The Relationship of Music to the Melody of Speech and to Syntactic Processing Disorders in Aphasia

ANIRUDDH D. PATEL

The Neurosciences Institute, San Diego, California 92121, USA

ABSTRACT: Two new empirical studies address the relationship between music and language. The first focuses on melody and uses research in phonetics to investigate the long-held notion that instrumental music reflects speech patterns in a composer's native language. The second focuses on syntax and addresses the relationship between musical and linguistic syntactic processing via the study of aphasia, an approach that has been explored very little. The results of these two studies add to a growing body of evidence linking music and language with regard to structural patterns and brain processing.

KEYWORDS: melody; prosody; aphasia; syntax; language; music

INTRODUCTION

Human cultures make use of two organized sound systems: those of music and language. While these systems have many obvious differences, both employ rhythmic and melodic patterns and rule-governed sequences. Scholars have thus long been interested in possible links between the domains. Indeed, the issue has engaged a wide range of thinkers over the centuries, including music theorists, linguists, poets, and philosophers. Although the topic is an old one, recent years have marked a watershed in the history of music–language studies, with the rise of empirical studies rooted in cognitive science and neuroscience. Here I illustrate the empirical approach with two new studies addressing questions of current interest in the relationship between music and language.

The first question is whether a composer's instrumental music reflects the prosody of his or her native language. A new quantitative model of intonation perception is used to study this issue. The second question is whether music and language overlap with regard to the neural bases of syntactic processing. This is addressed via the study of music perception in aphasia, an approach that has been virtually unexplored. Full scientific details of these studies are available in papers that have been submitted for publication by Patel, Iversen and Rosenberg,[1] and Patel, Iversen, and Hagoort.[2] Here I describe these studies in a larger historical context and provide an overview of the methods and findings.

Address for correspondence: Aniruddh D. Patel, The Neurosciences Institute, 10640 John Jay Hopkins Drive, San Diego, CA 92121. Voice: 858-626-0285; fax: 858-626-2099.
apatel@nsi.edu

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MUSICAL STRUCTURE AND LINGUISTIC PROSODY

Background

A number of musicologists and linguists have claimed that the rhythms and melodies of a culture's native language are reflected in its instrumental music.[3,4] For example, the noted English musicologist Gerald Abraham voiced this idea,[3] citing as one example Ralph Kirkpatrick's comment on French keyboard music:

"Both Couperin and Rameau, like Fauré and Debussy, are thoroughly conditioned by the nuances and inflections of spoken French. On no Western music has the influence of language been stronger."

Kirkpatrick (a harpsichordist and music scholar) was effectively saying that something about French keyboard music sounds like the French language. Similar claims have been made about the instrumental music of other cultures, including England.[5] Surprisingly, these provocative claims have gone largely untested from a scientific standpoint. Why is this the case?

The issue seems to be a practical problem, namely a lack of good tools for quantifying rhythmic and melodic patterns in language in a way that can be directly compared to music. Fortunately, new tools from phonetics are helping overcome this obstacle. For example, a measure of temporal patterning in sentences, the normalized pairwise variability index (nPVI), has recently been developed to explore rhythmic differences between "stress-timed" and "syllable-timed" languages.[6] The nPVI computes the degree of durational contrast between neighboring events in a sequence, and has been used to examine temporal patterns of vowel duration in sentences from a variety of languages.[7,8] The salient finding is that the nPVI is generally higher for languages classified as stress-timed (e.g. British English, Dutch, and Thai) than for languages classified as syllable-timed (e.g. French, Spanish, and Singapore English). This likely reflects a greater degree of vowel reduction in stress-timed languages.[9]

In previous research, we applied the nPVI to note durations in instrumental classical themes from England and France, and found that English music had a higher nPVI than French music.[10,11] This earlier study illustrates our general approach to comparing prosody to musical structure. Specifically, we choose two cultures, A and B, and compare their speech prosody using a quantitative method. If a difference is found, then instrumental music from A and B is compared using precisely the same method. The question of interest is whether the musics of A and B show also show a significant difference in the same direction as the linguistic difference (e.g., A > B for both speech and music). If so, then this suggests that musical structure reflects speech prosody.

Examining Melody in Speech and Music

Having conducted cross-domain research on rhythm, we have now turned our attention to melody. Using the same databases of speech and music from our previous work,[10,12] we ask if there is a difference between English and French speech intonation that is reflected in the music of the two cultures. When studying rhythm we had the benefit of an existing quantitative measure that differentiated between English and French speech and that could be applied to music in a straightforward way (the nPVI). In the case of intonation, no such measure was available. Furthermore, there has been very little work examining empirical differences between intonation in British English and French.

In searching for methods that could help us overcome these problems, our interest was captured by a recent computational model of speech intonation perception.[13,14] The central notion behind the "prosogram" model is that the raw fundamental frequency (Fo) contour of a sentence, although an accurate physical description of the speech signal, is not the most accurate representation of intonation as it is perceived by human listeners. In particular, empirical research suggests that pitch perception in speech is subject to two perceptual transformations. The first is perceptual segregation of the Fo contour into syllable-sized units due to the rapid spectral and amplitude fluctuations in the speech signal.[15] The second is temporal integration of Fo within a syllable, meaning that the perceived pitch of a syllable is actually a time-weighted average of the intrasyllabic Fo movement.[16] The prosogram instantiates this second transformation via an automatic algorithm (the first stage—phonetic segmentation—is provided by the user). As a result of these transformations, the original Fo contour of a sentence is converted to a sequence of discrete tonal segments. An example of the model's output is given in FIGURE 1.

This figure reveals why the prosogram is useful to those interested in comparing speech and music. The perceptual representation of intonation produced by the prosogram is quite music like, consisting mostly of level pitches. (Syllables are assigned pitch glides if the amount of intrasyllabic Fo change is large enough to exceed a perceptual threshold. In our corpus, only 3% of syllables were assigned glides). On a cognitive level, this is interesting because it implies that the auditory image of speech intonation in a listener's brain has more in common with music than has

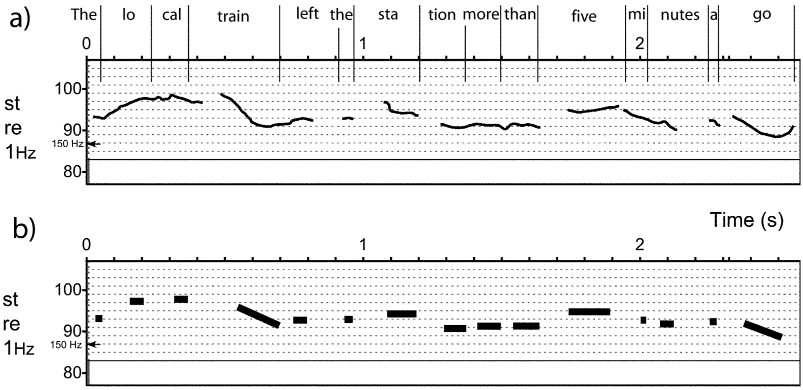

FIGURE 1. Illustration of prosogram analysis of speech intonation. Part **a** shows the original Fo contour of the British English sentence "The local train left the station more than five minutes ago." Syllables and their temporal boundaries are marked at the top of the figure. Part **b** shows a prosogram analysis of this sentence, with the tonal elements assigned by the prosogram, that is, level pitches or glides (1 per syllable). Units on the y axis are pitches in semitones (st) re 1 Hz; thin *horizontal dashed lines* mark 2 st intervals. The st value corresponding to 150 Hz is shown for reference. The prosogram runs under Praat, a freely available program for speech analysis: <http://bach.arts.kuleuven.ac.be/pmertens/prosogram/>.

generally been believed. This has implications for cross-domain transfer of statistical learning, as discussed in the next section. On a practical level, the dominance of level pitches means that intonation patterns in different languages can be compared using tools that can also be applied to music, for example, statistical measurements of pitch height or interval patterns. We adopt this approach in our studies as described below. Before turning to the details of our measurements, however, it is worth discussing the concept of statistical learning and how it guided our choice of what to measure.

Statistical Learning of Tonal Patterns in Speech and Music

Statistical learning (SL) refers to tracking patterns in the environment and acquiring implicit knowledge of their statistical properties, without any direct feedback. Research in music cognition has demonstrated statistical learning of tonal patterns in novel musical sequences. For example, listeners show sensitivity to the distribution of different pitches and to interval patterns.[17–19] These studies have shown that SL in music can occur with atonal or culturally unfamiliar materials, meaning that it is not confined to tonal patterns that follow familiar musical conventions.

Synthesizing these findings with the music-like representation of intonation provided by the prosogram, we hypothesized that SL of tonal patterns occurs for speech intonation in one's native language, especially since one has extensive exposure to such patterns from an early age. SL of speech patterns has been demonstrated for phonetic/syllabic patterns,[20] so it seems plausible that it could apply to speech tonal patterns as well. If this is the case, then composers (like other members of their culture) will have implicit knowledge of the statistics of their native language's intonation patterns, which could influence their creation of pitch patterns in another domain, namely music.

The question of interest then is What aspects of intonation patterns are learned and reflected in music? Since the speech intonation does not conform to any musical scale, SL of speech tone sequences is unlikely to involve categorical patterns (e.g., transitions between certain stable intervals). Thus we decided to investigate a simple statistical aspect of spoken pitch patterns, namely their variability.

Quantifying Variability in Spoken and Musical Pitch Patterns

Using the prosogram representation of intonation, we quantified the pitch variability of each sentence in two ways. First, we measured the variation of individual pitches about their mean. Second, we measured the variability of pitch intervals, where intervals were defined as the frequency distance between successive tonal elements. Semitone units were used in both measures to reflect the perceptual scaling of intonation.[21] In performing these measurements we only measured level pitches: glides were ignored (for interval measures, only intervals between immediately adjacent level tones were computed).

We then applied the same measurements of pitch variability to music, examining the ~300 instrumental classical themes that we had examined previously for rhythm.[10] These were taken from *A Dictionary of Musical Themes*[22] and represented the work of 6 English and 10 French composers whose lives spanned the turn of the 20th century, an era of musical nationalism (composers included, e.g., Elgar and

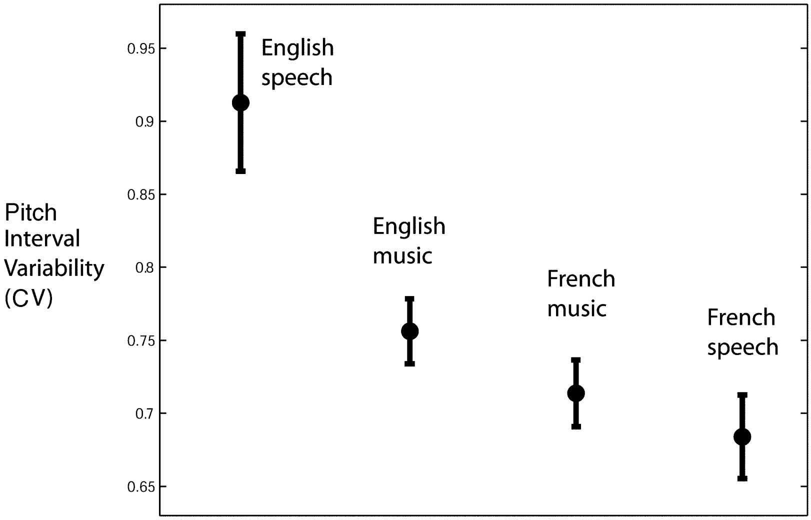

FIGURE 2. Pitch interval variability for language and music. Pitch interval variability is defined as the coefficient of variation (CV, SD/mean) of absolute interval size for a sequence, whether a sentence or a musical theme. Variability in language was measured from intervals between level tones in prosograms of British English and French sentences. Variability in music was measured from music notation of English and French classical instrumental themes. Semitones were used in both measurements. British English speech has significantly greater variability than French speech, and English music has significantly greater variability than French music. *Error bars* show standard errors.

Debussy). Musical measurements were made in semitone units directly from music notation.

Results

The primary result of interest was that music reflected a specific aspect of speech intonation, namely the variability of pitch interval size (which we have termed *melodic interval variability* or MIV). This variability was significantly higher in English than in French sentences, and in English than in French musical themes, as shown in FIGURE 2. By contrast, pitch variability about the mean did not differ between the languages or the musics.

Discussion

Our new work provides evidence that speech intonation is reflected in turn-of-the-century classical instrumental music in England and France. This provides further support for those scholars who have intuited a link between a culture's music and its linguistic prosody. Interestingly, the aspect of intonation that is reflected in music is pitch interval variability, which is lower for French than for English. That is, as the voice moves from one syllable to the next in a sentence, the size of each pitch change is more uniform in French than in English speech. Similarly, as a melody moves from one note to the next in musical themes, the size of each pitch change is more uniform in French than in English music.

Although we have focused on just two cultures in our studies, a principal goal of this work has been to develop methods that can be applied much more broadly in the study of music's relation to linguistic prosody. In the case of the nPVI, studies of speech and music in other cultures have already begun and are yielding promising results. The pitch interval variability can also be examined in other cultures, using the freely available prosogram as a tool (see legend for FIG. 1).

We have focused on a very simple aspect of the statistical patterning of pitch in this study (variability). Prosogram representations of intonation, with their sequences of level tones, clearly call for more sophisticated analyses of pitch patterns in speech, to see if other aspects of speech intonation that differentiate languages are reflected in music.

MUSICAL SYNTACTIC PROCESSING IN APHASIA

Background

Music and language employ sequences of perceptually discrete elements organized in principled ways. That is, both are syntactic systems. A growing body of research from neuroimaging points to overlap in the syntactic processing of language and music.[23–25] Yet this work must be reconciled with evidence for neuropsychological dissociations between musical and linguistic syntactic abilities.[26] In an attempt to unify these observations, Patel[27] suggested that language and music involve distinct and domain-specific syntactic representations stored in long-term memory (such as nouns and verbs vs. chords and their harmonic relations), but that neural resources involved in activating these representations during online processing are shared. One implication of this shared syntactic integration resource hypothesis (SSIRH) is that representations can be selectively damaged (leading to dissociations), but that damage to activation-related neural resources should result in deficits in both domains. Patel pointed out that a crucial test of this idea involved aphasics with linguistic disorders of syntactic comprehension. If, as has been hypothesized by some neurolinguists,[28,29] such disorders reflect a problem with activation of structural information (vs. a loss of stored syntactic representations), then according to the SSIRH, these aphasics should exhibit a musical syntactic deficit as well.

Music Perception in Aphasia: A Largely Unexplored Area

Remarkably, there has been virtually no work on musical syntactic (e.g., harmonic) processing in aphasia. This is particularly striking since an early study by Francès *et al.*[30] suggested that aphasic individuals with linguistic comprehension disorders also have a deficit in the perception of musical tonality. The researchers studied a large group of persons with aphasia and had them judge whether two short, isochronous melodies were the same or different. The melodies were either tonal or atonal. Under these circumstances, normal participants (even those with no musical training) show superior performance on the tonal stimuli. Aphasic individuals failed to show this tonal superiority effect, leading the authors to suggest that the perception of tonality "seems to engage preestablished circuits existing in the language area."

This idea has lain fallow for decades, with no further studies of tonality perception in aphasia. Why might this be? Good tools for testing linguistic comprehension in aphasia and for probing the perception of tonal relationships have long been available, yet no one has attempted to replicate or extend these results. This is made even more puzzling by the fact that the findings of Francès *et al.* were somewhat clouded by methodological issues, and thus naturally called for further work.

It is likely that the absence of research on this topic reflects historical and conceptual forces. In particular, within music cognition there has been an emphasis on cases of dissociation between aphasia and amusia. The most oft-cited example is that of Shebalin,[31] a Russian composer who continued to write music after becoming severely aphasic. Citing this and other reports of aphasia without amusia, Marin and Perry[32] concluded that "these cases of total dissociation are of particular interest because they decisively contradict the hypothesis that language and music share common neural substrates" (p. 655).

If this conclusion were true, then there would clearly be no reason to pursue the issue of music perception in aphasia. However, there is, in fact, a serious problem with this conclusion. As pointed out by Tzortzis *et al.*,[33] virtually all cases of aphasia without amusia represent composers or conductors, that is, individuals with an extraordinarily high degree of musical training. Modern research on neural plasticity has revealed that the brains of professional musicians differ from those of nonmusicians in a variety of ways, including increased gray matter density in specific regions of the frontal cortex and increased corpus callosum size.[34,35] Thus generalizations about language–music relationships in aphasia cannot be drawn on the basis of case studies of professional musicians.

The purpose of the current study was to apply well-established tests from cognitive psychology to explore the relationship between linguistic and musical syntactic processing in nonmusician aphasics. As with the other study described in this article (on prosody), full details are available in a paper submitted for publication.[2] Here I give an overview of the methods and results.

Participants and Tasks

Nine Dutch-speaking aphasics and twelve age- and education-matched controls were tested on linguistic and musical tasks. Some participants had played musical instruments as a hobby, but none had been a professional musician. The aphasics were classified as Broca's type based on the Aachen Aphasia Test and on clinical interviews, and had a mean age of 60.1 years. All were at least nine months poststroke and had left hemisphere lesions with variable locations, including frontal and temporal regions, not necessarily including Broca's area. Such variability is well known from studies of Broca's aphasia[36,37] and prevented us from addressing issues of localization. We focused instead on cognitive relationships between music and language based on performance of syntactic tasks in both domains.

For language, syntactic comprehension abilities were assessed with a sentence-picture matching task, which has been much used in studies of aphasia.[38] In this task the participant hears one sentence at a time and must point to the corresponding picture on a sheet with four different pictures. Sentences varied across five levels of syntactic complexity. For example, a sentence with an intermediate level of complexity (level 3) was the passive structure: "The girl on the chair is greeted by the man" (FIG. 3). Deter-

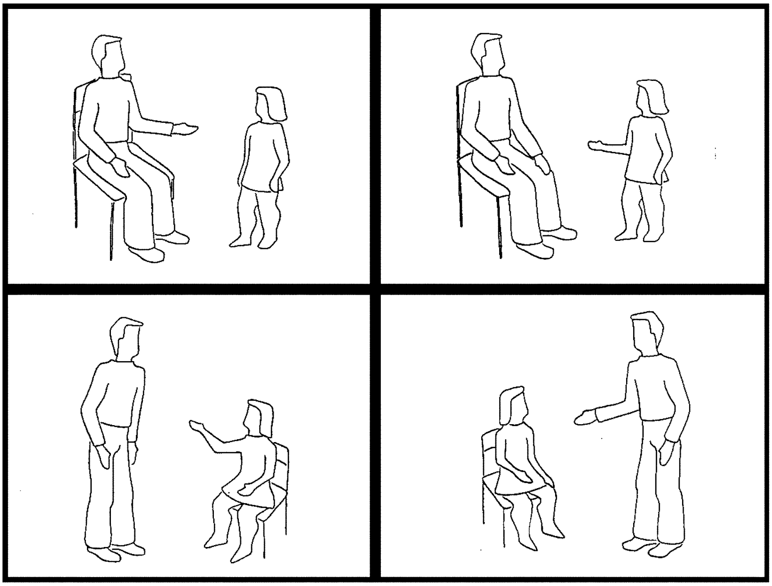

FIGURE 3. Example panel from the language syntax test (the sentence-picture matching task). In this case the participant heard the sentence: "The girl on the chair is greeted by the man." The task is to point to the corresponding picture.

mining who did what to whom in such sentences relies on syntactic information (e.g., simple word-order heuristics such as "first noun = agent" do not work).

For music, we used a harmonic priming task. Harmonic priming is a well-studied paradigm in music cognition and tests the influence of a preceding harmonic context on the processing of a target chord. Much research has shown that a target chord is processed more rapidly and accurately if it is close to (vs. distant from) the tonal center created by the prime. This indicates implicit knowledge of the harmonic conventions of tonal music and has been repeatedly demonstrated in nonmusician listeners in Western cultures.[39] We used the original two-chord version of the harmonic priming task,[40] with a single chord serving as the prime. (Prime and target were 1 s long each, separated by 50 ms). This places minimal demands on attention and memory and is thus suitable for use with aphasics. The harmonic distance between prime and target was regulated by the circle of fifths for musical keys. Harmonically close versus distant targets were 2 versus 4 steps clockwise steps away from the prime on the circle. This directly pits conventional harmonic distance against psychoacoustic similarity, since the distant target shared a common tone with the prime[41] (FIG. 4). The participants' task was to judge whether the second chord was tuned or mistuned (on 50% of the trials, it is mistuned by flattening one note in the chord). The main focus of interest, however, is in reaction times (RTs) to well-tuned targets as a function of their harmonic distance from the prime. A faster RT to close versus distant chords is evidence of harmonic priming.

Participants also completed two control experiments that tested for the ability to discriminate tuned from mistuned chords and tested auditory short-term memory.

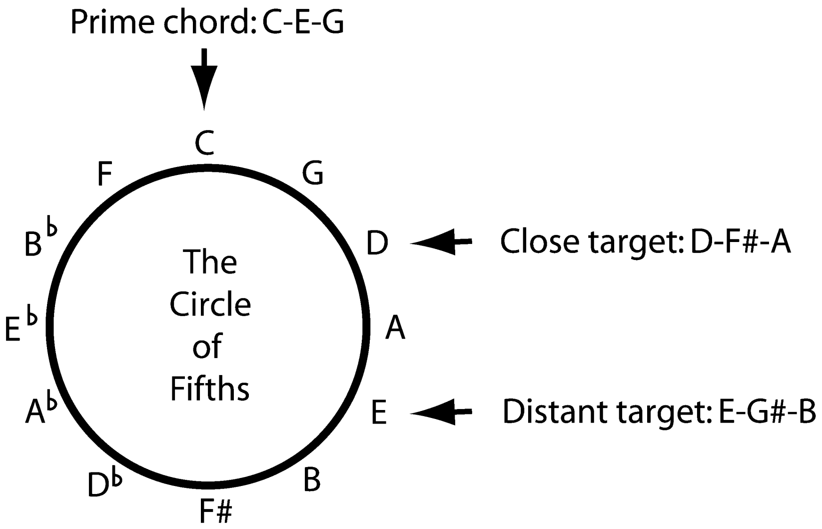

FIGURE 4. The circle of fifths for musical keys. Prime and target chords were the principal chord of each key. An example of a prime chord is shown (the C major triad), along with its close versus distant harmonic targets (the D major triad and E major triad, respectively). Note that the prime chord shares a tone with the distant chord (the note E in this case) but not with the close chord. This pits psychoacoustic similarity against conventional harmonic syntax with regard to distance along the circle of fifths.

Results

The language experiment showed that the aphasics had a linguistic syntactic comprehension deficit and thus were suitable for studying cross-domain syntactic processing. Turning to music, the control experiments revealed that aphasics and controls did not differ on basic auditory discrimination and short-term memory abilities. In contrast, the priming task revealed a significant difference between aphasics and controls. Controls showed normal harmonic priming, with faster reaction times to harmonically close versus distant well-tuned targets. Aphasics, however, failed to show a priming effect and even showed a nonsignificant trend to be faster on distant targets, suggestive of responses driven by psychoacoustic similarity rather than by harmonic knowledge. To check if aphasics would show priming if given enough time between prime and target (e.g., due to slow activation of structural information), we conducted an additional experiment in which the silent interval between prime and target chords was increased to 1 second. Aphasics still failed to show priming.

Discussion

Aphasics with syntactic comprehension problems in language also have a musical syntactic deficit; that is, they seem not to activate the implicit knowledge of harmonic relationships that Western nonmusicians normally exhibit. Importantly, this is not due to low-level acoustic deficits (e.g., difficulty discriminating tuned from mistuned chords), nor is it a generalized consequence of brain damage, since there are cases of individuals with bilateral cortical lesions who show normal harmonic priming.[42] This supports the SSIRH[27] for language and music. It also favors a "processing view" of syntactic disorders in aphasia, that is, a general problem activating stored syntactic representations (e.g., verbs together with their lexical category and thematic role information) rather than a language-specific disruption of these representations.[29] One direction for future work is to make tasks as comparable as possible across domains, for example, comparing performance on syntactic priming tasks in language[43] to harmonic priming tasks in music. When comparable tasks are used it will be particularly interesting to examine individual variation among aphasics to determine if there is a relationship between the severity of deficits in the two domains. More generally, the time is ripe for systematic work on musical syntactic processing in aphasia, especially since the results are of theoretical relevance to both music cognition and neurolinguistics.

CONCLUSION

The studies presented here provide new evidence for the relationship between linguistic prosody and musical structure, and between syntactic processing in music and language. In each case, a new approach is introduced that can be used for further work. Specifically, a good deal more can be done to compare melody in speech and music based on analyses of tonal patterns provided by prosogram representations of intonation. Similarly, much remains to be learned about the relationship between linguistic and musical syntactic processing via the study of aphasia, since many well-studied linguistic and musical tasks remain to be probed. Future work in these areas can help advance our understanding of basic principles in the human brain's processing of structured sound.

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[Competing interests: The author declares that he has no competing financial interests.]

REFERENCES

1. Patel, A.D., J.R. Iversen & J.C. Rosenberg. Comparing the rhythm and melody of speech and music: the case of British English and French. Submitted for publication.

2. Patel, A.D., J.R. Iversen & P. Hagoort. Impaired syntactic processing of language and music in Broca's aphasia. Submitted for publication.
3. Abraham, G. 1974. The Tradition of Western Music. University of California Press. Berkeley. p. 83.
4. Wenk, B.J. 1987. Just in time: on speech rhythms in music. Linguistics **25:** 969–981.
5. Hall, R.A. Jr. 1953/1972. Elgar and the intonation of British English. The Gramophone, June 1953: 6–7. Reprinted *in* Intonation: Selected Readings. D. Bolinger, Ed.: 282–285. Penguin. Harmondsworth.
6. Low, E.L., E. Grabe & F. Nolan. 2000. Quantitative characterizations of speech rhythm: syllable-timing in Singapore English. Lang. Speech **43:** 377–401.
7. Grabe, E. & E.L. Low. 2002. Durational variability in speech and the rhythm class hypothesis. *In* Laboratory Phonology 7. C. Gussenhoven & N. Warner, Eds.: 515–546. Mouton de Gruyter. Berlin.
8. Ramus, F. 2002. Acoustic correlates of linguistic rhythm: Perspectives. *In* Proceedings of Speech Prosody, Aix-en-Provence. B. Bell & I. Marlien, Eds.: 115–120. Laboratoire Parole et Langage. Aix-en-Provence.
9. Dauer, R.M. 1983. Stress-timing and syllable-timing reanalyzed. J. Phonetics **11:** 51–62.
10. Patel, A.D. & J.R. Daniele. 2003. An empirical comparison of rhythm in language and music. Cognition **87:** B35–B45.
11. Huron, D. & J. Ollen. 2003. Agogic contrast in French and English themes: further support for Patel and Daniele. Music Percept. **21:** 267–271.
12. Nazzi, T., J. Bertoncini & J. Mehler. 1998. Language discrimination in newborns: toward an understanding of the role of rhythm. J. Exp. Psychol. Hum. Percept. Perform. **24:** 756–777.
13. d'Alessandro, C. & P. Mertens. 1995. Automatic pitch contour stylization using a model of tonal perception. Computer Speech and Language **9:** 257–288.
14. Mertens, P. 2004. The prosogram: semi-automatic transcription of prosody based on a tonal perception model. *In* Proceedings of Speech Prosody 2004, Nara (Japan), March 23–26. B. Bel & I. Marlien, Eds.
15. House, D. 1990. Tonal Perception in Speech. Lund University Press. Lund.
16. d'Alessandro, C. & M. Castellengo. 1994. The pitch of short-duration vibrato tones. J. Acoust. Soc. Am. **95:** 1617–1630.
17. Oram, N. & L.L. Cuddy. 1995. Responsiveness of Western adults to pitch-distributional information in melodic sequences. Psychol. Res. **57:** 103–118.
18. Krumhansl, C.L. 2000. Tonality induction: a statistical approach applied cross-culturally. Music Percept. **17:** 461–479.
19. Saffran, J.R., E.K. Johnson, R.N. Aslin & E.L. Newport. 1999. Statistical learning of tone sequences by human infants and adults. Cognition **70:** 27–52.
20. Saffran, J.R., R.N. Aslin & E.L. Newport. 1996. Statistical learning by 8-month-old infants. Science **274:** 1926–1928.
21. Nolan, F. 2003. Intonational equivalence: an experimental evaluation of pitch scales. *In* Proceedings of the 15th International Congress of Phonetic Sciences: 771–774. Barcelona, Spain.
22. Barlow, H. & S. Morgenstern. 1983. A Dictionary of Musical Themes, revised edition. Faber and Faber. London.
23. Patel, A.D., E. Gibson, J. Ratner, *et al.* 1998. Processing syntactic relations in language and music: an event-related potential study. J. Cognit. Neurosci. **10:** 717–733.
24. Koelsch S., T.C. Gunter, D.Y von Cramon, *et al.* 2002. Bach speaks: a cortical "language-network" serves the processing of music. Neuroimage **17:** 956–966.
25. Maess, B., S. Koelsch, T. Gunter, *et al.* 2001. Musical syntax is processed in Broca's area: an MEG study. Nat. Neurosci. **4:** 540–545.
26. Peretz, I. 1993. Auditory atonalia for melodies. Cognit. Neuropsychol. **10:** 21–56.
27. Patel, A.D. 2003. Language, music, syntax, and the brain. Nat. Neurosci. **6:** 674–681.
28. Kolk, H.H. & A.D. Friederici. 1985. Strategy and impairment in sentence understanding by Broca's and Wernicke's aphasics. Cortex **21:** 47–67.
29. Kolk, H.H. 1998. Disorders of syntax in aphasia: linguistic-descriptive and processing approaches. *In* Handbook of Neurolinguistics. B. Stemmer & H.A. Whitaker, Eds.: 249–260. Academic Press. San Diego.

30. Francès, R., F. Lhermitte & M. Verdy. 1973. Le déficit musical des aphasiques. Rev. Int. Psychol. Appl. **22:** 117–135.
31. Luria, A., L. Tsvetkova & J. Futer. 1965. Aphasia in a composer. J. Neurol. Sci. **2:** 288–292.
32. Marin, O.S.M. & D.W. Perry. 1999. Neurological aspects of music perception and performance. *In* The Psychology of Music, 2nd edition. D. Deutsch Ed.: 653–724. Academic Press. San Diego.
33. Tzortzis, C., M-C. Goldblum, M. Dang, *et al.* 2000. Absence of amusia and preserved naming of musical instruments in an aphasic composer. Cortex **36:** 227–242.
34. Gaser, C. & G. Schlaug. 2003. Brain structures differ between musicians and nonmusicians. J. Neurosci. **23:** 9240–9245.
35. Schlaug G., L. Jancke, Y. Huang, *et al.* 1995. Increased corpus callosum size in musicians. Neuropsychologia **33:** 1047–1055.
36. Willmes, K. & K. Poeck. 1993. To what extent can aphasic syndromes be localized? Brain **116:** 1527–1540.
37. Caplan, D., N. Hildebrandt & N. Makris. 1996. Location of lesions in stroke patients with deficits in syntactic processing in sentence comprehension. Brain **119:** 933–949.
38. Hagoort, P., M. Wassenaar & C. Brown. 2003. Real-time semantic compensation in patients with agrammatic comprehension: electrophysiological evidence for multiple-route plasticity. Proc. Natl. Acad. Sci. USA **100:** 4340–4345.
39. Bigand, E., B. Poulin, B. Tillman, *et al.* 2003. Sensory versus cognitive components in harmonic priming. J. Exp. Psychol. Hum. Percept. Perform. **29:** 159–171.
40. Bharucha, J.J. & K. Stoeckig. 1986. Reaction time and musical expectancy. J. Exp. Psychol. Hum. Percept. Perform. **12:** 403–410.
41. Tekman, H.G. & J.J. Bharucha. 1998. Implicit knowledge versus psychoacoustic similarity in priming of chords. J. Exp. Psychol. Hum. Percept. Perform. **24:** 252–260.
42. Tramo, M.J., J.J. Bharucha & F.E. Musiek. 1990. Music perception and cognition following bilateral lesions of auditory cortex. J. Cognit. Neurosci. **2:** 195–212.
43. Friederici, A.D. & K. Kilborn. 1989. Temporal constraints on language processing: syntactic priming in Broca's aphasia. J. Cogn. Neurosci. **1:** 262–272.