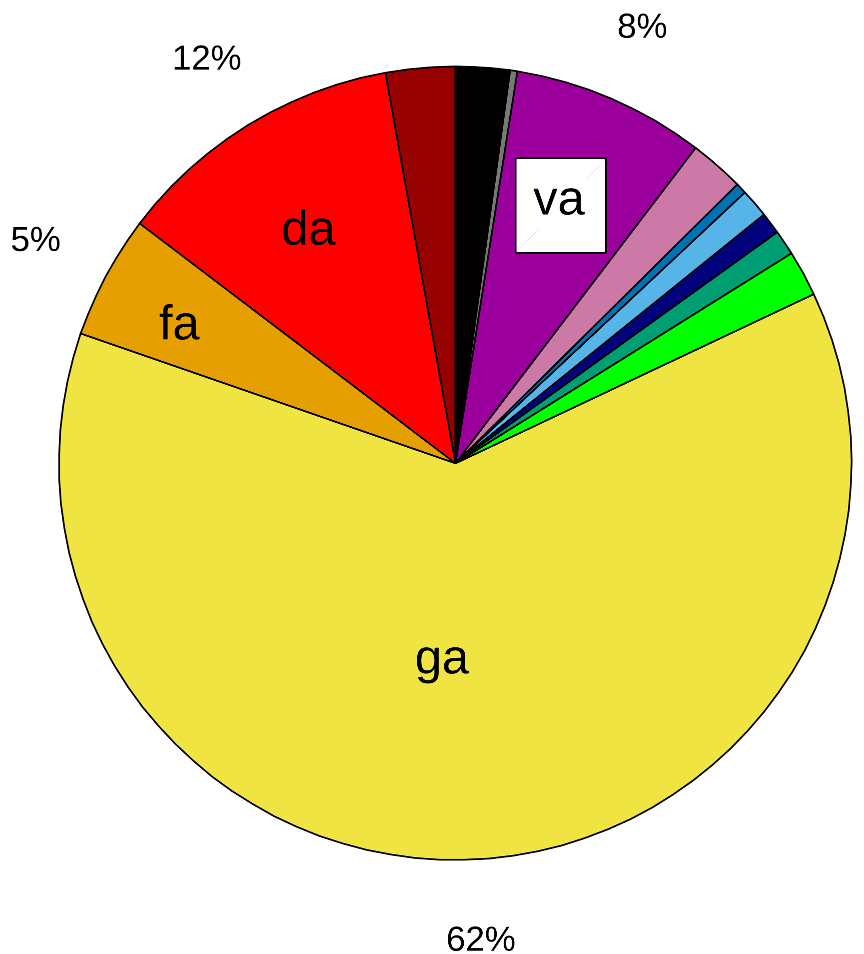
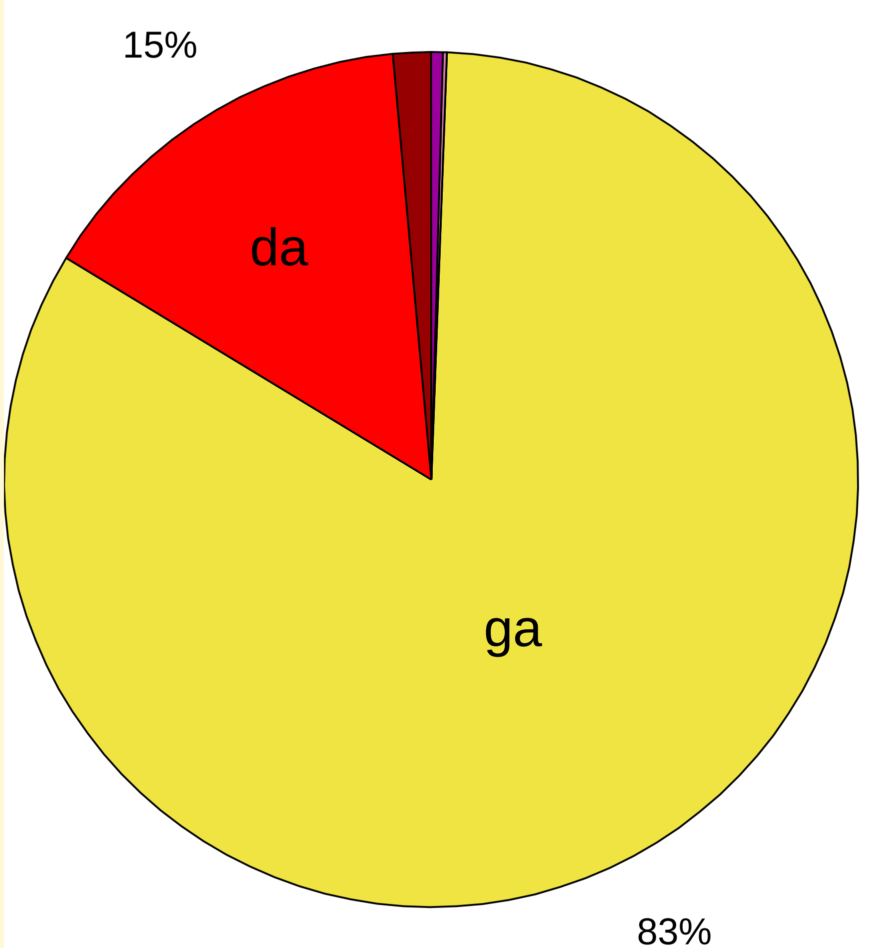
  - Do NOT average across tokens: SIN$_t$ #3 !





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Conclusion I

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  3. Data on discriminating consonants in noise, NH listeners use
     - Plosives: *Burst + timing to Voicing*
     - Fricatives: *Low-frequency edge + duration +* F_0 *modulation*

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1. Speech cue detection is binary (6 dB SNR range)

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2. How the AI works:
   - Burst, frequency-edge, timing & SNR_{50} distributions
   - $P_e(\text{SNR}) = e_{\min}^{\textit{SNR}}$ due to SNR^*_{50} distribution

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Conclusion III

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   - No two ears are the same
   - Low correlations between HL(f) and $P_e(SNR)$
2. Each ear has a different consonant recognition strategy

Conclusion III

- Findings re HI ears:

1. HI ears have huge individual differences
   - Individual differences dominate HI results
   - No two ears are the same
   - Low correlations between HL(f) and $P_e(\mathsf{SNR})$
2. Each ear has a different consonant recognition strategy
3. A better understanding of HI acoustic cue detection will lead to:
   - Improved understanding of HSR for NH & HI ears
   - Better signal processing methods
   - Speech-aware hearing aids in 5 years $>$c2016
     - Fittings based on confusions

Question your basic assumptions

Thank you for your attention

http://hear.ai.uiuc.edu/

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