Neuro-anatomy of Cognition - Timings

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Recap: Neuro-circuitry of cognition

1. Human intellectual functions

- Cognition and Expression
- Thinking
- Source of Learning
  - Stimuli from external world
  - Stimuli from internal organs
- Human intellectual development

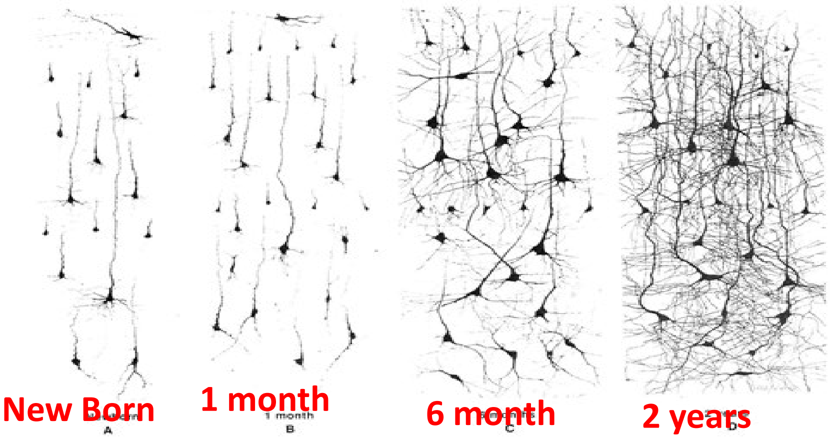
Stage	Age or Period	Description
Sensorimotor	Infancy: 0–2 years	Intelligence, Motor activity present; limited knowledge based on experiences/ interactions; some language skills develops; Achieves basic understanding of causality, time, and space.
Pre-operational	Toddler and Early Childhood: 2–7 years	Symbols or language skills are present; memory and imagination develops; intuitive problem solving; begins to see relationships; grasps concept of conservation of numbers; egocentric thinking predominates
Concrete operational	Elementary and Early Adolescence: 7–12 years	Logical and systematic form of intelligence; grasps concepts of the conservation of mass, length, weight, and volume; operational thinking predominates nonreversible and egocentric thinking
Formal operational	Adolescence and Adulthood : 12 years and on	Logical use of symbols related to abstract concepts; Acquires flexibility for abstract thinking and mental hypothesis testing; can consider possible alternatives in complex reasoning and problem solving develops

Recap: Neuro-circuitry of cognition

2. BRAIN

- Neuronal Tissue
- Synapses
- Neurotransmitters
- Synapses on neurons
- Development of:
  - Neural tube
  - Cellular components of human cerebral cortex
  - Nervous tissue
- Development of human cerebral cortex

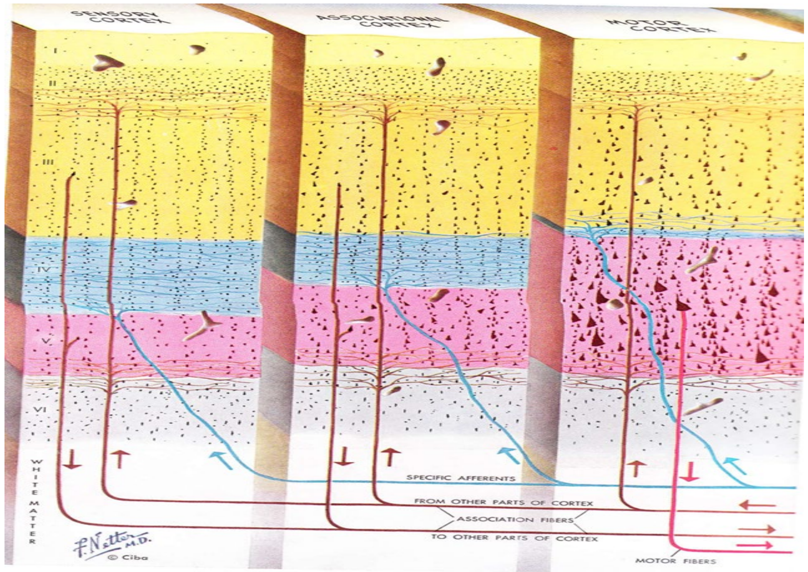
Development of the human cerebral cortex



Sensory Cortex

Association Cortex

Motor Cortex



Neuro-Anatomy of Cognition – Timings

Sound to perception process and timing

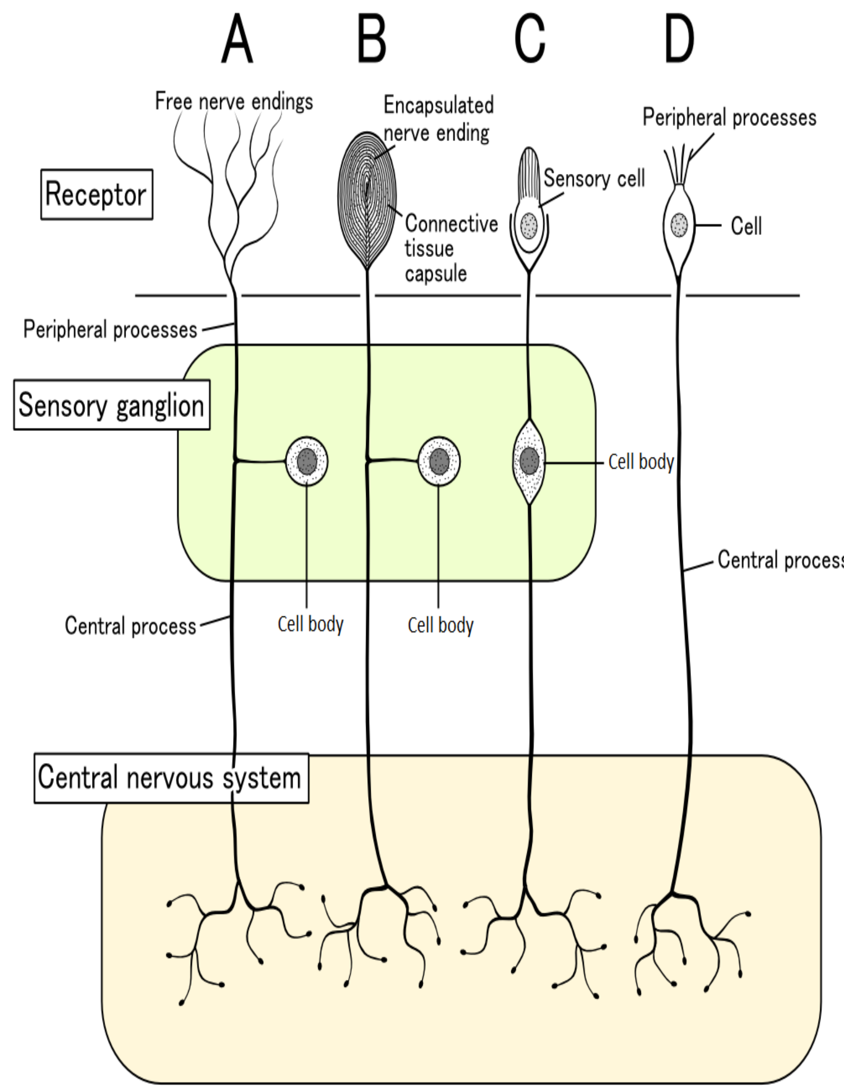
- Neuronal Components:
  - Stimulus, Receptors,
  - Nerve and Neurons, Synapses,
- How sound reaches brain
- Acoustic and Lexical Processing
  - Speech Perception
- Amplitude-modulated tone stimuli
- Word Listening – Perception
  - Core Process and
  - Timings

Stimulus

- Stimulus is detectable change in the environment that evokes a specific functional reaction in an organ or tissue.
- Ability of an organ to respond to external stimuli is called sensitivity.
- When a stimulus is received the sensory receptor’s does energy conversion (transduction) into action potential

Receptors

- Receptors are biological transducers that detect stimuli,
- Convert energy from both external and internal source into electrical impulses,
- Sensory receptors respond to one of four primary stimuli:
  - Chemicals (chemoreceptors),
  - Temperature (thermoreceptors),
  - Pressure (mechanoreceptors),
  - Light (photoreceptor)
- Connected to central nervous system by afferent nerve fibers,
- Brain, spinal cord or pancreas receives and processes information from receptors around the body



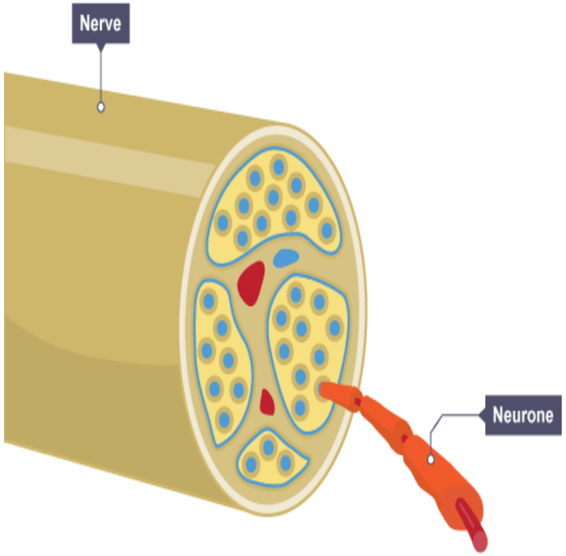
Receptors

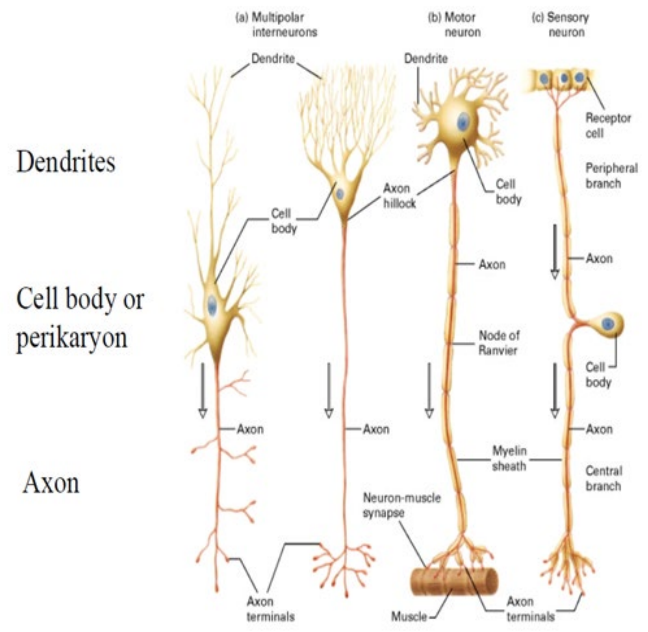
Sense organ	Stimulus	Receptors	Sensory processing centers
Skin	Touch, temperature and pain - Touch (tactioception)	Temperature (thermoreceptors; receptive portion of a sensory neuron), Pressure (mechanoreceptors-sensory neuron responds to mechanical pressure)	Somatosensory Cortex
Tongue	Chemicals (in food and drink) - Taste (gustaoception)	Chemicals (chemoreceptors; chemosensor -specialized sensory cell)	Gustatory Cortex
Nose	Chemicals (in air) - Smell (olfacception)	Chemicals (chemoreceptors; chemosensor -specialized sensory cell)	Olfactory Cortex
Eye	Light - Sight (ophthalmoception	Light (photoreceptor; neuroepithelial cell found in retina)	Visual Cortex
Ear	Sound and position of head - Hearing (audioception)	Pressure (mechanoreceptors; Auditory Receptor Cells (hair cells))	Auditory Cortex

Receptors transduces physical energy into a nervous signal

Neurons and Nerve

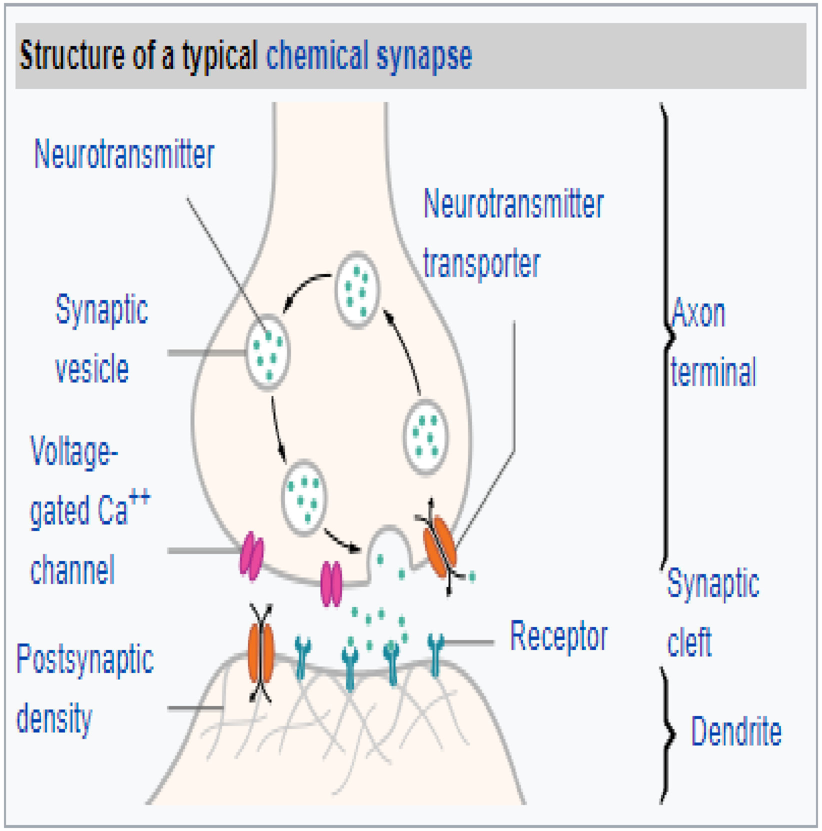
- Nerve cells are called neurons that carry electrical impulses,
- A bundle of neurons are called nerve that transmit impulses to brain or spinal cord, and impulses from these to muscles and organs
- Neurons are three main types: sensory, motor and relay, and have similar structure:
  - Long fiber, axon, to carry message up and down the body
  - Tiny branches, dendrons, branch as dendrites to receive incoming impulses from other neurons,
  - Neurotransmitters are released from axon terminal after an action potential reached synapse and neurons at dendrites receives them





Synapses

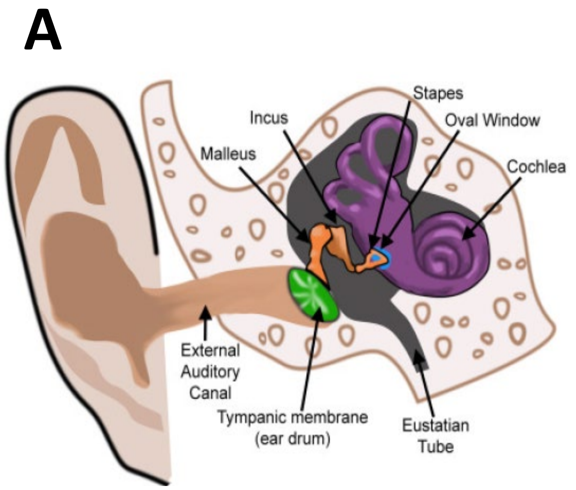
- End of each neuron is a gap called synapse; essential to neuronal function, to pass signals:
  - Signal-passing neuron, presynaptic neuron, comes in close apposition with target, postsynaptic
  - Both sites link two membranes together to carry out signaling process



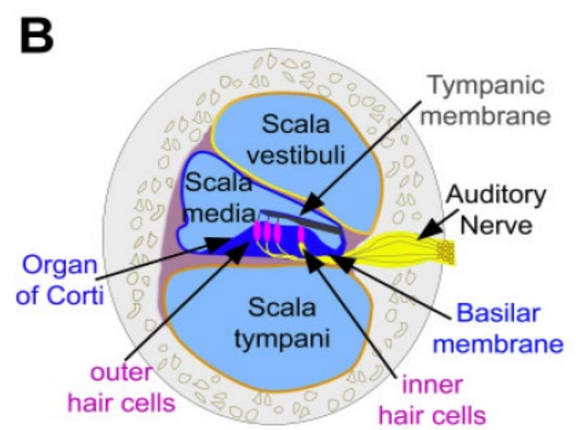
- When electrical signal reaches end of a neuron that triggers release of small sacs; vesicles that contain neurotransmitters, Sacs spill their contents into synapse and neurotransmitters move to neighboring cells,
- Neurotransmitter crosses synaptic gap and attaches to receptor of other neuron,

How sound reaches brain.

- Sound energy waves move in medium molecules and causes increases and decreases in pressure
- Energy waves reaches to external **acoustic meatus** and causes **movement of tympanic membrane**
- That creates **vibration of 3 small bones**
- This energy transfers into **cochlea** (filled with fluid) and vibration make fluid ripple
- This **mechanical energy converts into electrical energy by auditory receptor cells (hair cells),**
- From Top of hair cells, ions (neurotransmitter) falls into Inner hair cells cause release of chemicals that binds auditory nerve cell and create electrical signal that travels to brain through **Auditory Nerve**
- Different hair cell interprets different frequencies (low and higher pitch sound: 200 hz – 20,000hz)



A. Outer, middle, and inner ear

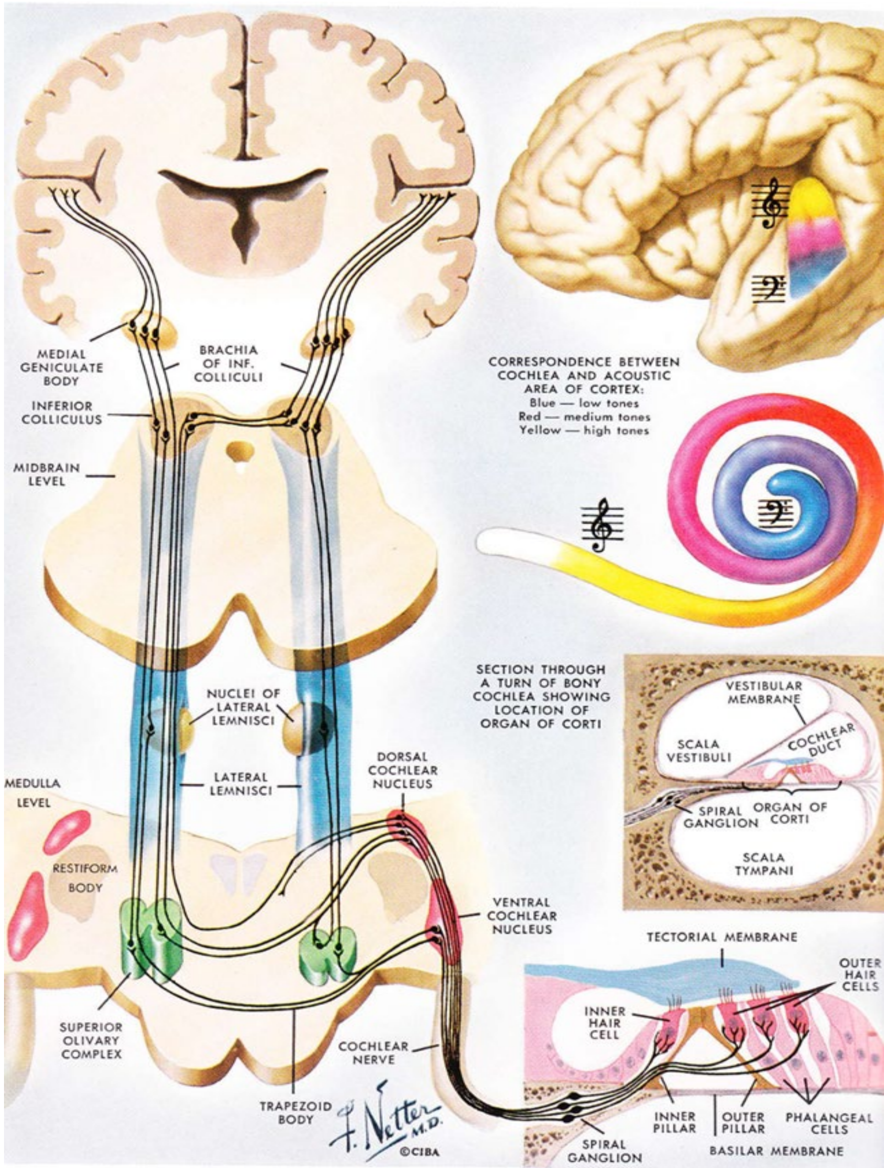


B. Cross section of the cochlea

Ref.: Neuroanatomy, Auditory Pathway - StatPearls - NCBI Bookshelf.pdf; StatPearls Publishing; 2019 Jan

Acoustic Neuronal Pathways

- Auditory Nerve synapse within cochlear nucleus
- Auditory information is then transmitted via superior olivary complex
- Central auditory system receive and process information from both sides: ipsilateral and contralateral
- Auditory brain circuits encode sound aspects: frequency, attenuation (intensity of a sound), location in space



Types of Processing

- Information reaches central auditory nuclei via auditory nerve to cortex where perception occurs,
- Descending circuits modulate auditory attention based on relevance, attention, learned behaviors, and emotional state of an individual.
- Higher order functions originate from e.g., prefrontal cortex, hippocampus, nucleus basalis of Meynert, and limbic circuits that have either direct and indirect connections with each other and auditory cortex

Sensory cortex

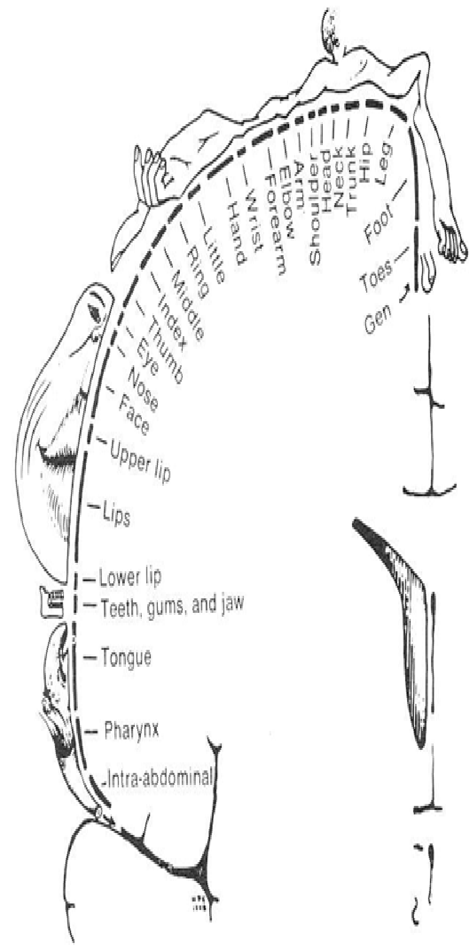


Fig. 4.21. *Relative size of the cortical regions representing various body parts.* Schematic section through the postcentral gyrus (SI) of the human brain. Based on electrical stimulation during brain surgery under local anesthesia. From Penfield and Rasmussen (1950).

Schematic section through Postcentral gyrus

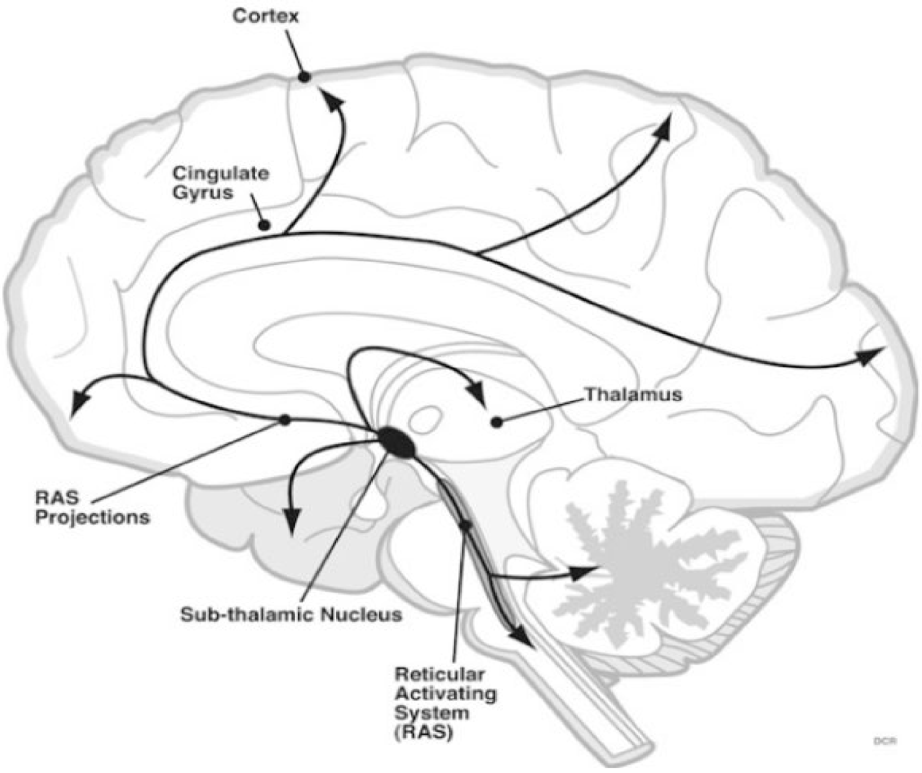
Ref.: Neuroanatomy, Auditory Pathway - StatPearls - NCBI Bookshelf.pdf; StatPearls Publishing; 2019 Jan

Neurotransmitters

- Neurotransmitters are more than 100 different kinds
- Major
  - Glutamate
  - Aspartate
  - Gamma-aminobutyric acid (GABA)
  - Glycine
    - Relatively simple & fast action
    - Central to basic life processes
- Slower Neurotransmitters
  - Serotonin
  - Norepinephrine
  - Dopamine
  - Noradrenaline

Monoamine Neurotransmitters and Reticular Activating System (RAS)

- Monoamine neurotransmitters are serotonin, noradrenaline and dopamine derived from one amino acid, that regulate emotions (Innate and Universal) and behavior,
- RAS for Perception and Motor Control:
  - Perception is based on **sufficient arousal**,
  - Motor control require a level of excitability to perform motions (RAS modulates fight-or-flight responses), and
- This phenomena **probably** enables prefrontal cortex hand off to motor cortex to generate a spoken response



RAS consists of neuronal networks originating in brainstem regions that project upward to the subthalamic nucleus and from there to many cortical and subcortical brain structures. **RAS is responsible for maintaining conscious activity**

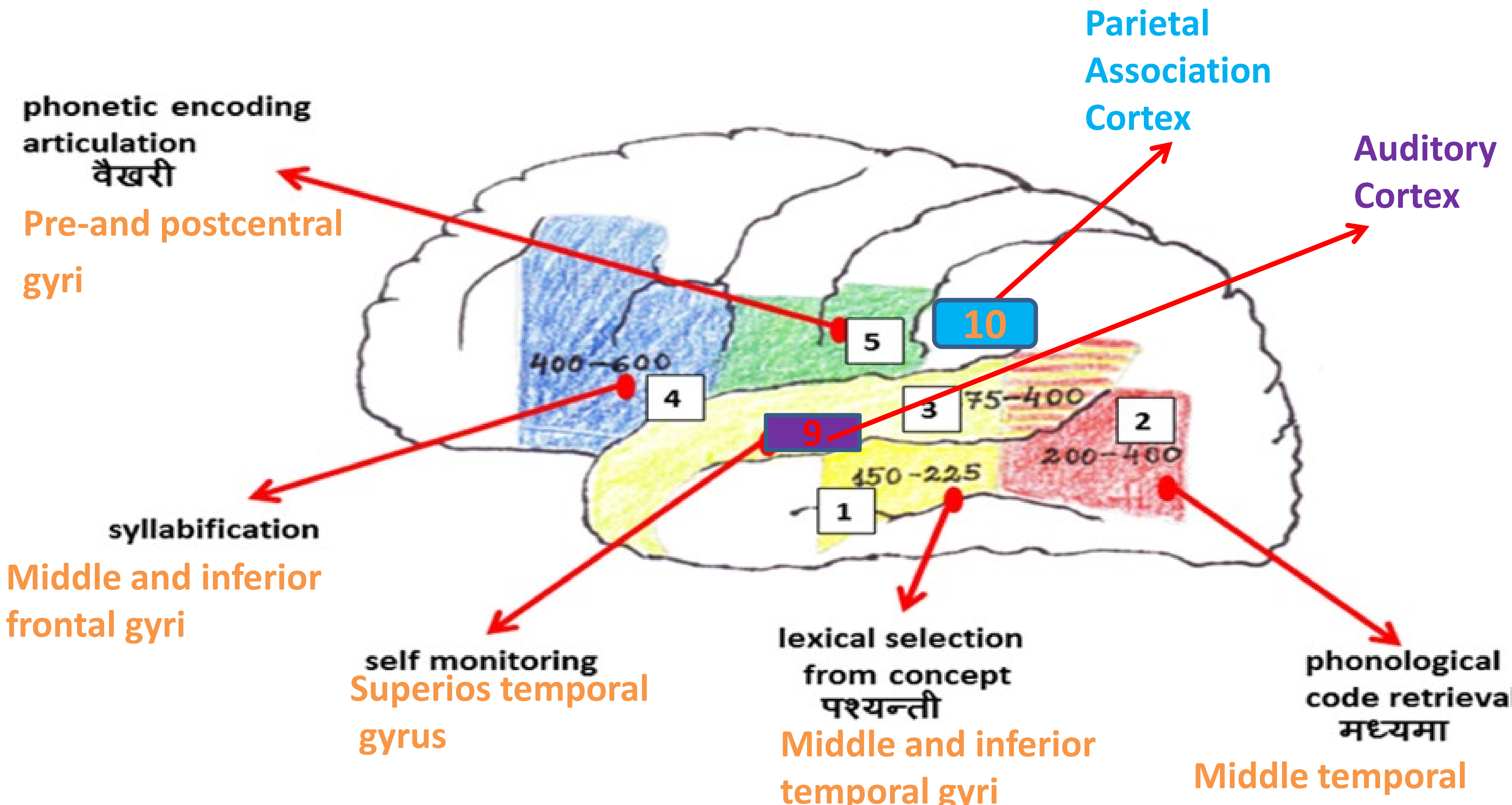
Monoamine Neurotransmitters and RAS

Researchers experimented on combination of three neurotransmitters and measured their effects:

Basic emotions, facial expression and assumed monoamine levels:				
Basic emotion	**Facial expression**	**5-HT serotonin**	**DA dopamine**	**NE noradrenaline**
Interest/excitement	Eyebrows down, eyes track, look, listen	High	High	High
Enjoyment/joy	Smile, lips widened up and out, smiling eyes (circular wrinkles)	High	High	Low
Surpriseb	Eyebrows up, eyes blink	High	Low	High
Distress/anguish	Crying, arched eyebrows, mouth down, tears, rhythmic sobbing	Low	Low	High
Fear/terror	Eyes frozen open, pale, cold, sweaty, facial trembling, with hair erect	Low	High	Low
Shame/humiliation	Eyes down, head down	Low	Low	Low
Contempt/disgust	Sneer, upper lip up	High	Low	Low
Anger/rage	Frown, clenched jaw, eyes narrowed, red face	Low	High	High
Psychologist Silvan Tomkins identified 8 emotions and developed comprehensive theory of basic emotions (innate affects-biological)				

(2011) A new three-dimensional model for emotions and monoamine neurotransmitters;

Prefrontal cortex interpret meaning to Perceive



Auditory Cortex uses Phonological code retrieval process to get to Lexical selection and its syllabification to perceive and Prefrontal cortex interpret meaning to perceive.

Sound Segmentation - Phonetic, Lexical, Semantics

- Phonetics is a speech sound that represent each syllable sound in a word
- Phonetic transcriptions provide profile of sound as pronounced
- Phoneme is a perceptually distinct units of sound to distinguish one word from another, in English *pad*, *pat*, *bad*, and *bat*
- Phonemic transcriptions represent how such sound is interpreted
- Lexical is a single word, a part of a word, or a chain of words (catena) that forms basic elements of lexicon (a vocabulary of a person)
- Semantics is the meaning of a word, phrase, sentence, or a semantic association to an object, action, or abstraction

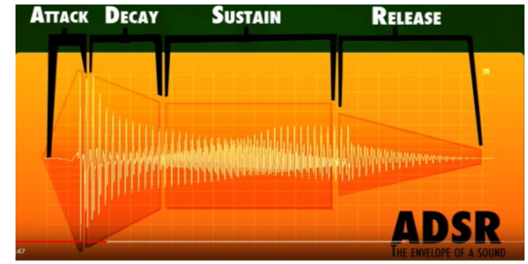
(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

Acoustic to Lexical - Envelops, Onset, Surprisal and Entropy

In speech perception phonemes incrementally informs word making up linguistic message:

- **Acoustic Envelop** of a sound describes how sound gets louder and softer over time
- **Acoustic onset** is when amplitude of stimulus rise linearly from zero to maximum
- **Phoneme onset** is the syllabic Sound segment of a word
- **Word onset** is beginning of first syllabic sound of a word
- Phonemes analyzed for information they convey:
  - **Phoneme Surprisal** is a predictor of hearer's **retrieval of lexicons which starts within 200ms,**

Sound Envelope



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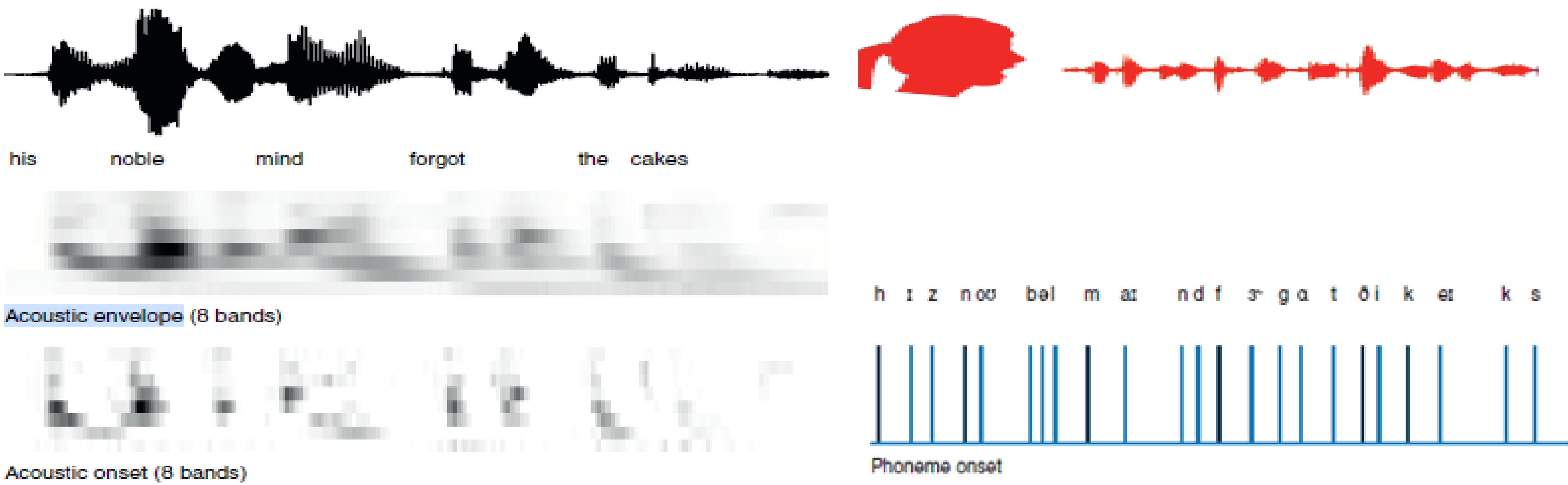
(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

Acoustic to Lexical - Analysis Framework and Illustration

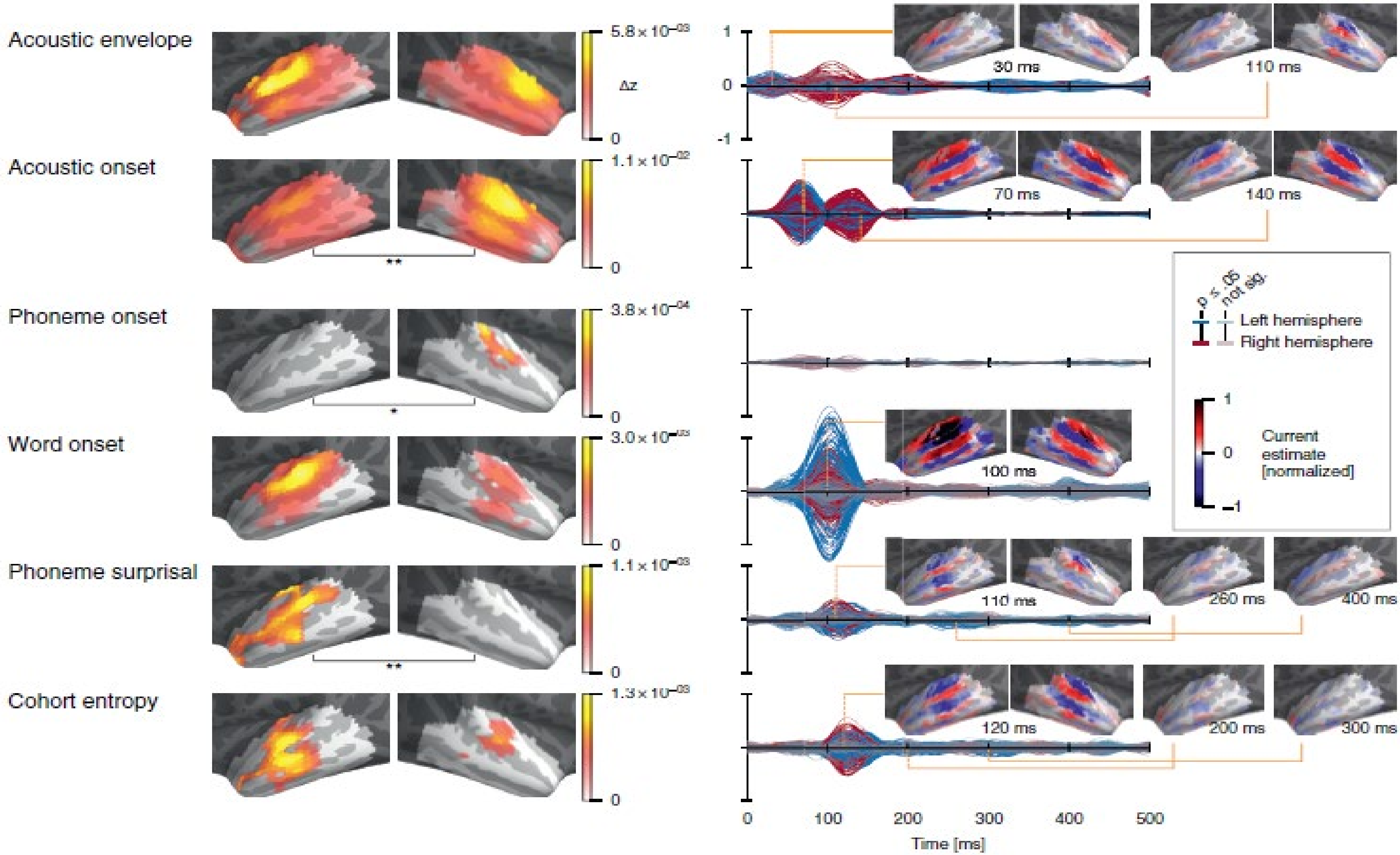


- Acoustic waveform shows each word is distinct and shows word onset
- Auditory spectrogram aggregated into 8 frequency bands,
- **Initial phoneme** of each word is drawn in **black**, and **subsequent phonemes are drawn in blue**
  - **Phoneme onset, distinct phoneme and word onset**
  - **Shows Sound segmentation related to Lexical segmentation**

(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

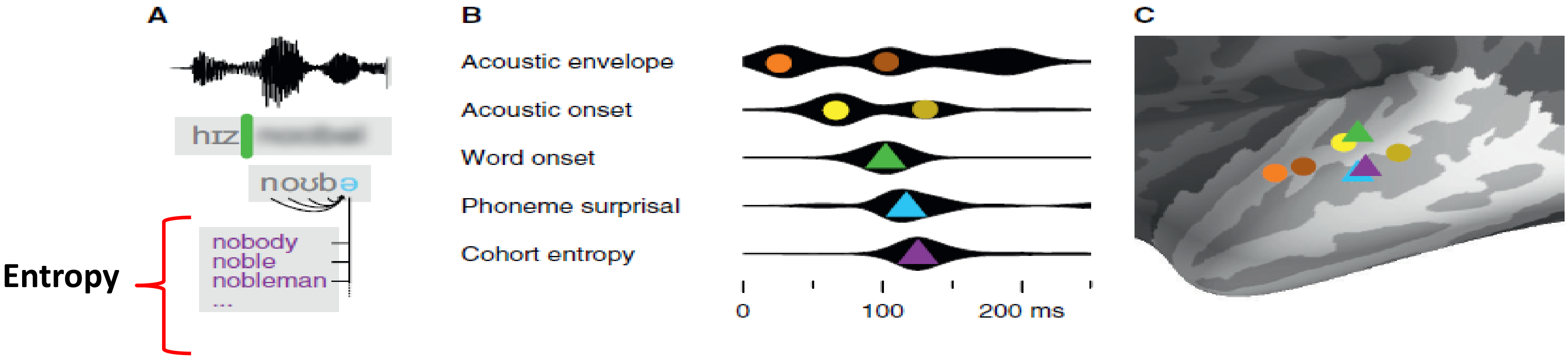
Acoustic to Lexical - Brain Process Response (500-800 ms)

Temporal Response Functions (TRFs)



(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

Acoustic to Lexical - Brain Process Responses (Timings)



- (A) Illustration of cohort model preceding phoneme sequence and surprisal (cohort entropy),
- (B) Acoustic envelope, Acoustic onset, Word onset, Phoneme surprisal, Cohort entropy > peaks marked with symbols used in (C)
- (C) Center of mass of average peaks shown B

Brain Process Responses (Timings)		
Stages	**Min (ms)**	**Max (ms)**
Acoustic Envelop	30	110
Acoustic onset	70	140
Phoneme onset		
Word onset	110	
Phoneme surprisal (prediction error)	110	260-400
Cohort Entropy (word initial phoneme)	120	200-300
Overall	**500 – 800 ms**	

(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

Acoustic to Lexical - Speech Perception

- Auditory cortex detect linguistic message included in phonetic representations, localized bilaterally in **superior temporal lobe**
- Phonetic representations reflect a transition that serve as input to access abstract word representations
- Research identified: neural signals arising from successful recognition of individual word as lexical
- Paper Reports: incremental integration of phonetic information for word identification, dominantly localized to **left temporal lobe,**
- Short response latency of 114 ms relative to phoneme onset suggests that phonetic information is used for lexical processing as soon as it is available, (Phonetic cues analyzed within 130 ms (20ms/cue)
- Responses also tracked word boundaries, confirming previous reports of immediate lexical segmentation

(2018)Rapid Transformation from Auditory to Linguistic Representations of Continuous Speech

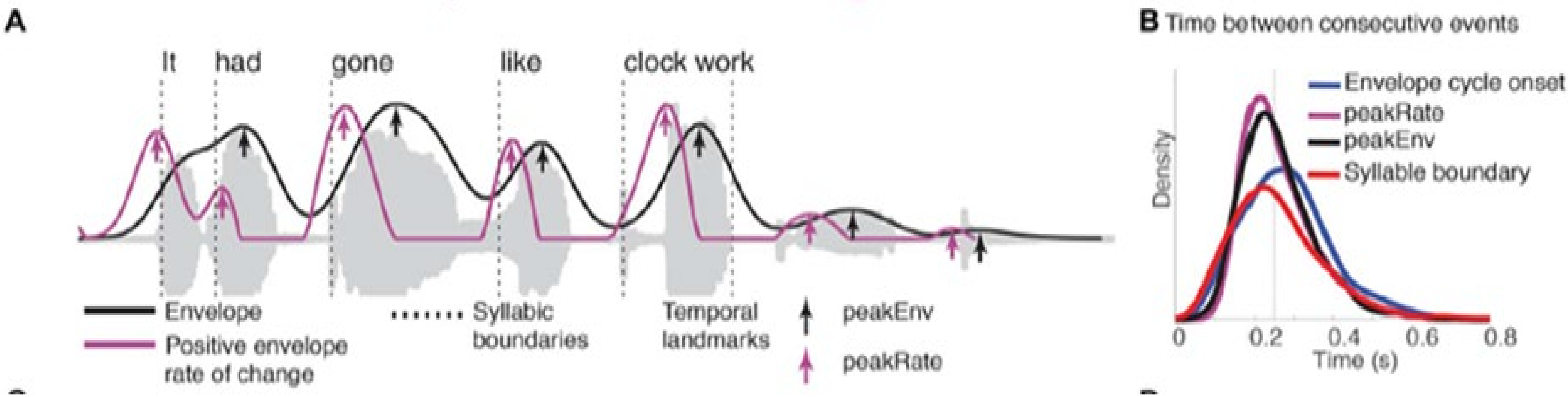
Amplitude-modulated tone stimuli

Electrodes located in higher auditory on superior temporal gyrus (STG)

- Acoustic features in speech is **modulations in its intensity** captured by **amplitude envelope,**
- Perceptually, this envelope is necessary for speech comprehension,
- Superior temporal gyrus (STG) encoding of timing and magnitude of acoustic onset edges **underlies perception of speech temporal structure**
- Note:
  - Concept of envelope and their linguistic implications are heavily debated.
  - Neural encoding of speech envelope using amplitude changes are highly correlated with concurrent changes in phonetic content,
  - One major reason is that **vowels have more acoustic energy (sonority) than consonants**

(2019) A speech envelope landmark for syllable encoding in human superior temporal gyrus

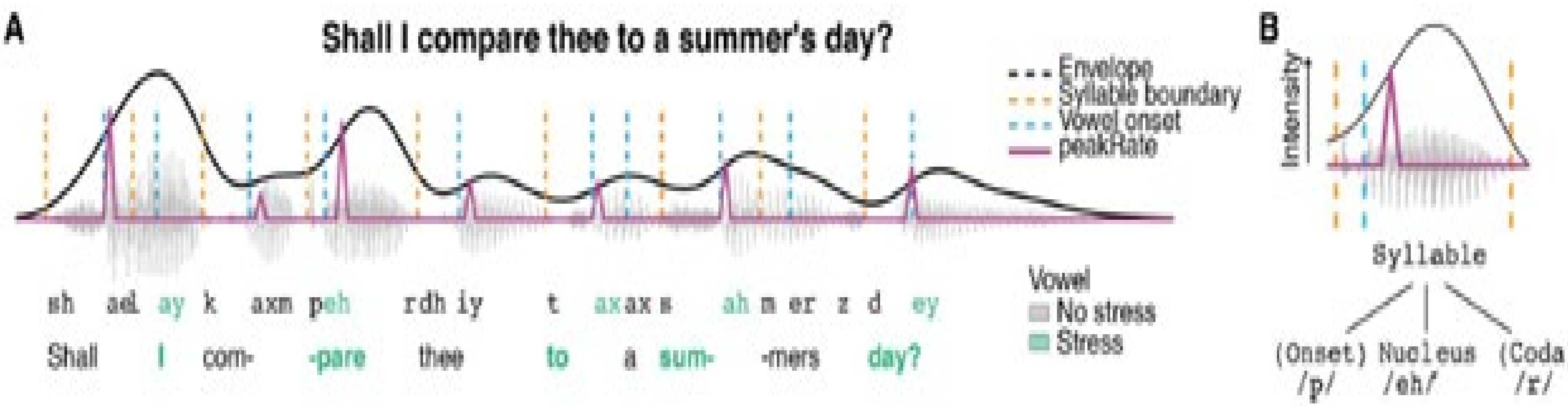
Superior Temporal Gyrus (STG) responses to speech amplitude envelope reflect encoding of discrete events



- Note: Amplitude in a sentence after every word (peaks and valley)
- **(A) Acoustic waveform:**
  - **Amplitude envelope (black) and**
  - **Rate of amplitude change (purple)**
  - **Arrows mark local peaks in envelope (peakEnv) and rate of change of envelope (peakRate)**
- **(B)** Rate of occurrence in continuous speech in stimulus set;
  - syllabic boundaries,
  - envelope cycles, and
  - peak in envelope and rate
- All events occur on average every **200 ms**

(2019) A speech envelope landmark for syllable encoding in human superior temporal gyrus

peakRate events cue transition from syllabic onset consonants to nucleus vowels



(A)Lexical stress, syllabic boundaries, vowel onsets, and peakRate events.

(B)Envelope profile for a single syllable and linguistic structure of a syllable.

Vowels for stressed and unstressed syllables separately in stimulus set.

(2019) A speech envelope landmark for syllable encoding in human superior temporal gyrus

Speech Signal: Phonological Processing of Speech

- Basic speech signal is acoustic waveform with peaks and valleys
- **Modulations in speech intensity** is captured by low-frequency **amplitude envelope** of speech critical for intelligibility
- **Well established that** Neural activity in auditory areas reflects **amplitude** fluctuations in speech envelope
- Goal of this Paper was to determine critical envelope features encoded in human **superior temporal gyrus (STG)** which is strongly implicated in phonological processing of speech

(2019) A speech envelope landmark for syllable encoding in human superior temporal gyrus

Spoken words

Spoken words are processed at phonetic features, segments, lexical phonological codes and lemmas. Core processes steps in Perception of a spoken word are:

- Phonetic features are properties to distinguish from one another
- Segments are ‘spelled-out’ segments of phonological code
- Grapheme to phoneme conversion is a task of converting letters (grapheme sequence) to their pronunciations (phoneme sequence)
- Lexical phonological input code is a phonological input code
- Lemma retrieval is the first step in lexical access (run, runs, ran and running are forms of the same lexeme, with run as the lemma)
- Multiple lemmas is defined by Cohort Entropy
- Lemma selection is semantically related lemmas
- Target lemma is activated
- Lexical concept is a conceptual representation of lexical

(2002) spatial and temporal signatures of word production components By: P. Indefrey*, W.J.M. Levelt

Written words

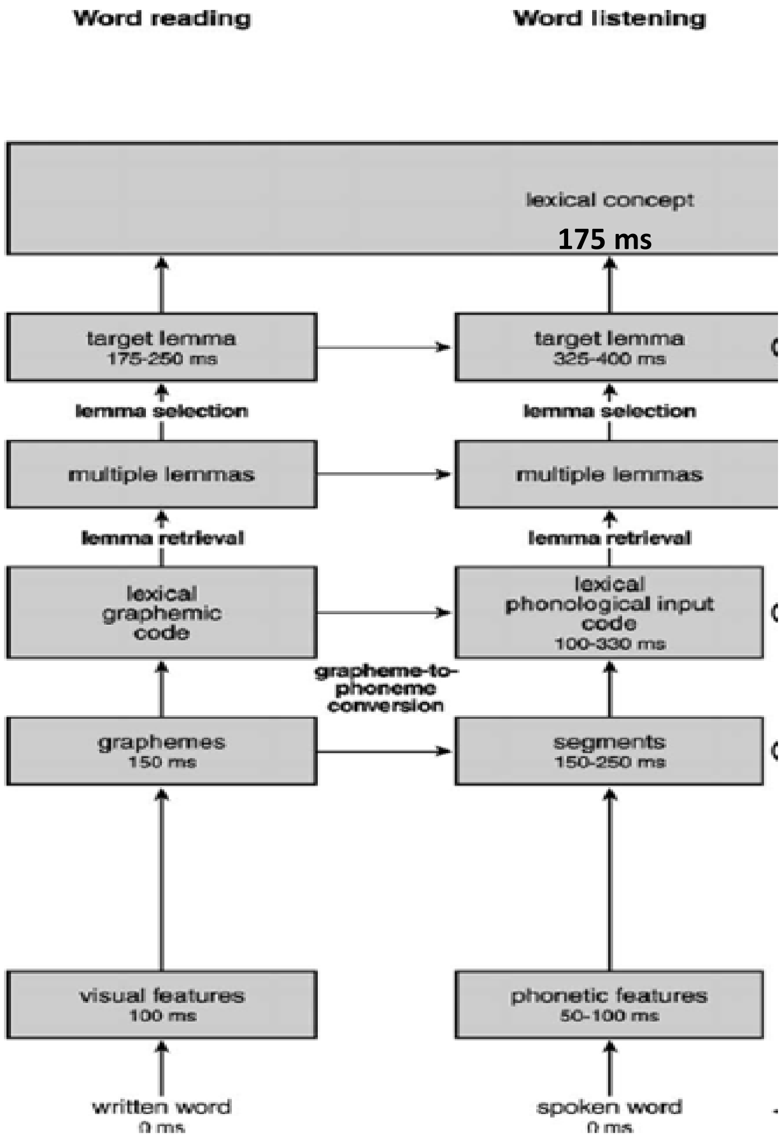
Written words are processed using grapheme-to-phoneme mapping that provides ordered pattern of phonemes. Core processes steps in Perception of a written word are:

- Lemma is a word (run, runs, ran and running are forms of the same lexeme, with run as the lemma)
- Lexical is a information stored in mind regarding a specific word
- Visual Features are properties of the character (s) read
- Graphemes is the smallest unit of a writing system of any given language
- Grapheme to phoneme conversion is a task of converting letters (grapheme sequence) to their pronunciations (phoneme sequence)
- Lexical graphemic code is a retrieval process for lemma
- Lemma retrieval is the first step in lexical access
- Multiple lemmas is defined by Cohort Entropy
- Lemma selection is semantically related lemmas
- Target lemma is a lemma activated
- Lexical concept is a conceptual representation of lexical

(2002) spatial and temporal signatures of word production components By: P. Indefrey*, W.J.M. Levelt

Network of processing components involved in perception: 2002, Core Process and Steps:

WORD READING
Written Word
Visual Features
Graphemes
Grapheme to phoneme conversion
Lexical graphemic code
Lemma retrieval
Multiple lemmas
Lemma selection
Target lemma
Lexical concept (175 ms)
Minimum Timings in ms 700



WORD LISTENING
Spoken Word
Phonetic features
Segments
Grapheme to phoneme conversion
Lexical phonological input code
Lemma retrieval
Multiple lemmas
Lemma selection
Target lemma
Lexical concept (175 ms)
Minimum Timings in ms 800

(2002) spatial and temporal signatures of word production components By: P. Indefrey*, W.J.M. Levelt

Timings

WORD READING	Timings	WORD LISTENING	Timings
Written Word		**Spoken Word**	
Visual Features	100 ms	Phonetic features	50-100 ms
Graphemes	150 ms	Segments	150-250 ms
Grapheme to phoneme conversion			
Lexical graphemic code	100-330	Lexical phonological input code	100 - 330 ms
Lemma retrieval		Lemma retrieval	
Multiple lemmas		Multiple lemmas	
Lemma selection		Lemma selection	
Target lemma	175-250 ms	Target lemma	325-400 ms
Lexical concept (175 ms)			
Minimum Timings in ms	**700**	**Minimum Timings in ms**	**800**

(2011) Indefrey and Levelt: Spatial and Temporal Signatures of Word Production Components: A Critical Update; by: Peter Indefrey1,2,* **Published online 2011 Oct 12.**

Thank you for listening

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