Advancing the comparative study of linguistic and musical syntactic processing

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A response to commentaries by Stefan Koelsch, Jessica Grahn, & Justin London on: Patel, A.D., "Language, music, and the brain: a resource-sharing framework".

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The empirical comparative study of linguistic and musical syntactic processing is a relatively young area of research. The first neuroimaging study of this topic was published a little over a decade ago, using event-related brain potentials (ERPs) (Patel et al., 1998). While there has been a good deal of research on musical syntactic processing since that time (see Koelsch 2009 for one review), studies using within-subjects designs to compare syntactic processing in language and music are still relatively rare. At present less than ten such studies have been published. These include ERP studies (Koelsch et al., 2005; Steinbeis & Koelsch, 2008; Jentschke & Koelsch, 2009), intracranial EEG studies (Sammler, 2009), a study of Broca's aphasics (Patel et al., 2008), and behavioral studies of normal individuals (Fedorenko et al., 2009; Slevc et al., 2009). Notably absent from this list are within-subject fMRI studies aimed at comparing patterns of brain activity associated with syntactic processing in language and music. Such studies would advance our understanding of the brain bases of syntax and provide important tests of the resource-sharing framework for music and language (Patel, this volume).

Given the recent growth of cognitive neuroscience research on music, it seems likely that further comparative studies of linguistic and musical syntax will be conducted soon. Such studies will benefit by attending to a number of issues raised in the commentaries in this volume by Stefan Koelsch, Jessica Grahn, and Justin London.

1. The importance of specifying cognitive mechanisms

As noted by Koelsch (this volume), comparative research will benefit from explicit hypotheses about "which cognitive mechanisms are actually shared between language- and music-syntactic processing (and which are not)." Focusing on Western tonal music, Koelsch offers a list of cognitive mechanisms involved in music syntactic processing, distinguishing domain-specific mechanisms (such as the extraction of a tonal center) from mechanisms which might be shared with language (such as the integration of incoming elements into complex hierarchical structures, or the serial prediction of upcoming elements in sequences).

The shared syntactic integration resource hypothesis (SSIRH, see Patel, this volume) focuses on the integration of incoming elements into hierarchical structures, but I would like to second Koelsch's suggestion that prediction of upcoming elements is another possible mechanism shared by music and language processing. "Predictive listening" has long been a major theme in music cognition, commencing with the influential theory of Leonard Meyer (1956) on expectancy in music (see Huron, 2006 for a review of empirical data). Prediction is also a growing research topic in psycholinguistics, as empirical evidence accrues that listeners predict (or "preactivate") upcoming linguistic information during sentence processing (e.g., DeLong et al., 2005) . Linguistic predictions are thought to occur at multiple levels (e.g., prosodic, semantic, pragmatic), including structural predictions about the syntactic categories of upcoming words (e.g., Gibson, 2006; Levy, 2008).

Structural prediction is a candidate for a shared cognitive mechanism between language and music. In his commentary, Koelsch states that "While listeners familiar with (Western) tonal music perceive a sequence of chords, they automatically make predictions of likely chord functions to follow." In other words, these listeners make implicit predictions about abstract structural categories (chord functions), such as “dominant” or “tonic”. Like syntactic functional categories in language (e.g., subject, direct object, etc.), chord functions are structural categories which are assigned by virtue of the context created by a sequence. Thus for example, the word “car” can be a subject, object, or indirect object of a sentence depending on the structure of the sentence. Similarly, a G major chord can serve a tonic, dominant, or subdominant function by virtue of the structural context in which it occurs. (This example is not intended to imply any direct mapping between specific linguistic syntactic functions and specific harmonic chord functions, only to point out that both domains have context-dependent structural functions).

If language and music both involve the prediction of upcoming structural categories in sequences, what is the relationship of the brain networks involved in making these predictions? What brain areas become activated when these predictions are violated? Neuroimaging could be used to address these and other questions about structural prediction in language and music, and thus refine our understanding of how the brain makes abstract structural predictions when processing complex sound sequences.

2. The importance of advanced neuroimaging techniques

Grahn argues that future fMRI studies on syntactic processing in language and music should go beyond traditional fMRI localization methods. She makes a persuasive case for multivoxel pattern analysis (MVPA) techniques, which examine fine-grained patterns of activation across multiple voxels within a brain region, rather than simply looking for broad regions of activation. Grahn points out that MVPA would be particularly useful for analyzing overlapping regions of activation associated with language and music processing. It is tempting to interpret such overlaps as evidence for shared networks involved in music and language. Another interpretation, however, is that “two overlapping but functionally independent neural populations are present and active within the common region.” MVPA analyses can be used to address this issue by computing voxel-by-voxel patterns of selectivity to musical or linguistic stimuli. As pointed out by Grahn, such analyses would be particularly useful in studying the role of Broca’s area (and its right hemisphere homolog) in linguistic vs. musical syntactic processing.

Grahn also notes that music-language research should consider interactions between brain regions, not just the locations of active regions. Complex sequences such as music and speech engage multiple brain regions, and may be distinguished more by patterns of brain interaction than by a simple list of regions involved (Patel, 2003). Fortunately modern fMRI methods include techniques for studying neural interactions, such as functional connectivity (which measures temporal correlations between brain activity in different regions) and effective connectivity (which measures the influence of activity in one brain region on activity in another). Grahn notes that such methods could be used to compare patterns of interaction between Broca’s region and superior temporal lobe regions during syntactic processing in language and music. I would add that such studies would benefit from approaches that combine the spatial resolution of fMRI with the temporal precision of MEG or EEG, in order to study interactions between brain regions at the timescale of actual neuronal activity (e.g., Freeman et al., 2009).

3. The importance of integrating theory and empirical data

London's commentary reminds us that many theorists remain skeptical of links between linguistic and musical syntax. He argues that musical structure and linguistic syntax have several important differences. For example, he notes that language has phonological markers for certain syntactic categories (such as the plural "s" maker in English). In contrast, musical tones lack "intrinsic sonic characteristics" which signal their structural properties (cf. section 1 above, where it was pointed out that an acoustically identical G-major chord can play a dominant or tonic chord function depending on its context). What London's argument overlooks, however, is that language can also have structural categories which are not signaled by sonic characteristics. For example, the syntactic category of direct object in English (e.g., "car" in "We gave our old car to Marta") is not marked phonologically. Rather, "car" is the direct object of the above sentence (vs., say, it's subject or indirect object) only by virtue of the context in which it occurs, i.e., by virtue of its structural relations to other words in the sentence (cf. Gibson, 2006).

Be that as it may, London correctly reminds us that we should be careful about making general claims about the structural roles played by different tones within a musical key. He provides an effective example of how the leading tone in a particular key ("ti") can vary considerably in its degree of perceived restlessness depending on the melodic context in which it occurs (his Figure 1). However, this mutability does not invalidate the basic point that pitches in a tonal music context *have* abstract qualities (such as stability and instability, or being in-key or out-of-key) that go beyond their merely psychophysical qualities (e.g., as high/low/loud/soft acoustic events). Such qualities emerge because the pitches of tonal music are not combined in random ways, but instead are combined according to certain structural norms. The resource sharing framework (Patel, this volume) assumes that listeners develop a sensitivity to these norms via implicit learning of the structural regularities of tonal music (Huron, 2006). It makes no assumption that this sensitivity is rigid and insensitive to local context. Indeed, as implied by London, the various factors that contribute to a tone's abstract qualities in real musical contexts is an interesting topic for empirical research.

Stepping back from the details of London's critique, it is worth noting that London is one of several theorists who are skeptical about parallels between linguistic syntax and musical structure (cf. Jackendoff, 2009). Such skeptics have an important role to play in helping us refine our hypotheses about what music and language share in cognitive terms. Indeed, differences between theories of linguistic and musical syntactic structure helped inspire the resource-sharing framework, which acknowledges several formal differences between the syntaxes of the two domains. For instance, linguistic syntax includes word categories, constituent relationships, and point-to-point long-distance dependencies have no obvious analogs in music. Conversely, the pitch hierarchies, harmonic relations, and tension-resolution patterns found in tonal music have no clear counterparts in language. Yet despite these differences, there are similarities at more general levels. For example, both domains create hierarchically organized sequences based on abstract structural categories (e.g., subject, object, tonic, dominant) which can be instantiated by different surface elements (Patel, 2008:267). Furthermore, incoming elements vary in how easy they are into integrate into the existing structure of the sequence. The resource-sharing framework (and more specifically, the SSIRH) posits that difficult structural integrations rely on a shared pool of limited neural resources, and makes predictions that have been empirically tested (see the references in opening paragraph of this essay).

Thus an important challenge for skeptics like London is to engage not only with theoretical arguments but also with empirical data. In other words, skeptics must account for evidence that the processing of tonality in music engages cognitive and neural mechanisms also used in the processing of grammatical relations in language. How does London account for this evidence? He argues that such evidence comes from studies that "correlate the activation loci of 'out of key' chords with those found in cases of incongruities of linguistic syntax." For London this raises the question of whether what is shared by music and language processing are simply resources for "dealing with surprises/incongruities of any sort that occur in higher-level auditory scene analysis".

There are two problems with this idea. First, while many comparative music-language studies have employed structural incongruities in the two domains, at least one study has used well-formed sentences without any linguistic incongruities (Federenko et al., 2009). In this study, syntactic processing demands in language were manipulated by changing the structure of a relative clause within fully grammatical sentences. Hence music-language interactions in this study cannot be attributed to shared mechanisms for dealing with incongruities in sequences.[1] Second, some studies that employ structural incongruities in both domains have also employed psychoacoustic incongruities to control for general "surprise" effects (e.g., Koelsch et al., 2005; Fedorenko et al., 2009; Slevc et al., 2009). For example, Slevc et al. (2009) showed that an unexpected out-of-key chord interfered with the syntactic processing of a sentence, while an unexpected out-of-timbre (but in key) chord did not have this effect. These results do not support the idea that music and language simply share processing resources for dealing with "incongruities of any sort" in higher-level auditory scene analysis.

I suspect London would have interesting responses to my comments above, and that his future ideas in this area (like his current contribution) will help me refine my own thinking. More generally, I believe that a lively dialogue between skeptics and proponents of music-language syntax relations, with both sides well informed about theory and empirical data, is essential for progress on this complex and fascinating topic.

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References

DeLong, K., Urbach, T., & Kutas., M. (2005). Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. *Nature Neuroscience,* 8, 1117-1121.

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[1] It should also be noted that not all neural studies of musical syntax have used out-of-key chords. For example, Koelsch et al. (2007) showed the early right anterior negativity (ERAN) can be elicited by a structurally unexpected in-key chord.

Fedorenko, E., Patel, A.D., Casasanto, D., Winawer, J. & Gibson. E. (2009). Structural integration in language and music: Evidence for a shared system. *Memory & Cognition*, 37, 1-9.

Freeman, W.J., Ahlfors, S.P., & Menon, V. (2009). Combining fMRI with EEG and MEG in order to relate patterns of brain activity to cognition. *Intl. Journal of Psychophysiology*, 73, 43-52.

Gibson, E. (2006). The interaction of top–down and bottom–up statistics in the resolution of syntactic category ambiguity. *Journal of Memory and Language*, 363-388.

Grahn, J.A. (this volume). Advances in neuroimaging techniques: implications for the shared syntactic integration resource hypothesis. In: *Language and Music as Cognitive Systems*. P. Rebuschat, M. Rohrmeier, J. Hawkins, & I. Cross (Eds.). Oxford: Oxford University Press.

Huron, D. (2006). *Sweet Anticipation: Music and the Psychology of Expectation.* Cambridge, MA: MIT Press.

Jackendoff, R. (2009). Parallels and nonparallels between language and music. *Music Perception*, 26, 195–204.

Jentschke, S. & Koelsch, S. (2009). Musical training modulates the development of syntax processing in children. *NeuroImage*, 47, 735-744.

Koelsch, S. (this volume). Response to target article "Language, music, and the brain: a resource-sharing framework" from Aniruddh D. Patel. In: *Language and Music as Cognitive Systems*. P. Rebuschat, M. Rohrmeier, J. Hawkins, & I. Cross (Eds.). Oxford: Oxford University Press.

Koelsch, S. (2009). Music-syntactic processing and auditory memory: Similarities and differences between ERAN and MMN. *Psychophysiology*, 46, 179–190.

Koelsch S., Gunter T.C., Wittforth, M., & Sammler, D. (2005). Interaction between syntax processing in language and music: An ERP study. *Journal of Cognitive Neuroscience*, 17, 1565-1577.

Koelsch, S., Jentschke, S., Sammler, D., & Mietchen, D. (2007). Untangling syntactic and sensory processing: An ERP study of music perception. *Psychophysiology*, 44, 476–490.

Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, 106, 1126-1177.

London, J. (this volume). Schemas, not syntax: A reply to Patel. . In: *Language and Music as Cognitive Systems*. P. Rebuschat, M. Rohrmeier, J. Hawkins, & I. Cross (Eds.). Oxford: Oxford University Press.

Meyer, L. B. (1956). *Emotion and Meaning in Music.* Chicago: University of Chicago Press.

Patel, A.D. (2003). A new approach to the cognitive neuroscience of melody. In: *The Cognitive Neuroscience of Music*. I. Peretz and R. Zatorre (Eds.), pp.325-345. Oxford: Oxford Univ. Press.

Patel, A.D. (2008). *Music, Language, and the Brain.* NY: Oxford University Press.

Patel, A.D. (this volume). Language, music, and the brain: A resource-sharing framework. In: *Language and Music as Cognitive Systems.* P. Rebuschat, M. Rohrmeier, J. Hawkins, & I. Cross (Eds.). Oxford: Oxford University Press.

Patel, A. D., Gibson, E., Ratner, J., Besson, M., & Holcomb, P. (1998). Processing syntactic relations in language and music: An event-related potential study. *Journal of Cognitive Neuroscience*, 10, 717–733.

Patel, A.D., Iversen, J.R., Wassenaar, M., & Hagoort, P. (2008). Musical syntactic processing in agrammatic Broca's aphasia. *Aphasiology*, 22, 776-789.

Sammler, D. (2009). The Neuroanatomical Overlap of Syntax Processing in Music and Language: Evidence from Lesion and Intracranial ERP Studies. *MPI Series in Human Cognitive and Brain Sciences*, 108.

Slevc, L.R., Rosenberg, J.C., & Patel, A.D. (2009). Making psycholinguistics musical: Self-paced reading time evidence for shared processing of linguistic and musical syntax. *Psychonomic Bulletin and Review*, 16, 374-381.

Steinbeis, N. & Koelsch., S. (2008). Shared neural resources between music and language indicate semantic processing of musical tension-resolution patterns. *Cerebral Cortex*, 18, 1169-1178.