Brains and Music, Whales and Apes, Hearing and Learning . . . and More

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Abstract:
This article is about whalesongs, hearing, musical brains, and a number of other topics explored over the past 35 years. Previous research is reviewed briefly, and more attention is given to recent efforts with an emphasis on collaborative research conducted with many wonderful colleagues. First is a brief account of the Institute for Music Research at the University of Texas at San Antonio, followed by more details on current projects at the Music Research Institute (MRi) at the University of North Carolina at Greensboro. Research at the MRi is divided into six topics: BioMusic, Music-Related Hearing Loss, Music Education, Music Performance, Ethnomusicology and Ecocriticism, and Neuromusical Research. The second half of the article is devoted to neuromusical research. This line of research includes earlier studies of pianists, conductors, and singers and more recent work on multisensory processing in musicians.
Keywords: *music research, music education research, music research institute, neuromusical research, biomusic, music-related hearing loss*

Article:
I am very pleased to take this occasion to share some of my work over the past 35 years, with a focus on the past several years. Early on I was drawn to a broad, interdisciplinary outlook. Perhaps the simplest way for me to describe an encounter that highly influenced my interest in research is to quote myself from a previous article (Hodges, 2003).

> As a college sophomore, I was assigned a term paper for a class and had chosen the grandiloquent topic "the nature of human musicality." After several weeks of fruitless searching in the library for relevant sources, I scheduled an appointment with Dr. E. Thayer Gaston. Considered by many the father of modern music therapy, Gaston did not teach any undergraduate classes and to a frightened sophomore he was an imposing figure. When I got in to see him and squeaked out my request in a timorous, quivering voice, his response changed my life. Rather than laughing at me, he said: "Son, musicians are like people in love. They're happy but they don't know what they are doing. If you want to understand musical behavior, look to the behavioral scientists—anthropologists, sociologists, psychologists, and biologists—for they are the ones who understand human behavior. And, music is, after all, a form of human behavior that is governed by the laws and principles that govern all human behavior." My encounter with Dr. Gaston began a lifetime of reading and research in what normally falls under the umbrella of "music psychology." (p. 31)

You can read Gaston (1968a, 1968b) for a more formal statement of his ideas, and incidentally, I finally did publish a more mature version of that sophomore paper in a chapter called "Human Musicality" (Hodges, 1996b). What that brief meeting with Gaston did was to launch me into a lifelong journey of exploring the rich, fascinating world of musical behavior. To elaborate on the interdisciplinary nature of my career, the remainder of this article is organized into two primary sections: Music Research Institutes and Neuromusical Research.

Figure 1
Institute for Music Research

Music Research Institutes

I have been fortunate to work with colleagues in two music research institutes. The first was at the University of Texas at San Antonio and the second at the University of North Carolina at Greensboro (UNCG).

In the last 15 years I was at the University of Texas at San Antonio, we established the Institute for Music Research (IMR logo shown in Figure 1; http://imr .utsa.edu/)). The IMR sponsored 2 music–brain conferences (1993, 2000), 2 international music medicine symposia (1994, 1996), 10 music technology conferences (1993–2003), and a music camp for Williams syndrome musicians (1999). Our Web site hosted the CAIRSS (Computer-Assisted Information Retrieval Service System**)** music research database and the *TDML ejournal*, a collection of nearly 300 full-text articles presented at the Technological Directions in Music Learning conferences. The IMR Press published the *Handbook of Music Psychology*, 2nd ed., and *Multimedia Companion CD-ROM*s (Hodges, 1996a); *A Scientific Model of Music in Therapy and Medicine* (Thaut, 2000); and three volumes of the *Young Band Repertoire Project* (Harris, 1996, 1998, 2000). IMR personnel included Susan Bruenger, Mary Ellen Cavitt, Stacey Davis, Scott Lipscomb, Peter Pfordresher, David Sebald, Kim Walls, Rosemary Watkins, and Ken Williams. While at the IMR, I was fortunate to secure $325,000 in grant funding for brain imaging work, described subsequently.

In 2003, I received an opportunity to move to the UNCG, and the next year, we established the Music Research Institute (MRi logo shown in Figure 2) within the School of Music. Our mission is to conduct research that advances the understanding of music and to share new knowledge for the good of society. Toward that end, my colleagues and I conduct research in six different areas: BioMusic, Music-Related Hearing Loss, Music Education, Music Performance, Ethnomusicology and Ecocriticism, and Neuromusical Research. Currently, more than 40 projects have been completed or are under way. Space permits only the most cursory mention here of separate studies; readers interested in specific projects can glean more information by visiting the MRi Web site (http://www.uncg. edu/ mus/mri/index.html) or by contacting the individual authors, whose e-mail addresses are also available on the Web site.

UNCG faculty members who participate in the MRi include, from the School of Music: Aaron Allen, Kelly Burke, Revell Carr, Gavin Douglas, Patricia Gray, Sandra Mace, Rebecca MacLeod, Constance McKoy, Brett Nolker, Patricia Sink, David Teachout, Jennifer Walter; Audiology: Susan Phillips, Denise Tucker; Biology (genetics): Vince Henrich; Communication Sciences and Disorders: Celia Hooper; Psychology, Susan Calkins; Wake Forest University School of Medicine, Advanced Neuroscience Imaging Research Lab: Jonathan Burdette, David Hairston, Joe Maldjian. In the ensuing descriptions, collaborative partners from other institutions are also acknowledged.

Before describing current MRi research, I want to note three qualifications: (a) The research described subsequently includes projects in which the MRi is clearly the principal sponsoring agency, those in which the MRi plays a collaborative role with other agencies, and those in which the MRi is a tangential partner. These latter include studies in which faculty members associated with the MRi have collaborated with colleagues from other institutions and the MRi played a limited or insignificant role. (b) In a similar vein, my own role is threefold. In some projects, I take an active, sometimes primary role; in some projects, I play a collaborative role; and in some projects, I play no other role than that as director of the MRi. (c) In reporting on MRi research, the reader will note the use of *in press* or *submitted* more often than is the normal case. Because the MRi is fairly new, some of the research programs are just now at a point where articles are beginning to appear. Many of these projects have been presented at various conferences, and unless published in proceedings, these are not listed. Many MRi researchers published significantly prior to the establishment of the MRi, and for the most part, these are not cited.

Figure 2
Music Research Institute

BioMusic

BioMusic is an interdisciplinary investigation of musical sounds in all species and the evolutionary basis for musicality (Gray et al., 2001). Patricia Gray heads up this unit of the MRi and its five active projects.

The initial BioMusic project was a traveling museum exhibition on the music of nature and the nature of music, called *Wild Music: Sounds and Songs of Life* (logo shown in Figure 3). Funded by a $2.7 million grant from the National Science Foundation, this exhibition was a collaborative partnership between the MRi (Gray, Co-PI; Hodges, consultant), the Science Museum of Minnesota, the Association of Science and Technology Centers, and the Cornell Laboratory of Ornithology. The exhibition opened in 2007 and will tour for 6 years (2007: St. Paul, Minnesota; Raleigh, North Carolina; Berkeley, California. 2008: Chicago; Muncie, Indiana; Newport News, Virginia. 2009: Ft. Lauderdale, Florida; Louisville, Kentucky; Boston. 2010: Wichita, Kansas; Cleveland, Ohio. 2011–2012: TBA). More information about the exhibition is available at http://wildmusic.org. A number of engaging, interactive programs on sound production and perception, soundscapes, and animal sounds are also posted on this Web site.

BioMusic Formal Education Initiative

Gray and David Teachout received a $330,000 grant from the National Science Foundation for UBEATS (Universal BioMusic Education Achievement Tier in Science), a project to incorporate BioMusic into elementary school curricula. The MRi and North Carolina State University’s Kenan Fellows Program are collaborating to prepare science and music teachers to work in teams, teaching students about biodiversity, acoustics, human evolution, and cultural diversity. UBEATS teams will develop, pilot, and refine curricular materials for students in Grades 2 through 5.

Rhythmic Entrainment in Bonobos

Bonobo apes are our closest primate cousins. Although their language skills have been studied for decades, only recently have their musical capabilities come under scrutiny. Gray and colleagues from the Center for Complex Systems and Brain Sciences at Florida Atlantic University (Gray, Large, Velasco, & Daniels, submitted) have obtained evidence that bonobos are capable of entraining rhythms during improvisational music making with humans, a skill that was previously thought impossible.

Figure 3
Wild Music: Sounds and Songs of Life

Figure 4
A Pianist Wearing a doseBadge

Note: The doseBadge rests on the shoulder, near the ear, and collects information on the sound levels being experienced.

Roger Payne Marine Acoustic Collection

Roger Payne is a world-renowned marine biologist who includes the study of whalesong as a primary research topic. The MRi has entered into a collaborative arrangement with Ocean Alliance, Payne's sponsoring organization, and the Cornell University Macaulay Library to make more than 40 years of Payne's whalesong recordings available for scientific, educational, and musical research and exploration. Access to these recordings should be available on the MRi Web site by summer or fall 2009.

Ashby Dialogues

The university has a fund to support interdisciplinary dialogue, and a group of us were fortunate to receive support for a yearlong discussion group on the topic "Mind, Music, and Language." At the time of this writing, we have met only once, but at that gathering were faculty members from biology, psychology, and philosophy and the School of Music, including musicology, ethnomusicology, music theory, and music education. We are working to recruit others from sociology, anthropology, and elsewhere to future sessions. Members read one or two assigned articles in advance and use those as springboards for discussion at the meetings. In the spring, the group will make a campus-wide presentation at the Center for Critical Inquiry. One desire is that collaborative research projects will emerge from these interdisciplinary exchanges.

Music-Related Hearing Loss

Musicians spend a considerable amount of time in loud environments and thus are vulnerable to the possibility of permanent hearing loss. At the MRi, we work with audiologists to measure sound levels to which musicians are exposed. To do this, we use Cirrus-Research doseBadges that collect average sound levels over time (see Figure 4). We have 17 of these devices, which allows us to put one on a conductor and spread 16 more throughout the ensemble or to let a number of music faculty or students wear them throughout the day.

Environmental Factors

In one study (Phillips, Shoemaker, Mace, & Hodges, 2008), we discovered that more than 50% of our music majors have the beginnings of a hearing decline at 4,000 and 6,000 Hz.

Genetic Factors

Preliminary evidence (Phillips, Henrich, & Mace, 2007) suggests that some individuals have a genetic predisposition for or protection against music-related hearing loss. Efforts are under way to collect a large number of DNA samples from student musicians to increase the database for more rigorous analysis.

Music Practice Rooms

Susan Phillips, audiology, and Sandra Mace, program coordinator for the MRi, measured sound levels in music practice rooms (Phillips & Mace, 2008) and found that many students reach their maximum allowable daily noise dosage in very short periods. For example, one trumpet player reached 100% in a 38-min practice session. Any additional exposure beyond that amount of time (e.g., in rehearsals, listening to an iPod) would put him at risk of permanent hearing loss.

Instrumental Ensembles

Jennifer Walter (in review) measured sound levels in three university bands. She found that 25 of 44 band members who were monitored (57%) reached their maximum dosage during one rehearsal, with dose percentages ranging from 104% to 296%. Brass players were most vulnerable, but some woodwind players and percussionists were also over the maximum allowable dosage. Members of a university basketball pep band, who were monitored while playing for two consecutive games, reached dose percentages from 941% to 5,951% (Mace, unpublished data). Sixteen members of a high school marching band achieved dosages from 327% to 3,925% (Walter, Mace, & Phillips, 2008). Douglas Presley (2007), a doctoral student now at Limestone College, found that percussionists in a drum and bugle corps reached dosages ranging from 898% to 9,455% during a 12-hr rehearsal day. Measurements of professional orchestral players in an opera pit resulted in dosages from 116% to 1,002% (Mace, unpublished data). Currently, data collection is under way with jazz ensembles at several regional universities (Walter & Mace).

Sound Shields

Rebecca Libera, doctoral bassoon performance student, and Mace (in press) have investigated the effectiveness of acoustic sound shields. These large plastic devices are placed behind the head of ensemble members who are seated in front of loud instruments, such as brass or percussion. Libera and Mace have tested three different sound shield designs and discovered that unless the shields are placed within 3 inches of the back of the head, they actually do more harm than good. Sound reflecting on both sides of the shield to players seated in front and behind increases the decibel level.

Hearing Conservation Policy at UNCG

These results are so disconcerting that the School of Music has enacted a Hearing Conservation Policy mandating that every undergraduate music major must have his or her hearing tested once every year he or she remains a music major. Intensive data collection is currently under way, with students wearing doseBadges throughout their routine school days. Logs of daily activities are kept to correlate noise dosages with particular events (e.g., private practice, lessons, rehearsals). Because we have found that more students have a hearing loss in the right ear than the left or bilaterally, many students are wearing two doseBadges, one on each shoulder. Through this means, we hope to determine why there is such a right-lateralized imbalance.

Public School Music Educators

Mace and Patricia Sink (submitted) asked public school instrumental, choral, and general music teachers to wear doseBadges for 2 days to achieve an average of a “typical” day. Noise doses ranged from 6% to 261%, with 10 of 12 instrumental teachers and 1 middle school choral/general teacher over the 100% limit. Middle school string, elementary general, and high school choral teachers were not over the limit. A multiyear project is now under way that will greatly increase the number of teachers studied.

University Music Performance Teachers

Mace (in review) asked 39 performance teachers to wear a doseBadge during 2 typical days; logs were kept of specific activities, such as studio teaching, individual practice sessions, and ensemble rehearsals. The average day was 7 hr and 33 min long, and daily noise dosages ranged from 69 to 93 decibels (dBA). Twelve of the 39 faculty members (32%) were at risk of permanent hearing loss while performing their normal duties. Those at risk included 4 out of 4 brass teachers, 1 of 2 percussion teachers, 2 of 6 woodwind teachers, 3 of 7 voice teachers, 1 of 2 accompanists, and 1 of 2 jazz conductors. None of the string or piano faculty or instrumental or choral conductors were at risk.

Figure 5
Sounds of Learning

Source: NAMM, The International Music Products Association

Music Education

With seven full-time music education faculty members and a number of doctoral students, there is a considerable amount of music education research being conducted at the MRi. Because of space limitations and an emphasis in this article on interdisciplinary work, only minimal mention is made of more conventional studies. Interested readers are encouraged to visit the MRi Web site for more complete information.

Teachout (2004) found that public school music teachers who were considered outstanding candidates for doctoral studies in music education rated “Training young teachers to provide worthwhile educational experiences for their students” (p. 238) as the highest positive influence on making a decision to enter a doctoral program. In a follow-up study, he found that recent doctoral graduates identified “Opportunity to teach at the college level in a tenure-track position” as the highest positive influence on entering and completing a doctoral program (Teachout, 2008). Constance McKoy and colleagues have investigated diversity and cultural competence in music education (Butler, Lind, & McKoy, 2007; McKoy, 2004, 2006, in press; McKoy, Lind, & Butler, in press). They have developed a conceptual model that frames relationships and interactions among variables associated with music teaching and learning in the context of race, ethnicity, and culture.

Brett Nolker (2006) compared individual versus ensemble sight-reading in choral ensembles. He found no significant differences in individual sight-singing scores between students in choirs that received high ratings in sight-singing and students in lower-rated groups. Rebecca MacLeod (in press) found that third- and fifth-grade students who were presented with audio and visual information preferred orchestra and band instruments in the following order: violin, flute, cello, clarinet, saxophone, trumpet, trombone, and horn. Of note is a recent $125,000 grant from the NAMM Foundation (National Association of Music Merchants) that will allow Susan Calkins, psychology department, and MacLeod to investigate the effects of Suzuki violin instruction on executive functioning in 4-year-old students, as monitored via EEG.

"Sounds of Learning: The Impact of Music Education" (Logo shown in Figure 5) is a major research initiative of the NAMM Foundation that examines the roles of music education in the lives of school-age children. Relevant information is posted on the MRi Web site, including Steering Committee members, consultants, funded projects, requests for proposals, an extensive review of related literature, and a fully searchable database with 566 abstracts of relevant research.

To date, more than $800,000 has gone to support 13 music education research projects and more than $1 million overall, including support of a postdoctoral fellow, Debra O'Connell, for 2 years. "Sounds of Learning" is fully committed to a peer-reviewed publication process. The first two projects have been published (Campbell, Connell, & Beegle, 2007; Johnson & Memmott, 2006), and others are currently under review. A sixth round of request for proposals was posted in fall 2008, with funding decisions to be announced in spring 2009. Interested researchers are encouraged to visit the MRi "Sounds of Learning" Web site (http://www.uncg.edu/mus/mri/education. html#Sounds) or the NAMM Foundation site (http:// www.music-research.org/Grants/guidelines.html) for additional information and current opportunities for funding.

Music Performance

The MRi has supported several studies of music performance involving interdisciplinary research.

Wind Instrument Timbre

Kelly Burke, clarinet professor at UNCG, devised a visual feedback system to assist clarinet students in improving timbre. By setting up two computer monitors, a clarinetist can see a real-time spectrographic analysis of his or her timbre while performing and compare it with the instructor's timbre. Using arthroscopic surgery equipment, a small camera affixed to a thin rod is inserted next to the clarinet mouthpiece, allowing the student to view tongue placement in the oral cavity. By observing the effects of different tongue placements, such as moving from *ah* to *ee*, the student can connect covert physical gestures with a visual display of formants in the acoustical spectrum.

Clarinet Embouchures

Loraine Enloe (2007), a doctoral student in music education (now at the University of Idaho), investigated two different approaches to clarinet embouchure. Prior to asking band directors whether they preferred one timbre rather than the other, she quantified the embouchures in two ways. First, she clarified that the two embouchures required different tension in risorius and zygomaticus major (smile) muscles by using surface EMG. Second, she found significant differences in signal strengths, as revealed by spectrographic analysis. Band directors did, indeed, prefer one timbre more than the other.

Vibrato Analysis

MacLeod (2008) demonstrated that pitch register and dynamic level significantly affected vibrato rates and widths in high school and university violin and viola players. Performers vibrated faster and wider during high pitches compared to lower pitches. They also had a wider vibrato rate in louder passages. Violinists tended to vibrate faster and wider than violists, and university players demonstrated more variety in vibrato width between soft and loud passages.

Laryngeal Tension in Singing

Beverly Smith-Vaughn (2007) investigated whether there were significant differences in laryngeal tension in adolescent singers based on different choral genres. Middle school and high school participants sang excerpts in three styles—classical choral, musical theater, and gospel. Using facilities in the Department of Communication Sciences and Disorders, laryngeal imaging was performed by means of video stroboscopy as participants sang. The results indicated that muscular tension was greatest while singing in musical theater style, next in gospel, and least in classical choral style. Excessive tension in the first two styles may be deleterious to good vocal health.

Ethnomusicology and Ecocriticism

In a series of articles, Gavin Douglas (2003a, 2003b, 2005b, 2007) examined state patronage of traditional music in Burma (Myanmar). In 1993, the military regime governing Burma began to promote national culture and the precolonial kingdom through a number of projects that are having a dramatic impact on current musical practices. Related articles (Douglas, 2005a, in press) explored differences in aesthetics among local Burmese musicians, the world music market, and globalization. Burmese musicians often have little control over how their music is presented to the world outside their country, and political discourse colors Burmese music with the struggle for human rights. Recent work on music and violence in Burma examines the role of music in state-sanctioned oppression, antistate demonstrations, and the globalization of violent images.

Revell Carr is a specialist in American vernacular and popular music in global contexts. He studies the music of transient, marginal American subcultures in two unique contexts: the music of American seafarers and the music and folkways of deadheads, devoted fans of the California rock band the Grateful Dead. Carr's (2007b, in press-a) research into the music culture of seafarers looks primarily at the influence maritime trades have had in the spread of musical ideas globally. As a major case study, Carr (in press-b) has investigated the musical relationship between American whalers and native Hawaiians in the 19th century, leading to the development of contemporary Hawaiian music, which in turn, has had a profound influence on American popular music. In his work on deadheads, Carr (2007a, 2007c) has examined how the mediascape created by the Grateful Dead, its complex of imagery, narratives, and sounds, has been manipulated and interpreted by fans to create a unique system of beliefs and folkways.

Aaron Allen (2008) recently cofounded the Ecocriticism Study Group of the American Musicological Society and is currently serving as its first chair. Ecocriticism is scholarship that highlights the manifold roles of nature and environment in the creation and interpretation of culture. As BioMusic investigates the music of nature, ecocriticism adds a human dimension by investigating art, literature, and music as cultural products from which humans derive meaning. Although this is a new field, the potential collaborations between Ecocriticism and BioMusic are promising.

MRi collaborators explore the phenomenon of music through research in BioMusic, Music-Related Hearing Loss, Music Education, Music Performance, Ethnomusicology and Ecocriticism, and Neuromusical Research. We meet on a monthly basis to share strategies, successes, and failures, to ask questions, and to challenge each other. Initially, the disparate nature of the various projects made the MRi seem like nothing more than an umbrella covering disconnected topics. However, increasingly, we see overarching themes emerging. Although there will never be an attempt to limit any individual's particular interests, we will continue to seek ways that different lines of investigation can inform each other.

Neuromusical Research

The role of the brain in musical processing has long been an interest of mine. Starting with a paper in graduate school, I wrote for many years as a synthesizer of neuromusical research. It was not until the early 1990s that I finally had the opportunity to move into the lab to conduct research with collaborative partners.

Initial Neuromusical Research

Prior to my appointment at UNCG, I was involved in a series of brain imaging studies with colleagues at the Research Imaging Center, University of Texas Health Science Center at San Antonio. These projects were supported, in part, by a $75,000 grant from the NAMM Foundation and $250,000 from the Texaco Foundation.

In one study (Parsons, Sergent, Hodges, & Fox, 2005), we asked professional pianists to perform three tasks while undergoing brain scans via positron emission tomography. The three task conditions were performances of the opening section of the third movement of the Bach *Italian Concerto* in F Major, BWV 971; bimanual performances of two-octave ascending and descending scales progressing chromatically; and a rest condition without movement or auditory stimulation. The greater performance requirements of Bach more strongly activated specific brain areas than did scales, including auditory association areas (involving higher-order musical processing) and motor areas (including thalamus, primary motor cortex, premotor cortex, supplementary motor cortex, basal ganglia, and cerebellum). In addition, there were very strong areas of decreased brain activity in frontal areas and elsewhere that presumably indicated an inhibition of processes likely to distract the performer; in other words, a higher degree of focused attention was required during Bach than scales.

In a second study (Parsons, Hodges, & Fox, 1998; Parsons, 2003), professional conductors participated in melodic, harmonic, and rhythmic error detection as they made judgments of perceived discrepancies between auditory and visual presentations of Bach chorales. The scores, in open, four-part choral notation, were always correct. Intentionally implanted pitch errors in the auditory presentation could appear in the soprano line (melody condition) or anywhere in the four voices (harmony condition); in the rhythm condition, pitches were correct but could enter too soon or too late. Each task showed a distinctive pattern of brain activations. Melodic error detection activated the brain bilaterally, whereas both the harmonic and rhythmic error detection conditions activated more left than right hemisphere areas. Although all three conditions activated the cerebellum, the rhythmic condition activated the cerebellum twice that of melody and harmony but few areas outside the cerebellum.

Next, we investigated the song system of the human brain (Brown, Martinez, Hodges, Fox, & Parsons, 2004). Undergraduate music students performed three increasingly difficult vocalization tasks. First, they simply repeated a presented tone (mono-tonic vocalization); second, they sang back a presented melody (melody repetition), third, they improvised a melody over a series of presented chords (harmonization). Monotonic vocalization activated numerous areas bilaterally, such as primary and secondary auditory cortex, mouth regions of primary motor cortex, supplementary motor cortex, and numerous other regions on either the left or right side. Interestingly, the melody and harmony conditions were quite similar and did not elicit many activations beyond the base-level task. They did, however, activate an area in auditory association cortex (planum polare, BA38), presumed to be involved in higher-level musical processing.

The next studies were presented via two posters at annual meetings of the Society for Cognitive Neuroscience, and after I left San Antonio, the group published these as two additional articles. As part of the foregoing experiment, participants also generated melodies and sentences (Brown, Martinez, & Parsons, 2006). In the melody generation task, participants heard an incomplete melody and had to spontaneously improvise an appropriate completion phrase (antecedent– consequence). In the language generation task, participants heard an opening sentence fragment (e.g., “August was the best month for them to take the Spanish course in Peru because . . .”) and were asked to complete the sentence (e.g., “Peru was a great place to be that time of year, and the weather was just fine”). Resulting brain activations indicated that some regions were shared, some were parallel, and others were distinct for music and language. In a final experiment, participants made same/different judgments of melodies and harmonic progressions while in the scanner (Brown & Martinez, 2007). Compared to passive listening, these discrimination tasks elicited activations in vocal-motor planning areas.

Current Neuromusical Research

Since moving to UNCG, I have been working with a group at the Advanced Neuroscience Imaging Research Laboratory, Wake Forest University School of Medicine. Joe Maldjian and Jonathan Burdette are both neuroradiologists and David Hairston, neurobiologist, was a postdoctoral fellow working in their lab. They had already done a number of studies in multisensory processing, so that seemed like a reasonable place to begin our music research program.

Multisensory Processing in Conductors

One of the requirements for being a successful musical conductor is to be able to locate sounds instantaneously in time and space. Because this requires the integration of auditory and visual information, we examined multisensory processing in experienced conductors and a matched set of control participants who had minimal musical training (Hodges, Burdette, & Hairston, 2006). Participants completed a series of behavioral tasks, including pitch discrimination; auditory, visual, and multisensory temporal-order judgments; and target localization. A subset of participants was then brain imaged using functional magnetic resonance imaging (fMRI).

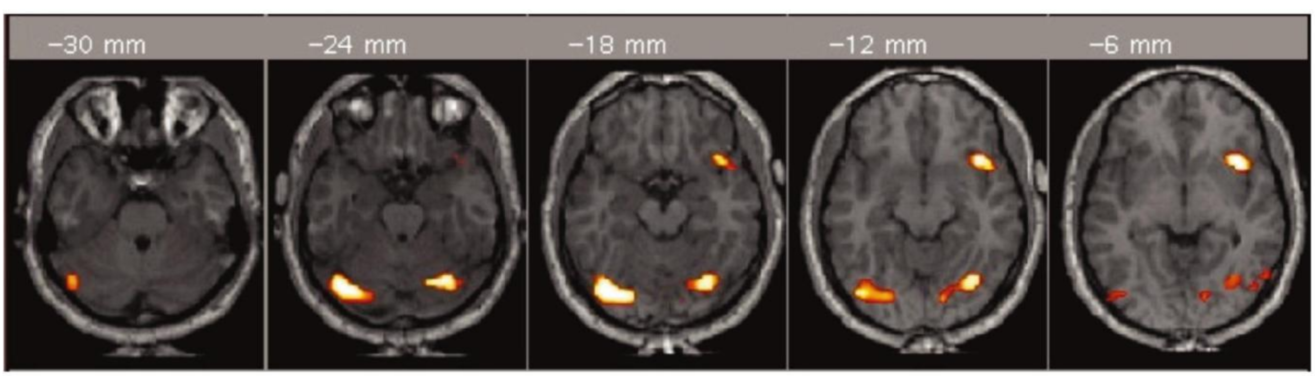
In the pitch discrimination task, participants indicated which of two tones occurred first, *high first* or *low first*. One tone was always A at 440 Hz, and the other tone was always higher. Correct responses caused the tones to be closer in frequency on the next presentation; incorrect responses meant they would be farther apart. Three such staircase procedures were interleaved until the pitches were so close together they were indistinguishable. An individualized thresh-old was determined for each participant. This procedure was repeated with the fixed tone being 500 Hz to rule out the possibility that the conductors were better at the commonly heard A-440.

In the auditory temporal order judgment (TOJ) task, participants heard two tones, A-440 Hz and E-660 Hz, presented sequentially. Although the pitches never varied, the order and time interval between them did. Participants again indicated *high first* or *low first*, but this time, a correct answer resulted in a shortening of the between-stimulus interval, and an incorrect answer lengthened it. Similar to the pitch discrimination task, an individualized threshold was determined for each participant. The visual TOJ task required participants to indicate which of two circles first appeared on a computer screen, the circle above a fixed + sign or below. As before, correct answers shortened the time interval between them, and incorrect answers lengthened the time. An individualized threshold was obtained for each participant. In the multisensory task, monotone beeps were added to the visual TOJ task. The first beep was congruent with the first circle, but the second beep could either be congruent or delayed by 50–350 ms. Measurements included both accuracy and speed of response.

In the target localization task, participants had to locate a light flash, a brief sound, or light and sound combined across a 180-degree horizontal arc in a dark chamber. Using a laser-pointing device, participants pointed toward targets 10, 20, 30, or 40 degrees to the left or right. Responses were scored in terms of both speed and accuracy.

Analyses of behavioral data indicated that conductors were more accurate in pitch discrimination, requiring a difference in frequency of only 0.67% (2.9 Hz) of the fixed tone, whereas controls required 2.95% (11 Hz). They were also much faster in the auditory TOJ task, requiring only 33.7 ms to respond, compared to 76.7 ms. However, they were not better at visual TOJ tasks. In the multisensory TOJ task, accuracy increased for both groups with the addition of sound, improving even more when the sound was delayed 100 ms after presentation of the second circle. Both groups also responded more quickly when the sound was added, and response time was best with a delay of 150–200 ms. Conductors were significantly faster across all test conditions. Conductors also demonstrated a benefit from the combination of auditory and visual information that was not observed in control participants when locating visual targets in space.

Figure 6
Multiple Images of One Conductor's Brain



Note: The second and third panels (–24 mm and –18 mm) show activation areas (yellow and red) in bilateral visual areas involved in multisensory processing.

A subset of participants—two conductors and four controls—underwent fMRI scanning while performing the multisensory TOJ task. Both groups showed activations in visual and motor cortex. However, conductors demonstrated greater activity in higher-order visual cortex. In particular, by constraining data analysis to a region of interest, conductors showed increased activity in bilateral areas known to be involved in multisensory processing (Figure 6).

Cortical Deactivation in Multisensory Processing

Numerous studies, including the one just discussed, have shown that response times can be quickened by the presentation of multisensory stimuli; however, here we demonstrated that such speeding up of responses can be seen even when the second sensory channel does not provide any task-relevant information (Hairston, Hodges, Burdette, & Wallace, 2006). Study participants performed a visual TOJ task, as described previously, in the presence of irrelevant auditory cues, with the second sound delayed relative to the second visual cue. Responses were most accurate and fastest when the auditory stimulus was delayed by a short time (i.e., 100 ms) relative to the second visual target. These results illustrate a unique benefit underlying a temporal interaction of auditory and visual information.

In the next study, we demonstrated the importance of the difficulty of an auditory task on decreasing activity in visual cortical areas (Hairston et al., 2007). Decreased brain activity, known as deactivations, can occur with stimulation of an opposing sensory modality. Participants performed an auditory TOJ task in conjunction with functional MRI at both moderate and high levels of difficulty adjusted for each individual's own threshold. With moderate difficulty, small deactivations were observed in several brain regions, including visual cortex. When the same task was more difficult, deactivations increased significantly to include a greater extent of functionally defined visual cortex. Together, these results suggest that cross-modal deactivations occur in compensation for task difficulty, perhaps acting as an intrinsic filter for irrelevant information.

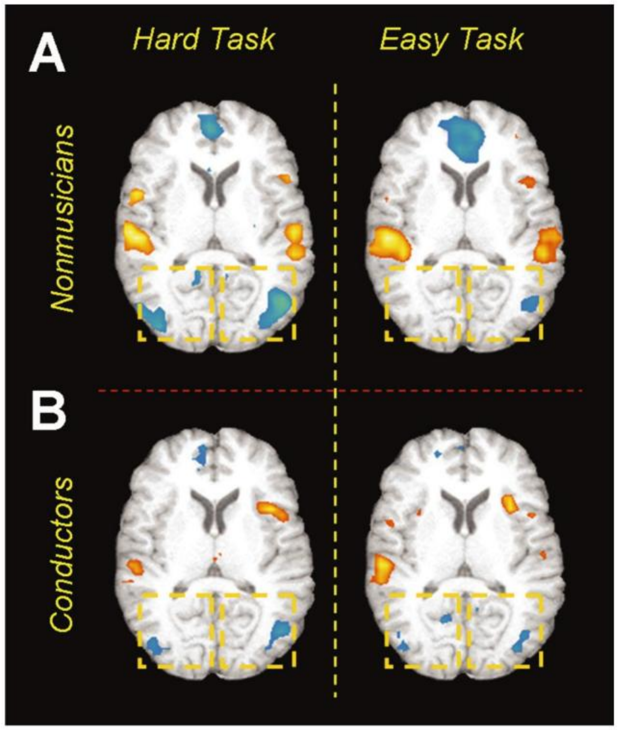
As shown in the previous study, cortical deactivation can occur when opposing modalities compete; for example, visual cortex activity decreased during an auditory task. Although these deactivations may be related to attention, it is also possible that they are related to the difficulty of the task at hand. In addition, extensive training may alter cross-modal deactivations. Accordingly, we investigated decreases in brain activity related to auditory task difficulty in experienced conductors and musically untrained individuals (Hairston, Hodges, Burdette, & Maldjian, in review).

Participants included musical conductors (*n* = 17; mean of 10 years of podium experience) and control participants (*n* = 18; variety of occupations and no formal musical training). Groups were matched on all other demographics, such as age, gender, and education. Each participant's individual threshold for auditory TOJ was determined prior to brain imaging. During fMRI scanning, participants performed the auditory task at threshold level ("hard task") or well above that level ("easy task") as well as a visual TOJ. Having each participant perform at threshold ensured consistent relative task difficulty. Task conditions alternated with baseline ("no task") conditions involving no stimulation (eyes remained open).

Control participants showed significant decreases in several brain regions, especially in visual cortex, and significant increases in auditory cortex activations during the hard-task auditory condition (Figure 7). These deactivations were reduced during the easy task version. In contrast, conductors showed only small visual cortical deactivations during both task conditions, despite behavioral confirmation of task difficulty.

These results indicate that cross-modal deactivations may be related to task difficulty, acting perhaps as an intrinsic filter for irrelevant information. However, that conductors experienced minimal changes in visual cortex during even hard-task auditory conditions suggests that their extensive training and daily experiences in multisensory integration allowed them to perform at higher levels without necessitating the same degree of intrinsic inhibition. Group differences related to other factors, such as gray matter volume, are being explored currently.

Figure 7
Brain Images of Conductors and Nonmusicians



Note: In the hard task, nonmusicians deactivate visual areas (blue) and activate auditory areas (yellow/red) much more so than conductors.

Overall Conclusions From Neuromusical Research

A number of broad conclusions can be drawn from the work done in Texas and North Carolina as well as from many other sources, such as the following:

- Music is represented in widely distributed but locally specialized neural networks. In contrast to the notion of a *music center*, music activates the front–back, top– bottom, and left–right parts of the brain. Specific aspects of music processing take place in localized areas, but these are connected to broadly diffuse networks.

- Activation sites change with varying stimuli, tasks, and participant attributes. Although some brain areas have been identified with various aspects of musical processing, using different musical stimuli, asking participants to perform a different task, or investigating different subject populations can often change activation patterns. Thus, it is not as simple as saying X activity hap-pens in Y location.

- Differences are found in the left and right hemi-spheres. Disparities between the two hemispheres were exaggerated in the 1960s and ’70s. Current understanding suggests that there are processing differences but that these are more subtle and over-lapping than previously thought.

    - Music and language are
    - processed in shared brain regions.
    - processed in parallel brain regions.
    - processed in distinct brain regions.

As with activation sites, one cannot simply say that language is processed here and music there. This is a highly complicated and somewhat controversial area of research that needs considerably more attention before a full understanding can emerge.

- Musical performance places a high demand on motor systems. Neurologist Frank Wilson (1986) has called musicians small-muscle athletes. Performing music strongly activates numerous brain regions involved in planning and executing motor movements. This makes sense because anything a performer wants the audience to hear in the music must be expressed through a body movement of some type (e.g., wider vibrato for the cellist, more air for the trombonist, different tongue placement for the singer).

- The cerebellum is involved even in the absence of motor behaviors. Although the cerebellum has long been known as dealing with motor/timing issues, recent discoveries demonstrate that it is also involved in integrating sensory input. Thus, nearly every experiment involving music, even when the participant makes no overt movement, activates the cerebellum.

- Trained musicians benefit from multisensory input. Musicians intuitively understand that seeing and hearing are integrated in many musical experiences, but only recently have modern research tools been able to document the degree to which this is so.

- Untrained musicians turn off the visual system to focus on auditory input, especially when task demand is high. Conductors only do so to a minimal degree. This is actually a subset of a more global statement: Musical training changes the brain. There is abundant evidence (e.g., see Edwards & Hodges, 2007; Hodges, 2006, for recent reviews) that the brains of adult musicians, especially those who started studying music seriously before the age of 7, are demonstrably different than those of untrained individuals.

Obviously, this is an exciting and rapidly changing area of research. Tentative applications to music teaching and learning are already being made (e.g., Gruhn & Rauscher, 2007), and the field of music education is poised to reap significant benefits from this line of inquiry.

MusicBIRD

There has been such a surge in neuromusical research in recent years that keeping up with the literature has become more difficult. To ameliorate that situation, a UNCG doctoral music education student, Richard Edwards (now at Ithaca College), developed the Music Brain Imaging Research Database (MusicBIRD) for his dissertation (Edwards, 2008). This fully searchable database, available on the MRi Web site, currently includes 473 citations and abstracts of neuromusical research. Users can access the data-base free of charge and conduct searches across any or all fields, including author, title, keywords, abstract, year, journal, volume, issue, and pages.

It is difficult to believe that the conversation with E. Thayer Gaston that opened this article took place in 1966. The years have flown by, and if I could hit the pause button and continue doing what I love indefinitely, I might consider it. In the meantime, I will enjoy reading, writing, and researching alone and with colleagues for as long as opportunities present themselves. Yesterday, Dr. Mace, Cindy Wagoner (doctoral music education student), and I just got IRB approval for a project we are beginning. We will be looking at rapid identification of musical genres in brief musical excerpts. Prior research (Bigand, Filipic, & Lalitte, 2005; Peretz, Gagnon, & Bouchard, 1998) indicates that music listeners can identify positive or negative valence of musical excerpts that are as brief as 1/8s. This makes sense in that brain stem responses allow for a very rapid alerting mechanism. Presumably, however, categorization judgments would take slightly longer. Accordingly, we will be asking trained and untrained music listeners to determine whether excerpts that are 1, 1/2, 1/4, and 1/8s long are examples of classical, jazz, country, metal, or rap/hip-hop musical genres. And so another adventure begins.

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