

Music and the brain: three links to language

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Introduction

A major theme in the neuroscience of music over the past decade has been the existence of specialized cognitive and neural mechanisms involved in music processing (Peretz & Coltheart, 2003). Research with brain damaged patients has been particularly important in demonstrating that music involves a neurocognitive system with many components, and that certain components can be selectively damaged without obvious effects on other cognitive abilities. These findings point to some degree of brain specialization for music, specialization that emerges even in the absence of any explicit musical training (Bigand & Poulin-Charronnat, 2006).

One can recognize that music is a unique confluence of component abilities, yet still search for connections between music cognition and processes involved in other cognitive domains, such as language, visuospatial thinking, or mathematics. Such comparative work can be revealing about the mechanisms underlying music processing, and can provide new avenues for exploring how these mechanisms work in the brain.

The goal of this chapter is to acquaint the reader with some of the evidence for links between music and language, and to encourage further exploration along these lines (see Patel, 2008 for a fuller treatment). The focus is on perceptual processes, and on links between mechanisms involved in the processing of instrumental music and of ordinary, day to day language.

Sensory encoding of sound

There is growing evidence that musical abilities and training have repercussions for language skills. For example, musical abilities predict unique variance in the ability to perceive and produce subtle phonetic contrasts in a second language (Slevc & Miyake, 2006) and in the reading abilities of young children in their first language (Anvari et al., 2002). Furthermore, musical training enhances the ability to interpret affective prosody (Thompson et al., 2004). Are these benefits simply a non-specific consequence of musical training on attention and executive functioning, or are there more specific links between musical abilities and language processing? Support for the latter view has emerged recently via neuroscientific investigations of brainstem encoding of sound. These studies suggest that musical abilities and/or training sharpen the brain's encoding of linguistic sound at a very early stage of processing.

The human brainstem contains many subcortical processing nuclei, which perform a significant amount of neural processing before sound reaches the cortex. Importantly, these lower brain centers are connected to cortical areas via both bottom-up and top-down connections (cf. Figure 1 of Patel & Iversen, 2007). The latter ("corticofugal") connections provide one possible mechanism by which long term auditory experience may influence early brain responses to sound, via mechanisms of neural plasticity.

Wong et al. (2007) first demonstrated an influence of musical abilities on linguistic sound encoding. These researchers examined the processing of linguistic pitch contours in Mandarin Chinese syllables by musically trained and untrained native English speakers (neither of whom was familiar with Mandarin). The participants listened passively to Mandarin monosyllables with different lexical tones while their brainstem

responses were recorded using electroencephalography (EEG). The researchers found that the musicians showed superior brainstem encoding of the linguistic pitch patterns. They also found a positive correlation between the quality of sensory encoding and amount of musical training, suggesting a role for musical experience (rather than innate differences between musicians and nonmusicians) in shaping the sensory encoding of linguistic sound.

An impact of musical abilities on linguistic pitch processing seems intuitively plausible because music places strong demands on the control and/or perception of pitch. However, speech also makes extensive use of structured auditory patterns not based on pitch (e.g., timbre-based differences between phonemes). Do musical abilities have any impact on the sensory encoding of timbre-based aspects of language sounds? Recent results by Musacchia et al. (2007) address this issue. Like Wong et al. (2007), these researchers measured auditory brainstem responses to speech using EEG, but this time to a familiar English syllable (“da”) with no salient pitch variation. They found that musicians had earlier brainstem responses than nonmusicians to the onset of the syllable. Interestingly, when the syllable was presented as a multimodal event (sound + video of a face saying the syllable), the latency of the brainstem response was shortened for both musicians and nonmusicians, but the musicians still showed an earlier response than the nonmusicians. The authors suggest that this difference in response latency indicates that musicians had more synchronous neural responses to sound onset, which is a sign of a high-functioning peripheral auditory system.

The superior encoding of linguistic sounds by musicians may be one possible mechanism underlying the linguistic benefits of musical abilities (cf. Tallal & Gaab, 2006; Patel and Iversen, 2007). These findings may also be relevant to research which has examined the impact of musical training on the cortical processing of linguistic pitch patterns. These studies have examined how well individuals can detect a deviation in voice fundamental frequency (F0) at the end of a spoken utterance. Using EEG, these studies have focused on cortical event related potentials (ERPs) which occur with a latency of a few hundred milliseconds after the onset of the deviant event. Research with French-speaking adults (Schön et al. 2004) and 8-year old children (Magne et al., 2006) has shown that musically trained listeners are better at detecting such deviations, and show enhanced cortical ERPs to these events. In fact, even when listening to sentences in a foreign language (Portuguese), French adults with musical training are better at detecting such deviations, and show substantially shorter latency in their cortical ERPs to those deviations (Marques et al., 2007). One notable finding of this line of research is that the influence of musical training on cortical responses emerges remarkably quickly: 8-year old children with just 8 weeks of musical training differ from their musically untrained counterparts in their cortical ERPs to intonational deviations in speech (Moreno & Besson, 2006).

Further work is needed to clarify the relationship between subcortical and cortical enhancements to linguistic sound processing associated with musical training. Since connections in the auditory pathway flow both bottom-up and top-down, experimental studies are needed to disentangle patterns of cause and effect at different levels of the nervous system as the brain changes in response to musical training. Ideally, such studies would measure subcortical and cortical ERP responses to linguistic pitch patterns within the same individuals as they undergo musical training programs, and relate these

measures to behavioral performance on pitch-related language tasks. Baseline measures of brain responses to linguistic sound (prior to musical training) would be desirable, to show that differences between musically trained and untrained groups are not present prior to training (cf. Norton et al., 2005).

Processing of melodic contours

Humans readily recognize a pitch pattern transposed upward or downward in frequency (e.g., the same melody played on a piccolo or a tuba). This sensitivity to relative (vs. absolute) pitch patterns seems commonplace to us, yet a cross-species perspective reveals that this is a rare ability (McDermott & Hauser, 2005). Most birds and nonhuman primates, for example, gravitate to absolute pitch cues in identifying pitch sequences, and extensive training is often needed before sensitivity to relative pitch can be demonstrated.

This specialization in human brains for sensitivity to relative pitch may be related to the importance of relative pitch in spoken intonation. A listener needs to be able to hear the similarity of intonation patterns when spoken in different pitch registers. For example, a child learning English needs to understand that a rising pitch at the end of an intonation contour can signal a question, whether the utterance is produced by another child or by an adult (with a much lower average F0). Similarly, the child needs to learn that a salient pitch excursion on a word in a sentence signals that the speaker is trying to put focus on that word (as in “give me the RED toy”), even though the precise size of the pitch excursion may differ from one speaker to the next. Thus speech intonation perception requires processing of melodic contour: the general patterns of up and down in a pitch sequence, independent of exact interval sizes or absolute pitch height (Dilley, 2005).

Many experiments on music have shown that melodic contour is an important component of music perception. For example, Dowling and colleagues have shown that melodic contour (vs. the pattern of precise intervals in a melody) plays a role in immediate memory for unfamiliar melodies among adults, (e.g., Dowling et al., 1995). Furthermore, melodic contour is one of the first aspects of music to be discriminated by infants, (Trehub et al., 1984), and 5-year old children rely heavily on contour in melody perception (Schellenberg & Trehub, 1999). Studies of patients with brain damage indicate that the right superior temporal gyrus plays an important role in musical melodic contour perception (Peretz & Zatorre, 2005, but cf. Stewart et al., 2008).

Given the importance of melodic contour in both speech and music, it is natural to ask whether melodic contours are processed by similar brain mechanisms in the two domains. Early evidence for this idea was provided by Patel et al. (1998), who studied two individuals with acquired amusia subsequent to cortical brain damage. The amusics were tested for their ability to discriminate between sentences that differed only in their intonation contour. Two types of sentence pairs were tested. In “statement-question” pairs, the intonation contours differed at the end of the sentence (e.g., “He likes to drive fast cars” spoken with a pitch fall or rise on “cars”). In “focus-shift” pairs, the intonation contours differed within the sentence (e.g., “Go in front of the bank, I said” spoken with a salient pitch accent on “front” or “bank”). The amusics were also tested for their ability to discriminate tone sequence analogs of intonation patterns. These analogs were created by replacing each syllable in a sentence with a tone whose pitch

was fixed at the frequency midway between the highest and lowest F0 of the syllable. Discrete tones were used rather than gliding tones (which would mimic intonation contours more precisely) in order to make the stimuli more music-like. The salient finding from this study was that for both amusics, performance on the linguistic intonation task was very similar to performance on the tone sequence task, suggesting shared processing of melodic contours across the two domains. (One amusic, whose problem was primarily with recognition of familiar music, did well on both tasks, while the other amusic, who had more basic problems with perception and discrimination of musical patterns, did poorly on both tasks.) Examination of the lesion profiles of the amusics suggested that right inferior frontal brain areas were important for the task of remembering and discriminating melodic contours (cf. Zatorre, 1994).

In contrast to these findings, subsequent research with musically tone-deaf individuals painted a different picture. Before discussing this work, it is worth briefly describing musical tone deafness (or congenital amusia). Congenital amusia (henceforth, “amusia”) is not due to brain damage and appears to be developmental in origin. Amusic individuals report lifelong problems with music perception. (Note that it is important to distinguish amusia from the informal label of “tone-deafness” that many people apply to themselves, usually to indicate that they do not sing well, cf. Cuddy et al., 2005). For example, amusics have difficulty judging if two melodies are the same or different, in detecting when music is out of key (including their own singing), and in recognizing what should be familiar tunes from their culture (Ayotte et al., 2002). These problems cannot be attributed to hearing loss, lack of exposure to music, or to any obvious nonmusical social or cognitive impairments. The core deficit in this disorder concerns pitch processing (Foxton et al., 2004; Hyde & Peretz, 2004). It appears that there is a genetic basis for this disorder (Drayna et al., 2001; Peretz et al., 2007), and evidence from neuroimaging has revealed specific structural differences between normal and amusic brains in right inferior frontal cortex and right superior temporal gyrus, as well as in left frontal and temporal cortical areas (Hyde et al., 2007; Mandell et al., 2007).

Amusia presents an excellent opportunity to study the relationship between melodic contour processing in speech and music. Ayotte et al. (2002) first examined speech intonation perception in congenital amusia, using the stimuli and methods of Patel et al. (1998). The amusics had no problem discriminating sentences with different intonation contours. In contrast, they had difficulty discriminating the tone sequence analogs of intonation. These results suggested that amusics were unimpaired in speech intonation perception, and prompted Peretz & Coltheart (2003) to include melodic contour analysis as a domain-specific aspect of musical processing, not shared with speech.

Subsequent work, however, has re-opened the issue of speech intonation perception in amusia. Lochy et al. (2004) tested a group of amusics using methods very similar to those of Ayotte et al. (2002), but with different results. This time, about 30% of the amusics had significant difficulty discriminating linguistic statements from questions, whereas they did well discriminating sentences with focus on different words. The critical difference between these tasks is that the statement-question task requires discriminating the direction of pitch movement on the same word (up versus down), whereas the focus-shift task simply requires detecting a salient pitch movement within a sentence, because different words bear the large movement in the two members of a

focus-shift pair. That is, sensitivity to the direction of pitch movement is irrelevant to the focus-shift task: As long as one can detect a pitch change, and can remember that this change happened on the same or different words in the two sentences, one can solve the task.

These findings were intriguing because psychophysical work on amusia has revealed a salient deficit for the perception of pitch direction (Foxton et al., 2004; Griffiths et al., 2007). That is, an amusic individual may be able to detect that pitch has changed, but not be able to discriminate an upward from a downward change. Lochy et al.'s findings suggest that such direction discrimination deficits may be relevant for speech intonation perception. Given the differences between the findings of Ayotte et al. (2002) and Lochy et al. (2004), it is important to determine which results replicate. Recently, Patel et al. (2008) replicated Lochy et al.'s findings with a different group of amusics, finding that about 30% had problems with statement-question discrimination but not focus-shift discrimination. Notably, this replication occurred in a different language (English-speaking amusics, vs. the French-speaking amusics of Lochy et al.). An important question raised by the results of Lochy et al. (2004) and Patel et al. (2008) is why only a subset of amusics (~30%) exhibit intonation perception deficits. Does this subset have a qualitatively different kind of deficit from amusics without such problems, or are they simply at the end of a continuum such that all amusics would show intonation perception problems if pitch contrasts are made subtle enough? These questions await further research, but the current findings are sufficient to indicate that melodic contour processing in speech and music may in fact have overlapping neural substrates.

Syntactic processing

Music and language involve hierarchically structured sequences built from basic units via rich combinatorial principles. That is, both are syntactic systems. Native listeners have implicit knowledge of these combinatorial principles, knowledge which requires no formal training and which can readily be demonstrated via judgments of the well-formedness of novel sequences and via a range of implicit tasks (Bigand & Poulin-Charronnat, 2006).

Despite these general similarities, however, it is also clear that musical and linguistic syntax differ in important ways. For example, fundamental grammatical categories in language (such as nouns and verbs) have no analog in music, and the function of linguistic syntax in indicating “who did what to whom” also has no musical parallel. Instead, (Western) musical syntax is based on selecting a set of seven discrete pitches within each octave and creating a musical “key” by using these pitches in such a way that a hierarchy of structural importance is created among them. This leads to certain pitches and chords being perceived as more stable than others. These stable elements act as cognitive reference points, with one (the tonic note or chord) being the most stable (Krumhansl, 1990). This syntax functions to build patterns of tension and resolution in musical sequences (Lerdahl & Jackendoff, 1983, Lerdahl & Krumhansl, 2007). Thus it is clear that musical syntax is not simply a trivial variant of linguistic syntax.

For many years, the evidence from neuroscience seemed to favor the independence of musical and linguistic syntax in the brain. Specifically, research on the

neuropsychology of music provided clear cases of dissociations between linguistic and musical syntactic abilities following brain damage. For example, Peretz (1993) documented a case of a non-aphasic man with bilateral temporal lobe damage (due to strokes) who lost sensitivity to musical key, even though his basic perception of pitch patterns was intact. This is one of several well-documented cases of “amusia without aphasia” (cf. Marin & Perry, 1999).

Yet in direct contrast to these findings, neuroimaging research has pointed to overlap in the syntactic processing of language and music. An early study which directly compared brain responses to musical and linguistic syntactic processing in the same individuals was conducted by Patel et al. (1998). The researchers used ERPs to compare brain responses (from musicians) to linguistic syntactic and musical syntactic incongruities. The linguistic incongruities involved manipulations of phrase structure in sentences, and the musical incongruities involved out-of-key chords in chord sequences. The linguistic incongruities generated a late positive ERP component known as the P600, previously known to be associated with syntactic processing in language (Osterhout & Holcomb, 1993). The main finding of interest was that the out-of-key chords generated a P600 which was statistically indistinguishable from the “linguistic” P600. The authors interpreted this to mean that processes involved in syntactic integration were shared across the two domains. In addition to the P600, out-of-key chords also elicited an early right anterior-temporal negativity (RATN) which had not been reported in previous neuroimaging studies of music. The functional significance of this component was not well understood, though it was thought to be involved in musical syntactic processing.

Subsequent ERP work by Koelsch et al. (2000) examined brain responses to out-of-key chords in nonmusicians, and found an early right anterior negativity (ERAN), which had a shorter latency than the RATN and a more anterior and bilateral scalp distribution. Many subsequent studies by Koelsch and colleagues have found the ERAN to be reliably elicited by structurally unexpected chords, in both musicians and nonmusicians, and in the absence of any task related to detecting these chords¹. Furthermore, elicitation of the ERAN does not require the use of an out-of-key chord: it can also be elicited by a structurally unexpected chord from within the key of the preceding sequence. This rules out auditory sensory incongruity as the driving force behind the elicitation of this component (Koelsch et al., 2007).

What is the relationship between the ERAN and the RATN? As suggested by Koelsch & Siebel (2005), it seems likely that they represent the same underlying brain process, and that the earlier latency of the ERAN is related to the temporal predictability of the chord sequences that have typically been used in studies of the ERAN. That is, most such research has used isochronous sequences of chords, rendering the temporal onset of each successive chord quite predictable in time. In contrast, when more temporally variable musical contexts are used (as in Patel et al., 1998, and Koelsch and Mulder, 2002), an early right negative component is elicited that is more similar to the RATN in latency and scalp distribution. Thus the precise latency and distribution of early right negativities to music is likely to be subject to rhythmic influences.

More interesting from the current standpoint are questions about the relationship of the ERAN to brain mechanisms involved in linguistic syntactic processing. Using MEG, Maess et al. (2001) localized the generators of the ERAN to Broca’s area and its right hemisphere homolog, suggesting an overlap with language processing. Other

research using fMRI also implicated Broca's area in the processing of syntactic (harmonic) structure in music (e.g. Tillmann et al., 2003). Yet the neuroimaging evidence for overlap between linguistic and musical syntax stood in sharp contrast to evidence from neuropsychology for dissociations between linguistic and musical syntactic abilities following brain damage, as discussed above. Thus it became clear that a theoretical framework was needed which could accommodate both the neuroimaging evidence (for overlap) and the neuropsychology evidence (for dissociation).

Patel (2003) proposed one such framework based on the idea that language and music have distinct and domain-specific syntactic representations (such as words and their syntactic features in language, and chords and their harmonic relations in music), but that activating these representations as part of online processing draws on a common pool of limited neural resources. This idea was termed the "shared syntactic integration resource hypothesis" (SSIRH). The SSIRH posits that linguistic and musical syntactic representations are stored in distinct brain networks (and hence can be selectively damaged), whereas there is overlap in the networks which provide neural resources for the activation of stored syntactic representations. It was hypothesized that such resources are needed when dealing with difficult structural integrations, because such integrations require the rapid and selective activation of items with low activation levels in representation networks (e.g., structurally unexpected words or chords).

How does this proposal map onto neural architecture? At the moment the answer to this question is not known. In its original formulation, the SSIRH combined the functional proposal outlined above with a rough localizationist proposal, namely that that neural resources reside in frontal brain regions, while syntactic representations reside in posterior regions. Hence syntactic processing is conceived of as involving the reciprocal interaction of fronto-temporal regions (cf. Tyler & Marslen-Wilson, 2008). Further research using localizationist techniques (such as fMRI) are needed to address this issue.

A principal motivation for developing the SSIRH was to generate predictions to guide future research into the relation of linguistic and musical syntactic processing. One salient prediction regards the interaction of musical and linguistic syntactic processing. In particular, because the SSIRH proposes that linguistic and musical syntactic integration rely on common neural resources, and because syntactic processing resources are limited (Gibson, 2000), it predicts that tasks that combine linguistic and musical syntactic integration will show interference between the two. In particular, the SSIRH predicts that difficult harmonic integrations in music will interfere with concurrent difficult syntactic integration in language (Patel, 2003). This idea can be tested in paradigms in which a harmonic and a linguistic sequence are presented together and the influence of harmonic structure on syntactic processing in language is studied.

Koelsch et al. (2005) conducted one such study, in which short sentences were presented visually in a word-by-word format simultaneously with musical chords, with one chord per word. In some sentences, the final word created a grammatical violation via a gender disagreement (The sentences were in German, in which many nouns are marked for gender. An example of a gender violation used in this study is: *Er trinkt den kühlen Bier*, "He drinks the_{masculine} cool_{masculine} beer_{neuter}). The chord sequences were designed to strongly invoke a particular key, and the final chord could either be the tonic chord of that key or an unexpected out-of-key chord from a distant key (e.g., a D-flat major chord at the end of a C-major sequence). The participants (all non-musicians)

were instructed to ignore the music and simply judge if the last word of the sentence was linguistically correct.

Koelsch et al. focused on early ERP negativities elicited by syntactically incongruous words and chords. Previous research on language or music alone had shown that the linguistic syntactic incongruities were associated with a left anterior negativity (LAN), while the musical incongruities were associated with an ERAN (Gunter et al., 2000; Koelsch et al., 2000). For their combined language-music stimuli, Koelsch et al. found that when sentences ended grammatically but were accompanied by an out of key-chord, a normal ERAN was produced. Similarly, when chord sequences ended normally but were accompanied by a syntactically incongruous word, a normal LAN was produced. The question of interest was how these brain responses would interact when a sequence had simultaneous syntactic incongruities in language and music. The main finding was that the brain responses were not simply additive. Instead, there was an interaction: the LAN to syntactically incongruous words was significantly *smaller* when these words were accompanied by an out-of-key chord, as if the processes underlying the LAN and ERAN were competing for similar neural resources. In a control experiment, Koelsch et al. showed that this was not due to general attentional effects because the LAN was not influenced by a simple auditory oddball paradigm involving physically deviant tones on the last word in a sentence. Thus the study supported the prediction that tasks which combine linguistic and musical syntactic integration will show interference between the two processes. Further behavioral studies by Slevc et al. (2007) and Fedorenko et al. (2007) using simultaneous presentation of sentences and musical sequences have provided additional evidence for the interaction of linguistic and musical syntactic processing, even in the absence of any explicit music-related task (cf. Patel [in press] for descriptions of these studies). Like the study of Koelsch et al. (2005), these studies have included control conditions to check that the interactions observed are not simply due to attentional factors.

One line of research which awaits exploration involves within-subjects comparisons of syntactic processing in language and music using fMRI. Such work could help localize shared resource networks for syntactic integration within specific regions of the brain.

Future directions

This chapter has discussed three points of contact between music and language processing in the brain. Many other areas of possible overlap await investigation, including the neural mechanisms involved in processing phrase boundaries, and the mechanisms involved in the affective appraisal of musical and linguistic sequences (for further discussion of these topics, see Patel, 2008). Another little-explored area concerns the relationship between the neural mechanisms involved in the generation of novel linguistic and musical sequences (cf. Brown et al., 2006).

Conclusion

The extent to which music processing overlaps with mechanisms used in other cognitive domains is an active area of research and debate (e.g., Peretz, 2006; Patel, 2008). One

fertile line of work that has grown out of this debate concerns relations between music and language processing. The evidence reviewed in this chapter suggests that music and language may have a number of common processes which act on distinct types of information, e.g., on musical melodies vs. linguistic intonation contours, or on chord progressions vs. sequences of words. Thus the distinction between the domain specificity of information vs. the generality of processing is an essential conceptual tool for research that examines the relationship between music and other cognitive domains (cf. Massaro, 1998 for an application of this distinction to the study of speech processing).

Comparative music-language research is still in its infancy. The ultimate promise of such work is not simply to resolve debates over modularity, but to gain a deeper understanding of the mechanisms humans use to make sense out of sound. This requires doing justice to both the differences and the similarities between the domains.

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Notes

1. Another ERP component that is often elicited by out-of-key chords is a negativity peaking around 500 ms after the onset of the target chord (the “N500”). For possible links between mechanisms involved in this brain response and in language processing, see Steinbeis & Koelsch, 2008.

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