Music and the self

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As we pass through life we interact with and experience music in many ways. Sometimes we pay attention to it; other times we do not. Often we move along with music, not only as performers but also as engaged listeners who tap their feet, bob their heads, or simply follow the music with their minds. Perhaps for most, music intertwines itself with our life narratives. Hearing songs from our past often evokes vivid memories and strong emotions (Sloboda and O'Neill 2001, Juslin and Laukka 2004, Janata et al. 2007). Given the many ways in which we experience music, and the central role it plays in cultures around the world, one is drawn to the questions of why music engages the human brain so strongly and how it is that the brain enables these various forms of musical experience? Part of answering these questions depends on understanding what constellations of brain areas might allow music to interact so profoundly with the self. In other words, what are the brain areas that allow music to move us or to evoke such strong memories?

In this article I suggest a context for thinking about these questions. The context is derived from the broader neuroimaging literature and it emphasizes the contrapuntal roles of two classes of brain networks, one for engagement with the external world and the other for engagement with one's own thoughts, memories, and emotions.

8.1. A network for external engagement

The best studied and understood of the networks is the network generally associated with cognitive functions of language, semantics, working memory, imagery, attention, error-monitoring, and preparation of near-term action sequences (see Cabeza and Nyberg 2000, Corbetta and Shulman 2002, Janata and Grafton 2003, Ridderinkhof et al. 2004, Rushworth et al. 2004 for reviews). The principal regions of this network are parietal areas around the intra-parietal sulcus (IPS), and regions surrounding the inferior frontal gyrus, in particular dorsolateral prefrontal cortex (DLPFC) and ventrolateral prefrontal cortex (VLPFC). This area is commonly known as Broca's area and serves a variety of sequencing functions (Fiebach and Schubotz 2006). The action portions of this network include both medial areas – the supplementary motor area (SMA) and pre-SMA – and lateral premotor cortex (PMC) (Fig. 1).

A simpler way of conceptualizing the functions of this network is in terms of a "perception/action" cycle, shown in abstract form in Fig. 2 and in neuroanatomical form

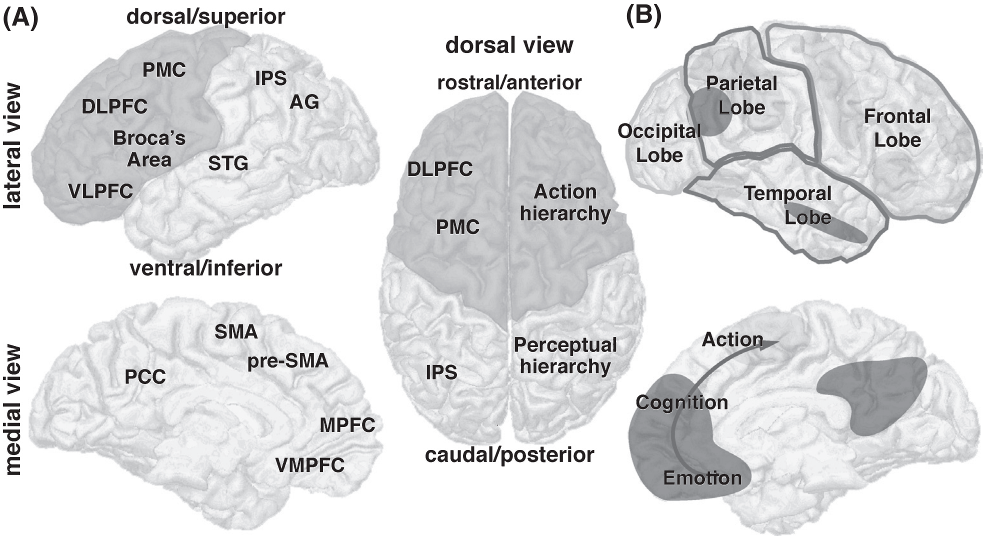

Fig. 1:
A guide to the cortical areas and organization principles discussed in the text, presented on lateral, medial, and dorsal views of the cortical surface of a human brain. (A) The large regions that are shaded pink (anterior) and violet (posterior) represent the gross functional division between action and perception areas of the brain, respectively (adapted from Fuster 2004). PMC – premotor cortex; DLPFC – dorsolateral prefrontal cortex; VLPFC – ventrolateral prefrontal cortex; STG – superior temporal gyrus; IPS – intraparietal sulcus; AG – angular gyrus; MPFC – medial prefrontal cortex; VMPFC – ventromedial prefrontal cortex; SMA – supplementary motor area; PCC – posterior cingulate cortex. (B) The different lobes of the brain are depicted in the lateral view. The light and dark gray patches demarcate a functional distinction between brain areas generally engaged by externally and internally directed attention, respectively (adapted from Fox et al. 2005, Raichle and Gusnard 2005). An action gradient is depicted by the arrow extending from VMPFC to the SMA, with VMPFC being associated primarily with emotional appraisals and motivation, more dorsal parts of the MPFC associated with more cognitive aspects of evaluation and action selection and planning, and the pre-SMA and SMA associated with the planning of imminent action sequences.

in Fig. 1A. The concept of the perception/action cycle captures the fact that natural behaviors unfold in time and rely on an interaction between our perception of the world around us and our actions in response to those perceptions. For example, as a violinist draws

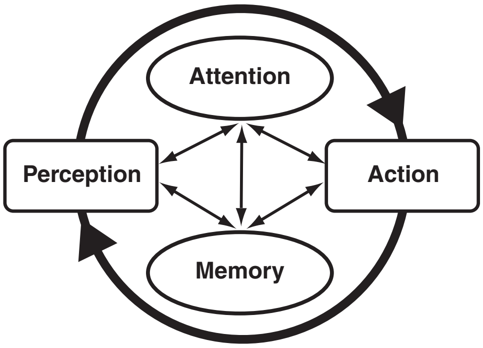

Fig. 2:
An abstract view of perception/action cycles that emphasizes the importance of attention and memory systems that interact with each other and may be biased either towards perceptual or action processes, depending on the goals of the behavioral situation.

her bow across a string, she may adjust the pressure in response to the sound she hears so that she can achieve the desired loudness or tone. Figure 2 also symbolizes that the iterations of the perception/action cycle are shaped by attention and memory processes. We can focus our attention to listen for specific features in a melody and we can do so either by virtue of familiarity with the specific melody or general familiarity with western tonal music, or the style of the melody. Alternatively, we can focus our attention on the action side of things, for example, when we sing or play a melody from memory with the desired phrasing.

The embodiment of a perception/action cycle is illustrated in Fig. 1A. In simplest terms, the back of the brain is involved in sensation and perception, whereas the front half of the brain is involved in the structuring of action. This idea has been articulated in considerable detail by Joaquin Fuster, one of the pioneering researchers of the frontal lobes (Fuster 2000, 2004). Of course, the situation is not quite that dichotomous, and both perception and action influence each other at multiple levels within those processing streams. One example of perception activating motor systems is the existence of neurons referred to as “mirror neurons” which, despite their location in premotor areas, respond to observed actions (Preston and de Waal 2002). An example of action systems influencing sensory systems is evidence that sensory cortices are activated during mental imagery tasks (Zatorre and Halpern 2005). The role of premotor cortices in the uniting of perception and action is nicely elaborated in a recent review article by Ricarda Schubotz (2007). The relevance of these systems to music will be reviewed in more detail below.

8.2. A network for internal engagement

For a long time, researchers whose experiments activated elements of the network for external engagement described above were puzzled by decreases in activation during task performance in a different set of brain areas. These deactivations were associated primarily with considerable sections of the medial wall – the region of cortex that is tucked between the two hemispheres – stretching from the posterior cingulate cortex (PCC) and precuneus area of the parietal cortex in the back of the brain, all the way to ventromedial prefrontal cortex (VMPFC) beneath the corpus callosum in front of the brain (Fig. 1B). Lateral inferior parietal areas are also part of this network. For quite a long time, activity within this network was dismissed as irrelevant to cognition. After all, meandering thoughts and daydreams are difficult to capture and a brain that is not engaged in the task at hand is a brain that is doing nothing of interest. However, due in large part to the interest in the “default-mode” hypothesis (Raichle et al. 2001, Raichle 2005), along with the blossoming of affective and social neuroscience (Lieberman 2007), the functional significance of this network has gained considerable attention over the past five years.

A consensus view that emerges across several recent meta-analyses and review articles is that the areas of this network along the cortical midline are engaged in various forms of self-referential processing (Wicker et al. 2003, Northoff and Bermpohl 2004, Northoff et al. 2006, Gilbert et al. 2006, Schmitz and Johnson 2007, Lieberman 2007). More detailed analyses reveal further functional distinctions within the medial prefrontal cortex (MPFC), though the interpretations of what the underlying processes/functions are for which there is a functional topography depend on the authors' points of view. Not surprisingly, the retrieval and re-experiencing of autobiographically salient information also engages the MPFC (Gilboa 2004, Maquire 2001, Svoboda et al. 2006).

Another way to think about the functional arrangement of the cortical midline in the frontal lobe is in terms of the degree of elaboration of action plans. A hierarchy of action control has been demonstrated in lateral prefrontal cortex, with increasingly specific actions being represented as one progresses from rostral prefrontal cortex to the premotor areas of the caudal prefrontal cortex (Fuster 2004, Koechlin et al. 2003). An argument for such a hierarchy can also be made for the cortical midline. The most posterior regions (the pre-SMA and SMA) are engaged in preparing specific actions and sequences of actions that will be executed in the immediate future, whereas more anterior areas are implicated in motivation and planning of goals and actions that unfold over more extended periods of time (Burgess et al. 2005). Thus, there appears to be a gradient of elaboration of action plans that proceeds from action plans that are largely uncoupled from immediate interactions with the environment to action plans that are part of in-the-moment sensorimotor coupling. One should note that this putative gradient of action elaboration along the cortical midline spans both the "internal" and the "external" networks, with the rostral parts of the MPFC belonging to the former and the pre-SMA and SMA belonging to the latter.

8.3. Music and the two networks

8.3.1 The external network

Numerous neuroimaging studies utilizing musical materials and tasks have demonstrated the engagement of what I like to think of as the "lateral" or "external" network. Most of these studies have been structured as target detection and categorization paradigms or simple listening tasks. A common paradigm for studying implicit knowledge of tonal structures in music is to present a context, either a sequence of chords or a melody, which is then followed by a target event. In some studies, subjects make some sort of explicit judgment about the target event whereas in studies that look at automatic processing of musical events the target events are ignored. Memory tasks in which a target pitch is compared with the pitches of a short melody have also been used. Overall, these studies have found involvement of elements of the "external" network, including the auditory cortex in the temporal lobe, the supramarginal and angular gyri in the parietal cortex, as well as ventrolateral and dorsolateral prefrontal cortex (Zatorre et al. 1994, Koelsch et al. 2002, Tillmann et al. 2003, Gaab et al. 2003).

Other types of music studies, including attentive listening to segments of polyphonic music, and a variety of imagery tasks have demonstrated the recruitment of both the parietal and the lateral prefrontal areas, as well as the "action-oriented" nodes of the external network (Janata et al. 2002a, Halpern and Zatorre 1999, Langheim et al. 2002, Meister et al. 2004). Similarly, these areas have been found to be active in studies of music reading and performance (Sergent 1992, Schön et al. 2002, Parsons et al. 2005), and performance of rhythmic tasks (Penhune et al. 1998, Ullen et al. 2003, see Janata and Grafton 2003 for a review). Attentive listening to simple metrical sequences in which the beat is apparent recruits both sensory and premotor portions of the external network, together with the basal ganglia and cerebellum, but without the parietal cortex (Grahn and Brett 2007). In the case of tapping along with a simple isochronous sequence in which the salience of the metric structure is manipulated, the set of brain areas that are involved is reduced even further. Beyond a simple circuit of auditory and motor cortices in conjunction with the cerebellum and thalamus that form the basis for the repetitive finger movement, a small region of auditory cortex and lateral premotor cortex shows an effect of the metric salience (Chen et al. 2006). Thus, a very small subset of the areas involved in the perception/action cycle is recruited for the relatively simple task of finding the beat in a simple auditory sequence.

Taken together, the studies mentioned here as well as numerous others indicate that musical tasks are capable of recruiting different components of the network for externally directed perception and action, and that the patterns of recruitment depend in large part on the perceptual, cognitive, and motoric demands of the task. While this dependence on task demands is in accordance with the ideas of hierarchical organization of perception/action cycles described above, it also indicates that the forms of musical engagement and experience are multi-faceted.

8.3.2 The internal network

In contrast to the studies mentioned above, relatively few studies of music have elicited or commented on activations within the “medial” network. This is somewhat puzzling, because, as I described above, the medial network is important for emotional, social, and self-relevant processes, which music is intimately associated with. On the other hand, it is not surprising insofar as the notion of the perception/action cycle does not encompass the concept of emotion explicitly. To the extent that studies of musical processes are structured as perceptual discrimination or judgment tasks with stimuli that are often brief, abstract, or artificial sounding, i.e. not particularly characteristic of the music we listen to, such tasks are expected to drive areas associated with the perception/action cycle and outwardly directed attention, but not areas involved in the processing of emotions.

The relatively few studies that have examined affective responses to, or required self-relevant judgments about, musical stimuli do, however, reinforce the notion that the medial network serves affective and autobiographical functions. Specifically, in one study, Blood and colleagues (1999) illustrated that the activity in the ventromedial prefrontal cortex (VMPFC) is modulated by the relative amounts of dissonance of harmonic accompaniments of piano arrangements of simple melodies. In another study, Blood and Zatorre (2001) found that the amount of activity in the VMPFC depends on the likelihood of experiencing a chill while listening to self-selected music. Similarly Brown et al. (2004) found that simple listening to unfamiliar but pleasant Greek songs activated VMPFC. A study by Platel et al. (2003) showed that the entire extent of the rostral MPFC was active during a task in which subjects made familiarity judgments about pieces of recorded music. A recent study that explicitly studied music familiarity also found heightened activity with increased familiarity in sections of the RMPFC (Plailly et al. 2007).

Further evidence that suggests that the MPFC mediates affective responses to familiar music comes from a pair of independent observations pertaining to Alzheimer's disease (AD). One of these is primarily anecdotal in nature, although empirical evidence is starting to accumulate (Cuddy and Duffin 2005). The observation is that even in advanced stages of AD, individuals, with whom one would otherwise be unable to have a conversation or normal interaction with, remain very responsive to autobiographically salient music from their past. They may even start singing along and continue singing once the piece of music is turned off. The second observation derives from a neuroanatomical study that examined the degree of atrophy of cortical regions with the progression of AD and found that medial prefrontal and sensorimotor regions of the cortex were those that exhibited the smallest degree of atrophy as the disease progressed (Thompson et al. 2003). In other words, those areas that functional neuroimaging studies show to be relevant for affect and self-relevant representations are also those that are relatively spared over the course of AD.

8.3.3 Coupling of the networks

Given two sets of music studies that find evidence for the activation of either the external or the internal networks, the question remains as to how these networks are actually coupled. At an anecdotal level we know that they must be coupled somehow. After all, we often find moving or dancing along with music to be pleasurable and spontaneous. Certain songs or melodies might remind us of our past, or we might hear an unfamiliar piece of music that nonetheless makes tears come to our eyes.

One suggestion for how these networks might be coupled comes from a study I performed a number of years ago in which the objective was to identify regions of the brain that displayed an organization of the tonal space underlying western tonal music (Janata et al. 2002b). The mechanism for doing this was to have subjects perform two different types of target detection tasks as they listened to a melody that systematically moved through all of the major and minor keys over the course of 8 minutes. Because the movement of a piece of music through tonal space can be modelled quantitatively (Janata et al. 2002b, Toivianen and Krumhansl 2003, Janata 2005, 2008), it is possible to analyze the functional MRI data using a parametric model that captures the dynamics of a piece of music as it traverses tonal space. In other words, the output of the model describes the music much more precisely than does a model that simply indicates that music is either playing or not playing, or even that the music is in G-major or f-minor. The most salient result of this study was the observation that the MPFC consistently followed the pattern of movement through tonal space. Using the more traditional analysis in which we simply modelled subject responses and whether the stimulus was playing or not, we also found that the regions of the external network that I described above were involved as subjects performed the target detection tasks. Thus, in this study we saw evidence that both networks were engaged by the music and task that the subjects were asked to perform.

8.4. Music-evoked autobiographical memories

The tonality-tracking result, together with the studies of affective responses to music, familiarity judgments, and Alzheimer's disease that had been published around that time, led me to hypothesize that parts of the MPFC might be intimately involved in binding music together with autobiographical memories and their associated emotions. To begin addressing this hypothesis I developed a paradigm for characterizing music-evoked autobiographical memories (Janata et al. 2007).

One of the challenges to studying autobiographical memories is finding stimulus material that will reliably evoke autobiographical memories without the aid of the subjects or confederates. In other words, it does not really work to have subjects identify songs that elicit strong memories because the act of doing so will generate a memory that is now directly associated with the experimental context. Additionally, there are many songs that we hear over the course of our lives that may not come to mind when we are asked to remember them. Similarly, we may not know the title of a song or even the artist who performed it, even though it is capable of evoking a strong memory or emotion. The music selection strategy that works well in my laboratory, with a population of UC Davis undergraduate students, is to choose short 30-second excerpts of songs from the Billboard Pop and R & B Top 100 charts. Songs are chosen randomly from a rather broad window of time when the subject was between 7 and 19 years of age. This strategy results in the rating of approximately 50% of the songs as familiar and approximately 30% as autobiographically salient. Upon hearing an autobiographically salient song, subjects provide additional details about the evoked memories with respect to the people, places, events, and emotions that are associated with the memories. In a population of 329 individuals, subjects most commonly reported that they were reminded of friends and periods in their lives. Although the songs sometimes evoke negative emotions, the most common emotion adjectives to be endorsed were positive emotions with rather high arousal, such as “happy”, “youthful”, “excited”, and “energized.” Nostalgia was the 3rd most common emotion. A full report of this study is available elsewhere (Janata et al. 2007).

I have also performed an adapted version of this study using fMRI in order to test the hypothesis outlined above that the MPFC will become more active when autobiographically salient pieces of music are experienced. Preliminary analyses of the data indicate that the experience of music-evoked autobiographical memories does indeed activate portions of the MPFC as well as a broader network implicated in previous studies of autobiographical memory retrieval (Maguire 2001, Svoboda et al. 2006). An extensive report of these data is presented elsewhere (Janata submitted).

8.5. Summary

My objective in this paper was to illustrate how different studies of the neuroscience of music illuminate the relationship between different forms of musical experience and what appear to be domain-general principles of the brain's functional organization. Although considerable attention has been devoted to investigating the parallels between the neural substrates underlying music and language (Patel 2003, Koelsch 2005), the parallels between music and other cognitive or affective functions and behaviors have generally not been emphasized (c.f. Panksepp and Bernatzky 2002). Rather, there has been a tendency, driven largely by the neuropsychological evidence of music-specific deficits, to identify neuroanatomical substrates that uniquely enable musical activities (Peretz and Coltheart 2003, Peretz and Zatorre 2005). While the existence of music-specific deficits associated with patterns of brain lesions is indisputable, it remains possible that there exist domain-general principles of the brain's functional organization at a coarser-grained level that also supports a core set of musical experiences. The principles of the perception/action cycle and attentional networks for internally and externally directed engagement are such coarse-grained principles that encompass significant regions of cortex. It is likely that a finer-grained organization exists within these regions that both provides for domain-specific organization as dictated by the specific mental operations that are necessary to enable domain-specific perception and action, and is shaped by individual life experiences.

Finally, the manner in which the networks for internal and external engagement interact in various musical situations is still poorly understood. While it is clear that we derive pleasure from perceiving and producing music, current neuroimaging paradigms have not been very successful in capturing the dynamic interplay of the two networks described above. It is likely that cognitive neuroscientists will need to rethink the nature of a subject's experience while performing a musical activity in a laboratory setting if progress is to be made in understanding the neural substrates of naturally occurring musical activities that mediate interactions between external sources of music and the self.

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