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Song, Speech, and Brain

A survey of the literature regarding brain processing of human vocal sounds

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Introductory Remarks

The current project is an attempt to encapsulate the state of accumulated knowledge regarding brain processing of human vocal sounds, and to determine how such brain processing differs in the contexts of speech and song. The overarching motivation for this project is a desire to ascertain the aspects of perceptual and cognitive research which could directly impact the greater questions: What is music? How does music fit into the scheme of human behavioral interactions? How does the activity of music differ from its near cousin language? Both music and language exist primarily in the manipulation and organization of directed sounds, with an intent to express or communicate ideas or emotions. Yet much greater dedication of resources has historically gone to the study of language. Evolutionary theorists seem strongly biased towards a recognition that the phylogenesis of language in *homo* has been the major factor in the establishment of culture in our species. However, a similar recognition has not been forthcoming for music. The well-known linguist and cognitive scientist Steven Pinker has referred to music as "auditory cheesecake," implying its significance is on a par with artifacts of gluttony and extravagance, not monuments of human achievement. In his 1997 book, "How the Mind Works," he wrote:

> *As far as biological cause and effect are concerned, music is useless. It shows no signs of design for attaining a goal such as long life, grandchildren, or accurate perception and prediction of the world. Compared with language, vision, social reasoning, and physical know-how, music could vanish from our species and the rest of our lifestyle would be virtually unchanged. Music appears to be a pure pleasure technology, a cocktail of recreational drugs that we ingest through the ear to stimulate a mass of pleasure circuits at once.* [1]

If this were a reasonable tack, it might seem odd then to realize that modern humans, across cultures, all engage in music. Mothers the world over sing to their children as early as they speak to them. Just as every society has language, so too all cultures have music. Could it be that such a widespread and highly developed behavior as music is irrelevant to general theories on the evolution of our species? Some researchers are even now engaged in a review of the archeological record in an attempt to find evidence of prehistoric musical behaviors. How might the phylogenesis of music in our species relate to its ontogenesis in children and adults, and in what ways does it compare to the development of language? As Brown, Merker, and Wallin (2000) put it:

> *The language-centered view of humanity has to be expanded to include music, first, because the evolution of language is highly intertwined with the evolution of music, and, second, because music provides a specific and direct means of exploring the evolution of human social structure, group function, and cultural behavior. Music making is the quintessential human cultural activity, and music is an ubiquitous element in all cultures large and small.* [2]

By examining the literature of brain processing of human vocal sounds, we can begin to formulate and reformulate theories about how our minds attend and engage the specific auditory environment which is universal to all peoples[3]—perhaps even to our evolutionary ancestors as well. Are music and language truly separable? And if so, in what ways, and which not? In singing, we see an unmistakable common ground, or so it seems. Undeniably, song is a blending together of linguistic and musical elements into a unified whole. Yet the history of neurological disorders reports numerous cases of dissociation of language and music. Patients have been reported to lose the ability to speak, yet retain the capacity to sing, sometimes including the words to familiar songs. There is a successful speech therapy program for aphasics called

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[1] *Steven Pinker,* How the Mind Works *(New York: W. W. Norton & Company, 1997), 528.*

[2] *Steven Brown, Björn Merker, and Nils L. Wallin , "An Introduction to Evolutionary Musicology," in The Origins of Music, ed. Wallin, Merker, and Brown (Cambridge, Mass: MIT Press, 2000), 3.*

Melodic Intonation Therapy, which is specifically based on the premise that individuals who have lost the ability to speak can exploit *different neurological pathways for singing*, in order to regain speech. In what ways is singing a linguistic activity and which ways is speaking a musical one? How can we distinguish these one from another? It is in an attempt to better understand the cognitive and perceptual divergences and convergences between these two domains of human vocal and auditory behavior that this paper is concerned.

The magnitude, relevance and scope of this research is far-reaching. My hope herein will be to focus only on the aspects of the literature which directly impact the narrower issue of brain processing of human vocal sounds; it should be considered a work-in-progress, rather than a definitive distillation of the field. What follows then is an annotated bibliography of much of the existing research on the subject.

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[3] *Clearly there are exceptions to this, most obviously inasmuch as there is congenital deafness throughout the world. However, the arguments in this paper will assume neurologically intact and normally functioning, hearing humans, unless otherwise stated.*

Annotated Chronology of the Literature

Articles & Book Chapters

1. MONRAD-KROHN, G. H. "Dysprosody or Altered 'Melody of Language'." *Brain* 70 (1947): 405-15.

The author, a neurologist, based in Oslo, reviews the case of a 30-year old Norwegian woman who suffered damage to the left frontal region of her brain, as a result of wartime bombing. The resultant syndrome was marked by a disturbance in the natural flow of melody, rhythm and accent in her speech. It appeared that she had acquired a foreign accent in her native language. Interestingly, the patient's musical abilities were unperturbed.

> *In respect of her musical faculties nothing abnormal could be found. Her sense of rhythm, as tested by drumming on the table, seemed to be excellent. When the examiner hummed the beginning of any well-known tune, she joined in at once and continued by herself correctly as to time and tune. She was never heard to sing a false note or out of tune. ...At request she could sing a fair number of songs quite correctly with a musical voice and correct rhythm. Her sense of melody as evidenced by humming thus did not seem to be impaired in the slightest degree.*
>
> *Nevertheless the melody of her spoken language was profoundly altered. (411)*

Thus, this is one of the earliest indications of a dissociation between musical ability and prosodic aspects of speech. The implication is that prosodic features of speech require an intact left frontal lobe; yet the same brain areas are not essential for singing.

2. NETTL, Bruno. "Some Linguistic Approaches to Musical Analysis." Journal of the International Folk Music Council 10 (1958): 37-41.

This article focuses on possible approaches to classifying music in terms of segmental elements, along the lines of linguistic analysis of the day.

> *Music consists of various elements, such as pitch, rhythm and harmony, each of which is, in analysis, divided into small units or segments such as tones, note-values, intervals, or chords. To put these elements into a form analogous to phoneme segments, corresponding to consonants and vowels, creates a problem of interpretation which may be solved in at least two ways. (1) A separate set of phonemes could be set up for each element. We would have pitch phonemes (tones), rhythmic phonemes (note values),*

> *harmony phonemes (chords), etc. Longer segments in music, structure phonemes, could be included. (2) The other alternative is to consider a piece of music analogous to a speech utterance, and each element of music could be analogous to a different level of phoneme in the same system. For example pitch phonemes could be considered analogous to vowels and consonants. (38-39)*

Since rejected by the author as naïve[4], this is one of the earliest attempts to find common ground between the modern fields of music and linguistics. While I would agree that the specific points of his method are flawed, it is not a fruitless enterprise to ascertain in what ways music and language correlate, and in what ways they differ.

Although this article does not address issues of cognitive processing, such preliminary comparisons between musical and linguistic elements are essential to develop well-formed questions for further research. As Monrad-Krohn (1947) discovered, even when features of singing and speaking appear to correspond, there may be fundamental differences in the underlying brain processes which control them.

3. MILNER, Brenda. "Laterality Effects in Audition." In *Interhemispheric Relations and Cerebral Dominance*, ed. V. B. Mountcastle, 177-195. Baltimore: Johns Hopkins Press, 1962.

Presents findings regarding unilateral (left and right) temporal lobectomies performed on patients to relieve severe focal epilepsies. Begins with a review of the existing literature dealing with asymmetries of auditory functioning between the left and right temporal lobes. Uses the Seashore Measures of Musical Talents to test nonverbal auditory functioning. The Seashore Measures consist of six subtests, which ostensibly test pitch, loudness, rhythm, time (duration), timbre, and tonal memory aptitudes. Each subtest provides a different task of discrimination between stimuli. Although these tests may have clear findings in terms of the abilities which they address, it is somewhat of a stretch to consider them as accurately measuring "musical talents."

Also uses the Broadbent Test, which presents verbal stimuli dichotically. Concludes that the right temporal lobe plays a major role in the processing of nonverbal auditory stimuli. Whereas, the left temporal lobe is dominant for verbal processing. This is an early study, which attempted to separate out verbal from nonverbal audition. Subsequent refinement of methods could be expected to yield more conclusive results.

4. BRIGHT, William. "Language and Music: Areas for Cooperation." *Ethnomusicology* 7/11 (1963): 26-32.

Briefly addresses issues of form and meaning as they relate and differ for music and language. Putting aside the complex issues of meaning, he suggests that the classification of formal analogues for linguistic elements (i.e. phonemes) can be found within music, by seeking out what he terms endosemantic structures. That is, within certain musical contexts one might consider triplet quarter-eighth rhythms allophones of a dotted quarter-eighth rhythm.

5. LIST, George. "The Boundaries of Speech and Song." *Ethnomusicology* 7/1 (1963): 1-17.

A preliminary attempt to categorize the variety of human vocal sounds along a continuum from speech-to-song, using melodic features as the sole criterion. Outlines one possible method for classifying a great range of vocal behaviors from many cultures. Points out the question of stable versus unstable pitch distinctions, though doesn't address it. Alludes to other methods of classification, for example by reference to the function of the activity rather than its melodic features. Also notes the difficulty of his method for classifying forms found in tonal language families. Neglects rhythmic features entirely, though current research indicates that these may be of primary importance in human mental categorization of vocal phenomena.[5]

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[4] *Bruno Nettl, personal email, 23 August 1999.*

[5] *Sandra Trehub, private comments.*

6. MONRAD-KROHN, G. H. "The Third Element of Speech: Prosody and Its Disorders." In *Problems of Dynamic Neurology*, ed. L. Halpern, 101-18. Jerusalem: Hebrew University, 1963.

Description of the functional types of prosody, according to the author's own classification system of: intrinsic prosody; propositional prosody; emotional prosody; and prosodic grunts. Brief treatment of comparison with animal vocal behaviors. Finally, a brief description of the three major forms of prosodic disturbance, classified as: Hyper-prosody; Hypo-prosody or a-prosody; and Dys-prosody. Presents the symptoms, but mostly avoids specific explanations or theories of possible causes for the underlying disorder.

> *As regards* the anatomical substratum subservient to the prosodic faculty*, we may safely claim that the extra-pyramidal structures affected in paralysis agitans form an integrating part of the anatomical substratum necessary for the production of the prosodic quality in speech. But let me emphasize a statement by* Hughlings Jackson *(1874) regarding speech in general, which applies equally well to the prosody in particular: "To locate the damage which destroys speech and to locate speech are two different things." The fact that the prosodic faculty is diminished by lesions of the extra-pyramidal structures involved in paralysis agitans does by no means prove more than that these structures are necessary for the expression of prosodic qualities*. (116)

7. KIMURA, Doreen. "Functional Asymmetry of the Brain in Dichotic Listening." *Cortex* 3 (1967): 163-178.

Explains the methodology and findings of dichotic listening experiments on adults and children. Establishes that left-hemisphere dominance for language appears as early as four years old (the youngest subjects tested), on the basis of dichotic listening techniques. Points the way toward future studies:

> *By varying the stimulus dimensions, we may be able to define more explicitly just what characteristics differentiate stimuli depending more for their perception on the left hemisphere, from those depending more on the right hemisphere. That is, we can ask which stimulus characteristics are associated with a right- or a left-ear superiority.* (173)

However, in discussing different types of stimuli, and their definition as verbal or nonverbal, she writes:

> *To say that they are verbal stimuli and that verbal processes are vested in the left hemisphere is only an apparent explanation, since it is not at all clear what verbal activity consists in. (176)*

And, further, she notes:

> *Investigators… have suggested that much of speech is perceived by reference to articulation experience. Conceivably, then, the features of speech sounds which distinguish them from non-speech sounds are related to articulability rather than to conceptual content.* (177)

In this light, it would be interesting to study how subjects would perceive different sorts of stimuli ranging from normal speech through various types and styles of singing. One might expect to find different results for trained singers and non-singers, in terms of their experience producing such varied sounds. One might expect to find different breaks in perception from the general population, due to broader corresponding articulatory experience.

8. FAGLIONI, P., H. Spinnler, and L. A. Vignolo. "Contrasting Behavior of Right and Left Hemisphere-Damaged Patients on a Discriminative and a Semantic Task of Auditory Recognition." *Cortex* 5/4 (1969): 366-89.

Reports on experiments designed to test for differences in performance between left-brain-damaged, right-brain-damaged, and control subjects on a group of five tests. The main tests of interest to the current program are the "meaningless sounds discrimination test," and the "meaningful sounds identification test." The *meaningless sounds* test consisted of blended sounds derived from 2 separate radio sound-effect tracks. The *meaningful sounds* consisted of sounds normally identified with a specific source, i.e. meowing: a cat; bleating: a goat. On the former, subjects were presented with two stimuli, and asked whether they were the same or different. On the latter, subjects were asked to name (or point to a picture, in the case where voluntary speech was impaired) the logical source of each sound. Neither of these tests used human vocal sounds. However, it was found that discriminations within each of these two groups was subtended by a different hemisphere.

> *It was assumed that performance on the Meaningless Sounds Discrimination Test reflected the ability to discriminate differences among acoustic patterns, while performance on the Meaningful Sounds Identification Test reflected the ability to identify the exact meaning of naturally-occurring sounds.* (371)

> *It is apparent that failure on each test was specifically associated with damage to a different hemisphere. On the Meaningless Sounds test, the left hemisphere-damaged group did as well as the controls, while the performance of the right group was significantly inferior to that of the other two groups. The reverse occurred with the Meaningful Sounds Test, on which the right brain-damaged group obtained the same mean score as the controls, while the left brain-damaged patients performed significantly worse that the other two groups.* (374)

Significantly, it was found that aphasic patients, although language-impaired performed equal with the controls in terms of the *meaningless sounds* test. This showed that their deficits were not due to damage to any central auditory processor, but rather specific to the aligning of sounds with meaning. Likewise, the fact that the right-hemisphere patients performed normally on the sound source identification task, but had difficulty comparing novel and unfamiliar sounds, suggests that there are redundant mechanisms at work under different auditory situations.

9. STUDDERT-KENNEDY, Michael and Donald Shankweiler. "Hemispheric Specialization for Speech Perception." *Journal of the Acoustical Society of America* 48/2-2 (1970): 579-94.

Follows along the lines of Philip Lieberman, considering the evolution of the human vocal tract and concomitant perceptual structures as the primary focus for research. This is in contrast to an approach that would focus on higher-level cognitive mechanisms. Argues that more fruitful investigations will proceed from studying such lower-level language functions (production and perception). Their stimuli consisted of nonsense (consonant-vowel-consonant) syllables, wherein the consonants of each pair remained constant, and different vowels were presented to each ear. Subjects were asked to identify both vowels. Findings show a weak (non-significant) overall preference for the right ear, with about a third of the subjects actually showing a left-ear advantage. While ostensibly building on Kimura (1967, above), there is little attempt to identify the acoustic features that properly distinguish linguistic speech from nonlinguistic sound. Although suggesting that research should focus on perception, the experimenters choose a linguistic description (i.e. "consonant-vowel-consonant"), not a perceptual or acoustic one to describe the stimuli under study. As Kimura intimated however it is not entirely self-evident that such a description is sufficient. Argues that hemispheric dominance for language is "due to possession of a linguistic device, not to specialized capacities for auditory analysis." (579)

10. WOOD, Charles C., William R. Goff, and Ruth S. Day. "Auditory Evoked Potentials during Speech Perception." *Science*, New Series, 173/4003 (Sep 24, 1971): 1248-1251.

Experimental attempt to establish left-hemisphere lateralization for processing of linguistic speech sounds, in contrast to processing of nonlinguistic sounds, by testing for differences in auditory invoked potentials.

> *Despite the large body of behavioral and clinical evidence for specialization of one hemisphere in speech perception, there is no evidence which clearly distinguishes neural activity specifically related to linguistic processing from that which occurs during the processing of any auditory stimulus. Empirical evidence for such a distinction requires a direct comparison of neural activity during linguistic and nonlinguistic processing conditions with other sources of variation in neural activity eliminated between conditions.* (1248)

> *If the analysis of linguistic and nonlinguistic parameters of an acoustic signal consists of the same neural events, then evoked potentials should be the same (within the limits of normal variation) for both tasks during the pre-response interval. ...These results indicate that neural events in the right hemisphere were identical for both tasks during the preresponse interval, regardless of the task requirements. In contrast, different neural events occurred in the left hemisphere during the same time interval, depending upon whether the task required analysis of linguistic or nonlinguistic parameters of the acoustic signal.* (1250)

11. BOLLER, François and Eugene Green. "Comprehension in Severe Aphasics." *Cortex* 8/4 (1972): 382-394.

Presents evidence that severe aphasics, while lacking comprehension of the meaning of words, can nonetheless distinguish between types of utterances (commands, requests, statements) by means of prosodic features in the utterance.

12. ALBERT, M.L., R.W. Sparks, and N.A. Helm. "Melodic Intonation Therapy for Aphasia." *Archives for Neurology* 29 (1973): 130-131.

Briefly presents the development of a new form of language therapy—dubbed melodic intonation therapy—for use with aphasic patients. The basis for the therapy was the common observation that even severely speech-impaired aphasics can often sing the melody and lyrics to popular songs. The idea was to attempt to reactivate speech processing, by exploiting the alternate, assumedly right-hemisphere, pathways involved in such singing. Therapy begins with unison singing of sentences by patient and therapist, eventually leading to more normal speech. Three cases, of patients with severe productive deficits who had not previously responded to standard therapies, are reported, with dramatic and rapid results. However, two other cases, with comprehension deficits did not improve by such therapy.

13. CROWDER, Robert G. "Representation of Speech Sounds in Precategorical Acoustic Storage." *Journal of Experimental Psychology* 98/1 (1973): 14-24.

Describes three experiments which tested subjects memory performance under highly constrained conditions, to ascertain causes for differences in performance relative to the order of vowel to consonant, contrasting terminal voiced consonant with initial voiced fricatives, in consonant vowel pairs. Stimuli were synthetically generated syllables. Suggests that differences in performance relates not to order of elements but rather to differences between steady-state and transient acoustic information. The research is along the lines of Studdert-Kennedy & Shankweiler 1970, above, in that it focuses on low-level perceptual functioning. It is not clear from this article how such data is meant to relate to larger questions, though it may be that such lower-level research is essentially foundational for formulating broader theories.

14. HALPERIN, Y, I. Nachshon, and A. Carmon. "Shift of Ear Superiority in Dichotic Listening to Temporally Patterned Nonverbal Stimuli." *Journal of the Acoustical Society of America* 53/1 (1973): 46-50.

Two dichotic listening experiments were conducted to test the hypothesis that sequential complexity will influence the hemispheric dominance for audition. Specifically, it was argued that "since one important feature of verbal material is its sequential character, it may be assumed that nonverbal but sequentially patterned sounds will be mediated by the left hemisphere." (46). The experiments consisted of testing for hemispheric superiority with frequency-varied and duration-varied stimuli. The variance was very simple, entailing only two levels of frequency (high and low), and two durations (long and short) in the respective experiments. Each trial presented subjects with three sounds, either all the same in pitch or duration, varying once in the respective domain, or varying twice. The findings suggest that as complexity increased hemispheric dominance shifted, beginning in the right hemisphere and moving to the left. The major conclusion is as follows:

> *Kimura (1967) implied hemispheric dichotomy in processing verbal and nonverbal stimuli—verbal stimuli being mediated by the right hemisphere. The data of the present study, however, do not support her implication. If under certain conditions, such as temporal patterning, nonverbal stimuli are mediated by the left hemisphere, then a simple verbal-nonverbal categorization of stimuli in terms of hemispheric specialization does not hold.*

15. BARTHOLOMEUS, Bonnie. “Effects of Task Requirements on Ear Superiority for Sung Speech.” Cortex 10/3 (1974): 215-223.

Opens with a review of the pre-existing literature regarding laterality effects in audition during dichotic listening experiments. Notes that none of the previous studies had sufficiently tested whether these effects were entirely due to stimulus variables (i.e. acoustic features) or possibly influenced or determined by task requirements. Bartholomeus presents the view that speech processing involves two stages: auditory and phonetic, citing earlier work by Shankweiler and Pisoni (1972). She proposes two alternate hypotheses: (1) the presence of phonetically-encoded acoustic input is sufficient to cause right-ear (left hemisphere) effects; (2) task requirements will influence these laterality effects, such that only a phonetic discrimination task will cause right-ear superiority. In the current experiment, a dichotic listening paradigm was used. Three task conditions were set, each presented on a different day, but with the same subjects and the same stimuli in all cases. In this way, it was possible to directly test the question of task-influenced changes in laterality. The stimuli consisted of "pairs of melodies sung to different sequences of letters by different singers." (217) The three tasks, performed on different days, required identification of singer, letter, or melody. The results were somewhat equivocal (in part because laterality effects were mostly nonsignificant), but weakly supported the second hypothesis that task influenced, in that "a trend towards right-ear superiority in perception of encoded acoustical information was observed only on the task which clearly demanded accurate phoneme recognition (letter sequence task)". (221) This study succeeds more in pointing up flaws in earlier experimental designs, and suggesting areas for future research, than in establishing a superior methodological paradigm.

16. BLUMSTEIN, Sheila, and William E. Cooper. "Hemispheric Processing of Intonation Contours." *Cortex* 10/2 (1974): 146-158.

Two perceptual experiments were conducted, exploiting dichotic listening techniques, to examine hemispheric lateralization for processing of intonation contours. Stimuli in the first experiment used filtered speech sounds, such that the phonetic information was veiled, but the intonational information remained. In the second, nonsense syllables were used, to ascertain whether recognizable phonetic information would alter the right-hemisphere superiority found in the first. It was concluded that there is a significant left-ear (right-hemisphere) advantage for attending to prosodic features of language. Comparison was made to findings by Van Lancker and Fromkin in 1972, which indicated that local pitch contours in Thai (a tone language) were lateralized to the left-hemisphere.

> *A comparison of intonation and pitch contours is relevant here, since both are similar acoustically, both serve a linguistic function, and yet, they demonstrate different ear advantages. ...Although both types of contours serve a linguistic function, the nature of their role in the linguistic message is very different. Pitch contours minimally distinguish individual words in language in a manner similar to consonant or vowel phonemes… Intonation contours, on the other hand, minimally distinguish different sentence types.* (156)

Mention is also made of the development of Melodic Intonation Therapy for aphasia (see Albert et al 1973, above), which generated marked improvement in the expressive ability of patients by encoding linguistic phrases with simple melodic patterns.

> *It may be that the use of these contours directly involves the non-dominant hemisphere in either the producing language or in enhancing its production by the damaged dominant hemisphere.* (156)

Finally, the authors speculate:

> *[N]ormal language perception may involve the simultaneous analysis of the linguistic input in both hemispheres — with the analysis of the phonetic and semantic components of language conducted primarily in the left hemisphere and the analysis of intonational and perhaps other components of the speech signal conducted primarily in the right hemisphere.* (156)

From this research, it seems apparent that speech is a complex stimuli, and that the brain accordingly processes it in complex ways. There are different aspects of the speech signal, however, which may be isolable (at least in experimental contexts) and dissociable in pathological contexts.

17. GORDON, H.W. and J.E. Bogen. "Hemispheric Lateralization of Singing after Intracarotic Sodium Amylobarbitone." *Journal of Neurology, Neurosurgery, and Psychiatry* 37 (1974): 727-38.

The experimenters examined subjected utilizing a presurgical screening procedure, which transiently depresses one hemisphere of the brain for 5-15 minutes, using a sodium amylobarbitone solution to one or the other carotid arteries. The procedure is used in part to identify hemispheric dominance and lateralization of function. All patients were severe epileptics being considered for cerebral commissurotomy, which cuts the fibers of the corpus callosum connecting the two hemispheres of the brain. During depression of each hemisphere, patients were requested or encouraged to speak and sing, by means of verbal requests and demonstrations, in order to compare functions attributable to each hemisphere singly. This has been described as a transient reversible hemispherectomy as it can permit the comparison of functioning under the control of one hemisphere to baseline functioning of both, before and after the procedure. The findings were that singing was more impaired than speech after depression of the right hemisphere, whereas the opposite was true during depression of the left hemisphere. However, notable was the fact that singing did not appear in either case until at least one spoken word had been elicited. While the authors claim speech intonation was normal during right hemisphere depression, despite loss of pitch control during singing, and suggest that control of pitch for speech may be lateralized opposite the same for song, their means of assessing speech intonation is not described. They mention phonetic pitch and stress as normal, but fail to distinguish the different types of prosody (i.e. linguistic vs. affective). Since a finding of normal affective intonation during right hemisphere depression would be remarkable considering the preponderance of evidence from later studies (cf. Zurif 1974, Ross & Mesulam 1979, and Ross 1981, below) suggesting otherwise, it is likely that the experimenters in this study failed to notice loss of affective expression, while sentence stress for example appeared normal

18. ROBINSON, George M. and Deborah Jo Solomon. "Rhythm is Processed by the Speech Hemisphere?" *Journal of Experimental Psychology* 102/3 (1974): 508-11.

Experiments were conducted using a dichotic listening paradigm. Subjects, wearing headphones, listened to two separate stimuli, one in each ear. The stimuli in this case were contrasting rhythmic patterns. Subjects were selected for right-handedness. The investigators sought "to directly investigate the hypothesis that complex nonspeech temporal patterns containing no phonetic information (rhythms) are processed by the speech hemisphere." (509)

They argue that "the results show that rhythmic patterns, unlike other nonspeech auditory stimuli, are processed better by the same hemisphere that is dominant for speech stimuli," and further that "because rhythm is the only nonspeech auditory feature found to be processed by the speech hemisphere, models of speech cognition based on rhythmic organization are to be encouraged." (509-10)

It should be noted that the long and short durations within the rhythmic patterns of the experiment were specifically selected for being "well within the range of spoken syllable durations." (509) Arguably, this experiment, rather than establishing speech-hemisphere dominance for rhythm generally, can be viewed as having presented subjects with rhythmic patterns that were processed in ways similar to the processing of speech. It is possible that the perception of rhythmic patterns falling within a range found in normal speech are therefore directed toward neural pathways specializing in speech processing. However, it is not at all certain that this effect is generalizable to all rhythmic patterns. One hypothesis is that certain rhythmic features are cues to the mind that the input is likely human speech. It remains to be seen whether rhythmic patterns outside such circumscribed limits would remain processed by the dominant hemisphere for language.

19. ZURIF, Edgar B. "Auditory Lateralization: Prosodic and Syntactic Factors." *Brain and Language* 1 (1974): 391-404.

Sets out to address whether "intonation is asymmetrically processed in the brain." (392) Notes that although there appears to be a right-ear (and thus left-hemisphere) advantage for processing intonation, the matter, viewed through the lens of dichotic listening techniques, is somewhat complex: "[A] listener is not normally required to adopt the analytic strategy of separating the contour from the utterance." (393) However, "ear advantage is determined less by the acoustic correlates of a linguistic property than by the use to which these correlates must be put." (395) That is there must be some mechanism that farms out the input to the relevant brain centers for processing based on the needs of the individual utterance. If it is not something locatable within the acoustic signature of the stimulus itself, it must then rest in part on the expectations of the listener. How such expectations are established and manipulated in the mind is an open issue. One might suspect that these issues of expectancies would bleed into attempts to define the distinction between speech and music. As Zurif concludes: "[I]f we are to understand how the left hemisphere mediates language, we need to continue to assess the properties of an utterance that are processed by the left hemisphere. As a corollary, isolating these properties will enable us both better to distinguish language from among other systems of communication and better to formulate psycholinguistic models in general." And, one might add, such research might help us to better understand the complex interactions between the various outward forms, which human expressiveness may take.

20. HEILMAN, K. M., R. Scholes, and R. T. Watson. "Auditory Affective Agnosia: Disturbed Comprehension of Affective Speech." *Journal of Neurology, Neurosurgery, and Psychiatry* 38 (1975): 60-72.

Attempts to draw a distinction between propositional and affective speech. Experiments were conducted on 12 right-handed patients with temporoparietal lesions, half of which were left-sided, the other half right-sided. Subjects were presented short tape-recorded sentences, and asked to make judgments regarding the content and the affective mood of the utterances. Both groups performed perfectly in terms of content. However, the right-hemisphere patients performed significantly worse in deciding the emotional content of the utterances. A description follows of relevant literature mostly from the 1960s which examine hemispheric functioning in the processing of affective auditory stimuli. No hypothesis is argued to explain the results of the experiment. They conclude: "Although it appears that lesions in the right hemisphere are important in the production of auditory affective agnosia, the mechanism of affective agnosia remains uncertain." (p. 72)

21. SHANKWEILER, Donald, and Michael Studdert-Kennedy. "A Continuum of Lateralization for Speech Perception?" *Brain and Language* 2 (1975): 212-225.

Motivated in large part by inconclusive experimental results, the authors of this study point to possible reinterpretations of broader questions of brain laterality. Just as handedness appears to be along a gradient, they suggest that language dominance may fall along a gradient as well. This is in part due to the fact that there appears to be a correlation between handedness and language dominance (in the contralateral hemisphere). They suggest that "we should be viewing lateralization not simply as a fixed anatomical characteristic… but rather as a process or function governing the relations between hemispheres, and open to variation among individuals." (222)

22. YAMADORI, A., Y. Osumi, S. Masuhara, and M. Okubo. "Preservation of Singing in Broca's Aphasia. *Journal of Neurology, Neurosurgery, and Psychiatry* 40 (1977): 221-24.

Prompted by contemporary studies, including Gordon and Bogen 1974, above, which indicated a dissociation between speaking and singing abilities, and a good deal of contradictory data in older articles, which correlated aphasia with vocal motor amusias, these authors chose to conduct a systematic study of singing abilities in patients with Broca's aphasia, and a corresponding critical review of the old literature on amusia. They found that 21 out of 24 Broca's aphasics in their study retained the ability to sing with good melodic production. Fully half of those studied also exhibited good text words during such singing. This lead the authors to speculate that the right hemisphere is dominant for singing. They note, however, that good melodic rendering does not necessarily lead to good text rendering. The significance of this finding is left for further inquiry.

23. ROSS, Elliott D., and Marek-Marsel Mesulam. "Dominant Language Functions of the Right Hemisphere? Prosody and Emotional Gesturing." *Archives of Neurology* 36 (Mar 1979): 144-48.

Describes two cases of loss of the affective qualities of speech due to a right-hemispheric lesion in the supra-Sylvian portions of the right posterior frontal and anterior parietal lobes. One of the patients eventually recovered affective prosody, while the other remained aprosodic. Both patients retained the ability to feel emotions and to perceive emotions in others, while lacking the ability to produce affective tones of voice in their speech. Argues convincingly for a revised understanding of cerebral dominance, and an expanded definition for the linguistic faculties.

> *The left hemisphere, because it possesses special language capabilities, has been designated as the "major" or "dominant" hemisphere. Nevertheless, there is compelling evidence to suggest that the right or "minor" hemisphere is superior if not dominant for modulating certain aspects of higher cortical functions; these include musical faculties, visuospatial analysis, the holistic perception of objects and faces, the copying of figures, and emotional behavior. In fact, as demonstrated by the two cases reported here, the right hemisphere may even contribute certain dominant linguistic features to spoken language. The concept of cerebral dominance becomes precise, therefore, only when it is stated that a given hemisphere is dominant for a specific function. Neuroanatomical studies of lesions causing aphasic disorders have clearly established that the left hemisphere in right-handed adults has a dominant role in the neural processes governing the production and comprehension of speech. In contrast, the contribution of the right hemisphere to linguistic functions is usually considered rudimentary at best. This dichotomy is principally based on observations concerning the lexical, grammatical, and articulatory aspects of language and does not take into account that the full spectrum of spoken language also includes prosody (the coloring, melody, and cadence of speech) and emotional gesturing. These two linguistic features are particularly crucial for allowing spoken language to acquire emotional and thus affective tone.* (p. 144)

24. ROSS, Elliott D. "The Aprosodias: Functional-Anatomic Organization of the Affective Components of Language in the Right Hemisphere." *Archives of Neurology* 38 (Sep 1981): 561-569.

Describes ten cases of right-hemispheric brain damage which resulted in prosodic disorders of various types. Attempts to draw a direct comparison between these types of aprosodias, from right-hemispheric damage, to corresponding aphasias, due to analogous damage in the left hemisphere. The author argues that there are strong similarities between such cases of aphasia and corresponding types of aprosodia. The reason for expecting such analogies, or their relevance is not explained. Provides detailed descriptions of the symptoms of these aprosodias, along with detailed explanations of the extent and type of brain damage involved. Concludes: "It has been my recent experience, as attending neurologist, that the aprosodias are as commonly encountered on the clinical services as are the aphasias." Such a statement, and the fact that this article is perhaps the first to categorize and detail these neurologically-based deficits to the comprehension and production of prosody and gesture in speech, points strongly at the need for expanded attention to these aspects of spoken language. Although these cases were noted for deficits of spoken language, none of the patients were examined for their functioning in spontaneous or imitative singing. Therefore the correspondence between processing of features in singing analogous to prosody in speech is undetermined.

25. ROSS, Elliott D. "Right Hemisphere's Role in Language, Affective Behavior and Emotion." *Trends in Neurosciences* 7/9 (Sep 1984): 342-6.

Summarizes the state of neurological understanding of the right-hemisphere's role in the modulation of affective prosody and gesture.

> *The pathophsyiological correlations in patients with aprosodia have, so far, only indicated that the right hemisphere may play a dominant role in the formal decoding and encoding of affective behaviors. Additional evidence suggests that this may reflect a more general specialization of the right hemisphere for all non-verbal and para-linguistic aspects of communication. However, we do not yet know if the right hemisphere is also specialized for modulating the entire range of emotional experience. ...Clearly, much work needs to be done in order to understand better the complex neurological organization of emotions, affective behaviors, and related phenomena by the brain.* (p. 345)

Because of the strong emotional impact of much music, it seems crucial that any research dealing with brain processing of emotion incorporate research into music processing as well.

26. SERAFINE, Mary Louise, Robert G. Crowder, and Bruno H. Repp. "Integration of Melody and Text in Memory for Songs." *Cognition* 16 (1984): 285-303.

The authors conducted experiments to ascertain how memory for new songs is encoded in the mind. Their approach was to build on existing research regarding linguistic and musical memory, to address the novel question of memory for songs. "Indeed, research on hemispheric differentiation, especially that which suggests left-hemisphere dominance for language and right-hemisphere dominance for music… leaves entirely open how melody and text in songs might be processed." (286) They concluded "that melody and text are integrated in memory to a considerable degree. …Moreover, we found no evidence that subjects can voluntarily reduce the degree of integration of melody and text." (300) Further, they note the natural asymmetry between melodies and spoken texts, that melodies can exist without words, but speech always contains some form of intonation.

> *In the context of a song, the musical tune in large measure takes over the function of prosody and thus becomes an aspect of the suprasegmental properties of the words. Viewed in this way, it is quite conceivable that memory for tunes is more dependent on memory for words than* vice versa*; certainly, outside the realm of music the prosody of speech is remembered, if at all, only as an aspect of the words by which it is carried. We hope to investigate this interesting parallel between speech and music in future experiments.* (301)

It is clear that further research needs to be done in teasing apart the cognitive differences between these two domains. Is it that, when anticipating speech, we process the melodic contour and details similarly or fundamentally differently than when in the context of singing? If similarly, then what is the difference between speaking and singing? If differently, then how do our minds prepare for the distinct expectations? Further, it remains to be experimentally shown what the authors assert, that the prosodic features of speech are not processed independently, but are fully integrated with the words. If so, it is an intriguing question just how we are able to suppress this natural encoding, in the context of singing, and replace the prosodic layer of speech with an artificial, musical melody.

27. ZATORRE, Robert J. "Musical Perception and Cerebral Function: A Critical Review." Music Perception 2/2 (1984): 196-221.

Considers disappointing the lack of firm conclusions to be drawn from the experimental and clinical literature regarding hemispheric specialization for music and language. “All we are able to deduce is that musical deficits can occur independently of linguistic ones, but that the two are often associated.” (197) Presents new findings, based on a sodium Amytal paradigm, which indicate bilateral participation in singing. One difference between this study and earlier amylobarbitone ones is that Zatorre sought to measure singing ability at a given point during hemispheric depression rather than merely describe the time line of recovery of functioning. As he points out, a careful reading of reports, such as Gordon & Bogen (1974), above, indicates that singing was partly impaired by depression of either hemisphere. A thorough and critical review of the literature on hemispheric specializations for music and language follows. The two major conclusions drawn are: first, that hemispheric specialization for music is not as strong as that for language; and second, that there is a great deal of individual variation in the distribution of abilities across hemispheres, and across subjects.

28. LIBERMAN, Alvin M., and Ignatius G. Mattingly. "The Motor Theory of Speech Perception Revised." *Cognition* 21 (1985): 1-36.

A highly involved and influential paper. This is a revision of the motor theory which had been developed during the early 1950s by Liberman and colleagues. Essentially the motor theory provides that the object of speech perceptions is not the acoustic elements of an utterance per se, but rather the productive gestures by which the auditory elements arise. The reason for such a theory is the simple fact that listeners consistently produce phonological categorization with a seeming disregard for the great variety in the actual stimuli that prompt them. It is the contention of the theory that phonological elements are naturally distorted, relative to the surrounding phonemes, on the basis of the physics of the vocal production. It is an implicit analysis of these distortions that leads a listener to classify sounds, in terms of the vocal procedures involved.

29. KELLEY, Darcy B. "A Motor Theory of Song Perception." *Trends in Neurosciences* 9/4 (Apr 1986): 149-150.

Kelley reviews some work done by researchers studying motor responses to auditory stimuli in songbirds. The findings indicate that a major factor in the processing (and by implication the comprehension) of conspecific-produced auditory stimuli is a motor neuron loop associated with the production of such sounds in the syrinx of the listening songbirds. This suggests "that song may only be totally intelligible to a nervous system capable of singing." Interestingly, in the birdsong species studied, it is the males who sing. The studies indicated therefore the possibility that the songs, rather than being courtship displays for the females, may be combat displays between the males.

Since research dealing with humans has made similar connections between auditory and articulatory processes (cf. 7. Kimura 1967, above), the potential ramifications of a motor theory of song perception, corresponding to a motor theory of speech perception, are wide ranging, especially in the realms of speech therapy and vocal pedagogy. In terms of comparative studies, it would be useful to ascertain whether there are gender differences in perception in humans. However, since male and female humans sing (in fact, females of our species appear to sing more than males), the process of the development of such skills may differ considerably from the process in birds.

30. ROSS, Elliott D., Jerold A. Edmondson, and G. Burton Seibert. "The Effect of Affect of Various Acoustic Measures of Prosody in Tone and Non-Tone Languages: A Comparison Based on Computer Analysis of Voice." *Journal of Phonetics* 14 (1986): 283-302.

Ross, et al. set out to compare the ability to signal affect through prosody in three tone languages (Taiwanese, Mandarin, and Thai) with such ability in English. The results indicate that the presence of tone in a language severely restricts the manipulation of local pitch frequencies (referred to as F_0, or *fundamental frequency*), for the purpose of signalling affect. This is primarily due to the fact that such local pitch manipulations might result in changes of semantic meaning:

> *In non-tone languages such alterations will not disturb linguistic information. However, in tone languages, in which the relative height between and among tones may be contrastive, such alterations could disrupt linguistic information. For example, if one had a low-mid sequence of two flat tones, a change in F_0 Variation might produce a low-high sequence.* (298)

In English, it is known that the right hemisphere tends to be dominant for the processing of prosodic features of speech. However, this study was largely motivated by difficulties in finding such effects for speakers of tone languages. Interestingly, the researchers note:

> *[I]f the modulation of a specific acoustical parameter is lateralized in the brain to either the right or left hemisphere, the lateralization is dependent on the behavioral properties of the parameter and not on its acoustical properties.* (300)

Again, we have further evidence, therefore, that a major factor involved in the process of audition, human minds are largely influenced by expectancies regarding what type of stimuli they are receiving. This leads one to suspect that much of this can be voluntarily altered by a listener, in order to perceive an input signal in various ways. For instance, it is quite possible that a skilled listener could choose to hear a spoken sentence as melody and rhythm, ignoring its linguistic function. Indeed, the composers Janáček and Mussorgsky are known to have made just such claims.

31. SERAFINE, Mary Louise, Janet Davidson, Robert G. Crowder, and Bruno Repp. "On the Nature of Melody-Text Integration in Memory for Songs." *Journal of Memory and Language* 25 (1986): 123-35.

Reports on experiments intended to follow up on possible theories explaining away the *integration effect* described in Serafine, Crowder & Repp 1984, above. The first new experiment tested an hypothesis which posited that apparent integration was the result of subtle semantic assignments of meaning to the melodies involved, in ways familiarly termed *word-painting* in musical fields. The target songs (original presentations) however, had their words replaced by nonsense syllables, which nonetheless sounded like words (i.e. "Cape Cod girls they have no combs" became "Tade top berf shey jaze mo tong"). Thus, any effect of semantics would be destroyed. The experiment however failed to support this hypothesis.

> *Melodies were recognized better when they were paired with their original text than when paired with another, even if equally familiar text. Since this effect held when nonsense texts were used, the semantic hypothesis must be ruled out as an explanation for the integration effect.*(129)

A second hypothesis was that the integration effect was not due to a strengthening of memory on the basis of pairing the melody with words, but rather the converse of a decrement effect due to the distracting influence of wrong words.

> *Perhaps the melody by itself could be recognized well without the original words, but adding new or mismatched words somehow disguises the retained melodic information.* (129)

This hypothesis was tested by counterposing a hummed version of the song with properly matched and mismatched stimuli. The original meaningful words were retained in this experiment. The argument is that a hummed version should be recognized more easily than a mismatched version, and equally well as the properly matched target (Experiment 2). The findings were somewhat inconclusive. Although they failed to support the decrement hypothesis, they did not strongly disconfirm it. However, "melodies were better recognized in the presence of their original words than on their own, without words." (131)

Likewise, the words on their own should be more easily recognized without a novel melody, and equally so with the original melody (Experiment 3). Experiment 3 returned to the nonsense syllables, counterposing the sung originals with spoken versions. The findings for Experiment 3 were strong, since recognition of the text without a melody (whether original or mismatched) was near chance. That is, memory for nonsense words was better in the context of the melody with which they were first presented, than it was without a melody.

In discussion of these findings, the experimenters note, however: "Integration of melody and text in memory for songs is an experimental result, not an explanation." (133) They suggest certain avenues for further investigation. Specifically, they identify that the subtle influences that melody and text have on one another result in minute changes in the acoustic signal, which may likely be perceptually salient to a listener.

> *[W]e suggest that integration in memory may result from other, more subtle effects that melody and text have on each other. These may be thought of, broadly, as prosodic effects in that they concern the nonsemantic sound pattern of either melody or text,. For example, a text's consonant pattern, vocal timbres, and accents may affect the attack and decay patterns, stresses, or other aspects of tones in a melody….What this means is that a melody is physically different depending on the words to which it is sung.* (133)

Although the authors argue that the hummed stimuli rule out the possibility that a melody could be equally recognized without its text, it would be interesting to test this hypothesis not with a hummed variation, but rather by pairing an instrument with the voice in the first presentation (say, a flute or violin, doubling the voice part), and playing only the instrumental version of the melody in the test condition. Would subjects be equally able to recognize the melody presented without a voice, and thus without the original words?

It has been shown that various stimulus conditions alter the mental mechanism by which sounds are processed. Perhaps the human voice (even without linguistically meaningful sounds) provides a certain degree of distraction which alters a listener's strategy in analyzing the sound signal. If that were the case, the decrement hypothesis might prove correct. However, rather than it being the deleterious influence of improper words, it is the presence of the human voice that alters the strategies employed to make sense of the input signal.

32. EDMONDSON, Jerold A., Jin-Lieh Chan, G. Burton Seibert, and Elliott D. Ross. "The Effect of Right-Brain Damage on Acoustical Measures of Affective Prosody in Taiwanese Patients." *Journal of Phonetics* 15 (1987): 219-33.

Examined eight right-handed native-speakers of Taiwanese, a tone language. All patients showed signs of emotional flattening in their speech, though none showed deficits in the production of tone or other segmental aspects of speech. As the authors wrote: "The major emphasis of this paper is to investigate loss of affective prosody from focal right-brain damage in patients who speak a tone language." (220) Comparison was made to findings for similar patients who were native-speakers of English.

The acoustic signals produced by patients' speech utterances was analyzed along 12 parameters. In general, as expected, it was found that somewhat different parameters are normally involved in altering the affective content of an utterance. Unexpectedly, however, the researchers found that there was a flattening of frequency modulation, even at the local level. Although the degree of flexibility available in normal tonal speech is significantly narrower than for non-tonal speech, it yet remains an important marker of emotional affect.

> *The authors believe the explanation for this finding may lie in the fact that tones in context are allowed some prosodic variation from their citation forms without disrupting lexical information. Although the presence of tones in a language clearly places constraints on the manipulation of F_0... enough freedom or play in the required precision of tone contrasts appears to remain for speakers to exploit this freedom for affective purposes.* (230)

In conclusion:

> *[I]t was once again found that communicative abilities of humans are lateralized according to behavior itself (affective vs. linguistic) and not according to the physical/acoustical carrier that expresses this behavior. ...[A]lthough difference acoustic profiles underlie affective prosody for Taiwanese vs. English patients, the behavioral consequences are the same, i.e. affective flattening of voice. Thus, human languages show the features of a composite that is the product both of specific neurological organization of brain tissue and of the brain's ability to react to the acoustical properties of a particular language, i.e. tone vs. non-tone, during the experience of language acquisition.*

Thus, we have further evidence that expectancies play a major role in the perception and production of speech sounds, such that when language exploits aspects of pitch manipulation as part of the segmental level, as is the case in tone languages, such features are processed in the brain in fundamentally different ways from the same parameters when not within a segmentally contrastive context, even for speakers of tone languages. It is yet to be understood just how the perceptual apparatus is able to obtain this effect from the acoustic signal, though the motor theory of speech perception suggested elsewhere appears to provide one likely explanation.

33. GORELICK, Philip B. and Elliott D. Ross. "The Aprosodias: Further Functional-Anatomical Evidence for the Organisation of Affective Language in the Right Hemisphere." *Journal of Neurology, Neurosurgery, and Psychiatry* 50 (1987): 553-60.

Reviews the recent literature regarding aprosodias, and presents further evidence to support the earlier contention (Ross 1981, above) that right-hemispheric focal lesions cause aprosodic deficits, which mirror aphasic deficits due to analogous lesions in the left hemisphere.

34. MEHLER, Jacques, Peter Jusczyk, Ghislaine Lambertz, Nilofar Halsted, Josiane Bertoncini, and Claudine Amiel-Tison. "A Precursor of Language Acquisition in Young Infants." *Cognition* 29 (1988): 143-78.

A series of studies were done on four-day-old French and 2-month-old American infants. Both groups were able to distinguish between utterances in the native speech of the mother, and speech utterances from another language. Follow up studies indicated that these infants were not likewise able to distinguish between the utterances of two foreign languages. Further experiments were conducted with filtered speech, such that the segmental features were no longer clearly present. These final experiments indicate that infants might possibly use prosodic cues to classify utterances as either native or non-native speech.

35. ROSS, Elliott D., Jerold A. Edmondson, G. Burton Seibert, and Richard W. Homan. "Acoustic Analysis of Affective Prosody during Right-Sided Wada Test: A Within-Subjects Verification of the Right Hemisphere's Role in Language." *Brain and Language* 33 (1988): 128-45.

Reviews evidence from a within-subjects study of five right-handed patients, each undergoing a WADA test (which causes transient "paralysis" to each brain hemisphere separately, as a presurgical screening procedure for epileptics being considered for prophylactic commisurotomies). Findings show the left-hemisphere condition causing loss of propositional speech, and the right-hemisphere condition causing a loss of affective speech. These findings further confirm the contention that "the right hemisphere modulates dominantly the affective components of language."

36. SHIPLEY-BROWN, Frances, William O. Dingwall, Charles I. Berlin, Grace Yeni-Komshian, and Sandra Gordon-Salant. "Hemispheric Processing of Affective and Linguistic Intonation Contours in Normal Subjects." *Brain and Language* 33 (1988)" 16-26.

Conducted dichotic listening experiments to test the hypothesis that processing of affective intonation is dissociable from processing of linguistic intonations. The distinction between these domains is based on Monrad-Krohn's categories of prosodic function (see Monrad-Krohn 1963, above). Affective intonation is presented as contrasts between emotional affect (happy, sad, angry), whereas linguistic intonation relates to different types of utterances (statement, question, continuation). The results indicated that both of these conditions exhibited a left ear advantage (right hemispheric processing), however this effect was stronger for the affective condition. The authors argue that this can be explained in terms of a continuum, wherein the more linguistic the function of intonation, the less dominantly it is processed by the RH.

Since they do not cite Edmondson et al 1987, above, I can only assume that they were unaware of the study, which demonstrated relatively normal functioning of linguistic tone, but flattening of affective pitch contours. It was argued therefore that linguistic tone remains LH dominant, even in the presence of RH dominance for affective prosody. On the one hand, this might support the argument that processing of pitch in speech is along a continuum, such that the more affective the more RH dominant, the more linguistic the more LH. Additionally, however, it raises questions as to the appropriateness of Monrad-Krohn's distinction (adopted by this study) between linguistic and affective prosody, without attending to the special case of lexical tone, which seems to be subsumed in his description of intrinsic prosody. Thus the experimental design of this study is weakened.

37. FERNALD, Anne. "Intonation and Communicative Intent in Mothers' Speech to Infants: Is the Melody the Message?" *Child Development* 60 (1989): 1497-1510.

Conducted a perceptual study, using 40 experienced parents and 40 students inexperienced with infants as informants. Stimuli were recordings were made of both infant-directed and adult-directed speech of 5 mothers of 12-month-old preverbal infants, which were then filtered to eliminate linguistic content, leaving only the prosodic information of each utterance. Subjects were asked to identify (forced choice) the speaker's intent for each utterance (attention-bid, approval, prohibition, comfort, game/telephone). Listeners were able to deduce speakers' intentions far more accurately for infant-directed speech than for adult-directed speech. This lead the researchers to conclude that the prosodic patterns of infant-directed speech are not only more animated but more informative than for adult-directed speech, and that these may provide reliable cues to preverbal infants in comprehending speaker's intent.

38. ROSS, Elliott D., Britt Anderson, and Anna Morgan-Fisher. "Crossed Aprosodia in Strongly Dextral Patients." *Archives of Neurology* 46 (Feb 1989): 206-9.

Reports on two cases of strongly right-handed individuals, suffering from left-hemisphere infarctions, but exhibiting aprosodias, rather than aphasias. Both patients showed deficits both in the imparting and comprehension of affective prosody .The resulting syndrome is called a crossed aprosodia, which corresponds to the rare incidence of crossed aphasias. This finding of crossed aprosodias is interpreted as evidence that propositional and prosodic aspects of language are encoded in opposite hemispheres, regardless of whether dominance is normal or anomalous.

39. BELL, William L., Diana L. Davis, Anna Morgan-Fisher, and Elliott D. Ross. "Acquired Aprosodia in Children." *Journal of Child Neurology* 5 (Jan 1990): 19-26.

Records case histories for two 10-year old girls who suffered from mild acquired right-hemispheric damage, and comparisons to seven age-matched female controls. Patients and controls were assessed for spontaneous and imitative affective prosody in speech, as well as spontaneous requested singing of "Happy Birthday." Both patients showed initial deficits in spontaneous affective prosody[6]. Case 2 exhibited severe loss of imitative affective prosody as well, whereas the affective repetition deficits for Case 1 were reported as minor. Similarly, relative to controls, singing was impaired for Case 1, whereas it appeared normal for Case 2. This lead the authors to suspect a direct correlation between modulation of pitch in speech and singing. Since the findings of Gordon & Bogen 1974, above, appeared to contradict this conclusion, the authors confirmed by private communication with Dr. Bogen, that the normality of speech reported therein referred only to propositional and not affective components of speech prosody.

It is interesting to compare this, however, with the findings of Yamadori, et al 1977, above, which note that text production is normally intact during singing by Broca's aphasics. Therefore, while pitch may be dominantly encoded in the right hemisphere for both speaking and singing (though I believe the evidence is inconclusive at this point[7]), text appears to have dual

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[6] *Happily, normal functioning was recovered by both patients within a matter of months.*

[7] *This is complicated by issues regarding the acquisition of song. Children and inexperienced singers often attend first to linguistic, then rhythmic, and only last to melodic elements of singing. It is possible that processing for melody in song is more variable in the population than other aspects of vocal production, which may account for ambiguous and contradictory evidence in the literature. This compares to findings that early musical training, in particular for pianists and violinists, often causes a shift to left-hemisphere dominance for procedures that are otherwise right-hemispheric in the general population.*

Additionally, it must be pointed out that pitch processing for music (and thus assumedly for singing) is more precise than it is for prosody in speech. Non-lexically significant pitch (i.e. non-tone-dependent intonation, in both tone and nontone languages) appears to be processed as a gestalt. Because of this, it seems a reasonable encoding in both hemispheres. It may be that right-hemispheric encoding of words is purely phonological, that the sounds of the words may be separately or redundantly encoded from a holistic representation in the opposite hemisphere, which includes sound or articulatory elements. Empirical studies could address this question, with brain scans of singers during production of songs with both familiar (native) and unfamiliar (foreign) words. However, if dual-encoding is found to be the case, it may be that singers switch back and forth between linguistic and phonological processing of text sounds, in the course of song production. Therefore brain imaging techniques that showed good temporal resolution would be essential[8].

40. MEREWETHER, Frank C. and Murray Alpert. "The Components and Neuroanatomic Bases of Prosody." *Journal of Communication Disorders* 23/4-5 (Aug-Oct 1990): 325-336.

A review of the literature for a psychiatric audience. Notes some contradictory findings. Of particular note was one reviewed article by Danly et al., which indicated severe disturbance of fundamental frequency (presumably in speech production) in aphasics, but not in RH lesions. This directly contradicts several studies by Elliott D. Ross and colleagues. They summarize the literature as "indicating the left hemisphere's dominance for inflection indicating syntax, and the right hemisphere's dominance for those aspects that indicate the speakers' intentions, emotions, or feelings." Also, reviewed are some studies regarding rate of speech, which appears to be moderated by dopamine levels in the brain.

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hypothesis to expect intonational pitch processing and musical pitch processing to be encoded differentially in the brain. Such redundancies in the brain may have arisen as a result of separate adaptive pressures converging on auditory processing. And this may explain some of the confusions which arise as a result of trying to define boundaries for musical and linguistic phenomena. It just may be that acoustic signals are processed redundantly, and varyingly, by different members of the population, and under different expectational conditions.

[8] *It is commonly acknowledged that fMRI, while giving better spatial data than PET scans, trades this off with lousy temporal data. New techniques combine both MRI and PET technologies, but these may still prove inadequate for the type of study proposed. We can only hope that the technologies will continue to progress, along with the greater complexity of the questions researchers ask.*

41. CROWDER, Robert G., Mary Louise Serafine, and Bruno Repp. "Physical Interaction and Association by Contiguity in Memory for the Words and Melodies of Songs." *Memory & Cognition* 18/5 (1990): 469-76.

42. SAMSON, Séverine, and Robert J. Zatorre. "Recognition Memory for Text and Melody of Songs After Unilateral Temporal Lobe Lesion: Evidence for Dual Encoding." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 17/4 (1991): 793-804.

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45. ZATORRE, Robert J., Alan C. Evans, Ernst Meyer, and Albert Gjedde. "Lateralization of Phonetic and Pitch Discrimination in Speech Processing." *Science* [New Series] 256/5058 (May 8, 1992): 846-9.

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48. FRIEDERICI, Angela D., Erdmut Pfeifer and Anja Hahne. "Event-Related Brain Potentials during Natural Speech Processing: Effects of Semantic, Morphological and Syntactic Violations." *Cognitive Brain Research* 1 (1993): 183-92.

49. ROSS, Elliott D. "Nonverbal Aspects of Language." *Neurologic Clinics* 11/1 (Feb 1993): 9-23.

50. TREHUB, Sandra E., Laurel J. Trainor, and Anna M. Unyk. "Music and Speech Processing in the First Year of Life." *Advances in Child Development and Behavior* 24 (1993): 1-35.

51. COHEN, Nicki S. "Speech and Song: Implications for Therapy." *Music Therapy Perspectives* 12/1 (1994): 8-14.

52. CHRISTOPHE, Anne, Emmanuel Dupoux, Josiane Bertoncini, and Jacques Mehler. "Do Infants Perceive Word Boundaries? An Empirical Study of the Bootstrapping of Lexical Acquisition." *Journal of the Acoustical Society of America* 95/3 (Mar 1994): 1570-1580.

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54. TREHUB, Sandra E., Anna M. Unyk, and Joanna L Henderson. "Children's Songs to Infant Siblings: Parallels with Speech." *Journal of Child Language* 21 (1994): 735-44.

55. WALLACE, Wanda T. "Memory for Music: Effect of Melody on Recall of Text." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 20/6 (1994): 1471-1485.

56. BERTONCINI, Josiane, Caroline Floccia, Thierry Nazzi, and Jacques Mehler. "Morae and Syllables: Rhythmical Basis of Speech Representations in Neonates." *Language and Speech* 38/4 (1995): 311-29.

57. MEHLER, Jacques and Anne Christophe. "Maturation and Learning of Language in the First Year of Life." In *The Cognitive Neurosciences*, ed. Michael S. Gazzaniga, 943-54. Cambridge, MA: MIT Press, 1995.

58. BELIN, P., Ph. Van Eeckhout, M. Zilbovicius, Ph. Remy, C. François, S. Guillaume, F. Chain, G. Rancurel, and Y. Samson. "Recovery from Nonfluent Aphasia after Melodic Intonation Therapy: A PET Study." *Neurology* 47 (Dec 1996): 1504-11.

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Presents a thoroughgoing overview of the question in its title. Explains many of the experiments and evidence, along with possible confounds to the resulting data. Suggests areas where continuing research is needed, in particular attempts to isolate neural specificity for speech versus non-speech domains. Covers the literature regarding memory for words and melody in song, and argues that a greater diversity of experimental data is required before firm conclusions can be drawn on the relation between musical and linguistic mental codes in song. In general, suggests that essential research is only now in the offing, and that many areas of inquiry remain to be examined.

> *The evidence reviewed in this chapter suggests that "music" and "language" are not independent mental faculties, but labels for complex sets of processes, some of which are shared and some different. Neuropsychology allows the empirical delineation of the boundaries between these domains, as well an exploration of their overlap. …[N]europsychological evidence suggests that the processing of pitch contour employs some of the same neural resources in music and language, while the processing of tonality appears to draw on resources used uniquely by music.*
>
> *Numerous other areas of convergence and divergence between music and language await more thorough investigation.* (p. 208)

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74. DOHERTY, Colin P., M Fitzsimons, B. Asenbauer, and H. Staunton. "Discrimination of Prosody and Music by Normal Children." *European Journal of Neurology* 6 (1999): 221-6.

In a very ambitious study, Doherty and colleagues set out on the first systematic attempt to study receptive processing by normal children of both affective and linguistic prosody, as well as receptive processing of affective cues in instrumental music. The study consisted of five separate tasks, combining various cross-modal methodologies. The first two experiments contained the presentation of recorded pairs of compound nouns, either repeated or followed by their corresponding noun phrases (i.e. blackboard/black board; racquet ball/racquetball). In the first experiment, the children were asked to say if the two presented stimuli were same or different. In the second, they were asked to point at the appropriate picture from a choice of two, corresponding to the meaning each presented separate example. The third task was to test children's ability to distinguish types of utterance (statement, question, command) on the basis of the relevant intonation contours. Sentences were devised which could fit any of the contours and whose intent could be inferred only by such cues. The final two experiments consisted in the recorded presentation of four sentences spoken in one of three emotional ways (happy, sad, angry), and 24 examples of emotional music to be judged according to the same three emotions. In both cases, the same face pictures paradigm as in experiment two was used. Their findings indicated early and reliable success with emotional cues in instrumental music, but much weaker and slower trends for comprehending affective cues in speech. They conclude that "adult-like ability in affective cue discrimination may develop later than the corresponding linguistic ability," suggesting that "affective prosody may not be as important to the child as previous thought"; and further that comprehension for "emotional cues in music develops earlier than prosodic affective perception", suggesting "that music and prosody are not, in fact, comodular" in the brain. (225)

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The current study utilized a Functional Magnetic Resonance Imaging (fMRI) technique to identify the neural areas involved in the recognition of emotional prosody and phonemic characteristics of spoken language by normal listeners. Ten right-handed male subjects, lacking any known neurological disorders, were presented with the recorded words: BOWER, POWER, DOWER, TOWER, spoken by a native-English speaker in one of four emotional tones of voice: happy, sad, angry, neutral. The stimuli remained the same (though in random order) for all conditions. What differed were the task requirements. In each case, the subjects were to depress a button upon detection of the target stimulus. There were four conditions: (1) identify POWER in any of its emotional forms; (2) identify BOWER in any of its emotional forms; (3) identify any of the words in a happy tone; and (4) identify any of the words in a sad tone. This is similar in intent to the study by Bartholomeus (1974), above, but more elegant in experimental design, and avoiding the limitations of the dichotic listening paradigm. In both the present experiment and Bartholomeus' the same stimuli were used with different tasks in order to test whether requirements on attention impact neural processing, in particular whether they alter laterality effects. The findings in the current case were affirmative, and defined the regions of the brain far more precisely than is possible with dichotic listening. The results demonstrate two major findings: first, bilateral activation during both phonetic and emotional detection tasks, in comparison with baseline (resting state) activity; and second, "significant lateralization of cortical activity during the perception of both emotional prosody and the perception of verbal characteristics of words" (236). In particular, it was found that detection of emotion tasks produced significantly greater activity in right frontal regions than corresponding verbal tasks; and verbal tasks involved significantly greater left frontal activity than emotion detection tasks with the same input. The authors point out that localization of activity in the frontal lobes is counter to the findings of some clinical studies, which would predict lateralized activity in temporoparietal regions. However, they explain: “This discrepancy most likely arises from the inherent differences between experiments involving patients with specific lesions and functional imaging experiments. While studies involving patients with lesions are able to demonstrate those areas critical for a specific function, functional neuroimaging studies are only able to demonstrate those areas that are involved in a specific function” (234).

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The authors discuss previous findings which indicate the production of language (words) and the production of melodies may be handled by “different cerebral networks.” (1997-1998) However, they point out that speaking and singing may in fact encompass both components, words and melodies combined. They contend that “in order to test the hypothesis that different networks support the generation of speech and melodies, sound structure and tonal aspects of acoustic communication must be teased apart.” (1998) That is, it is necessary to distinguish between aspects of intonation which convey purely linguistic information (i.e. type of utterance: statement, question, command; or, lexical stress: distinguishing PRESENT or CORRELATE [noun] from PRESENT or CORRELATE [verb]) from those communicating emotional cues. For the present study, eighteen healthy right-handed subjects were asked to speak the months of the year, and to sing a well-known instrumental tune without lyrics (derived from W. A. Mozart's Eine Kleine Nachtmusik, and familiar to all subjects), while undergoing fMRI. Additionally, in order to control for possible differences between overt and covert modalities, each of the tasks were performed aloud and silently. Extensive analysis of variation was conducted across experimental conditions. Findings reported specific localization of activity during tasks, which differed for each condition, including overt vs. covert performance. The effects were strongest for covert singing and silent speech, producing clear opposite lateralization effects in the right motor cortex/posterior inferior frontal gyrus and left cerebellum for song, and the opposite for speech. Bilateral activation in these regions was noted for overt tasks, with moderate lateralizations corresponding to those for covert performance. They conclude: "Two opposite cerebral networks comprising motor cortex, anterior insula, and cerebellum subserve speaking and singing, respectively. Since activation of the insula revealed to be bound to overt performance, this structure seems to mediate actual implementation of speech (words) and melody (tunes) patterns in terms of temporal spatial coordination of vocal tract musculature." (2000)

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