Introduction

I Love Music and I Love Science—Why Would I Want to Mix the Two?

I love science, and it pains me to think that so many are terrified of the subject or feel that choosing science means you cannot also choose compassion, or the arts, or be awed by nature. Science is not meant to cure us of mystery, but to reinvent and reinvigorate it.

—Robert Sapolsky, *Why Zebras Don't Get Ulcers*, p. xii

In the summer of 1969, when I was eleven, I bought a stereo system at the local hi-fi shop. It cost all of the hundred dollars I had earned weeding neighbors' gardens that spring at seventy-five cents an hour. I spent long afternoons in my room, listening to records: Cream, the Rolling Stones, Chicago, Simon and Garfunkel, Bizet, Tchaikovsky, George Shearing, and the saxophonist Boots Randolph. I didn't listen particularly loud, at least not compared to my college days when I actually set my loudspeakers on fire by cranking up the volume too high, but the noise was evidently too much for my parents. My mother is a novelist; she wrote every day in the den just down the hall and played the piano for an hour every night before dinner. My father was a businessman; he worked eighty-hour weeks, forty of those hours in his office at home on evenings and weekends. Being the businessman that he was, my father made me a proposition: He would buy me a pair of headphones if I would promise to use them when he was home. Those headphones forever changed the way I listened to music.

The new artists that I was listening to were all exploring stereo mixing for the first time. Because the speakers that came with my hundred-dollar all-in-one stereo system weren't very good, I had never before heard the depth that I could hear in the headphones—the placement of

instruments both in the left-right field and in the front-back (reverberant) space. To me, records were no longer just about the songs anymore, but about the sound. Headphones opened up a world of sonic colors, a palette of nuances and details that went far beyond the chords and melody, the lyrics, or a particular singer's voice. The swampy Deep South ambience of "Green River" by Creedence, or the pastoral, open-space beauty of the Beatles' "Mother Nature's Son"; the oboes in Beethoven's Sixth (conducted by Karajan), faint and drenched in the atmosphere of a large wood-and-stone church; the sound was an enveloping experience. Headphones also made the music more personal for me; it was suddenly coming from inside my head, not out there in the world. This personal connection is ultimately what drove me to become a recording engineer and producer.

Many years later, Paul Simon told me that the sound is always what he was after too. "The way that I listen to my own records is for the sound of them; not the chords or the lyrics—my first impression is of the overall sound."

I dropped out of college after the incident with the speakers in my dorm room, and I joined a rock band. We got good enough to record at a twenty-four-track studio in California with a talented engineer, Mark Needham, who went on to record hit records by Chris Isaak, Cake, and Fleetwood Mac. Mark took a liking to me, probably because I was the only one interested in going into the control room to hear back what we sounded like, while the others were more interested in getting high in between takes. Mark treated me like a producer, although I didn't know what one was at the time, asking me what the band wanted to sound like. He taught me how much of a difference to the sound a microphone could make, or even the influence of how a microphone was placed. At first, I didn't hear some of the differences he pointed out, but he taught me what to listen for. "Notice that when I put this microphone closer to the guitar amp, the sound becomes fuller, rounder, and more even; but when I put it farther back, it picks up some of the sound of the room, giving it a more spacious sound, although you lose some of the midrange if I do that."

Our band became moderately well known in San Francisco, and our tapes played on local rock radio stations. When the band broke up—due to the guitarist's frequent suicide attempts and the vocalist's nasty habit of taking nitrous oxide and cutting himself with razor blades—I found work as a producer of other bands. I learned to hear things I had never heard before: the difference between one microphone and another, even between one brand of recording tape and another (Ampex 456 tape had a characteristic "bump" in the low-frequency range, Scotch 250 had a characteristic crispness in the high frequencies, and Agfa 467 a luster in the midrange). Once I knew what to listen for, I could tell Ampex from Scotch or Agfa tape as easily as I could tell an apple from a pear or an orange. I progressed to work with other great engineers, like Leslie Ann Jones (who had worked with Frank Sinatra and Bobby McFerrin), Fred Catero (Chicago, Janis Joplin), and Jeffrey Norman (John Fogerty, the Grateful Dead). Even though I was the producer—the person in charge of the sessions—I was intimidated by them all. Some of the engineers let me sit in on their sessions with other artists, such as Heart, Journey, Santana, Whitney Houston, and Aretha Franklin. I got a lifetime of education watching them interact with the artists, talking about subtle nuances in how a guitar part was articulated or how a vocal performance had been delivered. They would talk about syllables in a lyric, and choose among ten different performances. They could hear so well; how did they train their ears to hear things that mere mortals couldn't?

While working with small, unknown bands, I got to know the studio managers and engineers, and they steered me toward better and better work. One day an engineer didn't show up and I spliced some tape edits for Carlos Santana. Another time, the great producer Sandy Pearlman went out for lunch during a Blue Öyster Cult session and left me in charge to finish the vocals. One thing led to another, and I spent over a decade producing records in California; I was eventually lucky enough to be able to work with many well-known musicians. But I also worked with dozens of musical no-names, people who are extremely talented but never made it. I began to wonder why some musicians become household names while others languish in obscurity. I also wondered

why music seemed to come so easily to some and not others. Where does creativity come from? Why do some songs move us so and others leave us cold? And what about the role of perception in all of this, the uncanny ability of great musicians and engineers to hear nuances that most of us don't?

These questions led me back to school for some answers. While still working as a record producer, I drove down to Stanford University twice a week with Sandy Pearlman to sit in on neuropsychology lectures by Karl Pribram. I found that psychology was the field that held the answers to some of my questions—questions about memory, perception, creativity, and the common instrument underlying all of these: the human brain. But instead of finding answers, I came away with more questions—as is often the case in science. Each new question opened my mind to an appreciation for the complexity of music, of the world, and of the human experience. As the philosopher Paul Churchland notes, humans have been trying to understand the world throughout most of recorded history; in just the past two hundred years, our curiosity has revealed much of what Nature had kept hidden from us: the fabric of space-time, the constitution of matter, the many forms of energy, the origins of the universe, the nature of life itself with the discovery of DNA, and the completion of the mapping of the human genome just five years ago. But one mystery has not been solved: the mystery of the human brain and how it gives rise to thoughts and feelings, hopes and desires, love, and the experience of beauty, not to mention dance, visual art, literature, and music.

What is music? Where does it come from? Why do some sequences of sounds move us so, while others—such as dogs barking or cars screeching—make many people uncomfortable? For some of us, these questions occupy a large part of our life's work. For others, the idea of picking music apart in this way seems tantamount to studying the chemical structure in a Goya canvas, at the expense of seeing the art that the painter was trying to produce. The Oxford historian Martin Kemp points out a similarity between artists and scientists. Most artists describe their work as experiments—part of a series of efforts designed to explore a common concern or to establish a viewpoint. My good friend and colleague William Forde Thompson (a music cognition scientist and composer at the University of Toronto) adds that the work of both scientists and artists involves similar stages of development: a creative and exploratory "brainstorming" stage, followed by testing and refining stages that typically involve the application of set procedures, but are often informed by additional creative problem-solving. Artists' studios and scientists' laboratories share similarities as well, with a large number of projects going at once, in various stages of incompletion. Both require specialized tools, and the results are—unlike the final plans for a suspension bridge, or the tallying of money in a bank account at the end of the business day—open to interpretation. What artists and scientists have in common is the ability to live in an open-ended state of interpretation and reinterpretation of the products of our work. The work of artists and scientists is ultimately the pursuit of truth, but members of both camps understand that truth in its very nature is contextual and changeable, dependent on point of view, and that today's truths become tomorrow's disproven hypotheses or forgotten objets d'art. One need look no further than Piaget, Freud, and Skinner to find theories that once held widespread currency and were later overturned (or at least dramatically reevaluated). In music, a number of groups were prematurely held up as of lasting importance: Cheap Trick were hailed as the new Beatles, and at one time the *Rolling Stone Encyclopedia of Rock* devoted as much space to Adam and the Ants as they did to U2. There were times when people couldn't imagine a day when most of the world would not know the names Paul Stookey, Christopher Cross, or Mary Ford. For the artist, the goal of the painting or musical composition is not to convey literal truth, but an aspect of a universal truth that if successful, will continue to move and to touch people even as contexts, societies, and cultures change. For the scientist, the goal of a theory is to convey "truth for now"—to replace an old truth, while accepting that someday this theory, too, will be replaced by a new "truth," because that is the way science advances.

Music is unusual among all human activities for both its *ubiquity* and its *antiquity*. No known human culture now or anytime in the recorded

past lacked music. Some of the oldest physical artifacts found in human and protohuman excavation sites are musical instruments: bone flutes and animal skins stretched over tree stumps to make drums. Whenever humans come together for any reason, music is there: weddings, funerals, graduation from college, men marching off to war, stadium sporting events, a night on the town, prayer, a romantic dinner, mothers rocking their infants to sleep, and college students studying with music as a background. Even more so in nonindustrialized cultures than in modern Western societies, music is and was part of the fabric of everyday life. Only relatively recently in our own culture, five hundred years or so ago, did a distinction arise that cut society in two, forming separate classes of music performers and music listeners. Throughout most of the world and for most of human history, music making was as natural an activity as breathing and walking, and everyone participated. Concert halls, dedicated to the performance of music, arose only in the last several centuries.

Jim Ferguson, whom I have known since high school, is now a professor of anthropology. Jim is one of the funniest and most fiercely intelligent people I know, but he is shy—I don't know how he manages to teach his lecture courses. For his doctoral degree at Harvard, he performed fieldwork in Lesotho, a small nation completely surrounded by South Africa. There, studying and interacting with local villagers, Jim patiently earned their trust until one day he was asked to join in one of their songs. So, typically, when asked to sing with these Sotho villagers, Jim said in a soft voice, "I don't sing," and it was true: We had been in high school band together and although he was an excellent oboe player, he couldn't carry a tune in a bucket. The villagers found his objection puzzling and inexplicable. The Sotho consider singing an ordinary, everyday activity performed by everyone, young and old, men and women, not an activity reserved for a special few.

Our culture, and indeed our very language, makes a distinction between a class of expert performers—the Arthur Rubinsteins, Ella Fitzgeralds, Paul McCartneys—and the rest of us. The rest of us pay money to hear the experts entertain us. Jim knew that he wasn't much of a singer or dancer, and to him, a public display of singing and dancing implied he thought himself an expert. The villagers just stared at Jim and said, "What do you mean you don't sing?! You talk!" Jim told me later, "It was as odd to them as if I told them that I couldn't walk or dance, even though I have both my legs." Singing and dancing were a natural activity in everybody's lives, seamlessly integrated and involving everyone. The Sesotho verb for singing *(ho bina)*, as in many of the world's languages, also means to dance; there is no distinction, since it is assumed that singing involves bodily movement.

A couple of generations ago, before television, many families would sit around and play music together for entertainment. Nowadays there is a great emphasis on technique and skill, and whether a musician is "good enough" to play for others. Music making has become a somewhat reserved activity in our culture, and the rest of us listen. The music industry is one of the largest in the United States, employing hundreds of thousands of people. Album sales alone bring in $30 billion a year, and this figure doesn't even account for concert ticket sales, the thousands of bands playing Friday nights at saloons all over North America, or the thirty billion songs that were downloaded free through peer-to-peer file sharing in 2005. Americans spend more money on music than on sex or prescription drugs. Given this voracious consumption, I would say that most Americans qualify as expert music listeners. We have the cognitive capacity to detect wrong notes, to find music we enjoy, to remember hundreds of melodies, and to tap our feet in time with the music—an activity that involves a process of meter extraction so complicated that most computers cannot do it. Why do we listen to music, and why are we willing to spend so much money on music listening? Two concert tickets can easily cost as much as a week's food allowance for a family of four, and one CD costs about the same as a work shirt, eight loaves of bread, or basic phone service for a month. Understanding why we like music and what draws us to it is a window on the essence of human nature.

To ask questions about a basic, and omnipresent human ability is to implicitly ask questions about evolution. Animals evolved certain physical

forms as a response to their environment, and the characteristics that conferred an advantage for mating were passed down to the next generation through the genes.

A subtle point in Darwinian theory is that living organisms—whether plants, viruses, insects, or animals—coevolved with the physical world. In other words, while all living things are changing in response to the world, the world is also changing in response to them. If one species develops a mechanism to keep away a particular predator, that predator's species is then under evolutionary pressure either to develop a means to overcome that defense or to find another food source. Natural selection is an arms race of physical morphologies changing to catch up with one another.

A relatively new scientific field, evolutionary psychology, extends the notion of evolution from the physical to the realm of the mental. My mentor when I was a student at Stanford University, the cognitive psychologist Roger Shepard, notes that not just our bodies but our minds are the product of millions of years of evolution. Our thought patterns, our predispositions to solve problems in certain ways, our sensory systems—such as the ability to see color (and the particular colors we see)—are all products of evolution. Shepard pushes the point still further: Our minds coevolved with the physical world, changing in response to ever-changing conditions. Three of Shepard's students, Leda Cosmides and John Tooby of the University of California at Santa Barbara, and Geoffrey Miller of the University of New Mexico, are among those at the forefront of this new field. Researchers in this field believe that they can learn a lot about human behavior by considering the evolution of the mind. What function did music serve humankind as we were evolving and developing? Certainly the music of fifty thousand and one hundred thousand years ago is very different from Beethoven, Van Halen, or Eminem. As our brains have evolved, so has the music we make with them, and the music that we want to hear. Did particular regions and pathways evolve in our brains specifically for making and listening to music?

Contrary to the old, simplistic notion that art and music are processed in the right hemisphere of our brains, with language and mathematics in the left, recent findings from my laboratory and those of my colleagues are showing us that music is distributed throughout the brain. Through studies of people with brain damage, we've seen patients who have lost the ability to read a newspaper but can still read music, or individuals who can play the piano but lack the motor coordination to button their own sweater. Music listening, performance, and composition engage nearly every area of the brain that we have so far identified, and involve nearly every neural subsystem. Could this fact account for claims that music listening exercises other parts of our minds; that listening to Mozart twenty minutes a day will make us smarter?

The power of music to evoke emotions is harnessed by advertising executives, filmmakers, military commanders, and mothers. Advertisers use music to make a soft drink, beer, running shoe, or car seem more hip than their competitors'. Film directors use music to tell us how to feel about scenes that otherwise might be ambiguous, or to augment our feelings at particularly dramatic moments. Think of a typical chase scene in an action film, or the music that might accompany a lone woman climbing a staircase in a dark old mansion: Music is being used to manipulate our emotions, and we tend to accept, if not outright enjoy, the power of music to make us experience these different feelings. Mothers throughout the world, and as far back in time as we can imagine, have used soft singing to soothe their babies to sleep, or to distract them from something that has made them cry.

Many people who love music profess to know nothing about it. I've found that many of my colleagues who study difficult, intricate topics such as neurochemistry or psychopharmacology feel unprepared to deal with research in the neuroscience of music. And who can blame them? Music theorists have an arcane, rarified set of terms and rules that are as obscure as some of the most esoteric domains of mathematics. To the nonmusician, the blobs of ink on a page that we call music notation might just as well be the notations of mathematical set theory. Talk of keys, cadences, modulation, and transposition can be baffling.

Yet every one of my colleagues who feels intimidated by such jargon

can tell me the music that he or she likes. My friend Norman White is a world authority on the hippocampus in rats, and how they remember different places they've visited. He is a huge jazz fan, and can talk expertly about his favorite artists. He can instantly tell the difference between Duke Ellington and Count Basie by the sound of the music, and can even tell early Louis Armstrong from late. Norm doesn't have any knowledge about music in the technical sense—he can tell me that he likes a certain song, but he can't tell me what the names of the chords are. He is, however, an expert in knowing what he likes. This is not at all unusual, of course. Many of us have a practical knowledge of things we like, and can communicate our preferences without possessing the technical knowledge of the true expert. I know that I prefer the chocolate cake at one restaurant I often go to, over the chocolate cake at my neighborhood coffee shop. But only a chef would be able to analyze the cake—to decompose the taste experience into its elements—by describing the differences in the kind of flour, or the shortening, or the type of chocolate used.

It's a shame that many people are intimidated by the jargon musicians, music theorists, and cognitive scientists throw around. There is specialized vocabulary in every field of inquiry (try to make sense of a full blood-analysis report from your doctor). But in the case of music, music experts and scientists could do a better job of making their work accessible. That is something I tried to accomplish in this book. The unnatural gap that has grown between musical performance and music listening has been paralleled by a gap between those who love music (and love to talk about it) and those who are discovering new things about how it works.

A feeling my students often confide to me is that they love life and its mysteries, and they're afraid that too much education will steal away many of life's simple pleasures. Robert Sapolsky's students have probably confided much the same to him, and I myself felt the same anxiety in 1979, when I moved to Boston to attend the Berklee College of Music. What if I took a scholarly approach to studying music and, in analyzing

it, stripped it of its mysteries? What if I became so knowledgeable about music that I no longer took pleasure from it?

I still take as much pleasure from music as I did from that cheap hi-fi through those headphones. The more I learned about music and about science the more fascinating they became, and the more I was able to appreciate people who are really good at them. Like science, music over the years has proved to be an adventure, never experienced exactly the same way twice. It has been a source of continual surprise and satisfaction for me. It turns out science and music aren't such a bad mix.

This book is about the science of music, from the perspective of cognitive neuroscience—the field that is at the intersection of psychology and neurology. I'll discuss some of the latest studies I and other researchers in our field have conducted on music, musical meaning, and musical pleasure. They offer new insights into profound questions. If all of us hear music differently, how can we account for pieces that seem to move so many people—Handel's *Messiah* or Don McLean's "Vincent (Starry Starry Night)" for example? On the other hand, if we all hear music in the same way, how can we account for wide differences in musical preference—why is it that one man's Mozart is another man's Madonna?

The mind has been opened up in the last few years by the exploding field of neuroscience and the new approaches in psychology due to new brain-imaging technologies, drugs able to manipulate neurotransmitters such as dopamine and serotonin, and plain old scientific pursuit. Less well known are the extraordinary advances we have been able to make in modeling how our neurons network, thanks to the continuing revolution in computer technology. We are coming to understand computational systems in our head like never before. Language now seems to be substantially hardwired into our brains. Even consciousness itself is no longer hopelessly shrouded in a mystical fog, but is rather something that emerges from observable physical systems. But no one until now has taken all this new work together and used it to elucidate what is for me the most beautiful human obsession. Your brain on music is a way to

understand the deepest mysteries of human nature. That is why I wrote this book. This book was written for the general reader and not for my colleagues, so I have tried to simplify topics without *oversimplifying* them. All the research described herin has been vetted by the peer-review process and appeared in refereed journals. The full details of "your brain on music" are contained in the notes at the end of the book.

By better understanding what music is and where it comes from, we may be able to better understand our motives, fears, desires, memories, and even communication in the broadest sense. Is music listening more along the lines of eating when you're hungry, and thus satisfying an urge? Or is it more like seeing a beautiful sunset or getting a backrub, which triggers sensory pleasure systems in the brain? Why do people seem to get stuck in their musical tastes as they grow older and cease experimenting with new music? This is the story of how brains and music coevolved—what music can teach us about the brain, what the brain can teach us about music, and what both can teach us about ourselves.

1. What Is Music?

From Pitch to Timbre

What is music? To many, "music" can only mean the great masters—Beethoven, Debussy, and Mozart. To others, "music" is Busta Rhymes, Dr. Dre, and Moby. To one of my saxophone teachers at Berklee College of Music—and to legions of "traditional jazz" aficionados—anything made before 1940 or after 1960 isn't *really* music at all. I had friends when I was a kid in the sixties who used to come over to my house to listen to the Monkees because their parents forbade them to listen to anything but classical music, and others whose parents would only let them listen to and sing religious hymns, in both cases fearing the "dangerous rhythms" of rock and roll. When Bob Dylan dared to play an electric guitar at the Newport Folk Festival in 1965, people walked out and many of those who stayed, booed. The Catholic Church banned music that contained polyphony (more than one musical part playing at a time), fearing that it would cause people to doubt the unity of God. The church also banned the musical interval of an augmented fourth, the distance between C and F-sharp and also known as a tritone (the interval in Leonard Bernstein's *West Side Story* when Tony sings the name "Maria"). This interval was considered so dissonant that it must have been the work of Lucifer, and so the church named it *Diabolus in musica.* It was pitch that had the medieval church in an uproar. And it was timbre that got Dylan booed. It