Neural resources for syntactic integration as a key link

Patel 5.4

Introduction

- Modularity?
  - Whether language is a cognitive module is a matter of debate.
    - Fodor 1983 vs. Elman et al. 1996.
  - It has also been proposed that music is a module.
    - Peretz & Coltheart 2003.
    - Evidence from double dissociations between language and music impairments.
  - Are musical and linguistic syntax neurally independent, or is there significant overlap?
    - SSIRH (Shared Syntactic Integration Resource Hypothesis)
      - Distinct representations but shared processing.
      - Note: This is different from the SSCLMH (Shared Sound Category Learning Mechanism Hypothesis)

Neuropsychology and dissociation

- G.L. (acquired amusia)
  - Bilateral temporal lobe damage due to strokes.
    - Damage to rostral superior temporal gyri (STG)
  - Could discriminate changes in pitch, was sensitive to changes in melodic contour in short melodies, and showed some sensitivity to intervals.
  - But he was completely insensitive to tonality.
    - How well does a tone fit a preceding tonal context?
      - G.L showed no effect of tonality.
      - Instead seemed to base his distinction on physical difference between the last two tones.
      - Also he failed to show a preference for tonal vs. atonal melodies in a short term memory task.
  - However, he showed normal performance on an aphasia (linguistic) test.

Neuropsychology and dissociation

- There are also many cases of congenital amusia (tone deafness) where subjects show no sensitivity to sour notes, but have normal language abilities.
- Aphasia without amusia
  - Russian composer Shebalin (1902-1963)
    - Two strokes affecting the temporal and parietal regions of the left hemisphere.
    - Severe difficulties producing and understanding language but produced 9 very competent musical compositions after the strokes.
  - Tzortis et al 2000 list 6 such cases of aphasia without amusia.
    - But all are professional musicians.
    - The brains of musicians are different from nonmusicians.
      Increased grey matter in frontal cortex and increased corpus callosum size.
    - There have been no convincing cases of aphasia without amusia of non-musicians.

Neuroimaging and overlap

- Patel, Gibson et al. 1998.
- Investigated whether chord incongruity in the context of a key would elicit the P600 ERP associated with syntactic incongruities in language.
  - Osterhout & Holcomb 1992, 1993; Hagoort et al. 1993.
    - Positive-going wave peaked 600 msec after 'was' in:
      - *The broker hoped to sell the stock was sent to jail.*
  - This is distinct from the N400 following semantically incongruous words
    - Kutas & Hilyard 1984
    - *I take my coffee with cream and dog.*
  - But both ERPs can be produced in well-formed sentences, due simply to relative unexpectedness.
    - N400: *The girl put the sweet in her mouth/pocket after the lesson*.
    - P600: *The broker hoped to sell the stock (was sent to jail)*.

Neuroimaging and overlap

- Patel, Gibson et al. 1998 constructed sentences in which a target phrase was easy, difficult or impossible to integrate with the syntactic context
  - Some of the senators had promised *an old idea of justice.*
  - Some of the senators endorsed promised *an old idea of justice*.
  - Some of the senators endorsed the *promoted an old idea of justice*.

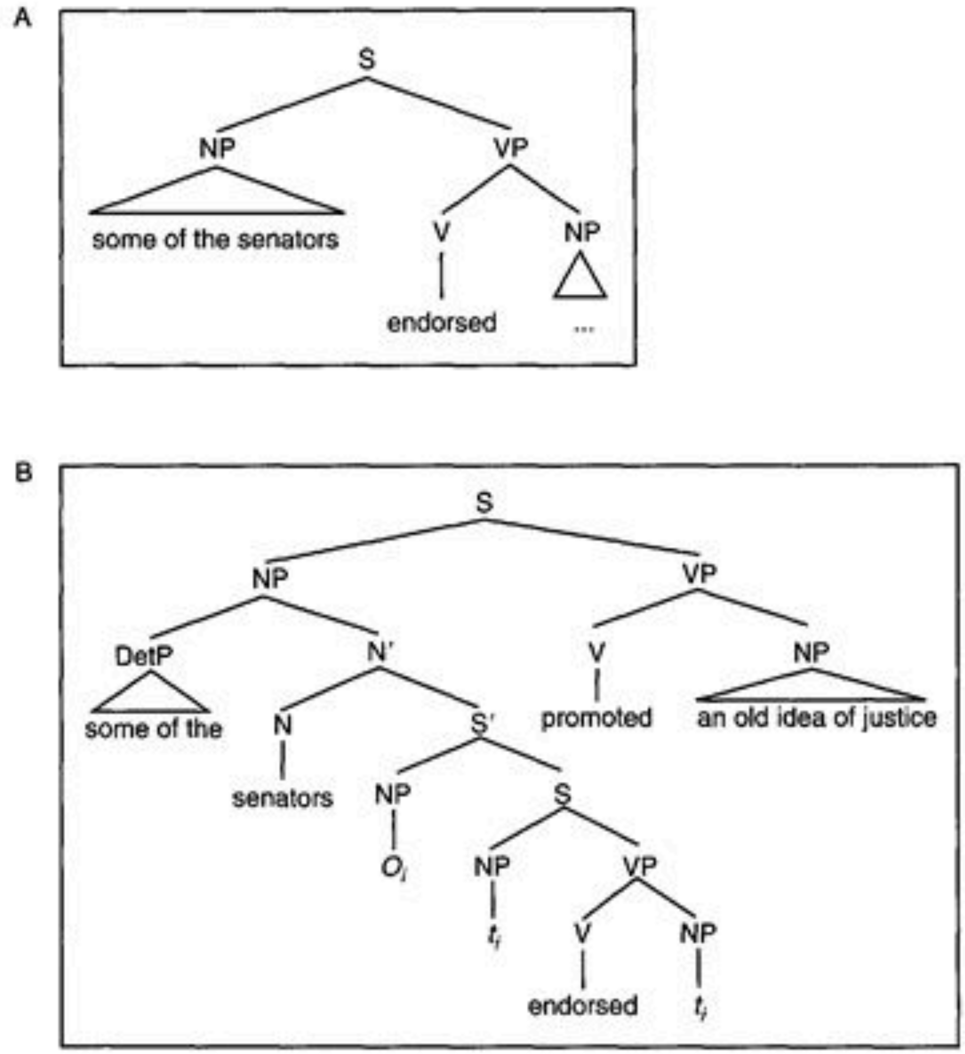

Figure 5.11 Syntactic structures for the simple and complex sentences in the study of Patel, Gibson et al. (1998). Most symbols are explained in the caption of Figure 5.8; N' = noun phrase projection, O = operator, *t* = trace. The sentence in (B) is substantially more complex than the sentence in (A) because the verb "endorsed" functions as a reduced relative clause (i.e., "some of the senators who were endorsed . . .").

Neuroimaging and overlap

- They also constructed musical phrases, where an internal chord was either:
  - the tonic chord.
  - the tonic of a close key (3 counterclockwise steps on the circle of fifths).
  - the tonic chord of a distant key (5 steps).
  - The out-of-key chords (E ♭ -G-B ♭ , D ♭ – F,-A ♭) had the same number of out-of-key notes relative to C major.
  - The target chord always appeared after a dominant chord (V or V7).
  - The chord sequences were composed in a popular rather than classical style, like jingles.

Recordings.

Figure 5.12 Example chord sequences from Patel, Gibson et al.'s (1998) study. The position of the target chord is indicated by the arrow. (A) The target chord is the tonic of the key of the phrase (a C major chord in this case, as the phrase is in the key of C). (B) The target chord is the tonic of a nearby key (E-flat major). (C) The target chord is the tonic of a distant key (D-flat major). Nearby and distant keys are defined as three versus five counterclockwise steps away from key of the phrase on the circle of fifths for keys (cf. Figure 5.6). Note that each stimulus has the same chord progression but differs slightly in terms of the inversion of chords before and after the target (though the two chords before and one chord after the target are held constant).

Neuroimaging and overlap

- 15 musically-trained listeners heard the stimuli, while their brain responses were recorded using EEG.
  - They judged whether it sounded normal or structurally odd.
  - ERPs to the target phrases in language were compared to ERPs in music.
- Incongruities in both domains elicited P600s.
  - These ERPs were statistically indistinguishable in terms of amplitude and scalp distribution at both the moderate and strong level of incongruity.
  - The P600 may thus reflect domain-general structural integration processing in both domains.

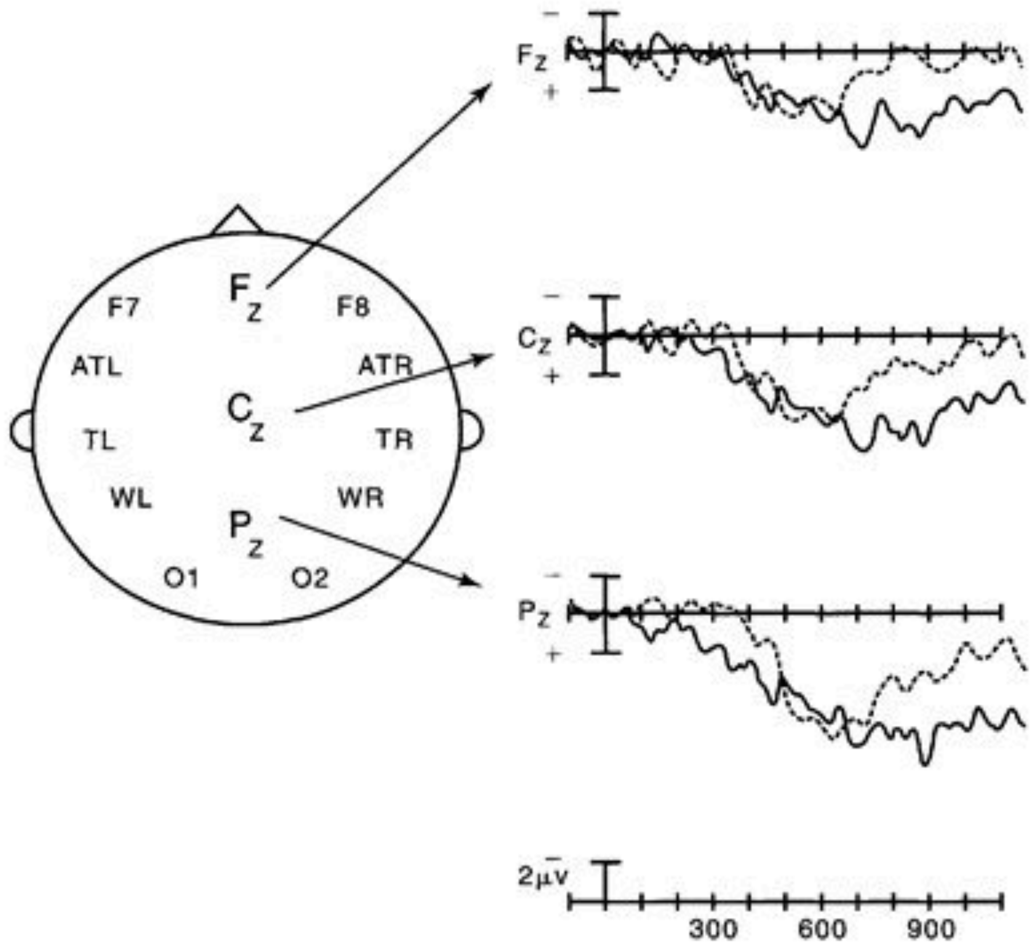

Figure 5.13 Traces show ERPs to linguistic (solid line) and musical (dashed line) syntactic incongruities from three electrodes along the middle of the head (Fz = front; Cz = vertex; Pz = back). (The schematic on the left side of the figure shows the electrode positions as if looking down on the head from above.) The ERP responses are highly similar in the vicinity of 600 ms. The continued positivity of the linguistic P600 beyond 600 ms is due to the continuing ungrammaticality of the sentence beyond this point. See Patel, Gibson et al., 1998, for details.

Neuroimaging and overlap

- Both the linguistic and musical P600s were maximal over the temporal and posterior regions of the brain.
  - But ERP has poor spatial resolution compared to excellent temporal resolution.
  - Still the generators of the P600s are unlikely to be lateralized, as the ERP is symmetrical across the left and right halves of the brain.
- Subsequent work has shown that musical syntactic processing activates “language” areas of the brain.
  - Maess et 2001: MEG data shows an early right anterior negativity (ERAN) for harmonic processing of music in Broca’s area and its right hemisphere homologue.
  - Using fMRI, Tillmann et al. 2003 and Koelsch et al. 2002 showed Broca’s and Wernicke’s areas at work in musical harmonic processing.
- How then can we reconcile the neuroimaging studies that show overlap with the neuropsychology studies that show dissociation?

Using Cognitive Theory to Resolve the Paradox

- Patel's proposal:
  - Long-term structural knowledge of linguistic and musical syntax is different:
    - Associative networks that store knowledge of words and chords.
  - But operations conducted on that knowledge for the purpose of forming a percept could be related.
- Dual system approaches to linguistic systems:
  - Caplan & Watters 1979
    - Frontal areas of the brain support a special working memory system for linguistic syntactic operations.
  - Ullman 2001
    - Frontal systems contain a symbol-manipulation system for linguistic syntax.
- What is proposed here is a dual system approach.
  - But what is shared is derived from comparison of cognitive theories of syntactic processing in the two domains.

Syntactic processing in language I: Dependency-Locality Theory

- Gibson 1998, 2000.
- Linguistic sentence comprehension involves two components:
  - Structural storage
    - Keeping track of predicted syntactic categories as a sentence is perceived in time:
    - E.g. a verb is expected after a noun is encountered.
  - Structural integration
    - Connecting each incoming word to a prior word on which it depends.
    - The cost of integration increases with the distance between the new element and the site of integration.
    - Distance is measured by the number of new "discourse referents" (nouns and verbs) since the site of integration.

Syntactic processing in language I: Dependency-Locality Theory

1. *The reporter who sent the photographer to the editor hoped for a story.*
2. *The reporter who the photographer sent to the editor hoped for a story.*

- "sent" is easier to integrate in (1).
- The theory can provide numerical predictions of the processing (storage + integration) costs at each word.
  - Reading time experiments have confirmed the predictions (Warner & Gibson 2002, Grodner & Gibson 2005).
- Take-home-point: mentally connecting distant elements requires more resources.

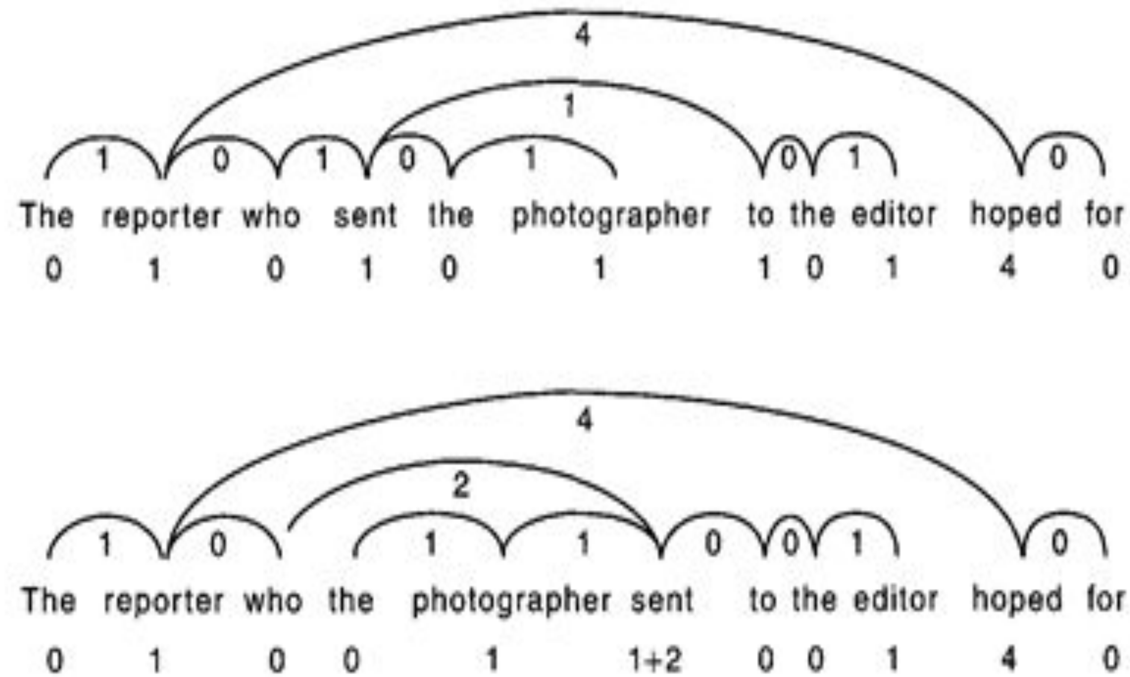

Figure 5.14 Example of distance computation in DLT. Links between dependent words are shown by curved lines, and the distances associated with each link are shown by the integers below the curved line. The number below each word shows the total distance of that word from its prior dependent words. The total distance is used as a measure of the integration cost for that word. Combining integration costs with storage costs (not shown) yields a total processing cost for each word, which can be compared to empirical data from reading time experiments.

Syntactic processing in language II: Expectancy Theory

- A different theoretical perspective suggests that syntactic integration difficulty reflects how well a word fits a perceiver's syntactic expectations at that point.
  - Narayanan & Jurafsky, 1998, 2002, inter alia.
  - When an unexpected word is encountered , resources must be reallocated to change the preferred structural interpretation.
- This approach can account for effects not predicted by DLT.

Syntactic processing in language II: Expectancy Theory

- Jaeger et al. 2005
  1. The player [that the coach met at 8 o'clock] bought the house…
  2. The player [that the coach met by the river at 8 o'clock] bought the house…
  3. The player [that the coach met near the gym by the river at 8 o'clock] bought the house….
- Reading times on "bought" became *shorter* as the length of the relative clause increased.
  - Because a verb is increasingly expected.
- DLT and expectancy theory are successful in different circumstances.
- Both posit that difficult syntactic integrations consume processing resources used in building structural representation of sentences.

Syntactic processing in music: Tonal Pitch Space Theory

- Lerdahl 2001.
- Tonal Pitch Space Theory (TPS) builds on findings about perceived relations between scale tones, chords and keys.
- The main formalism used to relate these relations is a "basic space" organized as a hierarchy of pitch alphabets.
- The basic space provides a mechanism for computing the psychological distance between any two musical chords in a sequence.
- The algorithm involves measuring how far one has to shift a chord's representation in the basic space to transform it into another chord.
  - Yields a single distance value that can be expressed as an integer.

A

level *a* :	C												(C)
level *b* :	C							G					(C)
level *c* :	C				E			G					(C)
level *d* :	C		D		E	F		G		A		B	(C)
level *e* :	C	D♭	D	E♭	E	F	F♯	G	E♭	A	B♭	B	(C)

B

level *a* :	0												(12 = 0)
level *b* :	0							7					(12 = 0)
level *c* :	0				4			7					(12 = 0)
level *d* :	0		2		4	5		7		9		11	(12 = 0)
level *e* :	0	1	2	3	4	5	6	7	8	9	10	11	(12 = 0)

Figure 5.15 Lerdahl's basic space for representing musical chords in a manner that incorporates multiple levels of pitch structure. Panel (A) shows the representation of a C major triad in the context of the C major key, and panel (B) shows the same in a numerical format. The basic space provides a mechanism for measuring distances between chords in a manner that reflects the tripartite psychological distances of pitch classes, chords, and keys. From Lerdahl, 2001.

Syntactic processing in music: Tonal Pitch Space Theory

- TPS also provides a method for deriving prolongation-reduction trees.
- Using the trees, one computes the distance between each chord and the chord it attaches to in the tree.
  - In addition, a chord "inherits" distances from the chords under which it is embedded.
  - This distance plays an important in predicting the ebb and flow of tension in a piece.
- The numerical predictions of TPS can be compared to tension profiles provided by listeners.
  - Such experiments provide support for TPS.
  - Listeners hear relations between chords in a hierarchical manner (Lerdahl & Krumhansl 2007).

Recording

Figure 5.10 A prolongation reduction of a phrase from a composition by J. S. Bach (*Christus, der ist mein Leben*). In this type of tree, right branching indicates an increase in tension and left branching a decrease in tension (i.e., a relaxation). The tree shows how local tensing and relaxing motions are embedded in larger scale ones. Modified from Lerdahl, 2001:32.

Convergence between syntactic processing in language and music

- Both language theories posit that difficult integration arises from activating low-activation items.
  - In DLT, the activation of long-distance words has decayed.
  - In expectancy theory, revising a syntactic interpretation involves boosting the activation of previously decayed structures.
- A listener of music is continually building a sense of key.
  - Relatively unexpected chords have a low activation level.
  - This results in a processing cost in integrating them.

Convergence between syntactic processing in language and music

- Overlap in the syntactic processing of language and music can be conceived of as overlap in the neural areas and operations that provide the resources for difficult syntactic integrations.
  - The "shared syntactic integration resource hypothesis" (SSIRH)
- The relevant brain networks are "resource networks" that serve to rapidly and selectively bring low-activation items in "representation networks" up to the activation threshold needed for integration.

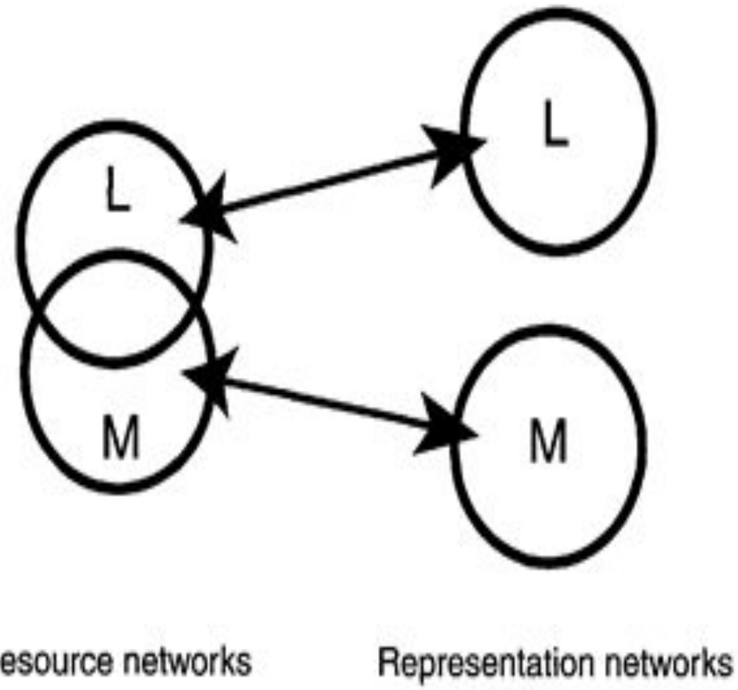

Figure 5.16 Schematic diagram of the functional relationship between linguistic and musical syntactic processing. L = language, M = music. The diagram represents the hypothesis that linguistic and musical syntactic representations are stored in distinct brain networks, whereas there is overlap in the networks which provide neural resources for the activation of stored syntactic representations. Arrows indicate functional connections between networks. Note that the circles do not necessarily imply highly focal brain areas. For example, linguistic and musical representation networks could extend across a number of brain regions, or exist as functionally segregated networks within the same brain regions.

Convergence between syntactic processing in language and music

- The location of the proposed overlapping resource networks does not yet have a firm answer
  - Perhaps in frontal brain regions that provide resources for computations in posterior regions where syntactic representations reside.
  - Within subjects comparative studies of language music using techniques that localize brain activity, such as fMRI, are needed.

Reconciling the paradox

- The SSIRH can reconcile the apparent paradox between neuroimaging and neuropsychology.
  - The P600 involves difficulty in syntactic integration, perhaps involving Broca's area and the anterior temporal lobe (Kaan & Swaab 2002).
  - Musical harmonic processing also involves frontal areas (Koelsch et al. 2002, Tillmann et al. 2003).
- Dissociations between linguistic and musical processing involve domain-specific representations.
  - Aquired amusics have damage in the superior temporal gyri.
  - Congenital amusics have never formed relevant representations.
  - Reported cases of aphasia without amusia are all musicians and are out of date. New studies are needed.

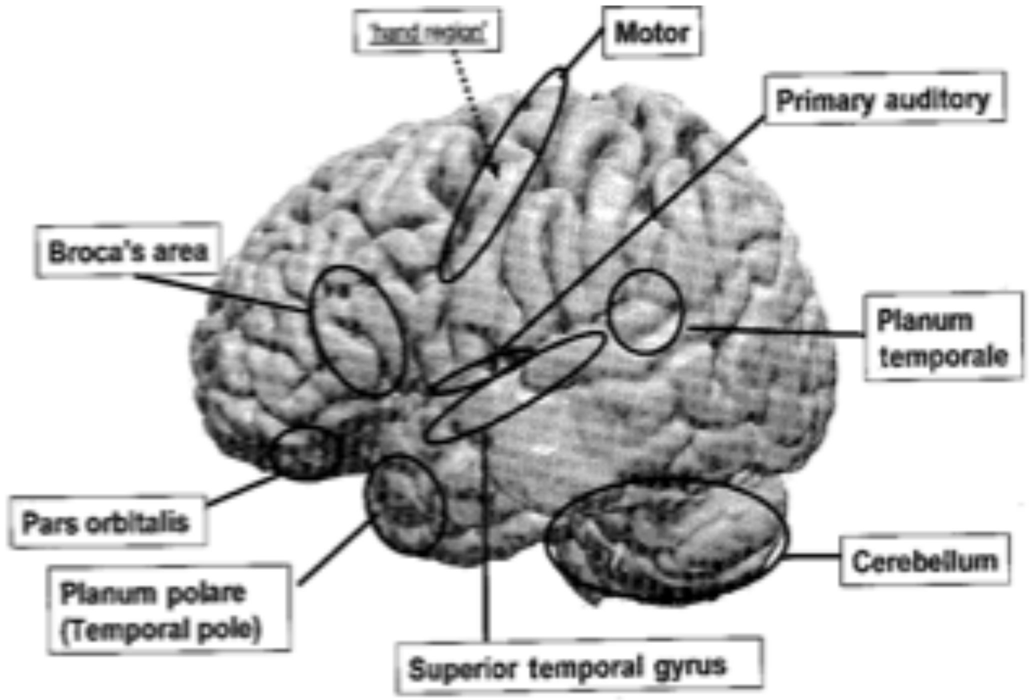

Figure 4.2 Surface regions of the brain associated with music. The left hemisphere of author PQP's brain is shown. Arrows are used to indicate regions on a more localized scale.

Source: Brain image scans produced in collaboration with the Buffalo Neuroimaging Analysis Center (Robert Zivadinov, M.D., Ph.D., Jennifer L. Cox, Ph.D.) www.bnac.net. Used by permission from BNAC.

Hickok & Poeppel 2007

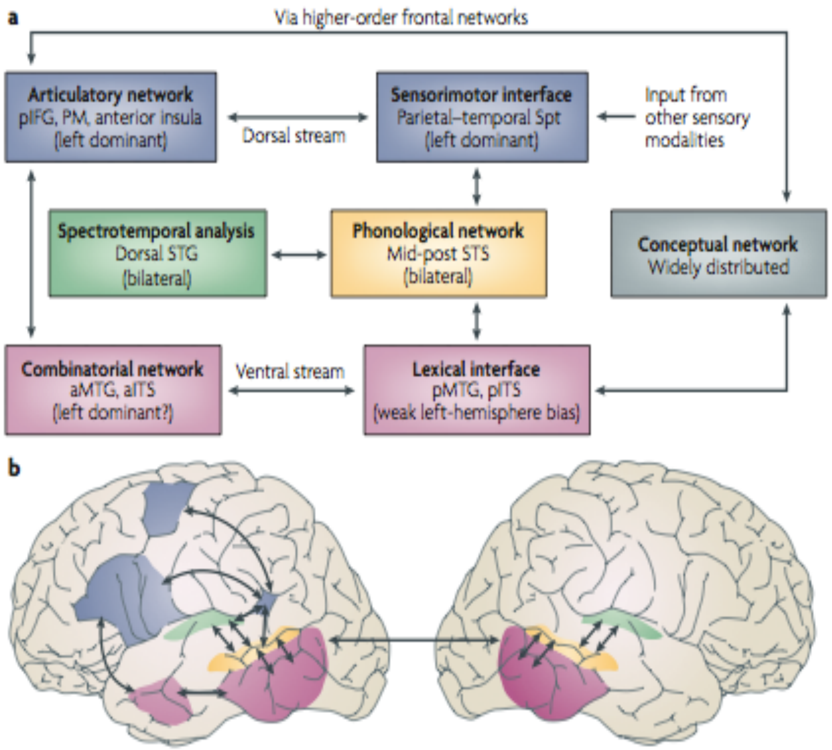

Figure 1 | **The dual-stream model of the functional anatomy of language. a** | Schematic diagram of the dual-stream model. The earliest stage of cortical speech processing involves some form of spectrotemporal analysis, which is carried out in auditory cortices bilaterally in the supratemporal plane. These spectrotemporal computations appear to differ between the two hemispheres. Phonological-level processing and representation involves the middle to posterior portions of the superior temporal sulcus (STS) bilaterally, although there may be a weak left-hemisphere bias at this level of processing. Subsequently, the system diverges into two broad streams, a dorsal pathway (blue) that maps sensory or phonological representations onto articulatory motor representations, and a ventral pathway (pink) that maps sensory or phonological representations onto lexical conceptual representations. **b** | Approximate anatomical locations of the dual-stream model components, specified as precisely as available evidence allows. Regions shaded green depict areas on the dorsal surface of the superior temporal gyrus (STG) that are proposed to be involved in spectrotemporal analysis. Regions shaded yellow in the posterior half of the STS are implicated in phonological-level processes. Regions shaded pink represent the ventral stream, which is bilaterally organized with a weak left-hemisphere bias. The more posterior regions of the ventral stream, posterior middle and inferior portions of the temporal lobes correspond to the lexical interface, which links phonological and semantic information, whereas the more anterior locations correspond to the proposed combinatorial network. Regions shaded blue represent the dorsal stream, which is strongly left dominant. The posterior region of the dorsal stream corresponds to an area in the Sylvian fissure at the parieto-temporal boundary (area Spt), which is proposed to be a sensorimotor interface, whereas the more anterior locations in the frontal lobe, probably involving Broca's region and a more dorsal premotor site, correspond to portions of the articulatory network. aITS, anterior inferior temporal sulcus; aMTG, anterior middle temporal gyrus; pIFG, posterior inferior frontal gyrus; PM, premotor cortex.

Friederici 2012: The cortical language circuit: from auditory perception to sentence comprehension

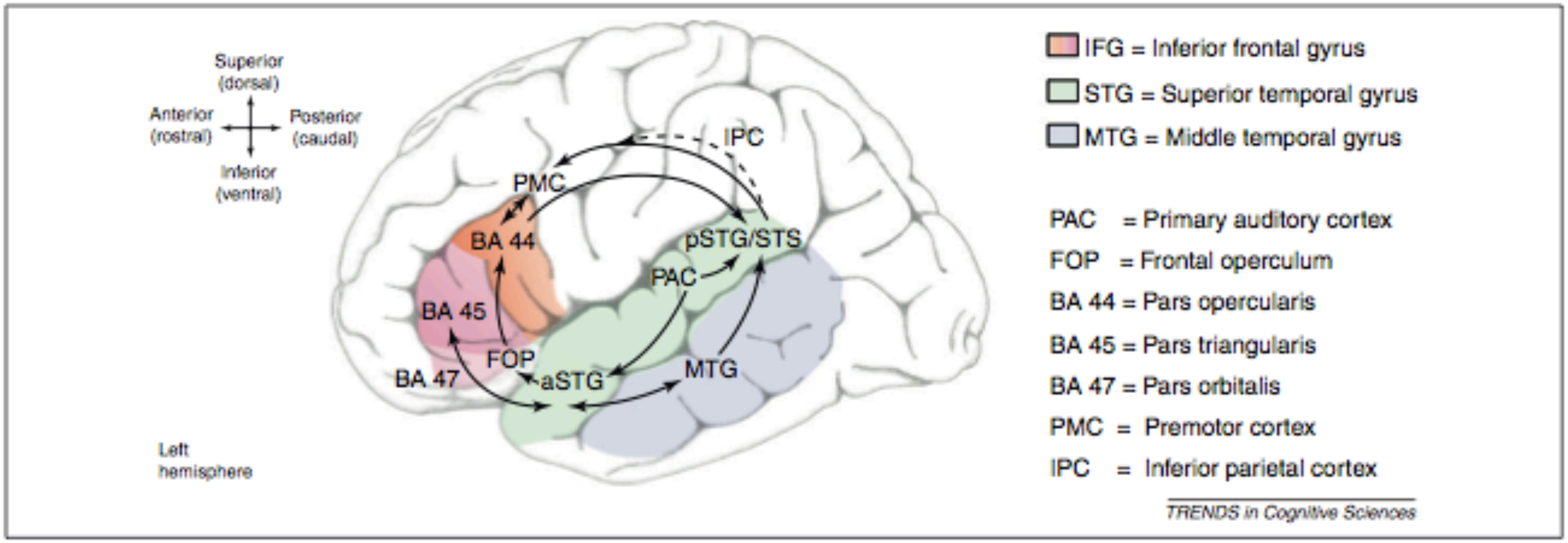

Figure 1. The cortical language circuit (schematic view of the left hemisphere). The major gyri involved in language processing are colorcoded. In the frontal cortex, four language-related regions are labeled: three cytoarchitectonically defined Brodmann [39] areas (BA 47, 45, 44), the premotor cortex (PMC) and the ventrally located frontal operculum (FOP). In the temporal and parietal cortex the following regions are labeled: the primary auditory cortex (PAC), the anterior (a) and posterior (p) portions of the superior temporal gyrus (STG) and sulcus (STS), the middle temporal gyrus (MTG) and the inferior parietal cortex (IPC). The solid black lines schematically indicate the direct pathways between these regions. The broken black line indicates an indirect connection between the pSTG/STS and the PMC mediated by the IPC. The arrows indicate the assumed major direction of the information flow between these regions. During auditory sentence comprehension, information flow starts from PAC and proceeds from there to the anterior STG and via ventral connections to the frontal cortex. Back-projections from BA 45 to anterior STG and MTG via ventral connections are assumed to support top-down processes in the semantic domain, and the dorsal back-projection from BA 44 to posterior STG/STS to subserve top-down processes relevant for the assignment of grammatical relations. The dorsal pathway from PAC via pSTG/STS to the PMC is assumed to support auditory-to-motor mapping. Furthermore, within the temporal cortex, anterior and posterior regions are connected via the inferior and middle longitudinal fasciculi, branches of which may allow information flow from and to the mid-MTG.

Interference between linguistic and musical syntactic processing

- The SSIRH predicts that tasks that combine linguistic and musical syntactic integration will show interference between the two.
- Testing this prediction requires experiments in which music and language are presented together.
- Some older studies have examined the relationship between musical harmonic processing and linguistics *semantic* processing.
- Newer studies examine the interaction of musical and linguistic syntactic processing.

Studies examining the interaction between linguistic semantics and musical syntax

- Besson et al 1998 and Bonnel et al. 2001.
  – Participants listened to sung sentences in which the last word was semantically anomalous and out of key.
  – Semantic violations gave rise to an N400 ERP, and out-of-key notes gave rise to a late positive ERP, explained by a simple additive model.
  – A dual task of judging incongruity of both did not result in a decrease in performance compared to a single task.
- Poulin-Charronnar et al. 2003
  – Employed a harmonic priming paradigm where a chord sequence ends in a I or a IV.
  – Sung sentences ended on a semantically expected or unexpected word.
  – Reaction Time to determining whether the last word was a real word did slow down when the final chord was a IV.
  – But this could have been due to attention being drawn to the IV chord because the sequence sounded incomplete.

Studies examining the interaction between linguistic and musical syntax

- Koelsch et al. 2005
  - Participants read words, where the final word was sometimes ungrammatical (gender error in German):
    - He drinks the$_{masculine}$ cool$_{masculine}$ beer$_{neuter}$.
  - Each word was accompanied by a chord with the final chord being either the tonic or an out-key-chord from a distant key.
  - An interaction was found:
    - Grammatical but out-of-key: a normal ERAN ERP was produced (effect also shows up in left hemisphere).
    - Ungrammatical but in-key: a normal LAN ERP was produced.
    - Ungrammatical and out-of-key: the LAN was smaller, as if underlying processes were competing.

Studies examining the interaction between linguistic and musical syntax

- Federenko et al. 2009
  - Sung sentences containing easy or difficult relative clauses with an in-key or out-of-key note on the last word of the relative clause:
    - *The cop that met the spy wrote a book about the case.*
    - *The cop that the spy met wrote a book about the case.*
  - Comprehension accuracy was lower for sentences with distant syntactic integrations.
  - This difference was larger when melodies contained out-of-key notes.
  - A 10 dB increase in volume on the relevant word did not produce this effect.
  - Some aspect of structural integration seems to be shared between language and music.

Studies examining the interaction between linguistic and musical syntax

- Slevc et al. 2009
  - Self-paced reading time paradigm where participants read sentences phrase by phrase, and each phrase was accompanied by a chord in a coherent Bach-style chord progression.
    - Syntactic manipulation*: The scientist| wearing | thick glasses | confirmed (that) | the hypothesis | was | being | studied | in the lab.*
    - Semantic manipulation*: The boss |warned |the mailman | to watch | for angry |dogs/pigs |when | delivering |the mail.*
  - Chords were in-key or out-of-key on the target word.
  - Syntactically and semantically unexpected words were read more slowly than expected words.
  - A simultaneous out-of-key chord caused substantial increased slow-down for syntactically but not semantically unexpected words.

Musical syntactic deficits in aphasia

- Study 1: Patel, Iversen, Wassenaar & Hagoort 2008.
  - 12 Broca's aphasics (known for production problems), none of whom had been a musician.
  - Used a picture task to confirm that the aphasics had syntactic comprehension deficits.
  - The aphasics with matched controls performed acceptability judgments on musical and linguistic sequences.
    - *The sailors call for the captain and <u>demands</u> a fine bottle of rum.*
    - *Anne scratched her name with her <u>tomato</u> on the wooden door.*
    - Melodic sequences containing an out of key chord

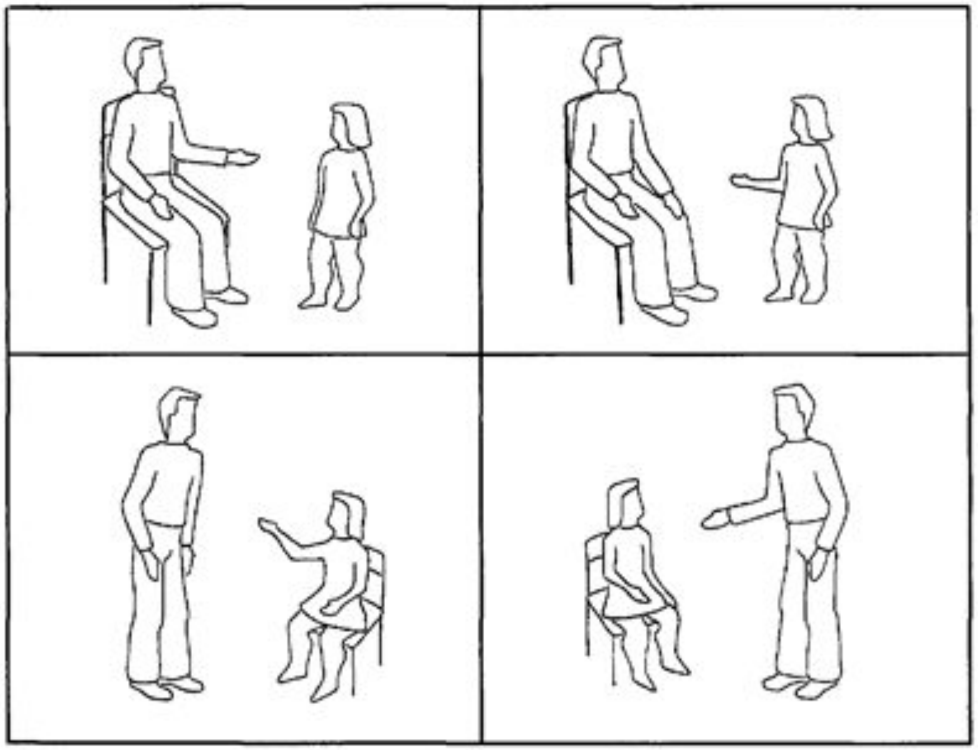

Figure 5.17 Example panel from the sentence-picture matching task for the sentence: "The girl on the chair is greeted by the man."

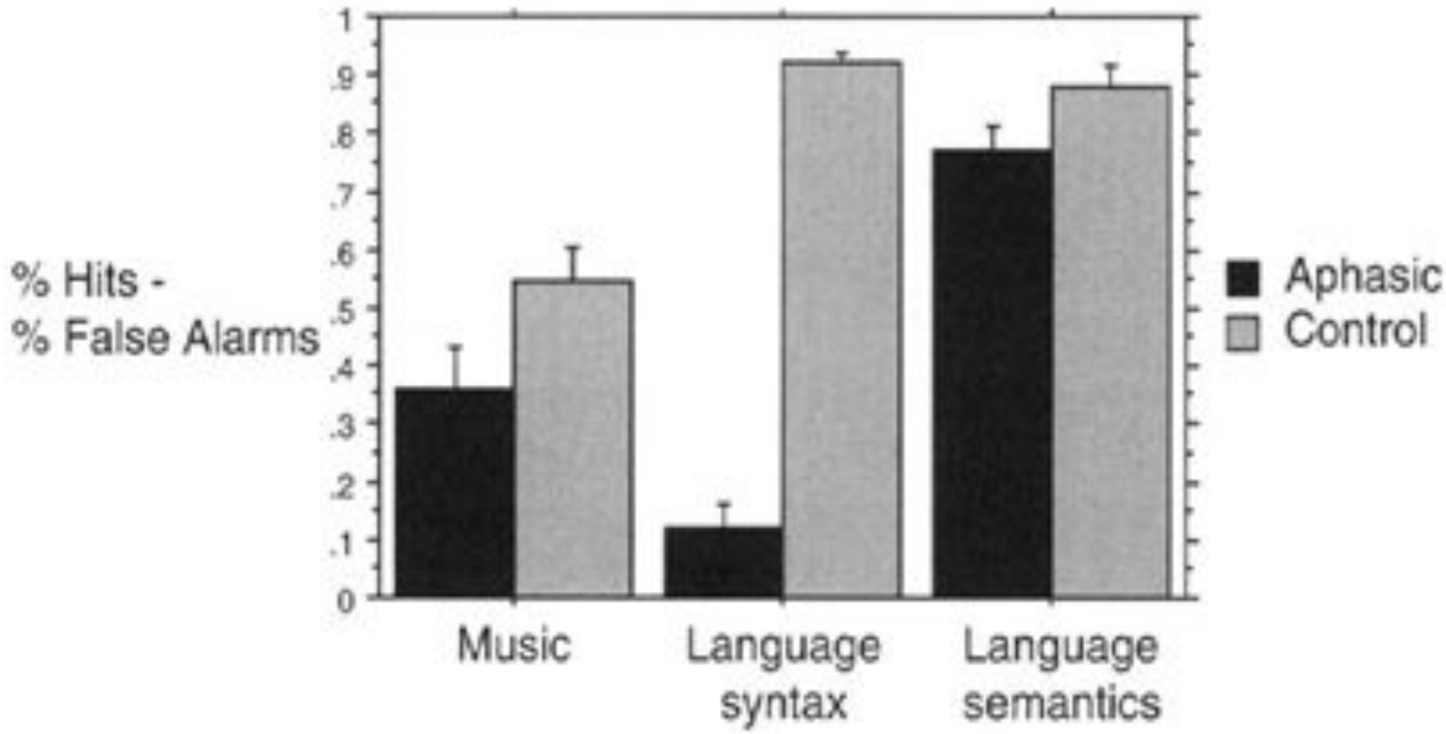

Figure 5.18 Performance of aphasics and controls on musical and linguistic tasks. The vertical axis shows percentage of hits minus percentage of false alarms in detecting harmonic, linguistic syntactic, and linguistic semantic anomalies. Error bars show 1 standard error.

Musical syntactic deficits in aphasia

- The aphasics performed significantly worse on the music task and the syntactic task, but not the semantic task.
- A correlation test was done to test whether the results were consistent across the group of aphasics and no correlation was found.
- But when the controls were included, performance on the music syntax task was a significant predictor of the performance on the linguistic syntax task.
- Not so with the linguistic semantics task.
- This points to some process common to language and music syntax that operates in both the controls and aphasics, although at a degraded level in the aphasics.

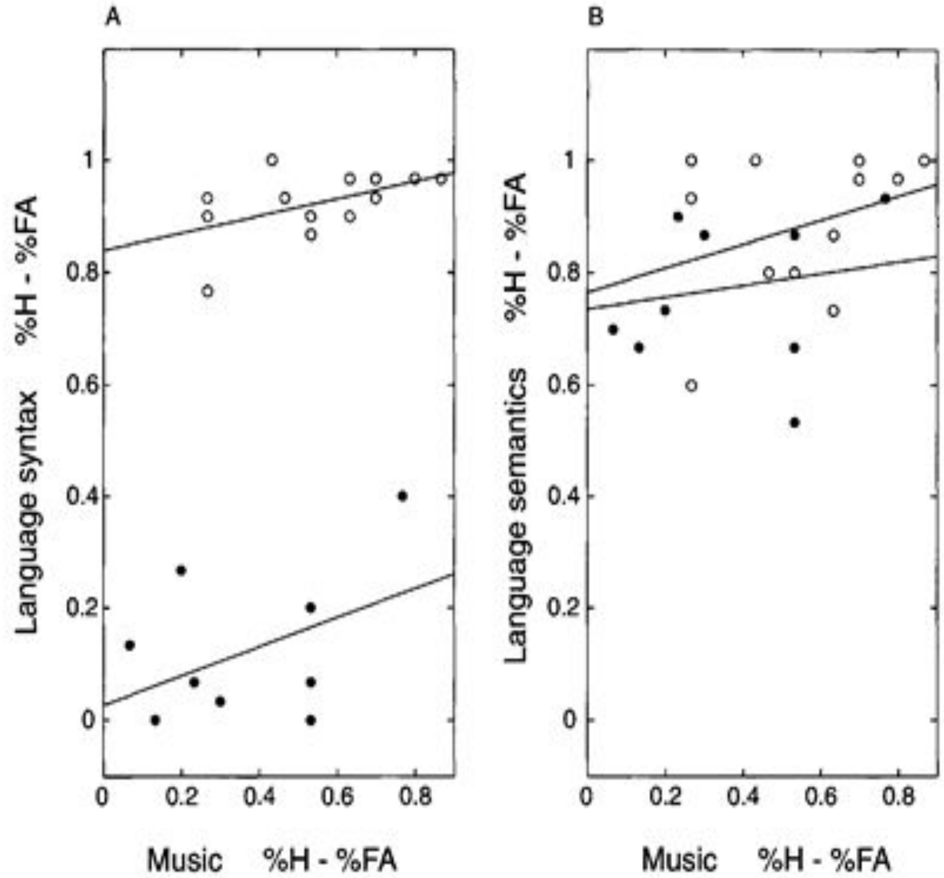

Figure 5.19 Relationship between performance on musical and linguistic tasks for aphasics (black dots) and controls (open circles). Separate best-fitting regression lines are shown for aphasics and controls. (A) shows relations between performance on the music task and the language syntax task, and (B) shows relations between performance on the music task and the language semantics task.

Musical syntactic deficits in aphasia

- Study 2: Patel, Iversen, Wassenaar & Hagoort 2008.
  - 9 additional Broca's aphasics with a syntactic comprehension deficit.
  - Harmonic priming task:
    - A target chord is normally processed more rapidly and accurately if it is harmonically close to a tonic center established by a prime.
  - Participants heard two chords and judged whether the second chord was tuned or mistuned.
  - Reaction time to well-tuned targets differed.
    - Controls showed a normal priming effect, with faster RTs to harmonically close vs. far well-tuned targets.
    - Aphasics did not show a priming effect, and even responded faster to distant targets, which shared a note with the tonic center, suggesting responses were driven by psychoacoustic similarity rather than by harmonic knowledge.

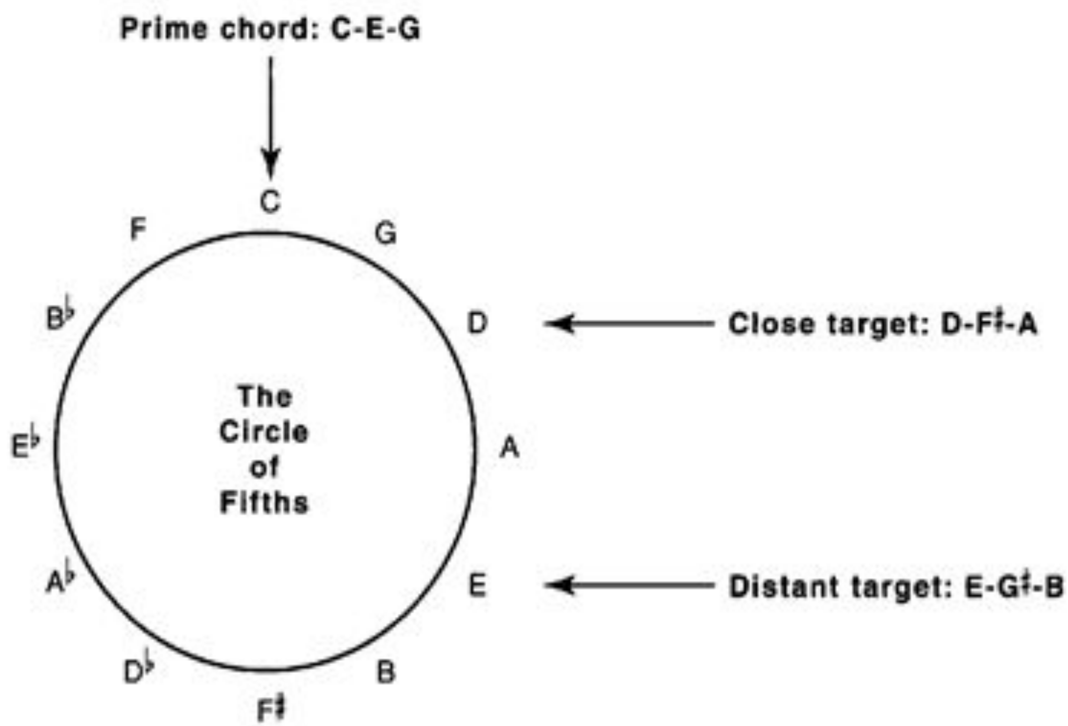

Figure 5.20 Example of prime and target chords for the harmonic priming task. All chords were major chords, being the principal chord of a key from the circle of fifths. In this case, the prime is a C major chord. The close target is a D major chord, and the distant target is an E major chord.

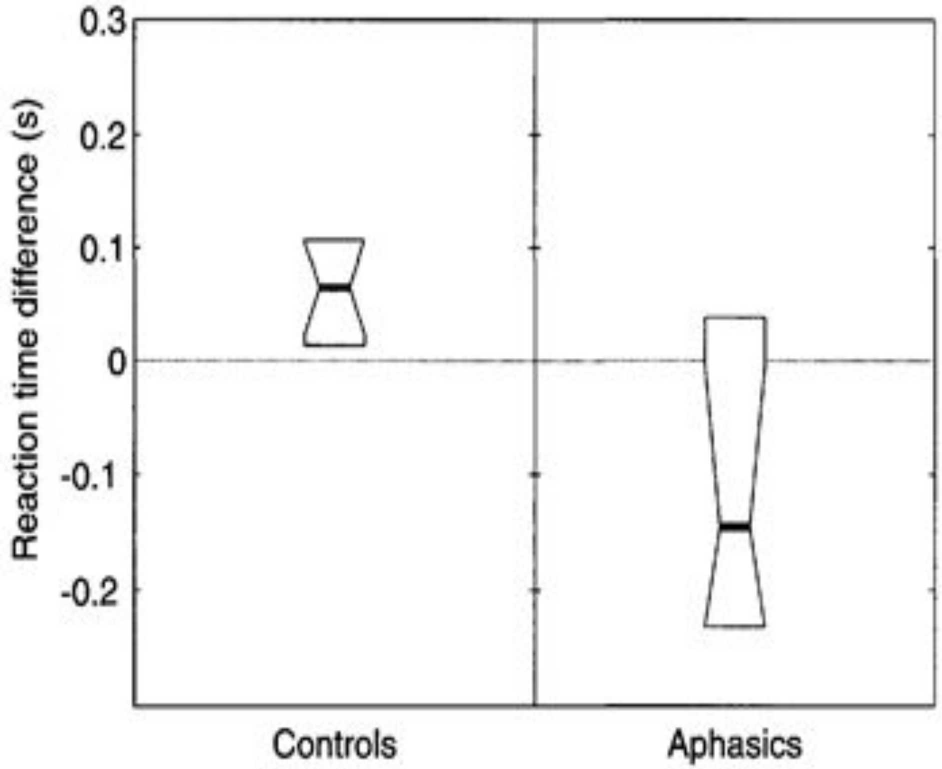

Figure 5.21 Box plots for RT difference to harmonically distant versus close targets. Data are for correct responses to tuned targets. The horizontal line in each box indicates the median value, the slanted box edges indicate confidence intervals, and the upper and lower bounds of the box indicate interquartile ranges. Absolute mean RTs for controls (s.e. in parentheses): close targets .99 (.07) s, distant targets 1.05 (.06) s. Aphasics: close targets 1.68 (.22) s, distant targets 1.63 (.17) s.

Musical syntactic deficits in aphasia

- Conclusion: aphasics do show syntactic musical deficits.
- Results are consistent with the SSIRH.
  - Music and language share neural resources for activating domain-specific representations during syntactic processing.
- The aphasics had left hemisphere deficits.
  - Left-hemisphere language circuits appear to play a role in musical syntactic processing even in non-musicians.
- Future work should employ aphasics with more tightly controlled lesion profiles.
- It is time to reawaken the study of music syntactic processing in aphasics.