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Introduction to Linguistic Theory

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Language Processing and the Human Brain

The Human Mind at Work

- **Psycholinguistics**: the study of linguistic performance in speech production and comprehension
  - Linking psychological mechanisms to grammar to understand language production and comprehension

Comprehension: The Speech Signal

- When we push air through the glottis, vibrating vocal cords produce variations in air pressure
  - The speed of these variations in air pressure determines the **fundamental frequency** of the sounds
    - Fundamental frequency is perceived as **pitch** by the hearer
  - The magnitude of the variations (or **intensity**) determines the loudness of the sound

Comprehension: The Speech Signal

- An image of the speech signal is displayed in a spectrogram

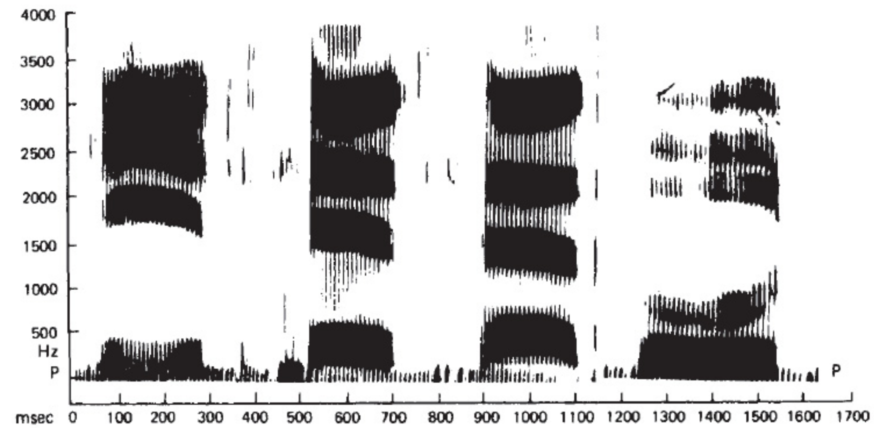


FIGURE 10.1 | A spectrogram of the words *heed*, *head*, *had*, and *who'd*, spoken with a British accent (speaker: Peter Ladefoged, February 16, 1973).
From LADEFOGED/JOHNSON. *A Course in Phonetics (with CD-ROM)*, 6E. © 2011 Cengage Learning. Reproduced by permission.

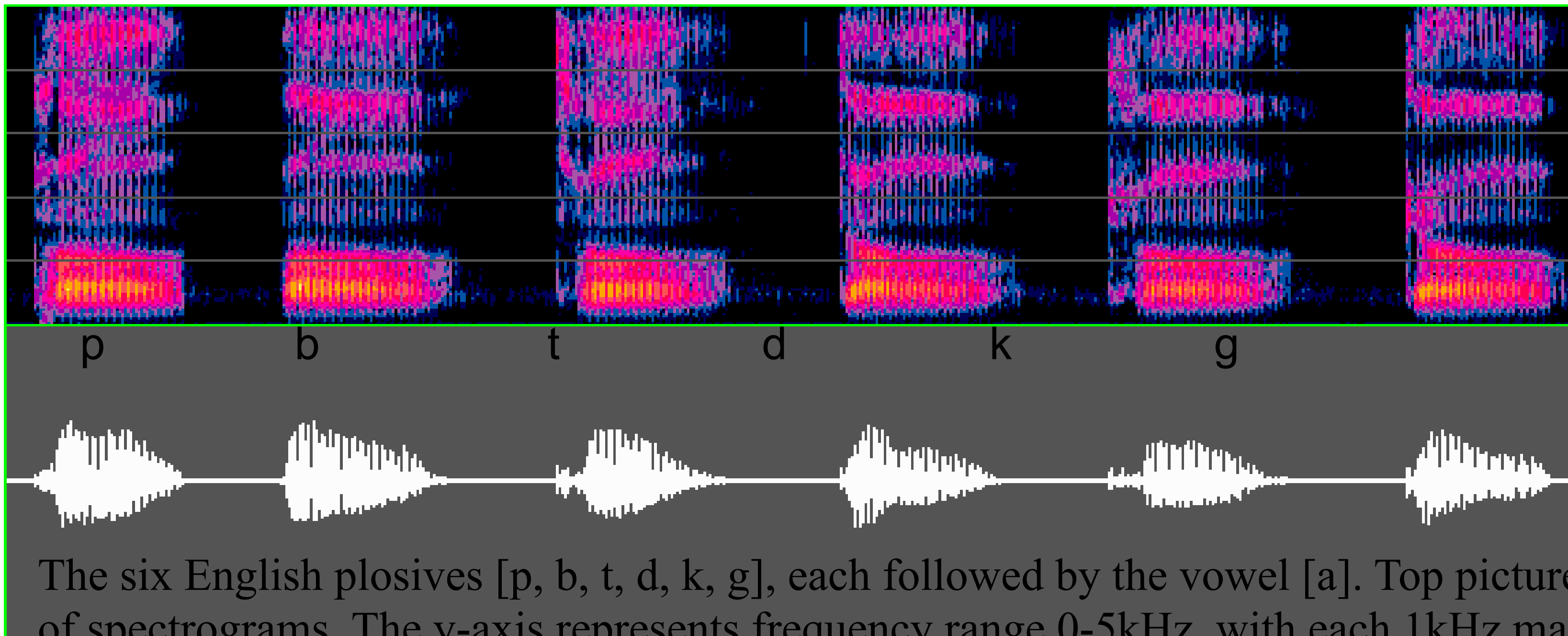
- Vowels are indicated by dark bands called **formants**

Parsing of sound

- Categorical perception
  - We do not perceive linguistic sounds as a continuum
- Duplex perception
  - Are able to integrate 'spliced' parts of a sound played into each ear

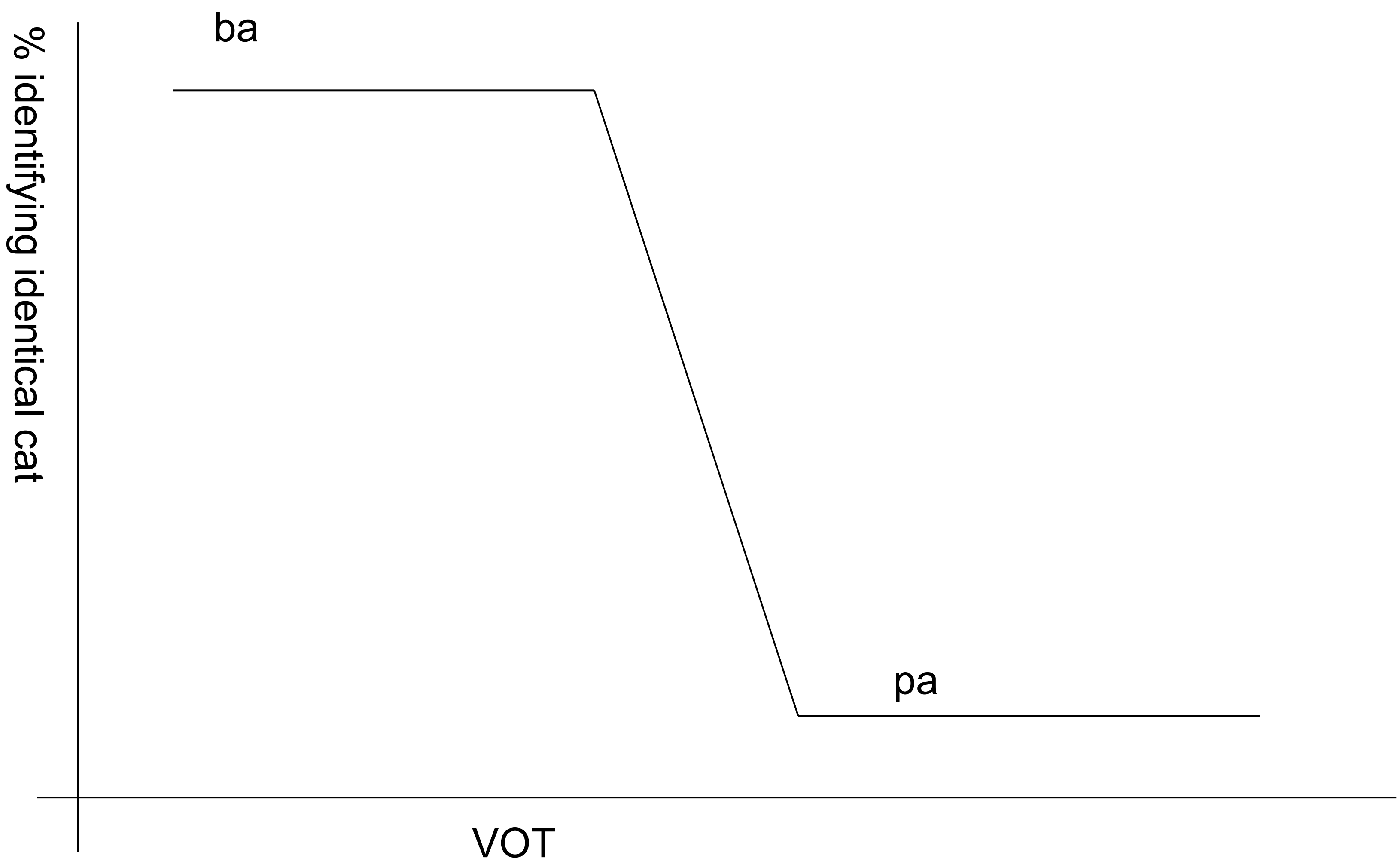
VOT

- Voice onset time differentiates voiced sounds from voiceless



The six English plosives [p, b, t, d, k, g], each followed by the vowel [a]. Top picture is of spectrograms. The y-axis represents frequency range 0-5kHz, with each 1kHz marked by a horizontal gray line. The x-axis is time - about 4s overall. The bottom picture is the same data in time aligned waveforms.

VOT perception



Formants - how to splice a sound

Frequency response curves (indicating the preferred resonating frequencies of the vocal tract). Each of the preferred resonanting frequencies of the vocal tract (each bump in the frequency response curve) is known as a **formant** .

They are usually referred to as F1, F2, F3, etc. For example, the formants for a typical adult male saying a schwa:

F1 first formant 500 Hz

F2 second formant 1500 Hz

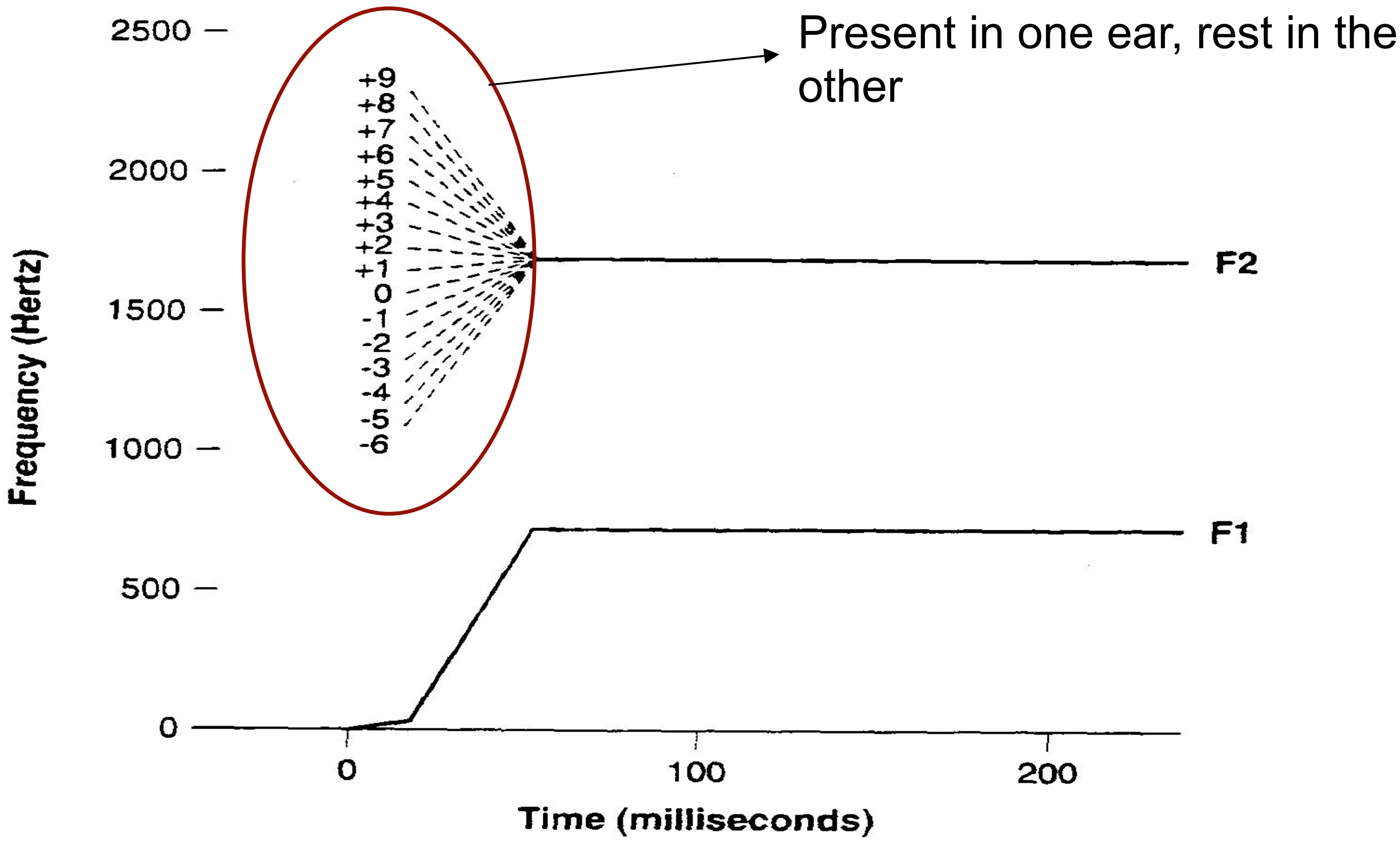
F3 third formant 2500 Hz

Duplex perception

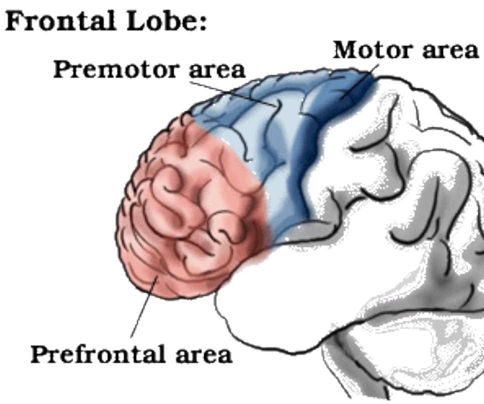
- Splice the formants apart
  - Play one set in one ear
  - Play the other set in the other ear
- What will happen?
  - Hear sound in one
  - Chirp in the other

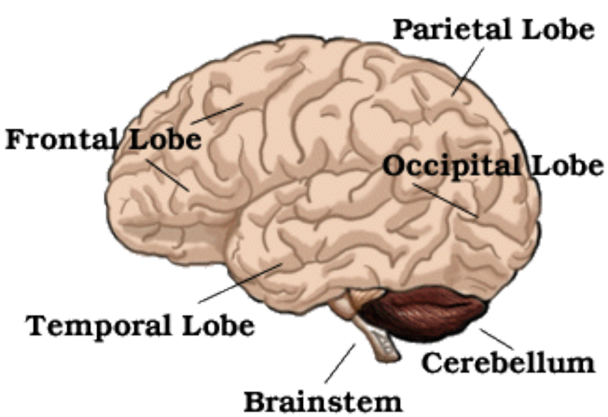
Manipulation of Synthetic Speech Sounds

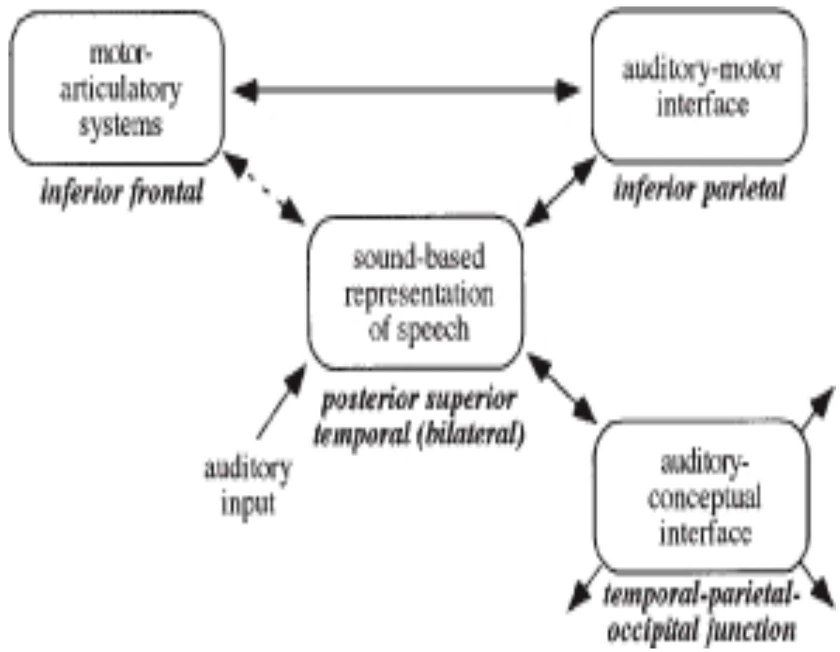
Here is a schematic drawing of how formants can be manipulated in synthetic speech. In this example, F1 is held constant and the initial portion of F2 can be produced in any of sixteen ways. As the F2 transition changes from the –6 position to the +9 position, the sound shifts from /ba/ to /ga/.



Hickock and Poeppel 2000







Comprehension: Speech Perception

- Our speech perception mechanisms allow us to understand speech despite the "segmentation problem" and "lack of invariance problem"
  - Normalization procedures let us control for individual differences, speed, accents, etc.
  - Knowledge of the underlying phonemic system aids in **categorical perception**

Comprehension: Lexical Access and Word Recognition

- **Lexical decision** tasks measure *response time*
  - Listeners respond more slowly to:
    - infrequently used words
    - possible non-words (rather than impossible non-words)
    - words with larger phonological neighborhoods
    - ambiguous words

Serial matching

- Forster 1989
  - Serial matching in word mapping
    - Use either:
      - Frequency ordered phonological list
      - Semantic associative list
  - Frequency effects on word recognition
    - More frequent words are accessed faster
  - Frequency interaction with context
    - Context plays a role and makes less frequent words be accessed faster

Priming

- Lexical priming
- Faster decision if target preceded by a semantically related word
- Faster decision if target preceded by a phonologically related word
  - As compared to unrelated

Priming

Nurse ##### Doctor

Faster here in deciding it is a word

Purse ###### Doctor

Cross modal priming (Swinney et al., 1978; Onifer & Swinney, 1981)

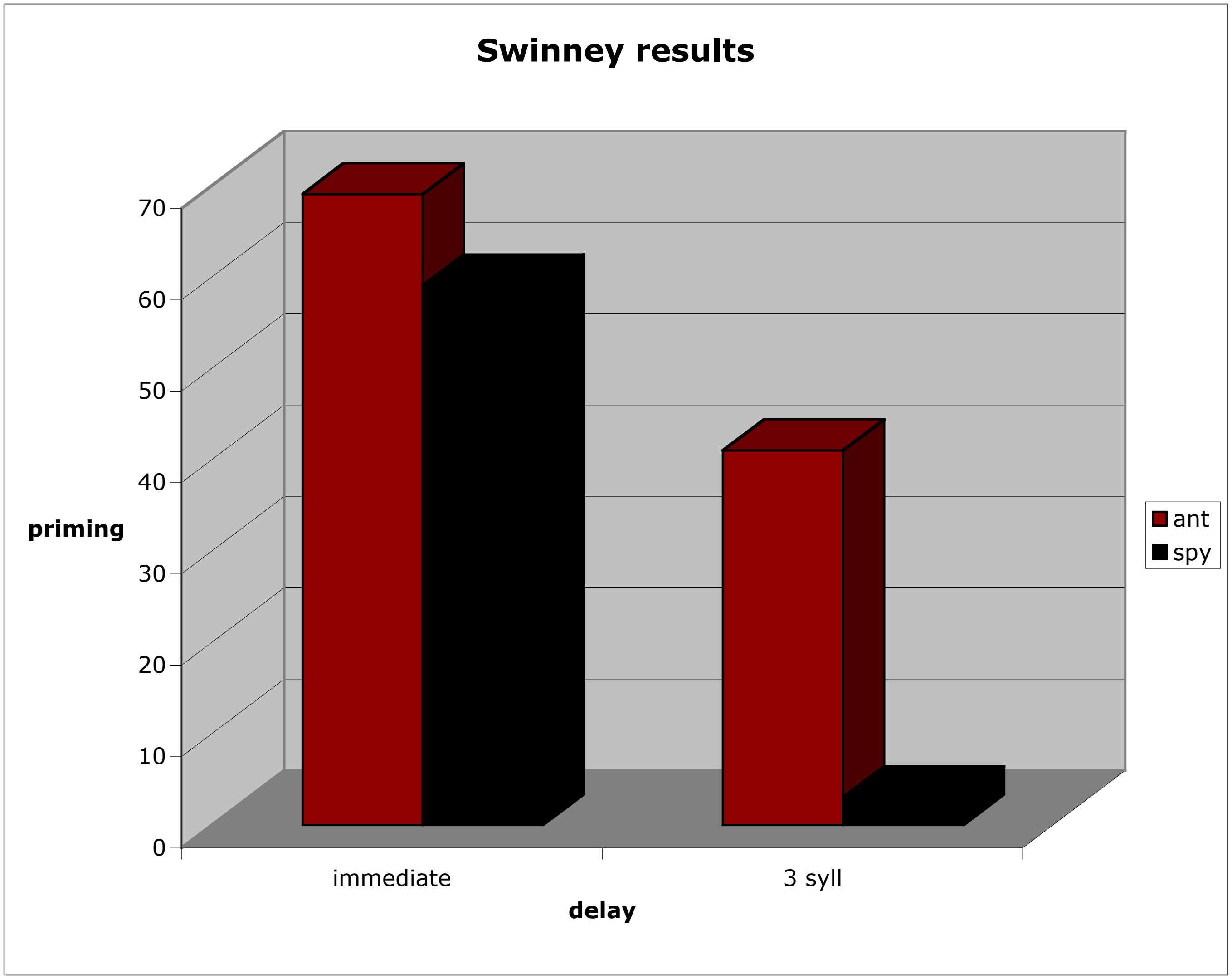
Auditory presentation

The stranger noticed **bugs** in my apartment

spy
ant
sew

spy
ant
sew

Visual



Priming = unrelated-related rt

Picture word Naming

- Name a picture with a word inside it
  - Asked to ignore the word
    - But you cannot!

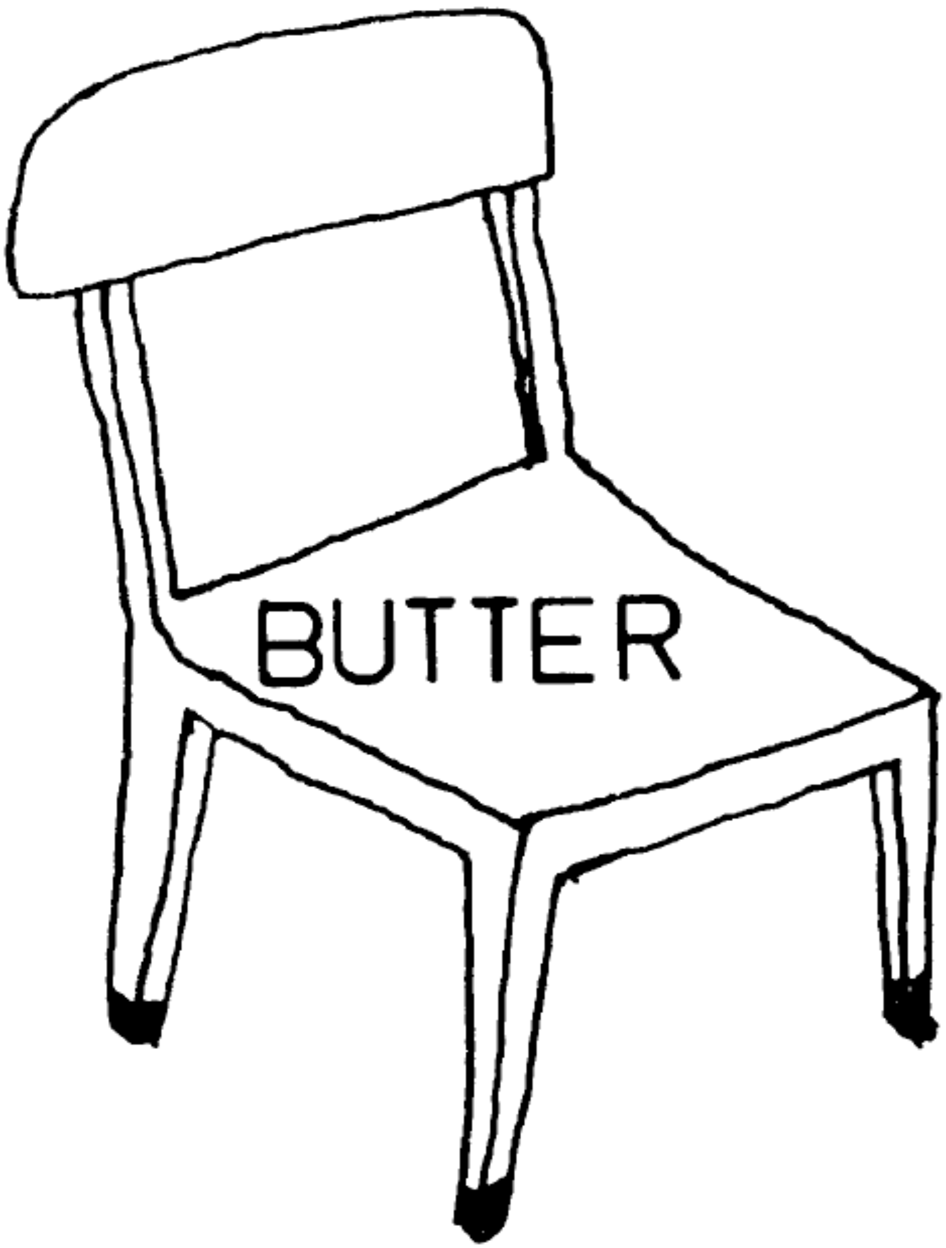


Figure 1. Typical picture-word stimulus.

Priming effects

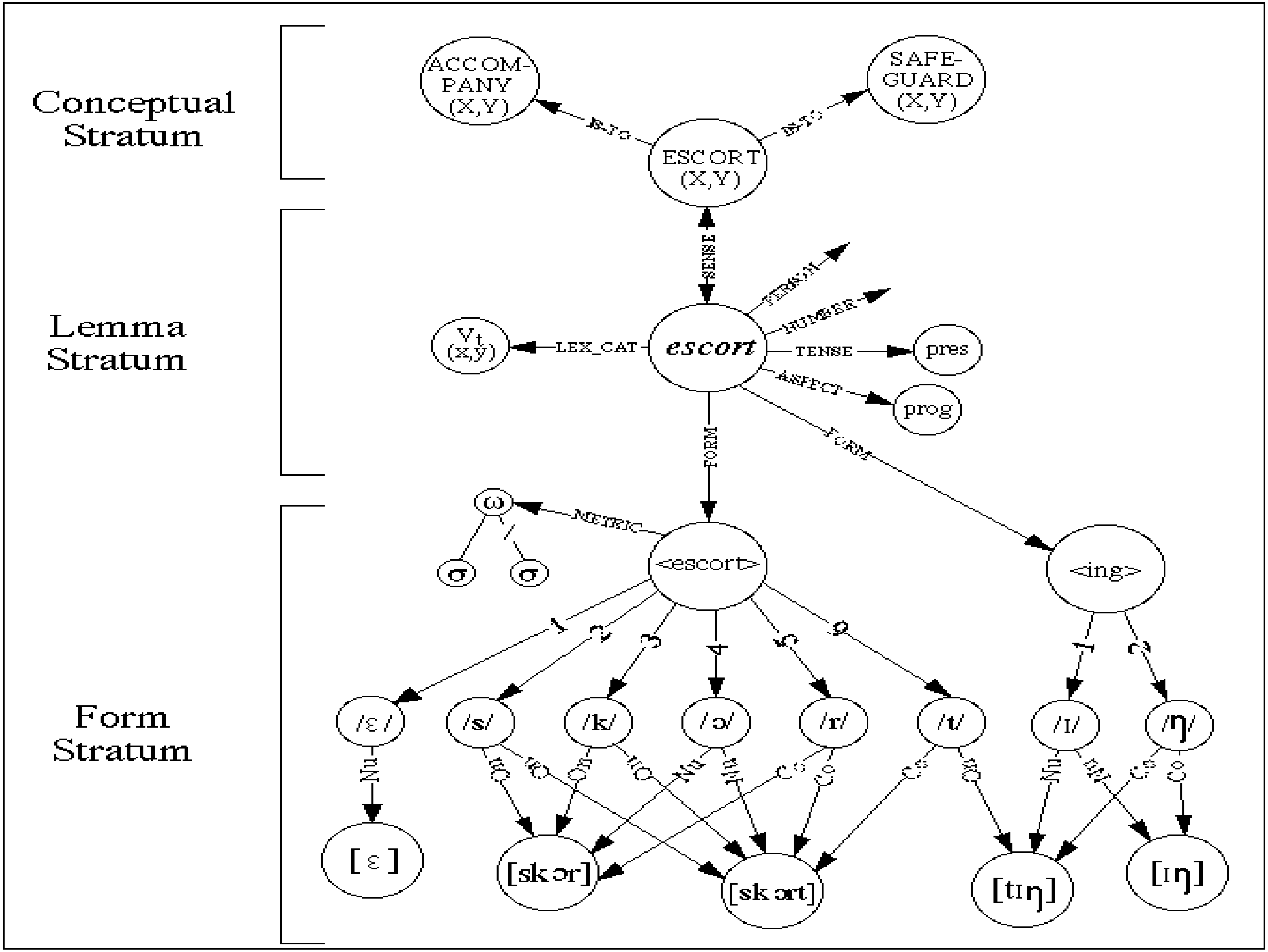
- When word is semantically related to the prime - rt slower
- When word is phonologically related to the picture - rt faster
- As compared to unrelated

SOA

- Effects disappear at different SOA’s (Levelt)
  - Negative SOA No Phonological effect
  - Positive SOA No semantic effect
- Supports a model where we have Semantic processing first and phonological processing second.

Comprehension: Lexical Access and Word Recognition

- **Semantic priming**: words can be activated by hearing semantically related words
  - Response time will be faster on the word *doctor* if the listener has just heard the word *nurse*
- **Morphological priming**: a morpheme of a multimorphemic word primes a related word
  - Response time will be faster on the word *wool* if the listener has just heard the word *sheepdog*


Conceptual Stratum
Lemma Stratum
Form Stratum
ACCOM-PANY (X,Y)
SAFE-GUARD (X,Y)
ESCORT (X,Y)
SENSE
escort
LEX_CAT
Vt (x,y)
TENSE
pres
prog
FORM
METRIC
<escort>
<ing>
/s/
/k/
/r/
/t/
[sk ɔr]
[sk ɔrt]
[tɪŋ]
[ɪŋ]
[ε]

Comprehension: Bottom-Up and Top-Down Models

- **Bottom-up processing** moves from the acoustic signal to phonemes, morphemes, words and phrases, and finally semantic interpretation

- **Top-down processing** starts with higher-level semantic, syntactic, and contextual information to analyze the acoustic signal
  - Supported by several types of experimental evidence

Top down - Bottom up

- Bottom up
  - Proceeds from lowest level of processing to highest
    - ‘Mary jumps’ after hearing ‘jumps’ you know Mary is the subject
- Top down
  - Proceeds from highest level to lowest
    - Hear; ‘the’ expect noun: ‘The cat’

Serial and Parallel Processing

- Serial Processing
  - Each process takes place one at a time.
- Parallel Processing
  - Multiple processes take place simultaneously.

Serial vs. Parallel

A Cat in the toilet

1 2 3 4 5

Articulation

A Cat in the toilet

Articulation

Serial vs. Parallel

- How do you know to produce ‘a cat’ and not ‘an cat’?

Comprehension: Syntactic Processing

- The mental process of **parsing** involves determining the syntactic relations among words and phrases
- Listeners build a structural representation of a sentence as they hear it
  - Resulting in "temporary ambiguities"
  - **Garden path sentences** are temporarily ambiguous sentences in which a constituent can fit into a sentence in two different ways

    The horse raced past the barn fell.

Garden path

- *The horse raced past the barn fell.*
- *When Fred eats food gets thrown.*
- *Mary gave the child the dog bit a bandaid.*
- *I convinced her children are noisy.*
- *Helen is expecting tomorrow to be a bad day.*
- *I know the words to that song don't rhyme.*
- *She told me a little white lie will come back to haunt me.*

Bottom up in language

- You wait for all the information before you assign structure.
  - #The horse raced past the barn fell
  - The horse raced past the barn fell

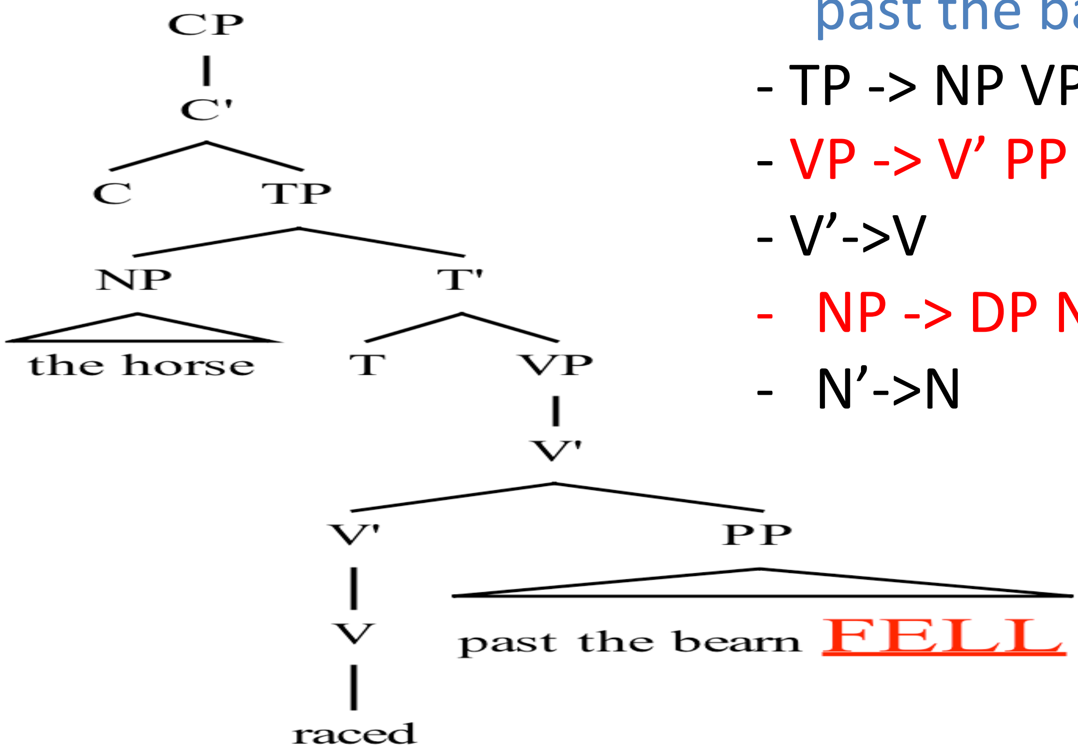
- The horse raced past the barn fell

- TP -> NP VP
- VP -> V’
- V’->V
- NP -> DP N’
- N’ ->N’ CP
- N’->N

- #The horse raced past the barn fell

- TP -> NP VP
- VP -> V’ PP
- V’->V
- NP -> DP N’
- N’->N

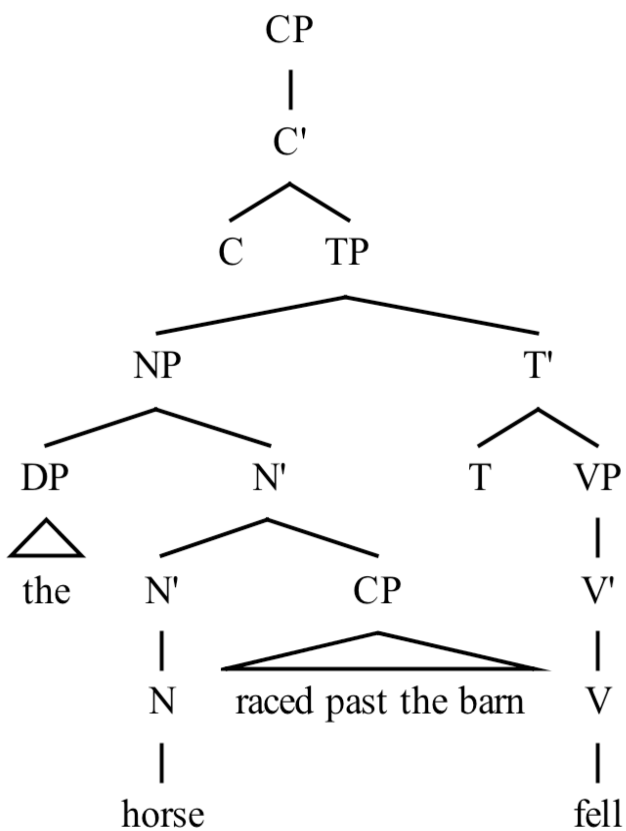
The problem



– #The horse raced past the barn fell

- TP -> NP VP
- VP -> V’ PP
- V’->V
- NP -> DP N’
- N’->N

The solution



- The horse raced past the barn fell

- TP -> NP VP
- VP -> V’
- V’->V
- NP -> DP N’
- N’ ->N’ CP
- N’->N

Bottom up in language vs top down

- You wait for all the information before you assign structure.
- Or do you parse structure on the fly
  - #The horse raced past the barn fell
  - The horse raced past the barn fell
- Seems on the fly

Comprehension: Syntactic Processing

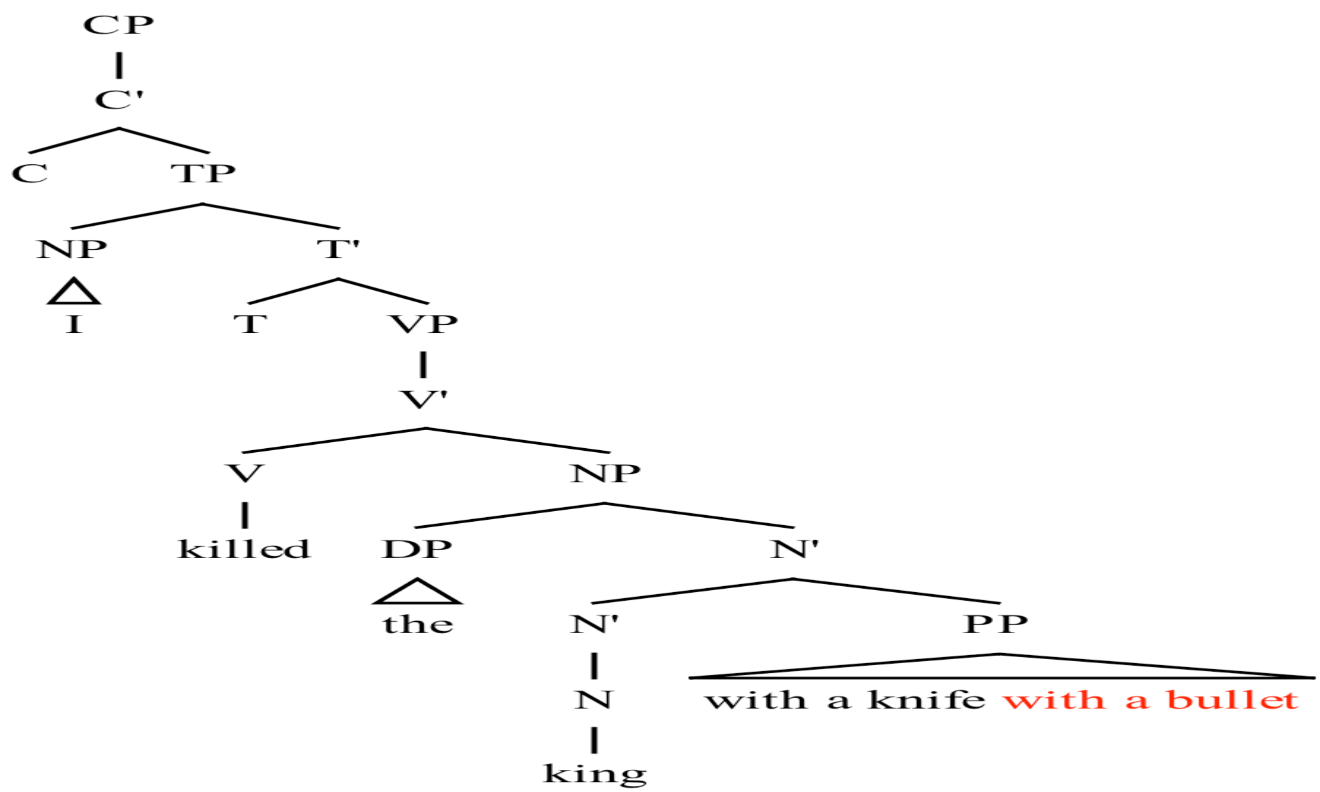
- **Minimal attachment principle**: build the simplest structure consistent with the grammar of the language

- **Late closure principle**: attach incoming material to the phrase that is currently being processed

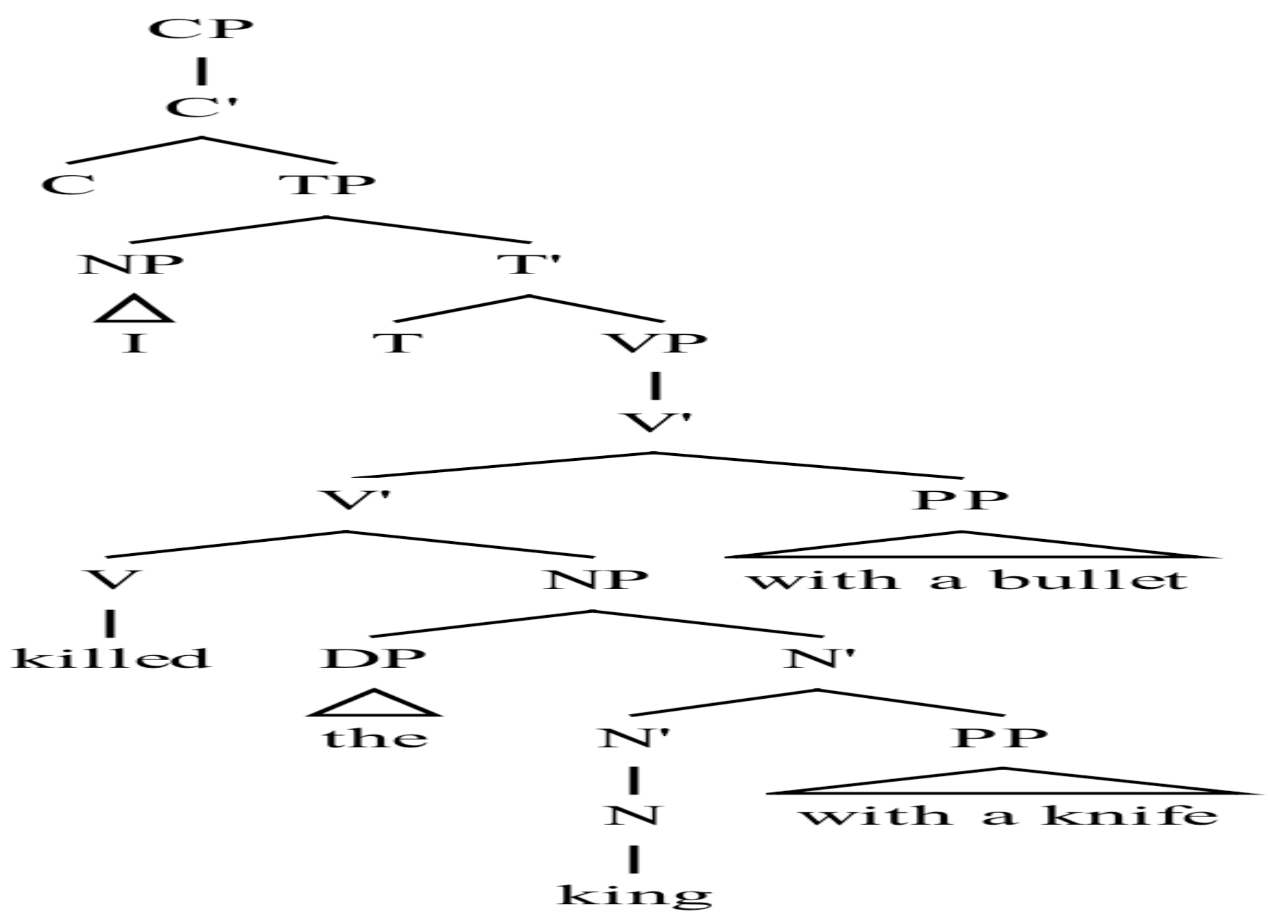
Minimal Attachment

- I killed the king with a knife with a bullet
- I killed the king with a knife with my hands

Minimal attachment Error



Late closure of one PP at least



Reading methods: Self-paced reading, eye-tracking

___ _________ ________ __ ___
______
______ ___ __ __ __________.

The --------- -------- -- ---

------ --- -- -- ----------.

--- defendant -------- -- ---

------ --- -- -- ----------.

--- ---------- examined -- ---

------- --- -- -- -----------.

--- --------- -------- by ---

------ --- -- -- ----------.

--- --------- -------- -- the

------ --- -- -- ----------.

--- --------- -------- -- ---
lawyer
------ --- -- -- ----------.

--- --------- -------- -- ---
------
turned --- -- -- ----------.

--- --------- -------- -- ---

------ out -- -- ----------.

--- --------- -------- -- --- ------

------ --- to -- ----------.

--- --------- -------- -- ---

------ --- -- be ----------.

--- --------- -------- -- ---

------ --- -- -- unreliable.

Did the defendant examine the lawyer?

Comprehension: Syntactic Processing

- Many factors can cause listeners or readers to be led down the garden path (or experience other processing problems):
  - Frequency factors
  - Prosody, lexical biases, visual context
  - Verb choice
  - Memory constraintsSyntactic structure
  - Word / structural frequency
  - Plausibility
  - Discourse context
  - Coherence
  - Working memory constraints
  - Intonational information

Information that is used in sentence comprehension

2. Lexical (Word) information, e.g., frequency

Unambiguous sentences: more frequent, faster: “class” vs. “caste”

Ambiguity: more frequent usages are preferred
The old man the boats.
The old man the boats.

Syntactic argument structure frequencies
E.g., many verbs can take either an NP or a CP complement

Mary discovered / believed the answer was in the back of the book.

More difficulty in comprehending the disambiguating region “was in the ...” for the NP-biased verb “discover” than for the CP-biased verb “believe”.

Information used in sentence comprehension

2. Lexical (Word) information, e.g., frequency

Words with multiple senses of roughly equal frequency are comprehended slower (e.g., “pitcher”) than unambiguous words or words which are highly frequency-biased towards one sense (e.g., “port”).

Information that is used in sentence comprehension

3. Plausibility of the resulting linguistic expression, in the world

Unambiguous examples:

The boy bit the girl. vs. The girl bit the dog.

Ambiguity: (Trueswell, Tanenhaus & Garnsey, 1994)

The defendant examined by the lawyer turned out to be unreliable.

The evidence examined by the lawyer turned out to be unreliable.

Information that is used in sentence comprehension

4. Context (Crain & Steedman, 1985; Altmann & Steedman, 1988; Tanenhaus et al., 1995)

Ambiguity:

There were two defendants, one of whom the lawyer ignored entirely, and the other of whom the lawyer interrogated for two hours.

The defendant examined by the lawyer turned out to be unreliable.

Information that is used in sentence comprehension

5. Working memory constraints (Miller & Chomsky, 1967)

The man [who the woman hugged] smiled.

The man [who the woman [who the child kissed] hugged] smiled.

The man [who the woman [who the child [who the dog followed] kissed] hugged] smiled.

Open question: The modularity of information use in language processing

The time course according to which different information sources become available:

Syntactic information first?

Lexical information first?

All information sources available simultaneously?

Two kinds of modularity

- Modularity of information: Different information sources may be computed using separate systems. E.g., syntactic information may be computed using a separate system from plausibility or contextual information
- Modularity of the time course of information use: Some information may become available before other information. In particular, syntactic information may be available before other kinds of information (Frazier, 1978).

Speech Production: Lexical Selection

- Word substitutions demonstrate that we make incorrect lexical selections based on relatedness of meaning
  - *Please set the **table** → Please set the **chair***
- In blends, segments stay in the same position within the syllable as they were in the target words
  - *splinters/blisters → splisters*
- Substituted words are often phonologically similar to the target word

Speech Production

- Spontaneous errors demonstrate that we apply (and misapply) grammatical rules as we speak

- While sounds are linearly ordered, slips of the tongue reveal that features, segments, words, and phrases are conceptualized well before they are uttered

  – **Spoonerisms**: "You have hissed my mystery lecture. You have tasted the whole worm."

Speech Production

- Planning also occurs at the sentence level
  - More planning is needed for passive sentences and subject-object relative clauses
  - Planning for complex structures happens at the beginning of the clause
    - Pauses occur more often at the beginning of clauses than within them and exchanges of linguistic units happen within units rather than across clause boundaries

The Human Brain

- The brain is the most complex organ of the body, composed of 100 billion nerve cells
- **Cortex**: the surface of the brain which receives messages from the sensory organs, initiates actions, and stores our memories and our knowledge of grammar
- **Cerebral hemispheres**: the left and right hemispheres of the brain function contralaterally
- **Corpus callosum**: a network of 200 million fibers that join the two hemispheres and allow the left and right hemispheres to communicate with each other

The Localization of Language in the Brain

- In the early 19th century, Franz Joseph Gall proposed the idea of **localization**, which is the idea that different cognitive abilities are localized in specific parts of the brain

- He also proposed the theory of **phrenology**, which is the practice of examining the "bumps" on the skull in order to determine personality traits and intellectual capacity

  – Phrenology is no longer followed as a scientific theory, but the idea of localization remains

Aphasia

- **Aphasia**: any language disorder that results from brain damage caused by disease or trauma

- Studies of aphasia have been very important for identifying the areas in the brain used specifically for language

  – Broca's area and Wernicke's area are both language centers found in the left hemisphere

Aphasia

- Damage to Broca's area of the brain may result in **Broca's aphasia**, which is characterized by:
  - Labored speech
  - Difficulty with sentence formation
  - **Agrammatism**: lacking articles, prepositions, pronouns, and auxiliary verbs as well as grammatical word endings such as past tense marker *–ed*

Aphasia

- Example of Broca's aphasia:

DOCTOR:	Could you tell me what you have been doing in the hospital?
PATIENT:	Yes, sure. Me go, er, uh, P.T. [physical therapy] none o'cot, speech . . . two times . . . read . . . r . . . ripe . . . rike . . . uh write . . . practice . . . get . . . ting . . . better.
DOCTOR:	And have you been going home on weekends?
PATIENT:	Why, yes . . . Thursday uh . . . uh . . . uh . . . no . . . Friday . . . Bar . . . ba . . . ra . . . wife . . . and oh car . . . drive . . . purpike . . . you know . . . rest . . . and TV.

Aphasia

- Broca's aphasics also have trouble understanding complex sentences that require knowledge of grammar rather than life experience
  - For example, *The cat was chased by the dog* may be difficult for a Broca's aphasic to understand because it requires knowledge of passive grammatical construction to understand
  - But, *The car was chased by the dog* may be understood because regardless of the word order, dogs tend to chase cars rather than the other way around, so the aphasia patient can rely on life experience to interpret the meaning

Aphasia

- Damage to Wernicke's area of the brain may result in **Wernicke's aphasia**, which is characterized by:
  - Fluent speech with good intonation that does adhere to the rules for sentence formation but is semantically incoherent
  - Difficulty in naming objects
  - Word substitutions and the creation of nonsense words
    - Severe Wernicke's aphasia is known as **jargon aphasia**

Aphasia

- Examples of Wernicke's aphasia:

I felt worse because I can no longer keep in mind from the mind of the minds to keep me from mind and up to the ear which can be to find among ourselves.

The only thing that I can say again is madder or modder fish sudden fishing sewed into the accident to miss in the purdles.

Aphasia

- The symptoms of Wernicke's and Broca's aphasia provide evidence for a **modular** organization of language in the brain
  - Grammar consists of distinct components or modules with different functions
  - For example, aphasia patients frequently may substitute words with similar sounds or meanings
    - *pool* may be substituted for *tool*
    - *table* may be substituted for *chair*
  - This tells us that neural connections exist between words that sound alike and words with similar meanings

Aphasia

- Reading in English:
  - An agrammatic aphasic could not read function words, even though he could read content words that sound the same
  - *witch* is OK, *which* is not
  - *hour* is OK, *our* is not
  - *eye* is OK, *I* is not
  - *wood* is OK, *would* is not
- Reading in Japanese:
  - People with damage in their left hemisphere cannot read *kana*, a writing system based on the sound system of the language
  - People with damage to their right hemisphere cannot read *kanji*, an ideographic writing system

Aphasia

- The **tip-of-the-tongue phenomenon**: difficulty in finding the word you want to say
- **Anomia**: the inability to find the word you want to say
  - This is the case with some aphasics
- Aphasics have linguistic symptoms due to damage to the language faculty
  - Rather than general cognitive or intellectual impairment or loss of control of speech organs

Aphasia

- Deaf aphasics have similar symptoms to hearing aphasics
  - Damage to Broca's area results in dysfluent, agrammatic signing
  - Damage to Wernicke's area results in fluent but semantically incoherent signs

Brain Imaging Technology

- MRI and CT scans can reveal lesions in the brain soon after the damage occurs
- fMRI, PET, and SPECT scans can show brain activity
  - These scans let researchers see the different areas of the brain that are used to accomplish various linguistic tasks, such as naming people, animals, and tools

Split Brain Patients

- Sometimes patients have their corpus callosum severed

- Linguistic experiments with split brain patients provide further evidence for the localization of language in the left hemisphere
  - If a patient sees an image with her right eye, it can be named, but if she sees an image with her left eye, she cannot name the object in the picture

Dichotic Listening and ERPs

- **Dichotic listening**
  - Subjects hear two different sounds or words simultaneously, one in each ear
  - Subjects more often accurately report hearing linguistic sounds coming into the right ear (left hemisphere) and nonverbal sounds coming into the left ear (right hemisphere)
- **ERPs**
  - Studies show that even nonsensical sentences cause more electrical signals in the left hemisphere

Neural Evidence of Grammatical Phenomena

- The brain recognizes phonemic differences and phonotactically permitted sounds
- The brain reacts similarly to grammatically well-formed sentences, regardless of whether or not they actually make sense
- The brain reacts immediately to morphosyntactic violations even when the person is not paying attention

Young Children and Brain Plasticity

- Lateralization begins very early
  - Language appears more dominant in the left hemisphere even in infants
- However, while language is predisposed to be localized in the left hemisphere, children's brains display a remarkable amount of **plasticity**
  - If the left hemisphere of a child's brain is removed (in a **hemispherectomy**), the right hemisphere may take over the language duties

Brain Plasticity

- Plasticity of the brain decreases with age
- Adults undergoing surgery to remove the left hemisphere then suffer from severe language impairment
- The right hemisphere is also important for first language acquisition
  - Children with damage to the right hemisphere may experience problems with vocabulary
  - If the right hemisphere is removed before the age of two, language may never develop

The Critical Period

- The **critical-age hypothesis** assumes that the ability to learn a native language develops between birth and middle childhood (the **critical period**)
  – After this critical period, the acquisition of grammar is difficult, and is never fully achieved for most people
- The critical period for species-specific, biologically based behaviors seems to be present in other species as well
  – For example, during the period of 9 to 21 hours after hatching, ducklings will follow the first moving object they see
  – Some birdsongs must be acquired within a set period of time

The Critical Period

- There are several instances of children being deprived of linguistic exposure during the critical period for various reasons
  - Victor, Genie, Chelsea
- These children did not know any language when they were reintroduced to society
- They were able to learn words but were unable to fully acquire grammar

The Critical Period

- Genie was deprived of all but minimal human contact until she was 14 years old
- Genie was able to learn a large vocabulary
  - And was a very skilled nonverbal communicator
  - But, she lacked grammatical skills
  - She never acquired articles, auxiliary verbs, inflectional suffixes, question words, and was unable to create complex sentences and questions
- Dichotic listening and ERP experiments showed that Genie's language was lateralized to the *right* hemisphere
- It is hypothesized that the language centers in Genie's brain atrophied since she received no linguistic input during the critical period

The Critical Period

- Chelsea was born deaf but was wrongly diagnosed as intellectually disabled
- At age 31 she was finally diagnosed as deaf, was fitted with hearing aids, and began years of intense language training and therapy
- She also has acquired a large vocabulary
  - But, like Genie, she has not acquired grammar
  - And, like Genie, Chelsea's brain activity shows unusual lateralization of language; Chelsea's language ability is equally located in both hemispheres

Language and Brain Development

- Deaf children born to hearing parents also provide information about the critical-age hypothesis
  - Hearing parents often don't know sign language, and so their deaf babies may be exposed to language later on
  - Babies who are exposed to American Sign Language (ASL) up to age 6 are significantly more fluent than those not exposed until after age 12
- The cases of Genie and Chelsea and studies of late learners of ASL show that people cannot fully acquire a language unless they are exposed to it during the critical period

Linguistic Savants

- **Savants** are intellectually disabled people who have remarkable talents in certain areas
  - Laura: could produce complex sentences and could detect grammatical errors
  - Christopher: could not only produce language as complex as any other native speaker but could also translate fifteen to twenty languages into English
- The cases of Laura and Christopher provide strong evidence that linguistic ability is separate from general intelligence

Specific Language Impairment

- **Specific Language Impairment (SLI)**: some children who have not suffered brain damage and have no general cognitive deficits have trouble acquiring language
  - Children with SLI have problems with articles, prepositions, auxiliary verbs, inflectional suffixes
  - Different components of language may be selectively affected in children with SLI
- Children with SLI provide further evidence that language ability is separate from general cognitive ability

Genetic Basis of Language

- There is evidence that language has a biological basis:
  - Children with Turner syndrome, Williams syndrome, and Klinefelter syndrome
  - SLIs seem to be hereditary
  - Identical twins are more likely to both suffer from SLI than fraternal twins