Intro to MMN and phon

EGG course 1

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Overview of classes

Week 1

- Review classical literature on MMN and language
  - Language specific vs general sensitivity to speech sound differences
  - Category differences across languages
  - Phonotactic repair processes indicated by MMN
  - Category-specific MMN
  - Child vs adult MMN
  - Mono- vs bilingual MMN

Week 2

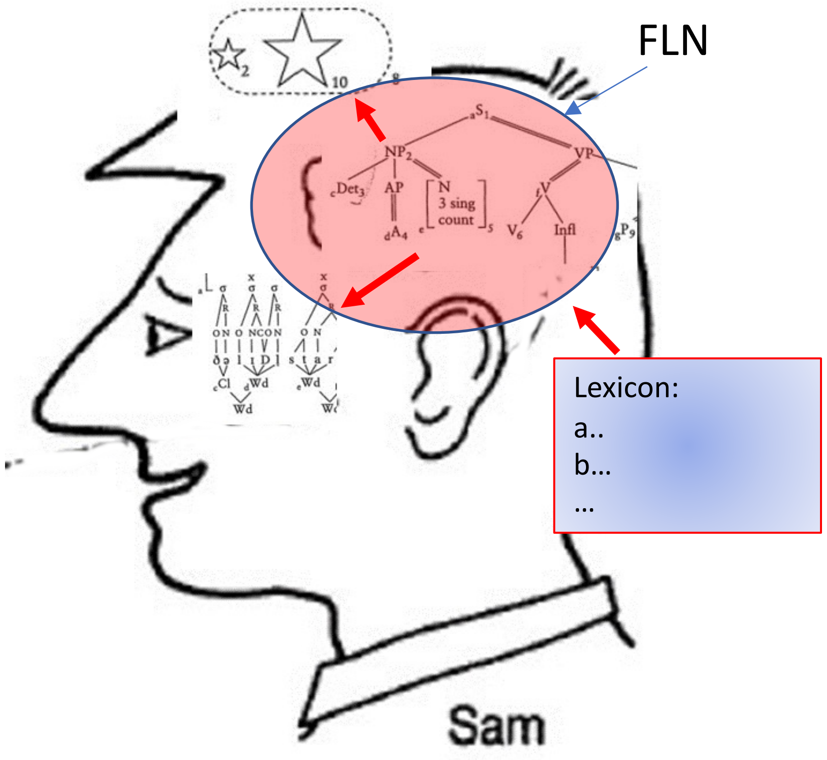
- Review literature on underspecification using MMN
  - Voicing underspecification
  - Cross-ling differences
  - Phonetic distance effects in MMN
  - Within-category MMN
  - How strong is evidence that MMN can isolate and measure the purely symbolic phoneme?

Mapping sound to meaning

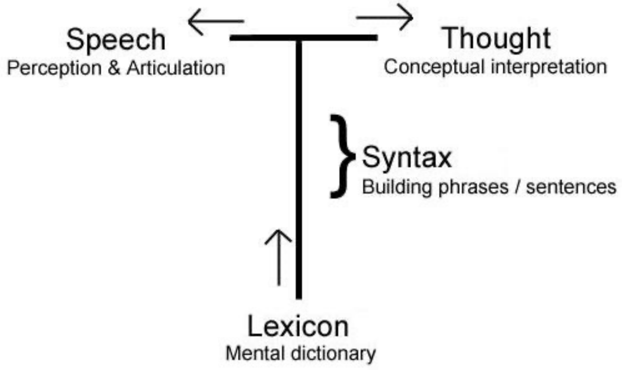
- Linguistic knowledge hierarchy:
  - Speech sounds
  - Words and morphemes
  - Sentences and discourses
  - Meaning representations
  - Discourse representations
  - ….
  - Language of Thought

Mapping sound to meaning

Internal language:

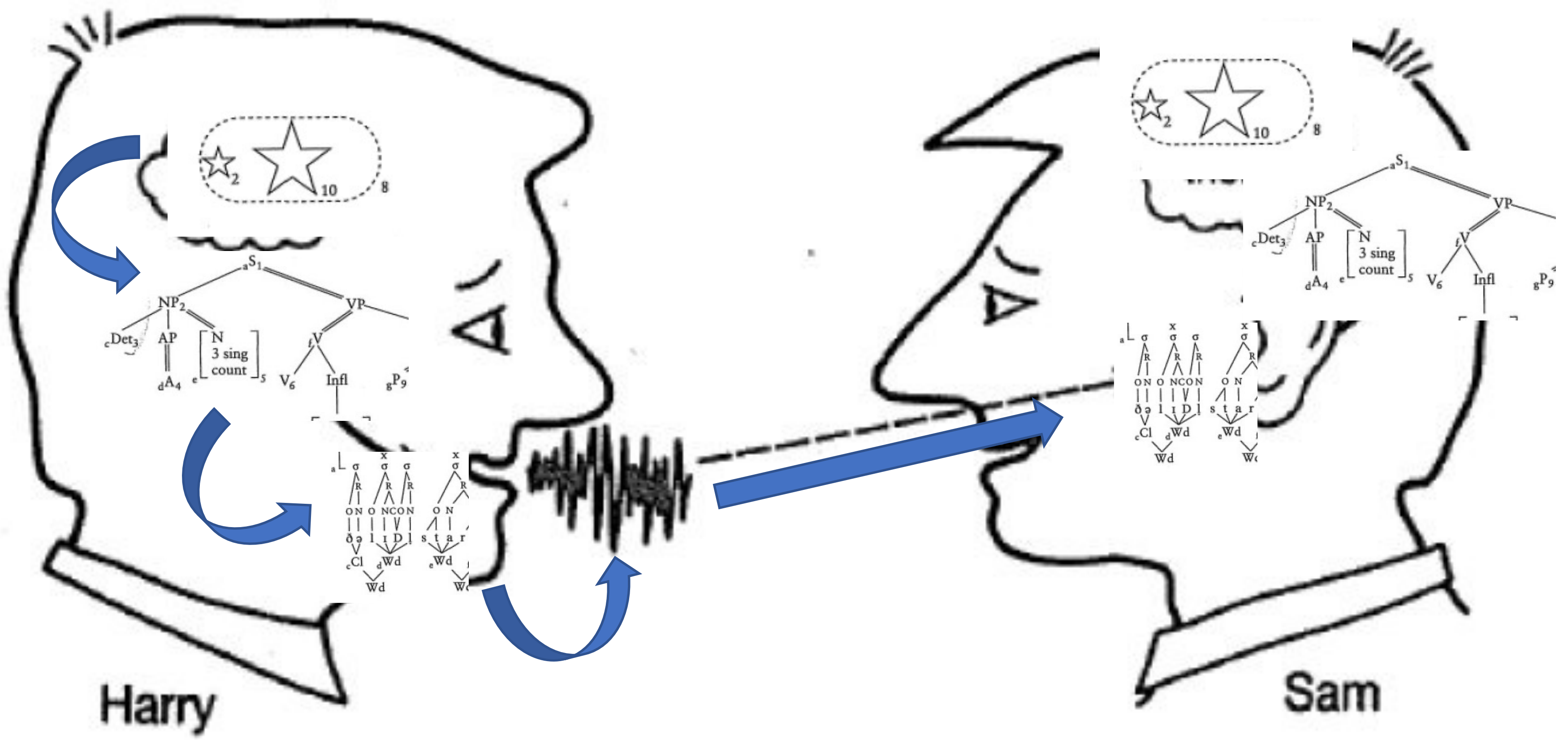


Chomsky's I-language (T-model):



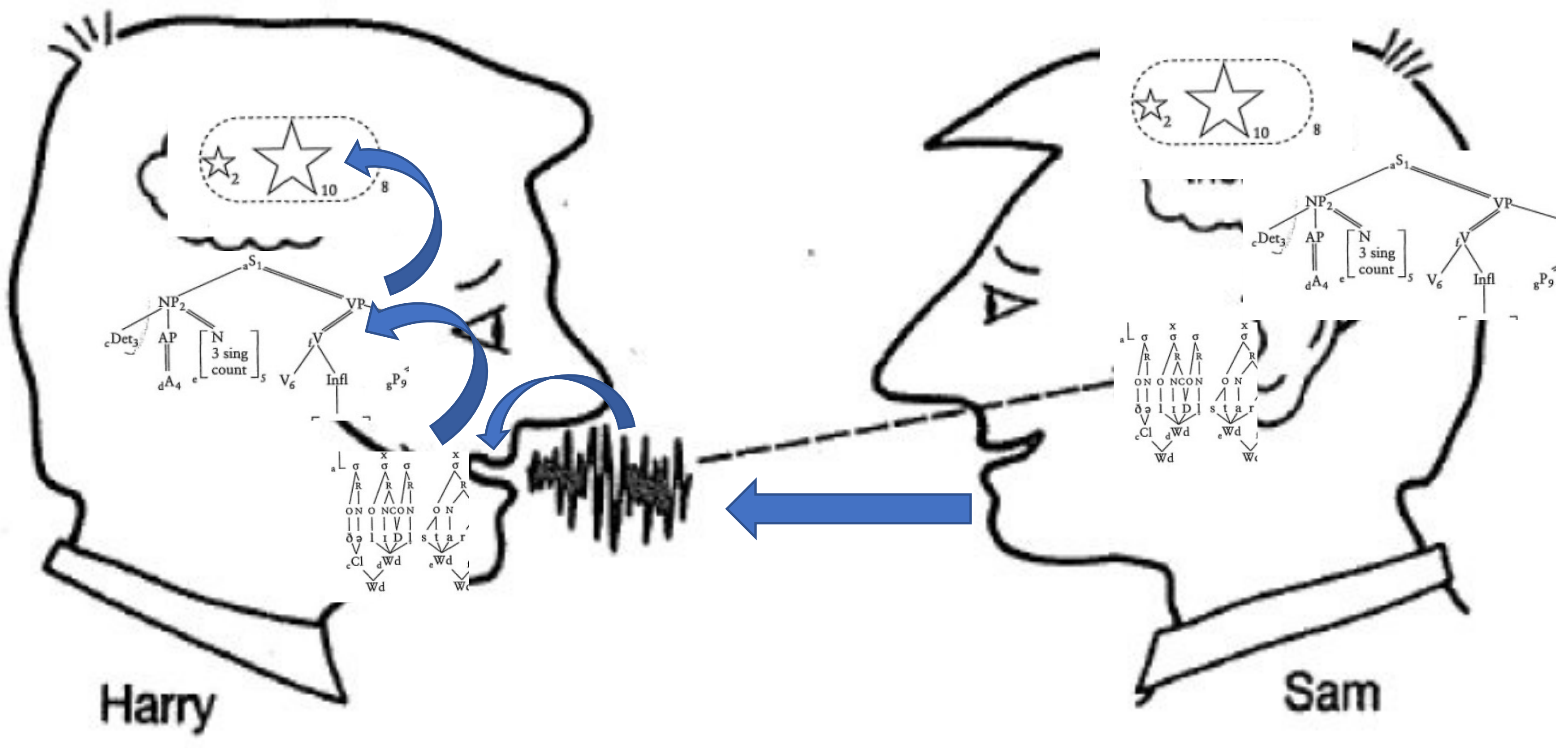
Mapping sound to meaning: externalization

- The internal language can be transduced to a different format suitable for transmission through a medium
  - E.g. air
- Can then be used to transmit a thought and establish the same thought in another person’s head (with some probability, success not guaranteed)!
  - = communication (information transmission)



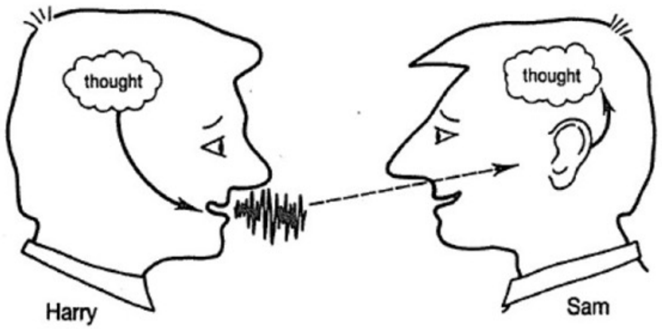
Through this process. we can communicate even though all language is “private” in the Wittgensteinian sense

Symmetry: at some level, the representational chain for <u>expressing</u> a thought must be the **reverse** of the representational chain of <u>perceiving</u> a thought.

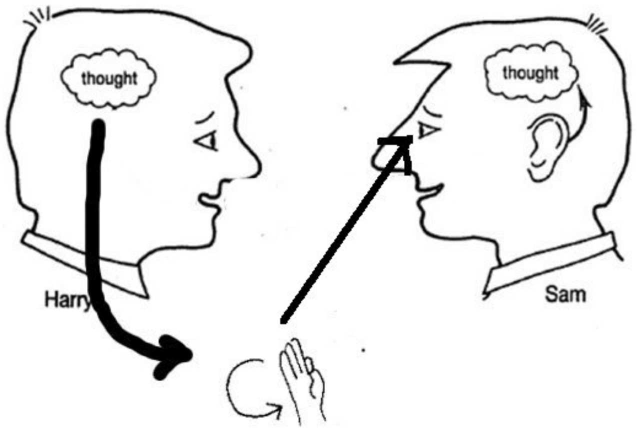


Algorithm for transmitting i-language is independent of knowledge level

- Signal via SOUND

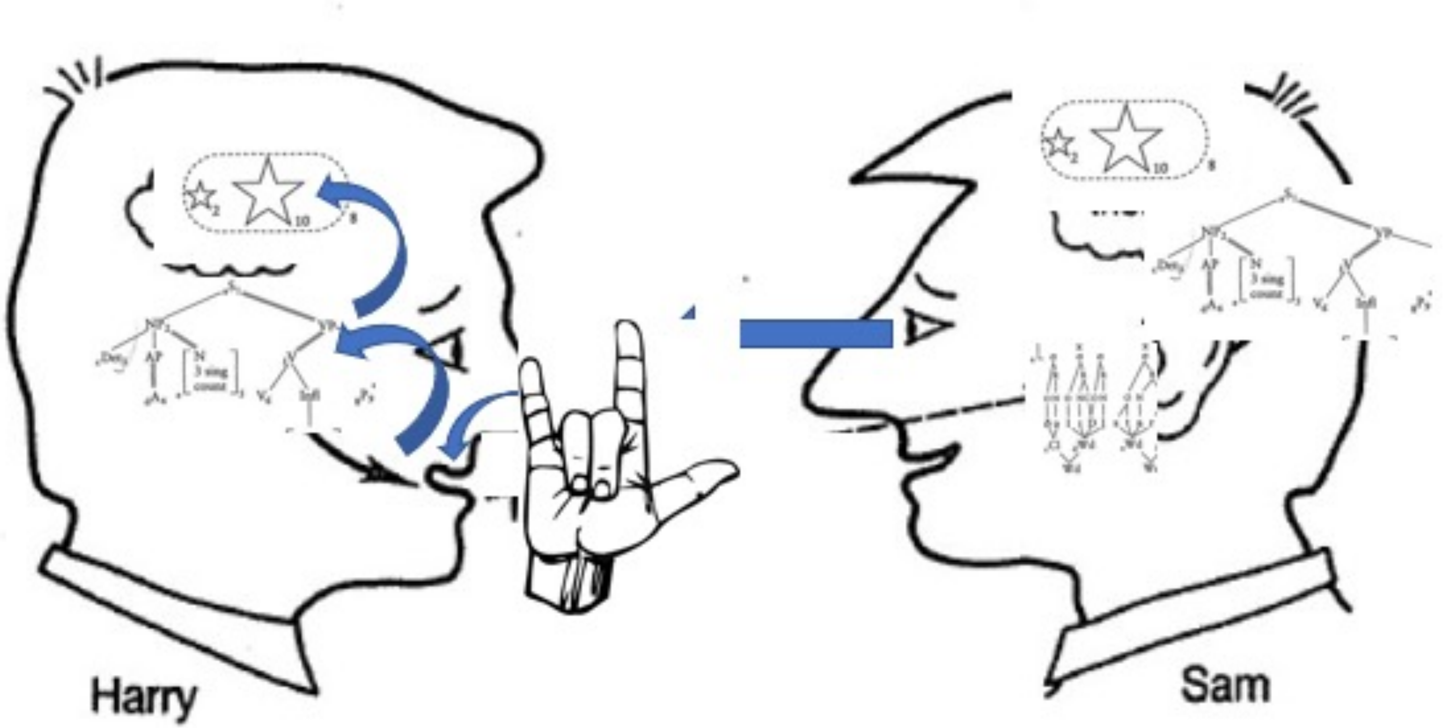


- Signal via VISION



Two different algorithms (and implementations) for conveying the same thoughts

Alternative medium: light, motion, hand shapes



Question: do you think everything else will be the same inside when you switch the modality of the signal transmission?

Competence – performance distinction

- Linguistic theory <u>statically</u> describes the internal language
- Communicative behavior (language use) <u>dynamically</u> connects internal representations to the physical sensory system and sound generating system (the ”mouth” and “ear” performance systems)
- It is only via observing the dynamic externalization of language that we can study the knowledge state (grammar)
  - Hence all data are performance data

Competence vs. performance

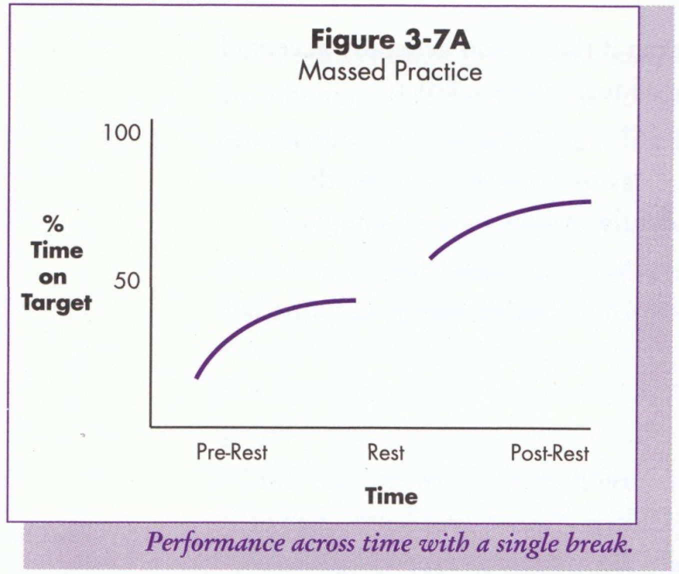
- When we are measuring something (e.g., mental grammar) we get measurement error
- This happens because the measure is obtained via, or filtered through, several other cognitive and behavioral systems
  - i.e., we are inferring something about the internal system (e.g. mental imagery) via performance on a task

A banal example: Pursuit rotor

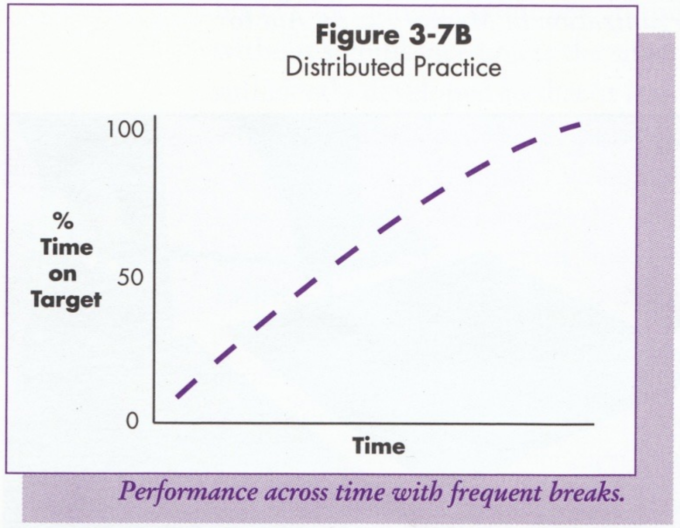
- Target travels at 60rpm
  - Dependent variable: percent time on target
  - Buzzer when hit
  - Train 10 mins, rest 5

Typical results

Condition A:



Condition B:



Source: St. James, J. D. (2006). *Exploring research methods in psychology using PsychMate*. Book, Pittsburgh, PA: Psychology Software Tools, Inc.

Reminiscence effect

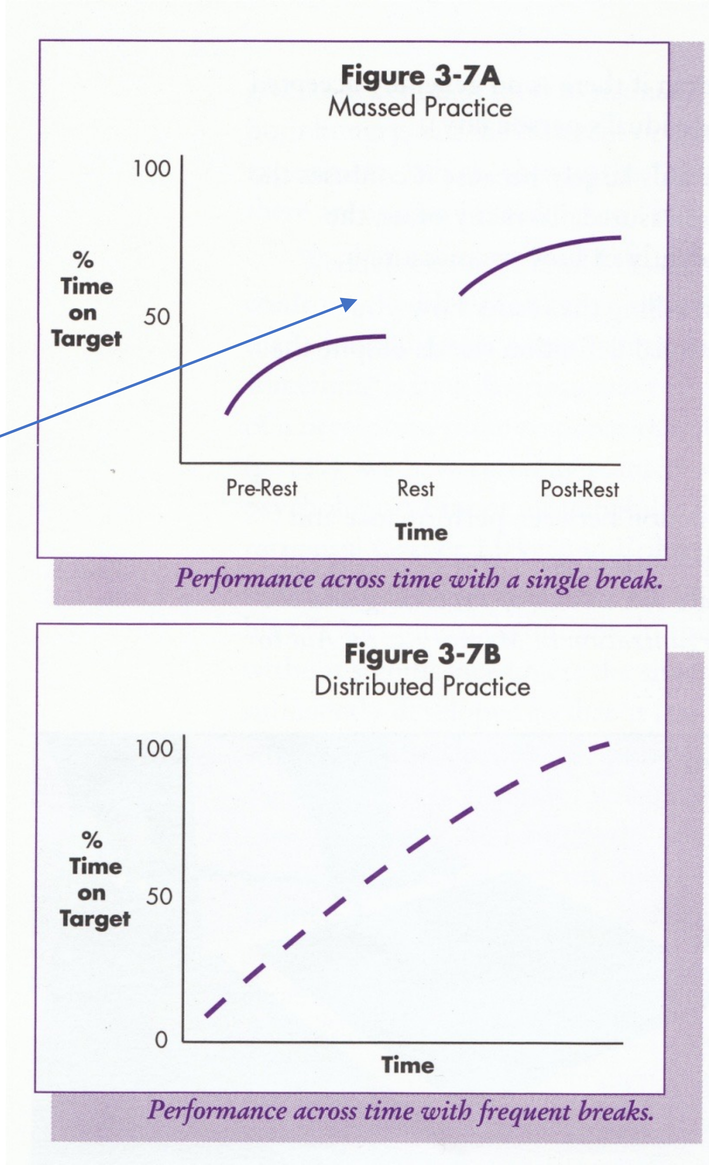
Condition A:

Question:

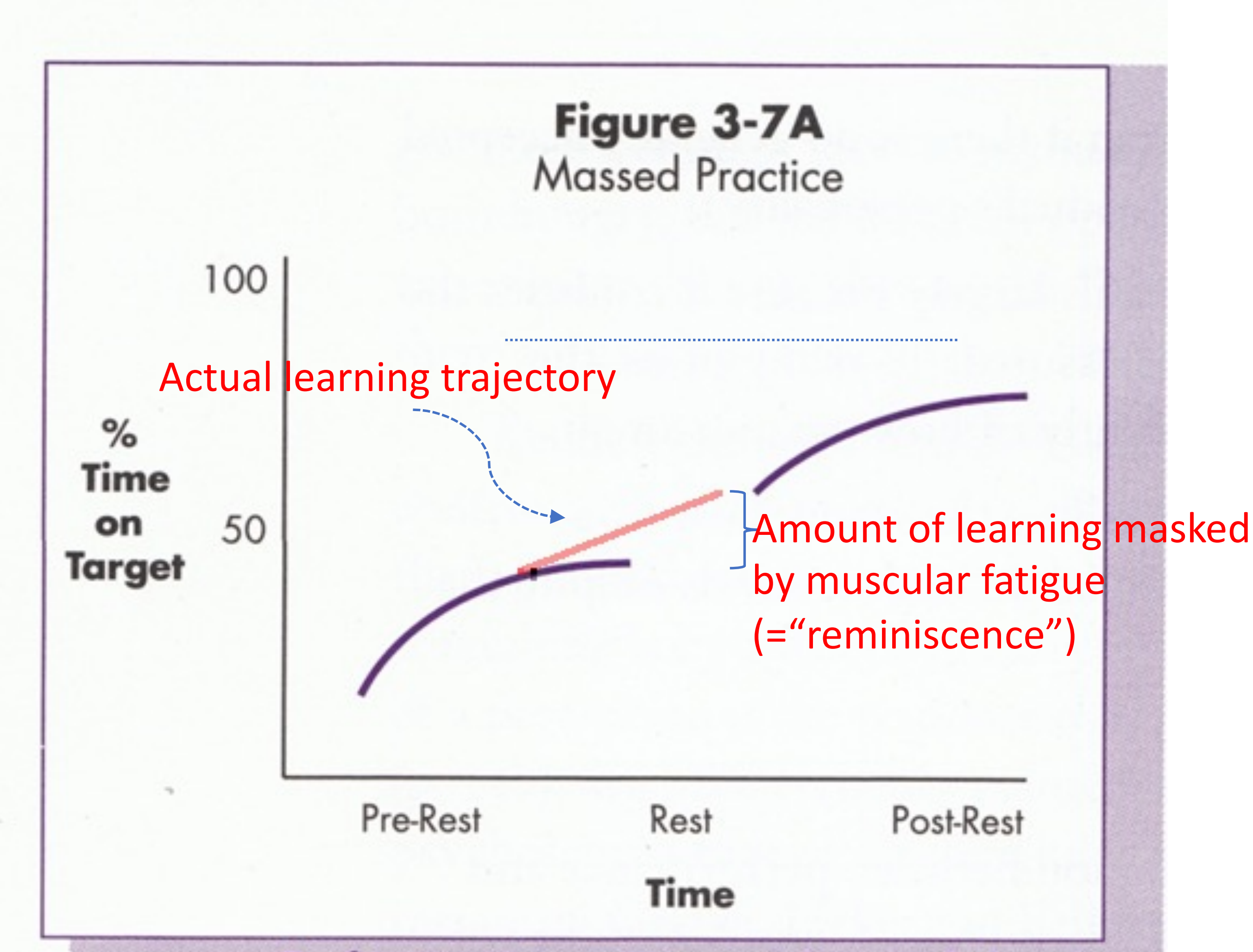
It looks like learning took place during rest??

Reminiscence: an apparent increase in learning during rest

Condition B:



Reminiscence effect



Performance across time with a single break.

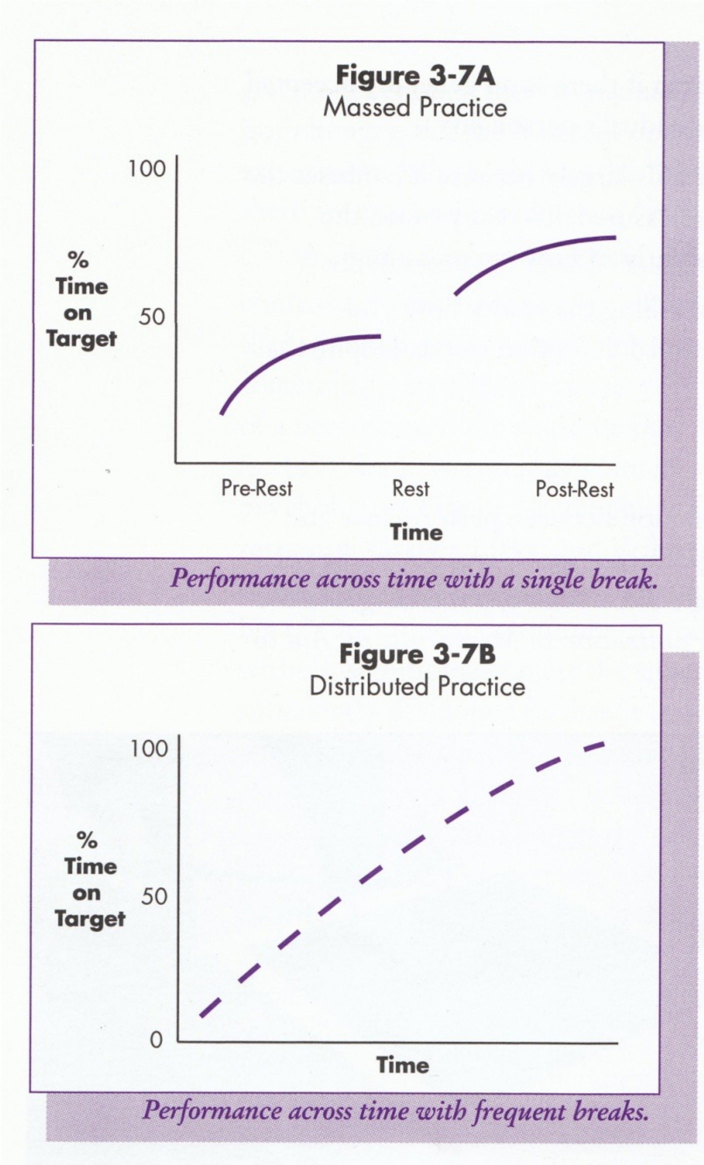
Reminiscence effect

Condition A:

Question:
It looks like learning took place during rest??

Condition B:

No reminiscence with shorter test period and frequent breaks: reduced muscular fatigue



Reminiscence effect

- Due to muscular fatigue at end of pre-rest period
- Learning is leading to improved performance, but fatigue is masking it
  - Thus, fatigue is a performance factor that introduces error into the measure of learning
  - So the measure of the underlying process (learning) is masked by performance

Performance vs. internal states

- “The history of experimental psychology over the last 50 years …has been a history of [this] attempt to infer internal structure and function from performance”
    - *St. James, J. D. (2006). Exploring research methods in psychology using PsychMate*. Pittsburgh, PA: Psychology Software Tools, Inc.

Performance vs. internal states

- Grammar = a knowledge state
- Performance data is used to infer what this knowledge state is
- <u>All linguistic data are performance data</u>
- We can only make inferences about the “hidden” knowledge system via measuring performance (the active use of language in real time and physical place)

Example: Chess

Computational theory (static)	Algorithms (performance)	Physical implementations
Elements, moves, knock-outs, chess mate (goal)	A specific sequence of moves, set of strategies	Your grandmother's chess pieces; computer

Marr (1982)'s three levels

Table 5.1 The three levels at which any machine carrying out an information-processing task must be understood

Computational theory	*Representation and algorithm*	*Hardware implementation*
What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?	How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?	How can the representation and algorithm be realized physically?

Example: The study of economics

- A level of <u>abstract principles</u>
  - Goal": exchange of goods
  - Goods have prices (laws of supply and demand)
    - Principles hold regardless of <u>medium</u>
    - Actual $$$, gold, electronic coding of numbers
- A procedural level
  - Systems for <u>how</u> to exchange goods or trade things by value
    - Near simultaneous switching of hands (but note: "futures")
    - Barter system
    - Gold (has fixed value)
    - Money (symbolic of gold)
- A level of <u>instantiation</u> (or implementation)
  - the actual goods
  - Actual value transferring entities
    - USD "greenbacks", gold
  - means of transmission
    - Cash, wire transfer, numbers changing in computer

Example: Neuroprosthetics

- Computational level: does it perform the same function?
- Algorithmic level: does it perform the same function with the same algorithm?
- Implementational level: did you get a new brain?

Andersen, R. A., Hwang, E. J., & Mulliken, G. H. (2010). Cognitive Neural Prosthetics. *Annual Review of Psychology*, *61*(1), 169–190. https://doi.org/10.1146/annurev.psych.093008.100503

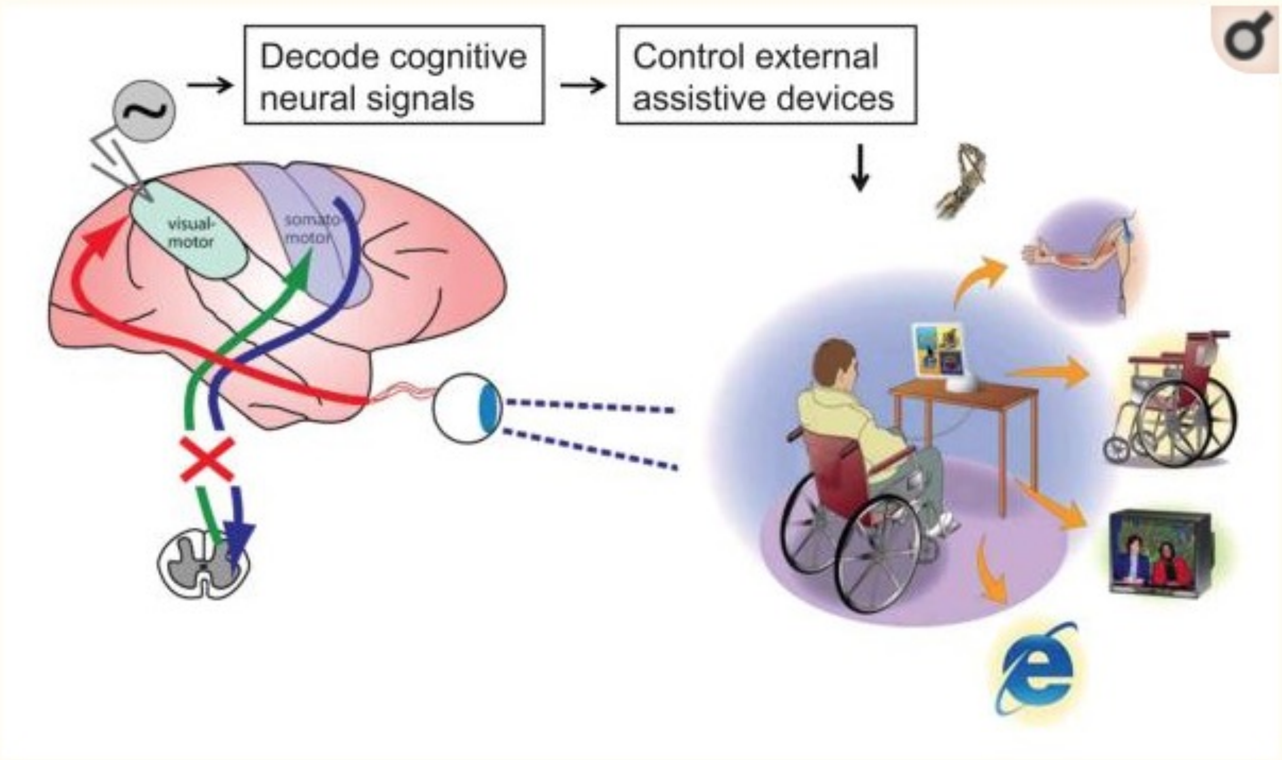


Figure 1

Schematic representation of a cognitive neural prosthetic. In this example, the patient has a lesion of the spinal cord, represented by the red X on the brain drawing on the left. The patient can still see the goal of a movement and can plan the movement, but cannot execute it. The electrodes are positioned in sensorimotor cortex in the parietal reach region, which is involved in reach planning. The recordings are decoded to obtain the meaning of the cognitive signal and then transformed into processed control signals to operate an external device. The schematic on the right indicates that this signal can be used, among other things, for controlling a robot limb, stimulating the muscles to animate the paralyzed limb, navigating a wheelchair, controlling a television, and using the Internet and email. (Modified from www. cyberkinetics.com.)

Class: can you think of other examples?

- Separate a specification of a computational system from a choice of algorithm and implementation

Performance vs. internal states

- Performance data are generated by a *processing mechanism*
  - The “language comprehension system” builds linguistic representations at multiple levels in real time
- ***<u>We’re measuring the processing system, not directly the internal grammar</u>***

Back to language: Mapping sound to meaning

- Sound (acoustic signal-everything!)
- Phonetics (linguistically related continuous and categorical variables)
- Phonemes (representation of lexically relevant categorical variables)

Back to language: Mapping sound to meaning

- How do we measure whether an organism has these things?
- Externally observable behavior by the "user":
  - reaction time, decisions, comprehension (behavior by itself implies a neurally instantiated symbolic system, cf. Piantadosi and Gallistel 2024)
- Internally observable behavior:
  - in order to say "that was a /d/!" your brain first has to decode an acoustic signal and map it to a mental representation of the linguistic unit
  - Observe: Blood flow, energy use (oxygenization/deoxygenization), electrical transmission of signals between neurons, population-level neutral activity (oscillations, event-related potentials)

Piantadosi, S. T., Charles, |, & Gallistel, R. (2024). Formalising the role of behaviour in neuroscience. *European Journal of Neuroscience*. https://doi.org/10.1111/EJN.16372

Back to language: Mapping sound to meaning

- Knowledge state: Mind/brain representation

/d/ ←→ ?

-we can ask, can we measure the ? inside the brain that corresponds to the abstract knowledge unit?

-what do we expect to find? Some isomorphic encoding of the same unit (in terms of the vocabulary of the brain level behavior--Poeppel)

Always ask: Why bother?

-So much more work/harder…

-a scientific question in its own right: how is the knowledge system actually implemented (in humans/martians/Apple's "Siri"/chatGPT)

-we might find evidence about the nature of the knowledge system that is not discernable in externally observed behavior

Back to language: Mapping sound to meaning

- Knowledge state: Mind/brain representation

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a scientific question in its own right: how is the knowledge system actually implemented (in humans/martians/Apple's "Siri"/chatGPT)

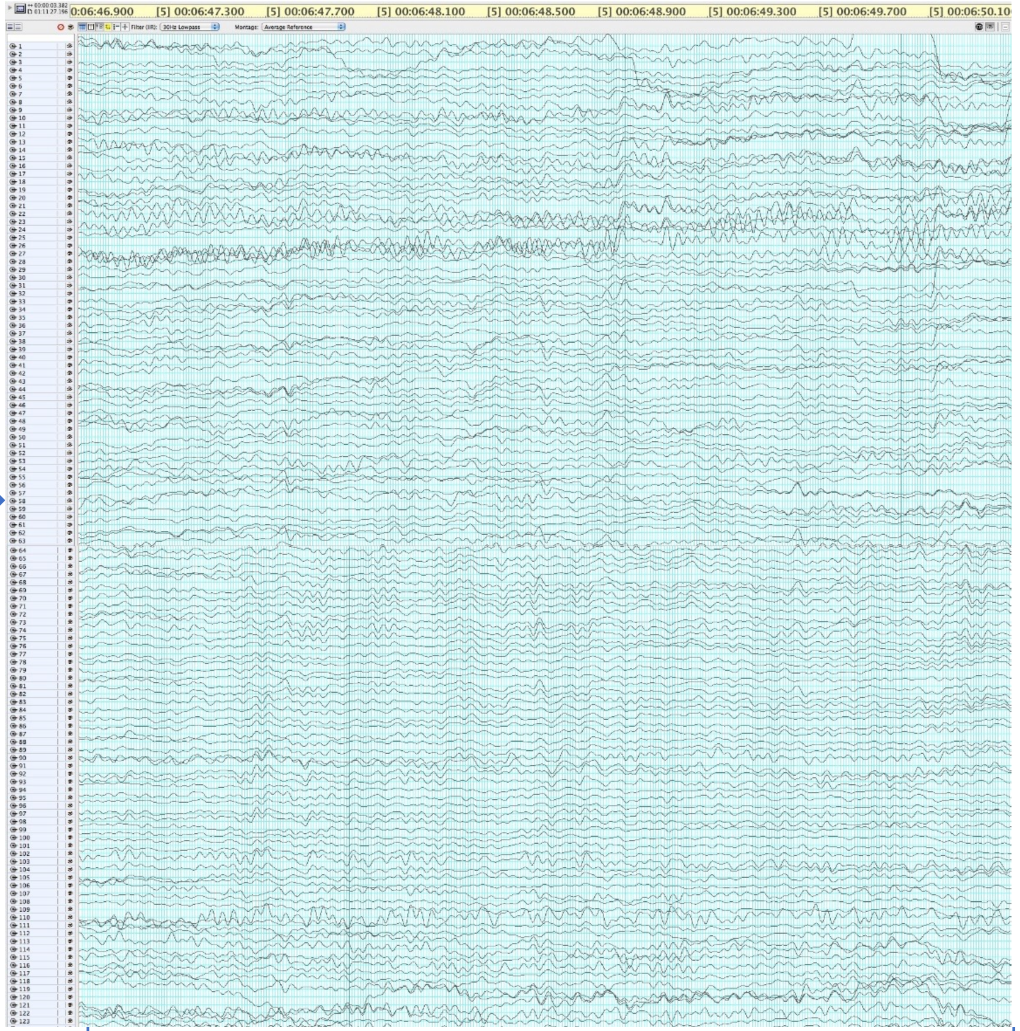
My lab!

Attach 128 electrodes embedded in saline-soaked sponges

Play stimuli, record EEG:

Voltage amplified and sampled every 4ms (display 30Hz lowpass filtered)

“the..”

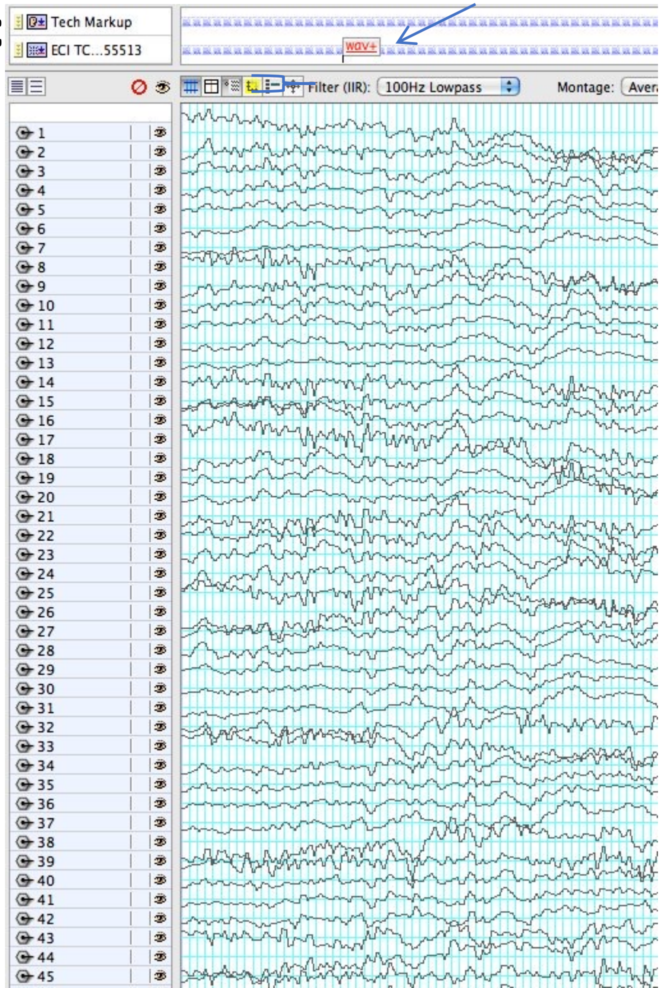


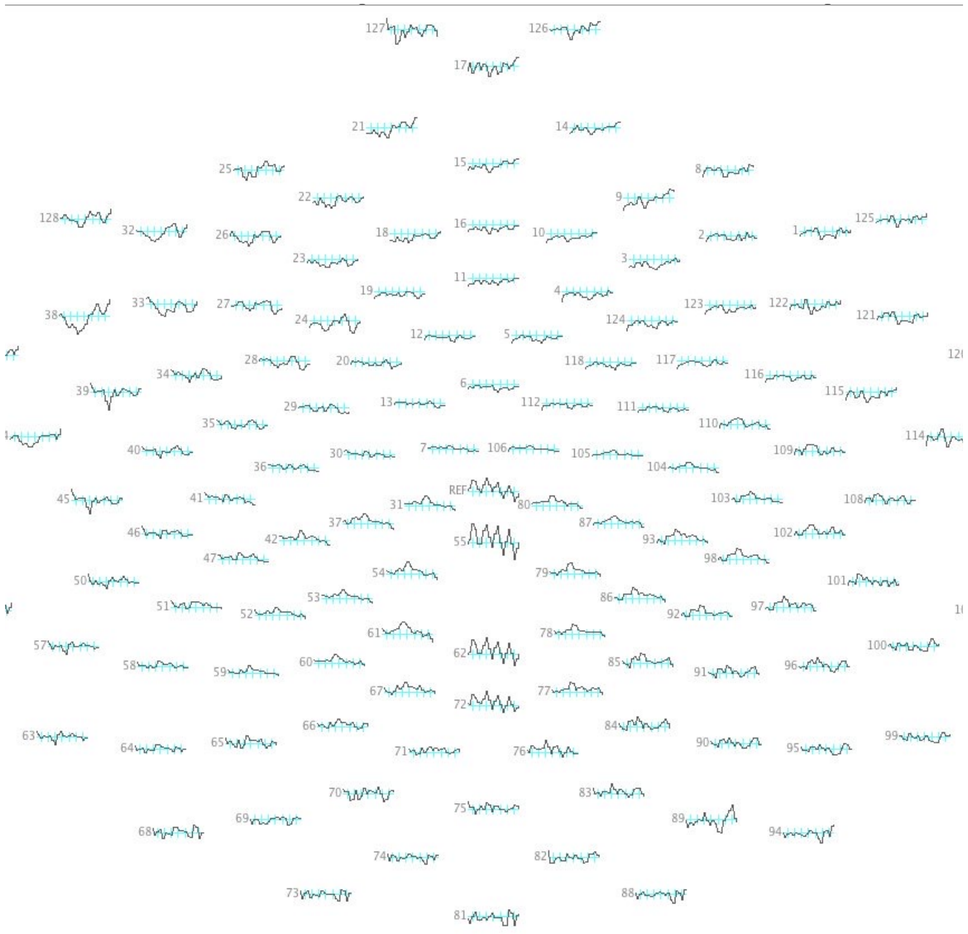
~3 ½ seconds = 875 samples x 128 electrodes = 112000 data points!

A single segment

-200 to 400ms

Time-loc





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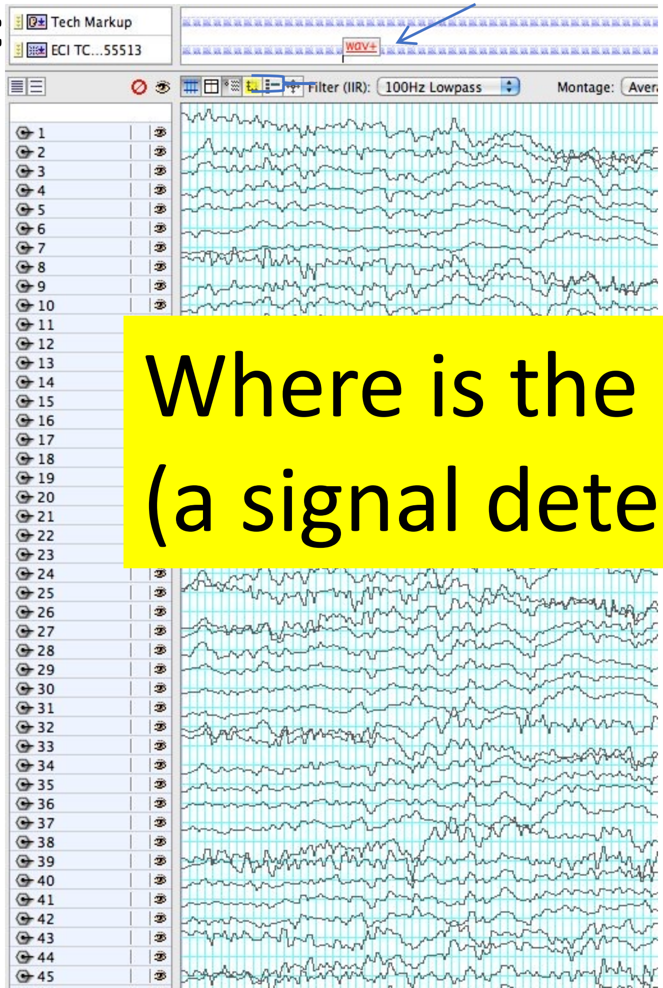
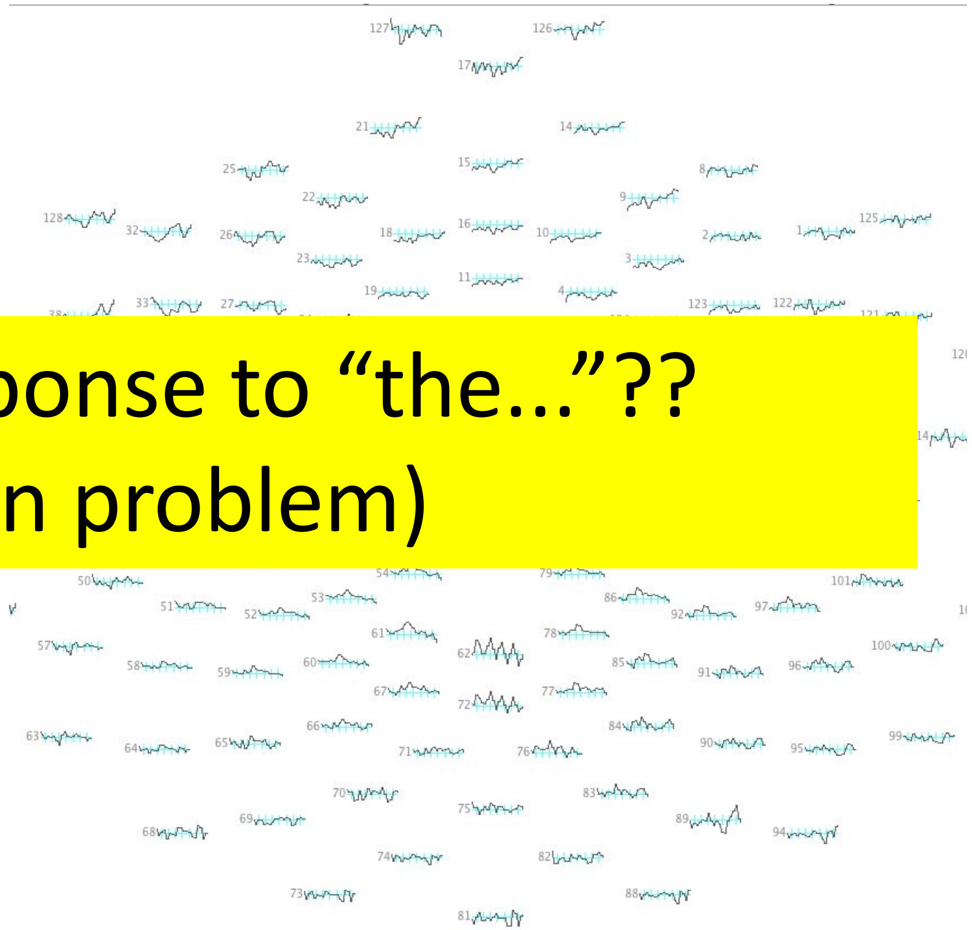
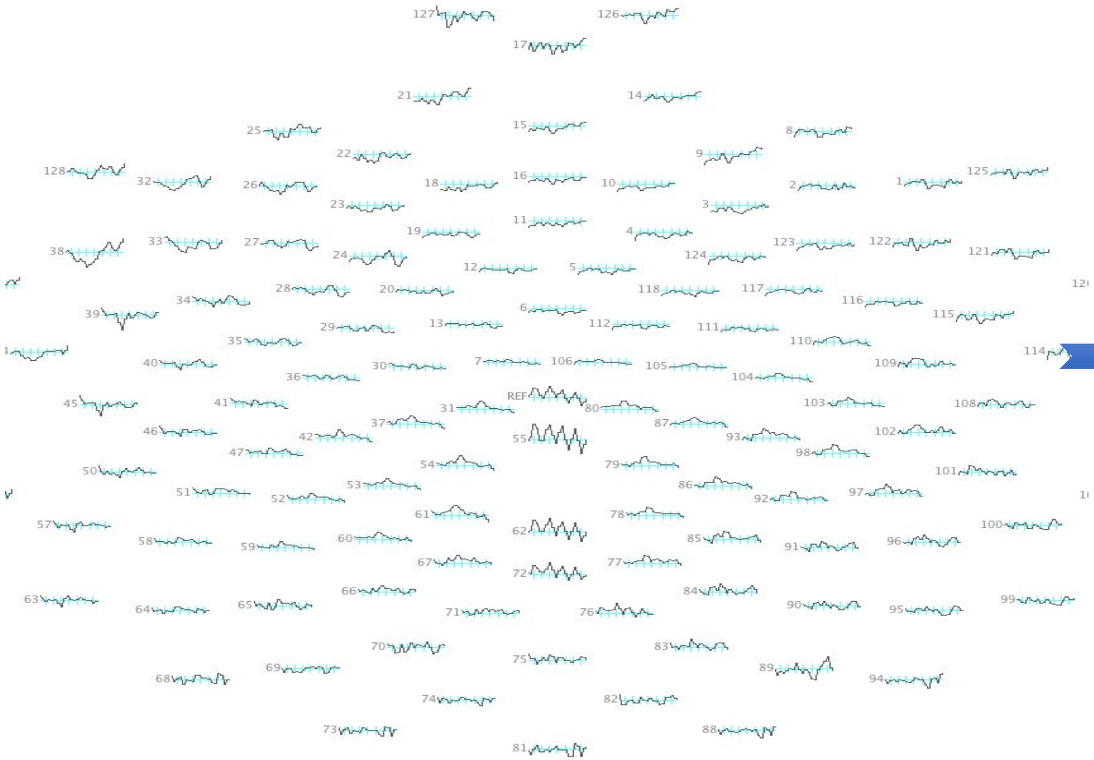




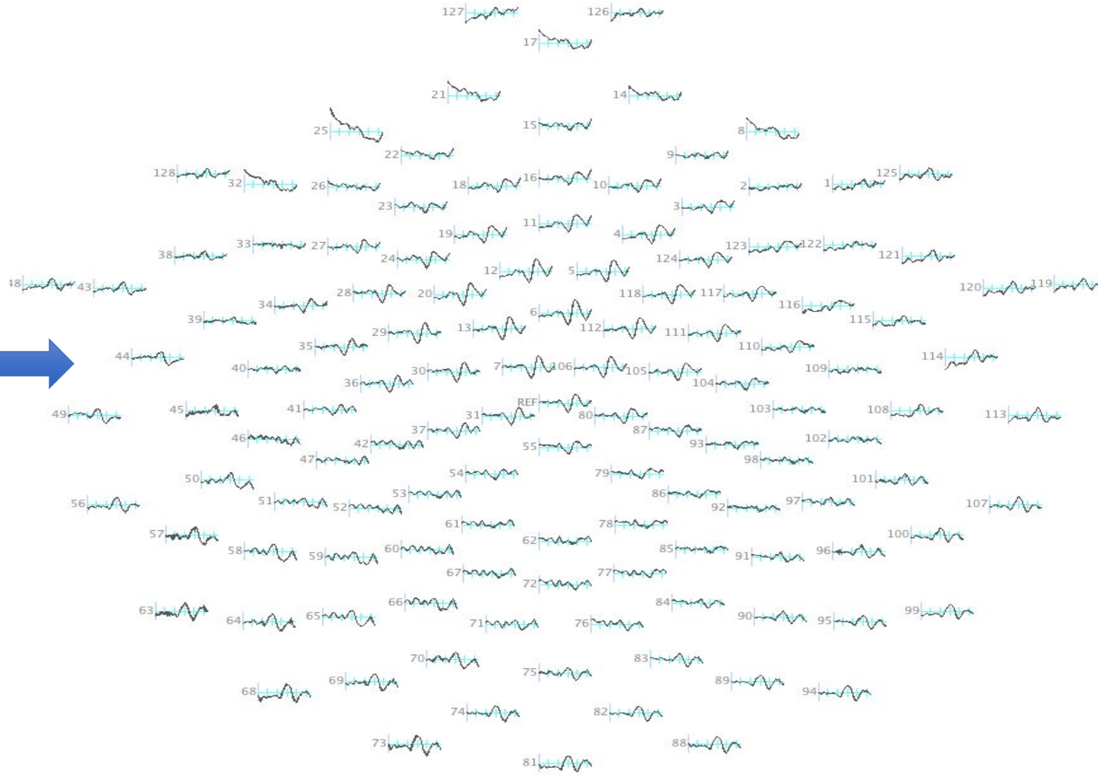
Where is the response to “the...”??
(a signal detection problem)

A tiny signal embedded in lots of "noise"→ signal averaging:

Topo plot (from above head):



Single subject, 118 trials:



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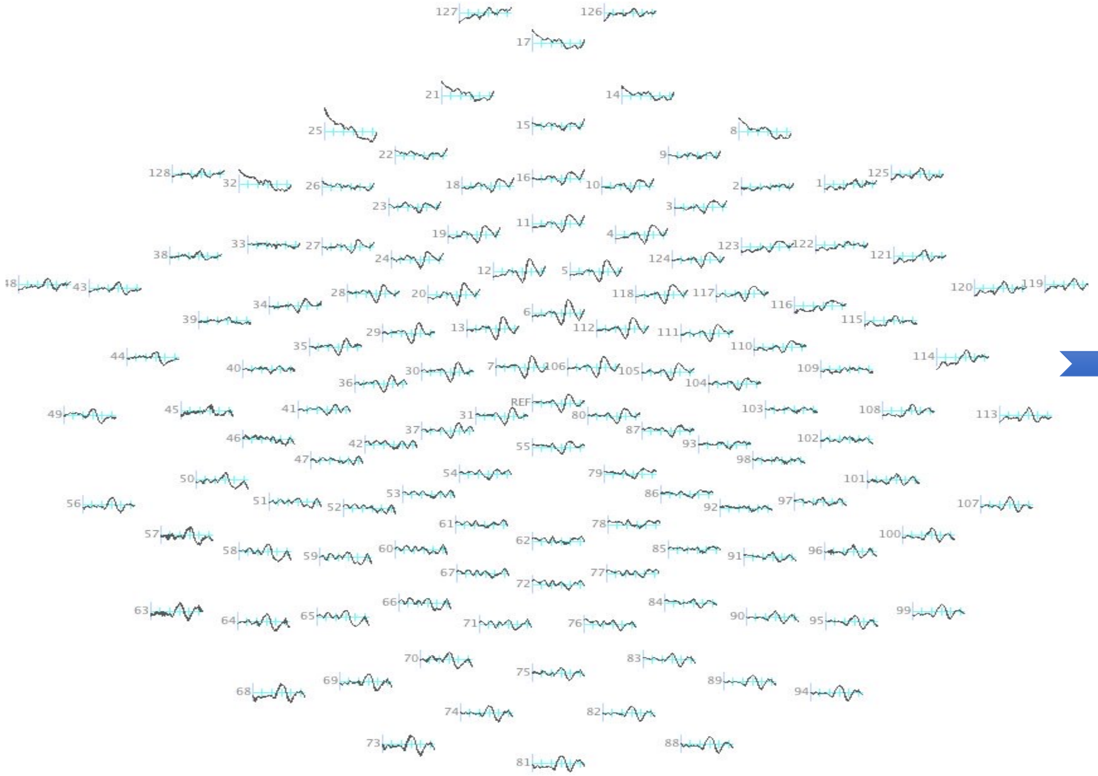
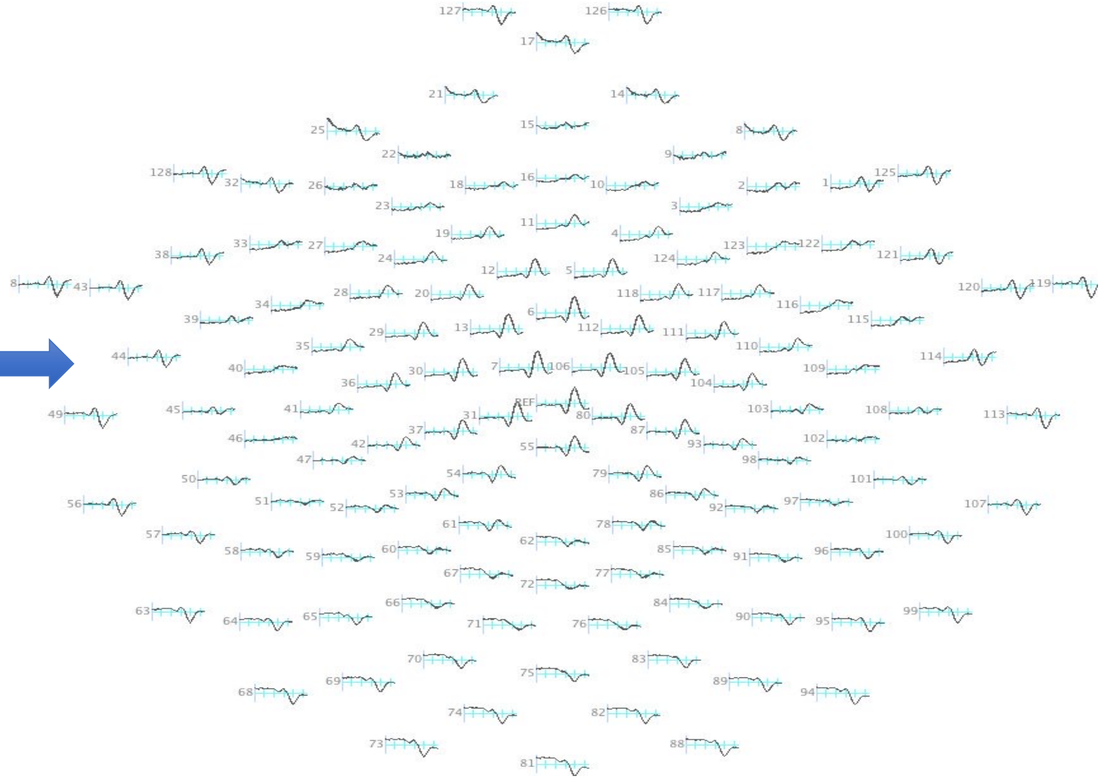
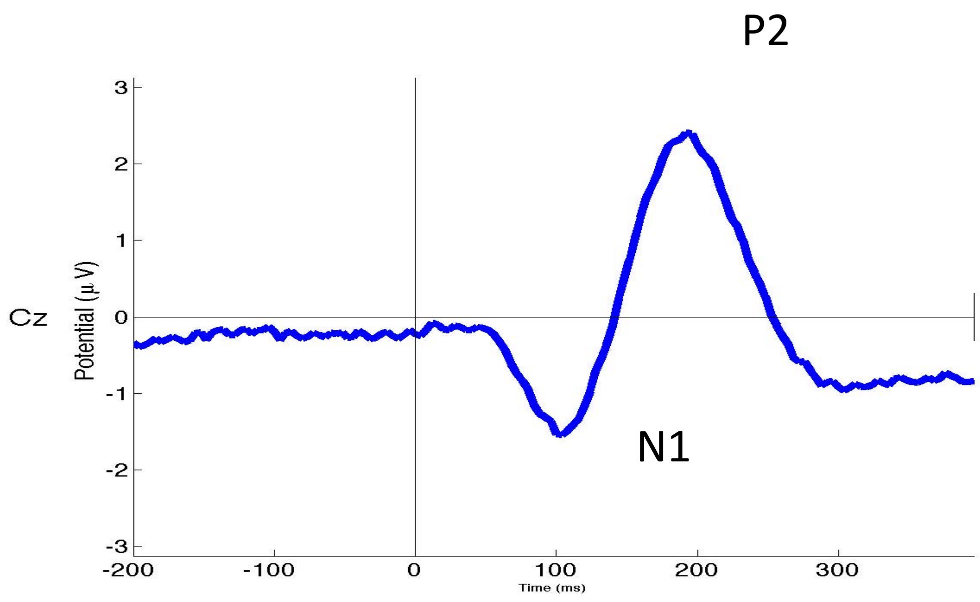


35 such subjects:



The Auditory Evoked Potential!

Single electrode (Cz)



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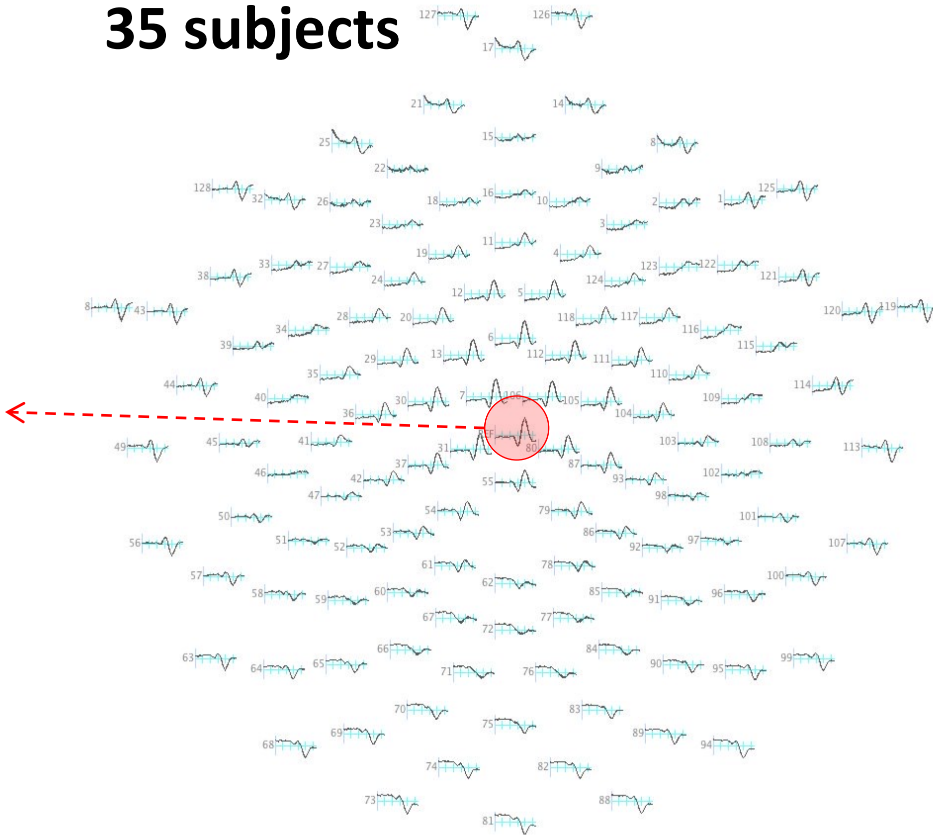

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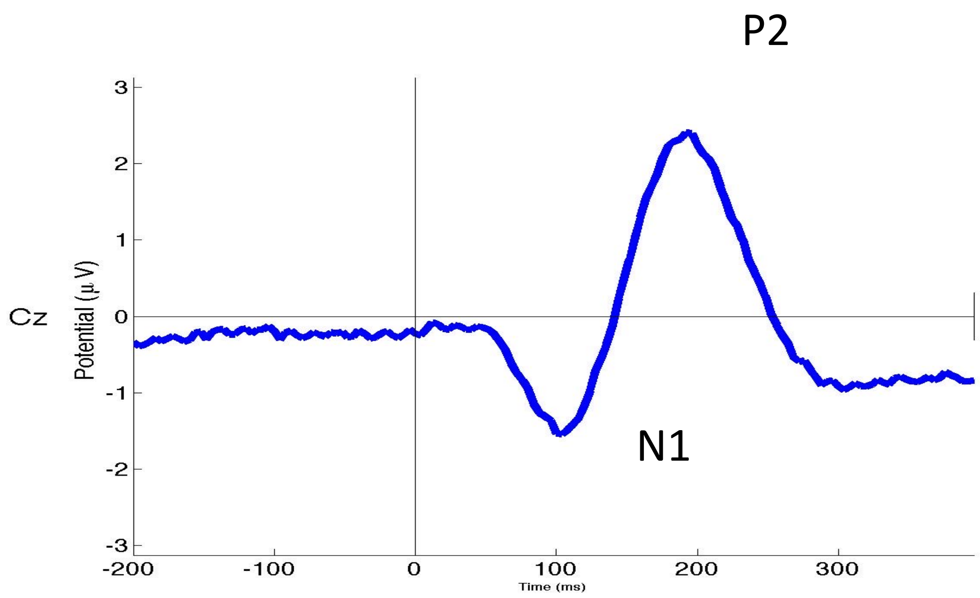

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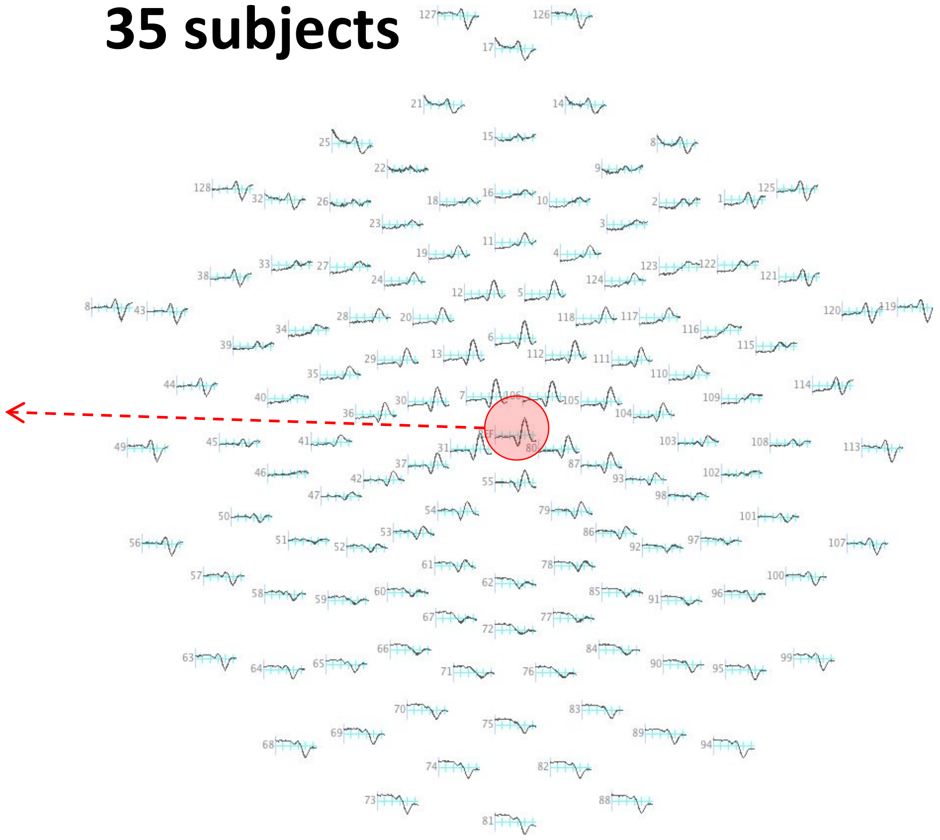


Note: This is an average of thousands if trials; it is <u>not</u> how a single response to the single initial sound in “the…” looks like in your brain!

Stimulus category differences

- We (and our brain) can certainly notice “just noticeable differences” in sounds
- But just because you can sense a difference doesn’t mean that’s evidence of an underlying abstract category system
  - Although we can imagine creating such a system where a high dB “cat” means tiger and a low dB “cat” means kitten
- Some acoustic distinctions <u>do</u> map to different categories, and if so the information can be “used” by the owner of the brain in a domain specific computation

Some gradient distinctions can be observed

- VOT difference results in in P2 latency difference

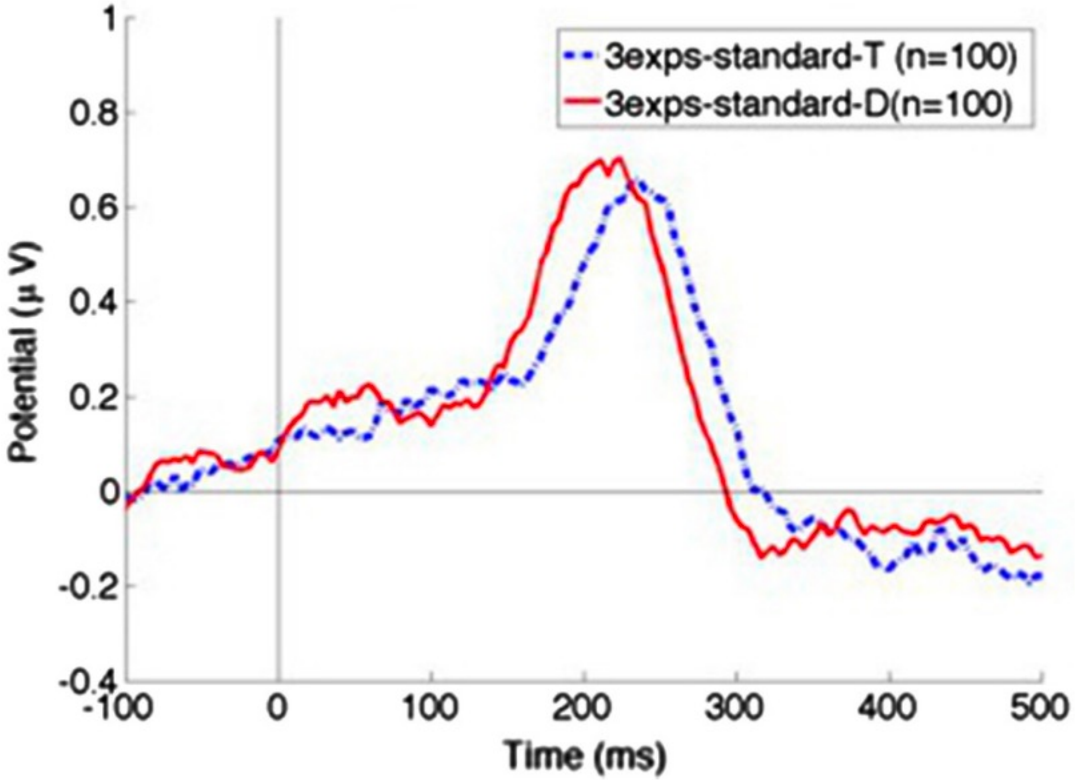
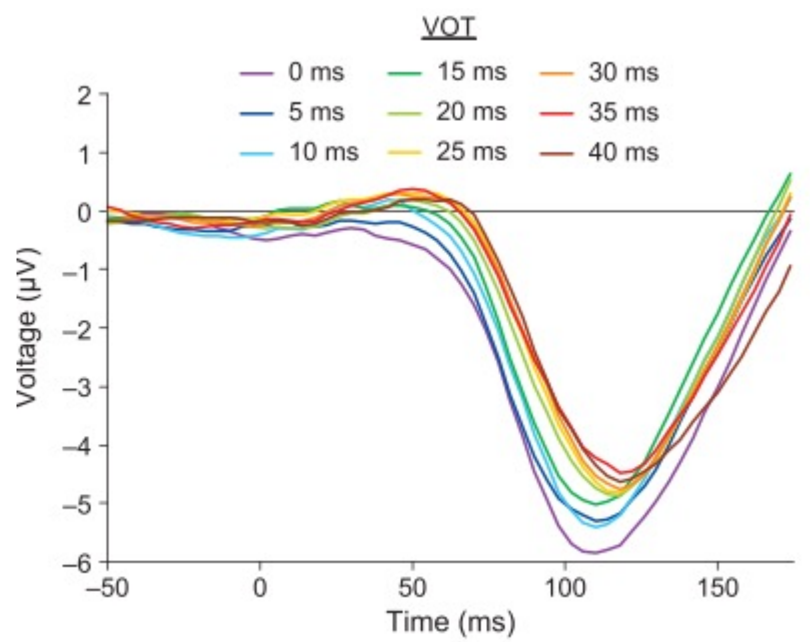


Fig. 10. Latency difference (but not significant amplitude difference) between the mean Auditory Evoked Potential to /d/ vs. /t/ (averaged across all tokens and all subjects in all three experiments).

Some gradient distinctions can be observed

Toscano et al 2010: N1 amplitude modulation related to VOT



Toscano, Joseph C., Bob McMurray, Joel Dennhardt, and Steven J. Luck. 2010. “Continuous Perception and Graded Categorization: Electrophysiological Evidence for a Linear Relationship Between the Acoustic Signal and Perceptual Encoding of Speech.” Psychological Science 21 (10): 1532–40.

Rhodes 2019 thesis

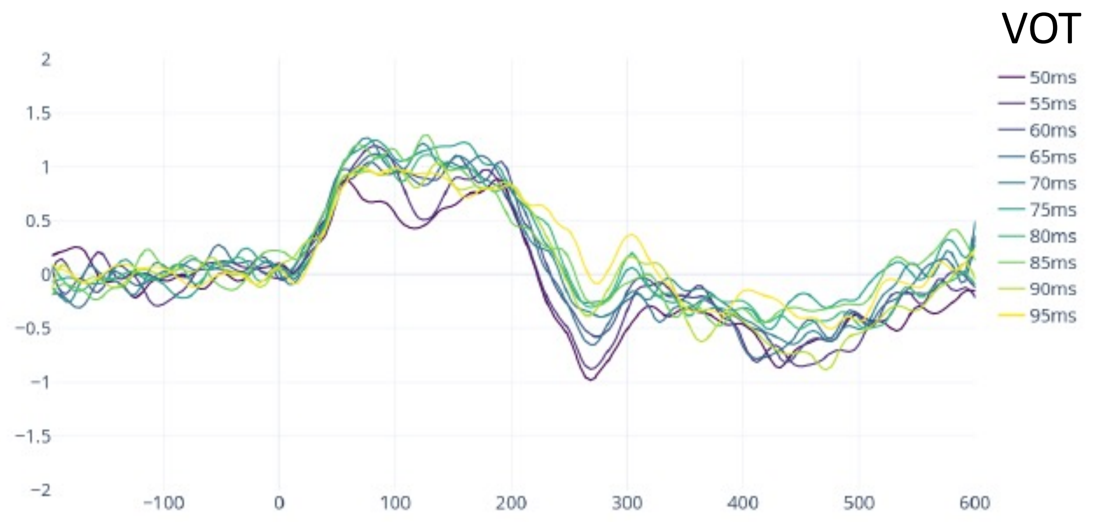
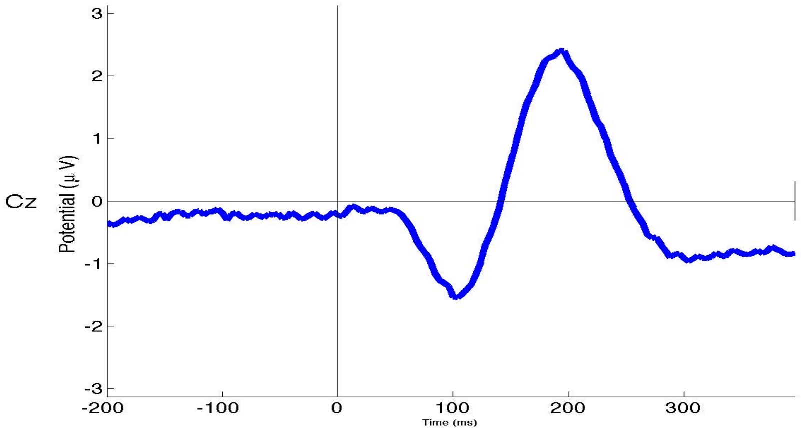


Figure 66. Absolute waveforms to each stimulus in the Random Standards Control condition.

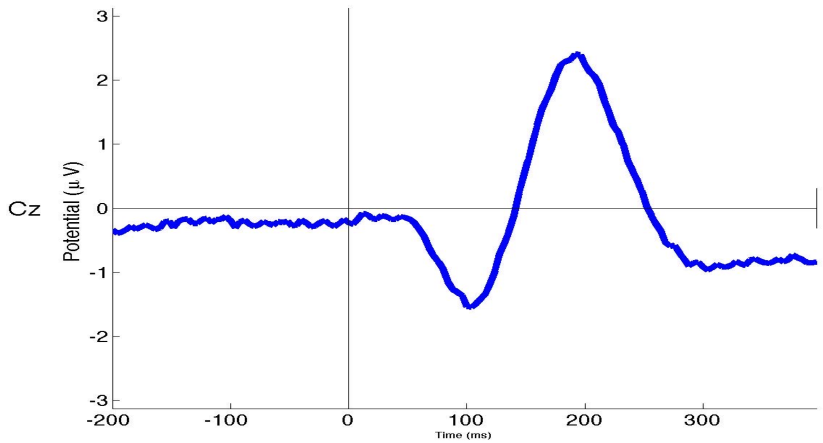
Grammatical vs. physical distinctions

- Suppose we instead presented a voiceless “th-” (as in *think*), can we tell from the AEP whether the brain (a) respond differently or (b) responded in a way that would distinguish between voiced/voiceless?
- →No. AEP just says ”I got a sound”. There is no unique absolute ERP signature for each sound (but Chang’s group has found populations of neurons responding to specific phon features)

[the]



[think]



Grammatical vs. physical distinctions

- different VOTs, as long as within the range of a category (e..g 0-30sms), would all “count as the same” for purposes of lexical access

- The N1 modulations by VOT reflect sensitivity to a sensory difference but not necessarily a <u>grammatical</u> difference

  - “cat” spoken at different measurable intensities also don’t carry linguistic information

Introducing: a change detection mechanism!

- However, there is a way to measure whether auditory cortex detected a difference between two sounds, such that sound A <> sound B

- (which begs the question, what counts as ”not identical”

- ->>NEXT CLASS!