The Musical Brain

by best-selling author Abel James

The Musical Brain:

Its Evolutionary Origins and Profound Effect on Our Lives

By Abel James

Contents

What People Are Saying about The Musical Brain

“The Musical Brain is a technical review of extraordinary breadth. In seeking to answer the question, "What is the origin of music, and why does it play such an enormous role in our lives?" James raises many additional questions as well as paths for continued exploration into the causes and effects of musical expression. That being said, there are books that you read and there are books that you study. For me, "The Musical Brain" fell into the latter category. I had been lagging in my own musical practice routine and after discovering the myriad benefits of musical training, I dusted off my guitar, tuned it, and went to YouTube to learn how to play "Dust in the Wind" (Don't judge! It's great practice for learning how to finger pick!).”
- Tony Federico

“Brilliantly written and incredibly interesting! The Musical Brain explores the mysteries behind why music is a part of human existence. This thorough investigation guides readers through different theories including biology, development, and cultural influences. References are cited throughout this well-researched piece of literature.”
- Alyson Bridge

“Fascinating and Info-Packed! The Musical Brain goes into depths about music and cognitive function rarely explored. It gives plentiful references for research-hungry music or neuroscience enthusiasts while keeping the connections between music, evolution and the brain woven in an orderly and cogent fashion. It's a true eye-opener about music – a human ability so easy to take for granted and yet so perplexing in its origins and function!”
- Samantha Belyeu

“This was an enjoyable read. I have 4 little ones and I am constantly observing how they are developing. It’s true that music has assisted them educationally as well as emotionally. Great information. Thanks Abel James.”
- Nikki B.

“This book has a ton of great and insightful information covering the neuroscientific aspects of music and its evolutionary origins; this is fantastic! Not a lot of active musicians take the time to read up on the great amount of literature out there from authors like Daniel Levitin and Oliver Sacks and it has benefited me greatly, so it's awesome to have a guy like Abel throw his hat in the ring and bring this information to the table in a really concise format. If you play music and combine the science behind it to your repertoire of knowledge in this field, you're going to be able to bring more to the table than just your run of the mill stuff that most will pass over without a second thought. See what it's really all about and check this book out!”
- BJammin'

“Abel James covers a lot of ground in this book in terms of research about the evolution of our musical ability and the effects of music on our brains and thus our lives. In explaining these concepts, he uses a considerable array of primary sources comprising several published research papers. The presentation of such a huge list of sources is the book's strong suit as similar books on these topics are generally based not solely on primary research papers but also other books and articles, which may have cited such sources. This certainly provides great authenticity to this book.”
- Venkat Ramanan

Prelude

"Music is a secret and unconscious mathematical problem of the soul."

– Gottfried Wilhelm Von Leibniz, 1914

Music is everywhere; it pumps through earbuds, elevators, commercials, arenas, and it's even beamed out to space. But – despite its rampant abundance in human experience, history, and culture – music has no clear adaptive function.

This begs the question: What are the origins of music, and why does it play such an enormous role in our lives?

I spent my childhood nestled in the frosty backwoods of New Hampshire without the distractions of cable television, most forms of culture and entertainment, or, at times, electricity. While my classmates played Nintendo and watched MTV, my brother and I filled our quaint farmhouse with music. We jammed unrepentantly to The Meters, Stevie Ray Vaughan, James Brown, Bob Marley, The Clash, and Tom Waits. Armed with a $50 drumset and a shoddy electric guitar, we shook the walls with sound.

I've often remarked, "If I didn't have music, I'd be certifiably insane." And I stand by it.

Music taps into the brain, the heart, and the soul like nothing else I've ever experienced. Music is – and always has been – my outlet for processing and releasing deep-seated emotions. When tragedy struck in my teens, I shut myself in my room, cranked my amplifier, and played until I literally collapsed. It was the only way I could cry.

Now, if you've ever met a musician, it's clear that we're a "unique" bunch. I have no doubt that the countless hours we spent listening to and creating music has shaped our minds and, indeed, our brains.

This begs a second question: How does musical experience influence the human brain?

I spent years with my nose in the research (and my fingers on the strings) in search of the answers to these questions. This book is the result; may you enjoy the journey as much as I have.

Cheers,
Abel James

Part One:

What is the Evolutionary Basis for Musical Ability?

"As neither the enjoyment nor the capacity of producing musical notes are faculties of the least use to man in reference to his daily habits of life, they must be ranked among the most mysterious with which he is endowed."

– Charles Darwin, 1871

Although it has appeared in vastly different forms and served various functions throughout history, music has had a ubiquitous presence in cultures across the world. As a perceptual phenomenon, music is fascinating to cognitive scientists because it raises important questions about perception, emotion, learning, and memory.[1]

Despite its omnipresence, science has yet to identify a clear adaptive function for music. There are a number of theories about its origins; some argue that music arose from sexual selection,[2] directly from the faculty of speech,[3] as a group-oriented communication device,[4] and others concede that it is merely a fortuitous side effect of various perceptual and cognitive mechanisms that serve other functions.[5] A recurrent theme in recent research, however, cites an indelible link between music and speech, perhaps because they both evolved from a common origin.[6]

In their review of the evolution of the music faculty, Hauser and McDermott (2003) raised three important questions about our epistemological state of musical knowledge:

1. What is the initial, innate state of knowledge of music prior to experience with music?
2. How is this initial state transformed by relevant experience into the mature state of musical knowledge?
3. What is the evolutionary history of the initial state and the acquisition processes that guide the development of musical knowledge?[7]

In order to satisfactorily answer these questions, biology, development and cultural influences will be explored. Only a calculated investigation into the influences of nature and nurture can provide an explanation of our relationship with music, as there are biological universals as well as developmental and culturally based influences that determine the dynamic state of musical knowledge.

Throughout history, the origin of music has been a controversial topic, and scientists have arrived at varied conclusions. Some, including Charles Darwin, argue that the origin of music, like birdsong, lies in the process of sexual selection. In *The Descent of Man and Selection in Relation to Sex* (1871), he writes,

> In the class of Mammals . . . the males of almost all the species use their voices during the breeding season much more than at any other time, and some are absolutely mute excepting at this season.[8]

Darwin continues to explain that, like animals, the primitive man was to some extent dependent on the beauty of his voice to attract a mate. Through sexual selection, those characteristics of the voice that were attractive to the opposite sex would have been passed on to succeeding generations, with the final outcome being vocal music.[9] Thus, he believed, all music was originally vocal.

Darwin also posited that the origins of speech are found in music itself, a belief that was shared with his contemporary, the German composer Richard Wagner.[10] Wagner writes,

> As we have every reason to suppose that articulate speech is one of the latest, as it certainly is the highest, of the arts acquired by man, and as the instinctive power of producing musical notes and rhythms is developed low down in the animal

> species, it would be altogether opposed to the principle of evolution if we were to admit that man's musical capacity has been developed from the tones used in impassioned speech. We must suppose that the rhythms and cadences of oratory are derived from previously developed musical powers.[11]

Despite his written works about the origins of music, however, Darwin was, by his own admission, largely ignorant of musical matters, and Wagner had a limited scientific background.[12]

In his critique of Darwin's theory, Kivy (1959) put it well, "Today Darwin's theory of music remains merely a curiosity – an interesting but rather insignificant appendage to the theory of sexual selection."[13] Modern science largely discounts the direct connection between sexual selection and the faculty of music.

Darwin's beliefs stood in stark opposition to a number of his contemporaries, including the philosopher Herbert Spencer. In 1857, Spencer published "The Origin and Function of Music," an essay in which he stressed that the origins of music lay in speech. Spencer argued that there were five characteristics of vocal utterances: loudness, quality or timbre, pitch, intervals, and rate of variation.[14]

During emotional speech, the increased emotional energy tends to lead to an increase in loudness and sonority, raised pitch, widened intervals, and the production of a greater variety of sounds. This excited speech, he argues, begins to resemble music, "These vocal peculiarities which indicate excited feeling, are those which especially distinguish song from ordinary speech."[15] The majority of modern cognitive scientists agree, however, that this theory's reliance upon speech itself as the origin is reductive as there are some aspects of music, such as harmony, that have no corollary in speech.

Juslin & Laukka (2003) argue that music arose during various cultural activities of the distant past, beginning with vocal chanting. They suggest that the vocal expression of discrete emotions such as happiness, sadness, anger, and love could have become gradually meshed with vocal music that accompanied related cultural activities such as festivities, funerals, wars, and care-giving.[16]

There is evidence that listeners can accurately categorize songs that serve different emotional functions (e.g., festive, mourning, war, lullabies) that come from different cultures and that there are similarities in certain acoustic characteristics used in such songs.[17] For instance, mourning songs typically have slow tempo, low sound level, and soft timbre, whereas festive songs have fast tempo, high sound level, and bright timbre.[18] Thus, they suggest, it is reasonable to hypothesize that music developed from a means of emotion sharing and communication to an art form in its own right.[19] While more probable than the theories of Darwin and Spencer, it is accepted by only a small minority of modern scientists.

The fourth theory offered by Hauser & McDermott (2003) is the one that is favored by this review. As there seems to be no adaptive significance for music, cross-cultural, cross-species, and developmental similarities in musical perception cannot, then, be seen as adaptations for music but instead should be regarded as side effects of more general features of perception or cognition.[20] These same adaptations likely allowed and encouraged our faculty for speech. So, music did not come *from* speech, or speech *from* music, but instead both arose from similar perceptual and cognitive adaptations that evolved around the same time.

It is now generally accepted that many of the mechanisms underlying speech perception are shared with other animals, as it is unlikely that these mechanisms evolved for the specific purpose of perceiving speech.[21] Hauser and McDermott (2003) write, "A more parsimonious explanation is that the mechanisms [involved in perceiving speech] reflect more general solutions to problems of auditory perception that, over evolutionary time, were co-opted for speech perception."[22] These mechanisms have also been seen to function in the perception of music in humans.

There is evidence that animals reared without exposure to music develop characteristics of human music perception, giving credibility to the theory that these characteristics are probably innate features of the brain. Furthermore, since nonhuman mammals do not under normal circumstances create or experience music on their own, the features in animals of music perception cannot be related to an adaptation for music, but instead must represent a capacity that evolved for more general auditory perception and analysis.[23]

One of these features has to do with the diatonic system, and more specifically with the significance of the octave in pitch perception. Wright and colleagues (2000) demonstrated that, like humans, rhesus monkeys have the ability to identify octaves. Rhesus monkeys tended to judge two melodies to be the same when transposed by one or even two octaves when chroma, or key, was preserved.[24]

Melodies were transposed and moved on the frequency scale with virtually undiminished recognition, provided that the frequency change is some multiple or factor of two. Frequency doubling is a fundamental property of the stimuli (i.e., harmonics), the ear (i.e., basilar membrane), and music perception by both humans and nonhuman primates.[25] Unlike humans, the monkeys failed to demonstrate octave generalization if melodies were transposed by .5 or 1.5 octaves.

Additionally, generalization only occurred for melodies that were taken from the diatonic scale, reflecting the monkeys' lack of relative pitch.

The implications of these findings are that, like humans, animals show a preference for octaves and the diatonic scale, giving credence to Walker's theory (2004) that the diatonic structures of Western harmony somehow ideally match brain structures isomorphically, and that tonal melodies have special status even in nonhuman primates.[26]

These findings also demonstrate that there are fundamental differences in the way that tonal and atonal melodies are encoded by the brain.[27] Furthermore, the fact that primates, but not songbirds, have the faculty to transpose melodies suggests that this ability evolved after the evolutionary divergence of birds and mammals.[28] These conclusions have profound implications for nature-nurture origins of music perception, as they suggest similar transduction, storage, processing, and relational memory of musical passages in humans and nonhuman primates.[29]

A second comparative study explores the neurophysiological differences and similarities of responses to consonant and dissonant chords in macaques and human patients suffering from epileptic seizures. A well-known theory in science is that consonance and dissonance may be distinguished by the amplitude modulation (also known as beating) that occurs in dissonant chords due to the interaction of overtones at the level of the cochlea.[30]

Fishman and colleagues (2001) attempted to distinguish how consonant and dissonant stimuli are represented in the cortex. Their results indicated that there are differences in neural responses, with the magnitude of the oscillatory phase-locked activity significantly correlated with the extent of dissonance.

In both humans and rhesus monkeys, synchronous, phase–locked activity of neurons in the primary auditory cortex were found to signal the degree of sensory dissonance, while consonant chords exhibit no phase-locked activity.[31] Thus, the differences in the peripheral encoding of consonant and dissonant stimuli seem to be perceptually similar in and important to both humans and some nonhuman primates.

Another preliminary study by Hauser and colleagues finds that both human infants and tamarins (nonhuman primates that lack language) demonstrate the ability to discriminate languages on the basis of rhythmic cues.[32] This evidence suggests that the capacity of discrimination evolved not for language in humans, but as a solution to some other problem in auditory perception in some animals. Thus, some aspects of rhythm perception in music may be co-opting domain-general auditory mechanisms that likely evolved well before humans began producing music.[33]

Just as humans share similar auditory and musical abilities with animals, they also share some perceptual limitations. Many birdsongs exhibit the principles of rudimentary harmony, and do not stray from the diatonic system.[34] For instance, Hawkins (1682) finds that the blackbird sings a triadic fanfare in F major, the cuckoo repeats a monotonous descending minor third, and the hen sings a repeated ascending sixth.

Animals other than birds regularly produce calls and sounds that have a mathematical ratio to each other, and often follow in the diatonic system.[35] These animals' capacity for song may be limited by the same perceptual constraints that lead to tonal and diatonic preferences in humans.

With the acknowledgement of similar abilities and constraints in music among animals, cultures, and throughout human development, scientists including Trehub and colleagues (1999) are beginning to assemble a list of music universals. Among them are the equivalences of tones an octave apart, the use of discrete pitches rather than infinitely variable pitches in composition and performance, and, more generally, the preference for the diatonic system itself.[36]

Across cultures, musical scales typically have five to seven pitches per octave, remaining within the range of the capacity of working memory.[37] These limitations are probably not isolated to music, but could rather be indications of general features of auditory perception and analysis or working memory.[38] While these cross-cultural, cross-species, and developmental universals exist, what is not universal is the manner in which they are shared and eventually acculturate.[39]

Because of its omnipresence in music from cultures across the world as well as animal song, the diatonic system and, more specifically, tonality, is widely researched. As with nonhuman primates, even adults without formal musical training are sensitive to tonality and are better at processing melodies that conform to the diatonic structure.[40] For instance, adults from Western cultures more readily detect changes to a standard melody if it conforms to the rules of Western tonality, and such changes are more salient when diatonic structural rules are violated.[41]

Trehub and colleagues (1986) find similar results in that listeners are better able to detect semitone changes in melodies that conform to diatonic structure, and, in turn, commit more errors in melodies with increasing violations of diatonic structure.[42] This evidence suggests that both animals and humans innately favor the diatonic system.

A more recent study by Trehub and colleagues (1999) presents a brief explanation of the pattern in which the scales that create harmony and tonality are developed and possible psychological explanations for their structure,

> Compared with intervals, scales in any musical culture describe a more complex set of relations among tones, one that specifies how an octave interval is filled with intermediate pitches. The resulting scale proceeds, in ascending sequence, ending on the tone an octave above the initial tone. Although there is considerable variation in the component pitches of scales across cultures, similarities are evident aside from the number of different pitches in the scale (5 to 7) and the prevalence of specific intervals (e.g., the 3:2 ratio).

> For example, variation in step size (e.g., 1 or 2 semitones in the case of Western scales) is the general rule for non-Western as well as Western scales. Various psychological advantages have been posited for this "unequal interval principle, or intervallic asymmetry, such as increasing the possibility of melodic variation, providing the listener with a sense of location, facilitating the perception of tension and resolution, and allowing different notes to assume distinctive functions. Although the division of the octave into equal steps is a possible feature of scales, it is especially notable for its rarity.[43]

These findings provide insight into the development of the diatonic system and its psychological and aesthetic implications.

Equal-step scales, such as the chromatic scale (division of the octave into 12 equal steps of 1 semitone) and the whole-tone scale (division of the octave into 6 equal steps of 2 semitones), are utilized in much 20th century art music.

However, relatively few listeners seem to understand or appreciate such compositions.[44] This could be explained by the fact that, in adulthood, the limited capacity of working memory is thought to constrain the number of different tones used in scales to a maximum of seven per octave.[45] As a result, many listeners find it difficult to understand and difficult to enjoy modern "art" music, which is often composed with scales that exceed this limit.[46] The ubiquity of unequal-step scales, then, may be based on perceptual processing predispositions rather than familiarity or historical tradition.[47]

Developmental studies provide insight into the importance of both nature and nurture in the perception of music in infants and adults. Results from a study by Trehub and colleagues (1999) imply that, although unequal-step scales are inherently easier to perceive than are equal-step scales, adults' superior performance on familiar (the major scale) over unfamiliar (a fabricated scale), unequal-step scales highlights the importance of culture-specific exposure.[48] Knowledge of and experience with the major scale likely interfered with the adults' processing of other unequal-step scales, just as adults' knowledge of native-language sounds interferes with their perception of some nonnative phones, suggesting yet another link between music and speech.[49]

Significant differences in musical perception between infants and adults have also been found. For instance, Trainor and Trehub (1992) found that adults easily detected changes that violated Western musical structure (i.e., non-diatonic) but had difficulty with changes that preserved such structure (i.e., diatonic).[50] Infants, however, detected both changes equally well, implying that there are qualitative differences between infants' and adults' processing of musical information. These results demonstrate that developmental changes or exposure may lead to alterations of musical perception.

The expanding list of similarities in music perception between infants and adults suggests a biological preparedness for the processing of musical sequences.[51] For instance, infants and adults readily retain the melodic contour, or pattern of successive pitch reversals (up or down) in a melody, and infants' attention to the pitch contours of speech sequences is a notable linguistic parallel.[52]

The internalization of diatonic structure and tonality is a topic that reveals interesting changes throughout development. Recent developmental research has revealed that infants can discriminate frequency differences smaller than a semitone between isolated tones, while the majority of adults have more difficulty.[53] By 6 or 7 years of age, children show a preference for scale (diatonic) over non-scale (non-diatonic) tones, reflecting an internalization of diatonic scale structure.[54] By 8 or 9 years of age, children prefer specific diatonic tones, more specifically the tones of the tonic triad, suggesting an increased awareness of Western tonal structure.[55]

In memory tasks, older children also show superior retention of tonal over atonal melodies.[56] For instance, Dawling and Goedecke discovered that musical training contributed little to the detection of reordered pitches in a melody in 6-year-olds, but did enhance performance for 8-year-olds.[57] These developmental changes reflect a significant shift in musical and auditory perception from infancy to adulthood.

Schellenberg and colleagues (2002) offer another link between the perception of music and speech. They found that the perception of pitch reversal in musical phrases was underdeveloped among 8 and 11 year olds compared with adults, as well as among 5 year olds compared to older children.[58] This developmental change in musical expectancies can be explained in three ways; as the consequence of maturity and exposure to music, as a by-product of general developmental progressions in perception and cognition that exert influence across domains and modalities, or that learning and exposure in one auditory domain (speech) directly influences expectancies in another auditory domain (music).[59] For instance, young children's failure to expect pitch reversals after large intervals in melodies may be a consequence of being exposed to frequent and large pitch shifts that they hear in speech, which are often not followed by changes in direction.

Across cultures, adults and older children alter their speech patterns when addressing infants and younger children,[60] which may have effects on their perception of both speech and music. Compared with normal speech, infant-directed speech is produced with a higher pitch, exaggerated pitch contours (i.e., upward and downward shifts in pitch), slower tempo, shorter utterances, and extensive repetition, as well as larger pitch range, greater rhythmicity, slower tempo, and repeating pitch contours.[61] Speech directed to toddlers and young children has similar modifications, although these become attenuated with the increasing age of children.[62] Consistent exposure to this type of speech could alter the musical expectations of infants.

Other intriguing findings demonstrate that it may be the musical quality of infant-directed speech that makes it an effective means of emotional communication.[63] Fernald (1989) also suggested that the melody communicates emotional content during infant-directed speech. Young infants use prosodic cues in infant-directed speech to segment the speech stream into clauses,[64] much like the way they use pitch contour and tone duration to segment music into musical phrases.[65] Rock and colleagues (1999) suggest that music may be a more powerful medium than speech for effective communication with infants, which is partly supported by the view that maternal singing modulates the arousal of pre-linguistic infants.[66]

Various studies have found response proclivities to certain musical stimuli that seem to reflect biological predispositions. For example, Dolgin and Adelson (1990) found that 4-year-olds correctly identified emotions, including happiness, sadness anger, and fear, from sung melodies. Additionally, Kastner and Crowder (1990) found that 3-year-olds consistent with adults in matching positive (happy/interested) and negative (sad/angry) faces to melodies played in either the major or minor chord. Studies of infants' looking and listening preferences suggest that they perceive many properties of music similarly to adults, including information about tempo, pitch, melody, and musical phrase structure.[67]

The idea that there is a close relationship between music and the human voice has an extensive history.[68] One of the pioneers of music psychology, Helmholtz (1863/1954) suggested that, "an endeavor to imitate the involuntary modulations of the voice, and make its recitation richer and more expressive, may therefore possibly have led our ancestors to the discovery of the first means of musical expression."[69] Marcel Proust writes, "There are in the music of the violin... accents so closely akin to those of certain contralto voices that one has the illusion that a singer has taken her place amid the orchestra."[70] Richard Wagner noted that "the oldest, truest, most beautiful organ of music, the origin to which alone our music owes its being, is the human voice.[71] Stendhal commented that "no musical instrument is satisfactory except in so far as it approximates to the sound of the human voice."[72] This notion is supported by the view that most musical instruments have a voice-like character.

However, while there are noted similarities between musical instruments and the voice, many instruments far exceed the human voice in terms of speed, pitch range, and timbre. Consequently, there is speculation that many musical instruments are processed by brain modules as super-expressive voices.[73] They write,

> If human speech is perceived as angry when it has fast rate, loud intensity, and harsh timbre, a musical instrument might sound extremely angry in virtue ofits even higher speech, louder intensity, and harsher timbre. The "attention" of the emotion-perception module is gripped by the music's voice-like nature, and the individual becomes aroused by the extreme turns taken by this voice. The emotions evoked in listeners may not necessarily be the same as those expressed and perceived but could be empathic or complementary.[74]

These speculations could lead to further research that would offer a theoretical economy by providing yet another link between the modalities of speech and music.

Certain analogies can be found between speech in the research by noted linguist Noam Chomsky and psychology and music researcher, Eugene Narmour, who proposes innately specified rules governing the order of tones in melodies, known as the "universal grammar" of melodies.[75] Chomsky sought to explain how mature speakers of a language can interpret and generate an infinite number of sentences. He focused especially on the issue of grammaticality: in any given language, certain sentences intuitively seem grammatical to nearly all speakers of a language, whereas other sentences seem ungrammatical.

Chomsky coined the phrase "knowledge of language" to refer to these unconscious principles that guide judgments about grammar as well as sentence comprehension and construction.[76] The principles that humans share can be considered a universal grammar, and Chomsky's framework for comprehending language is reliant upon understanding what these principles are and how they develop in the brain through the combination of genetic predispositions and constraints and linguistic experience.[77]

Similarly, music also seems to have a diatonic vocabulary and certain acoustic stimuli are considered to be musical by the majority of a given culture, even if the sounds have never been heard before. Conversely, there are other stimuli that most people recognize as unmusical (e.g., violations of diatonic structure in a melody).[78] Schellenberg and colleagues find that the basic rules governing melodic expectancies and their development likely stem from perceptual and cognitive biases that extend beyond music in particular and audition in general.[79] Just as Chomsky proposed a universal grammar for speech, Narmour continues to search for similar correlates in music.

Three experiments by Thompson and colleagues (2004) found that there may be a link between musical experience and the ability to identify emotional cues in speech. They find that music lessons may promote sensitivity to emotions conveyed by speech prosody. After hearing semantically neutral remarks uttered with emotional (i.e., happy, sad, fearful, or angry) prosody, or tone sequences that emulated the prosody of the remarks, participants identified the emotion conveyed, with musically trained adults outperforming untrained adults.[80]

In another study, Brandler and Rammsayer (2003) found that musicians demonstrated superior performance on verbal memory tasks, supporting the notion that musical training exerts beneficial effects on verbal memory, which is most likely due to changes in cortical organization.[81] This research provides further evidence of a link between the faculties of music and speech.

Like music, languages also have unique rhythmic properties. While rhythm is generally regarded as self-explanatory in music, Ramus and colleagues (2000) propose an empirical measure of rhythm in language defined as the proportion of the time occupied by vowels.[82] Research has consistently shown that intonation and accurate prosodic segmentation are important sources of verbal information.[83] Thompson and Cuddy (1997) found that there are comparable cues to segmentation in music, with phrase endings associated with decreases in loudness and increases in duration.[84]

Developmental studies in humans demonstrate that infants have the ability to discriminate sentences from two non-native languages in different rhythmic classes if sentences are played in their normal, forward direction, primarily making judgments based on rhythm.[85] Requiring the use of similar perceptual mechanisms, rhythmic patterns influence recognition and comprehension both in speech and music.

While they share numerous similarities, there are also aspects of both music and speech that are unique to each modality. For example, neuropsychological research indicates that certain aspects of music (e.g., timbre) share the same neural resources as speech, whereas others (e.g. tonality) draw on resources that are unique to music.[86] Additionally, harmony and tonality have no corollaries in speech.

It is a recurrent notion that music is a means of emotional expression.[87] One possible explanation is that music is reminiscent of vocal expression of emotions, or, more generally, that the same processes in auditory analysis are involved. Another possibility is that, through classical conditioning, a musical piece may have developed a strong association with a particular emotion experienced in the past, which leads to an expectancy to respond in a similar manner with successive encounters.[88]

Langer (1957) offered the theory that music involves a number of dynamic patterns such as tension and release, motion and rest, agreement and disagreement, and sudden or surprising change, which are inherently linked to emotion.[89] Research has also found that violations in listeners' musical expectation are arousing, which leads to appropriate emotional responses.[90]

Since the time of Darwin, animal vocalizations have been known to reflect and convey specific information about the caller's emotional state. For instance, many friendly or submissive calls tend to be harmonically structured; attention-getting signals commonly have contours of rising frequency; and aggressive calls are often short, staccato bursts.[91]

There is also evidence that many of these patterns also are present in human vocalizations, including our purely emotive sounds such as laughter and crying, the paralinguistic signals that are communicated in conjunction with our linguistic utterances, infant-directed speech, and even the sounds we use to train animals.[92]

Thus, human and nonhuman animals encode emotional information in their vocalizations and also have perceptual systems that have evolved to respond appropriately to such signals. Hauser and McDermott (2003) argue that we may well have co-opted this mechanism for use in music, even if it did not evolve for this function.[93]

Cross-cultural studies have offered insight into the biological predispositions for the modalities of both music and speech. A recent cross-cultural study examined whether Westerners perceive the same emotions in North Indian ragas as to native Indians.[94] Results showed that Westerners and native Indians tend to make very similar judgments of emotion, suggesting that at least some of the emotive cues in music are shared across cultures. This provides further evidence that there may be innate mechanisms for perceiving emotion in music that composers and musicians seek to engage.[95]

Music has also been found to evoke physiological responses that accompany emotions such as tears, tingles down the spine, and changes in heart rate, breathing rate, blood pressure, and skin conductance levels.[96] Indeed, adults report that they frequently listen to music in order to alter their physiological and emotional state.[97] However, as related earlier, the physiological responses to music may not be due to the listening to the music itself but instead could be a result of classical conditioning that occurs when listening to a certain kind of music and it becomes linked with a particular emotive response.

There is evidence that emotions in music and speech are encoded and perceived in a similar manner. Both music and speech use variations in rate, amplitude, pitch, timbre, and stress to communicate different emotions.[98] Pitch contour and rhythmic grouping are critical dimensions in both music and prosody.[99] In music, temporal relations and pitch define musical tunes, which retain their identities across transformation in pitch level and tempo for most humans. In speech, pitch variation and/or intonation provides an important source of semantic and emotional information, and temporal properties aid listeners in determining boundaries between words and phrases.[100]

Descending pitch contours and syllables or notes of long duration generally denote ends of phrases in speech and in music.[101] Even young infants parse speech and music using this information.[102] Musical pitch and speech intonation are also processed primarily by the right hemisphere, while rhythms in music and speech are less clearly lateralized.[103] Furthermore, music and speech share neural resources for combination of their basic elements (i.e., musical tones and words, respectively) into rule-governed sequences.[104] This similarity in processing suggests that speech and music are closely related in evolutionary and/or perceptual terms.

Absolute pitch (AP), the musical ability to identify or sing pitches without an external reference, has been a recent focus of music research. While there are a number of controversial theories about AP, most scientists agree that this ability is apparently neither inherited nor completely teachable.

Chin (2003) offers that the reason why some musicians have AP and others do not depends on both the developmental age at which musical instruction began and individual differences in cognitive style, with children who had a particular type of music training before the ages of 5 to 7 years and who have a more analytical cognitive style are most likely to develop AP.[105] Some researchers believe in a genetic explanation for AP and are searching for a single "Absolute Pitch Gene."[106] Most, however, believe that the ability comes from a combination of both nature and nurture.

While some genetic researchers believe there is a genetic condition that is necessary, but not sufficient, for the presence of AP, some recent studies have begun to support a theory of early learning; this dictates that everyone has the potential to develop AP but only during a critical period of childhood.[107] Chin found that the mean age at which AP possessors began musical activities was at 5.4 years, whereas the mean age at which non-AP students began activities was 7.9 years.[108]

It is important that children be exposed to musical activities before the age of 6 years, Chin argues, because the "preoperational period" of Piaget (1950) – ages 3 to 6 years – is when children have not yet begun to think of music in a more relativistic manner. Those children who are predisposed to interpreting the world with an analytic cognitive style are more likely to develop AP if they have particular kinds of musical experience during the critical period of the preschool years.[109]

Saffran and Griepentrog (2001) offer the unlearning hypothesis, which suggests that certain types of experiences could lead learners to maintain AP abilities. Research finds that people who are congenitally blind and that people with autism demonstrate better AP memory than the general population.[110] This evidence suggests that attending to different aspects of the environment may affect the degree to which AP is unlearned.[111]

Saffran and Griepentrog have found that infants are more likely to track patterns of absolute pitches than of relative pitches, and, like songbirds, can even represent the absolute pitches of tone sequences and can do so given complex and unsegmented input.[112] Unlike infants, adult listeners rely primarily on relative pitch cues. These results suggest a shift from an initial focus on AP to the eventual dominance of relative pitch, a characteristic that is unique to humans, which is more useful for both musical and speech processing.[113]

Trehub and colleagues (1997), remarking that nonhuman animals demonstrate a tendency to respond primarily to absolute pitch, offer a similar developmental account whereby relational pitch processing supersedes the less mature strategy of absolute pitch processing. They remark that this change of focus may be due to a more general developmental change in focus from absolute to relative features in representational systems.[114]

Although further research is clearly warranted to bolster our understanding of the acquisition of musical knowledge, limitations of study design inhibit rapid progress. For instance, it is nearly impossible to control for the level of early exposure to music, especially because even the fetus can hear a filtered version of sounds in the external environment by as early as the third trimester of pregnancy.[115]

With further research into the biological basis of music, it may be beneficial to anchor it in a framework similar to that laid out by Chomsky for language, as well as to raise more specific questions about its evolutionary ancestry.[116] Is there something unique to the human brain that allows us to understand and create music, or can other animals appreciate it just as readily and simply lack the capacity to produce it? By researching patterns of convergence and divergence with music capacities with other animals, uniquely human aspects of the music faculty as well as the mechanisms that provided the foundation for its evolution will be brought to the fore.[117]

Additionally, cross-cultural research should be carried out regarding the mysterious ability of absolute pitch. For example, Indian and Balinese musicians, many of whom can sing in quarter-tone, could be investigated to ascertain whether they have this sort of perfect pitch according to their own more segmented tonal structure, and, if so, can it be used for other non-native types of music?[118]

Researchers may also be interested in identifying whether or not there is a "poverty of the stimulus problem" for the musical faculty in general as there is for speech. Is there a critical period for music perception and comprehension during which a child must be exposed to music in order to develop normal musical perceptual abilities?[119] Studies could be conducted testing wolf-children who have a limited capacity for speech or children with language deficiencies to investigate if they have similar limitations in their perception of music.

The research of music as a biological phenomenon remains in its infancy. One consequence of musical cultures building on perceptual processing dispositions is that their exposure and training result in progressive improvement of the very skills that are favored by nature.[120] While posing a challenge to researchers, this has allowed music to evolve from its primitive origins into the diversity of genres, styles, and forms we appreciate today. Over the course of history, music has come to have a ubiquitous presence in art and culture, and begs further investigation into the manner in which it gained its unique position in human experience.

Part Two:

How Does Musical Training Affect the Human Brain?

"If I were to begin life again, I would devote it to music. It is the only cheap and unpunished rapture on earth."

- Sydney Smith, 1844

The investigation into the development of musical ability has a long and controversial history. Many researchers have been particularly interested in the brain structure of musicians, whether it differs from that of non-musicians, whether training could account for those differences, and whether these differences are related to disparities in skills.[121] Others have been interested in the relationship between musical skill and specific mental abilities, following the notion that musical and intellectual abilities might use similar cognitive functions and that musical training has beneficial effects on nonmusical abilities as a result of transfer effects or neural plasticity.[122] Only a comprehensive exploration of the influences of both nature and nurture can one provide an explanation of the differences between musicians and non-musicians.

Musical training involves daily practice with long periods of focused attention, reading of notation, memorization of extended passages, and exposure to variety of structures, pattern recognition, and mastery of technical skills.[123] It is supposed that this combination of experiences might have a positive impact on cognition. This could be especially true during childhood, when brain development is highly plastic and sensitive to environmental influence.[124] Whether the unique musical abilities and structural differences that exist in the brains of musicians result from learning, perhaps during critical periods of brain development and maturation, or whether they reflect innate abilities and capacities that might be cultivated by early exposure to music is largely unknown.[125]

Many musicians are skilled in performing complex mental and physical operations such as translation of visually presented musical symbols into sequential finger movements, memorization of long musical phrases, and improvisation.[126]

Playing a musical instrument generally requires the simultaneous integration of multimodal sensory and motor information with multimodal sensory feedback mechanisms that monitor performance.[127]

Several behavioral, neuroimaging, and neurophysiological studies have explored the exceptional and highly specialized sensorimotor, auditory, visual-spatial, auditory-spatial, and memory skills of musicians.[128] Functional imaging studies have shown differences between musicians and non-musicians while performing motor, auditory, or somatosensory tasks.[129] Many of these authors argue that the differences in these skills are directly related to amount of musical experience.

Neurophysiological findings, especially regarding hemispheric specialization, have also stimulated research in understanding the differences between musicians and non-musicians. Numerous studies have found that musical information processing requires dynamic cooperation between several cortical areas of both hemispheres and that musical processing in experienced musicians often includes left hemispheric functions, and is marked by higher cortical connectivity.[130]

Several studies are consistent with the notion of a positive relationship between musical and verbal, mathematical, and visual-spatial abilities.[131] Barrett and Barker (1973) argue that musical aptitude is a complex of a number of separate and relatively independent attributes,[132] and others argue that these skills are transferable to non-musical activities. Differences between musicians and non-musicians have also been found in hand skill, flexibility of closure, perceptual speed, hidden object detection, spatial processing, speech, and even general intelligence.

In their study of hand-skill asymmetry in professional musicians, Jancke and colleagues found that right-handed musicians show right-hand superiority as well as a lesser degree of hand skill asymmetry due to increases in dexterity.[133] These results were replicated with both pianists as well as string-players. The authors concluded that early commencement of musical experience led to this adaptation process as a result of performance requirements interacting with cerebral maturation during childhood.[134]

Interestingly, musicians show a slight but significantly higher incidence of left or mixed handedness.[135] Musicians also exhibit the tendency to perform "secondary tasks" such as unscrewing a lid or dealing cards, more often with the non-dominant hand due to their increased left-hand skills. These results suggest a link between musical training and ambidexterity.

Differences have been found between musicians and non-musicians in processing-related mental tasks, as well. Helmbold and colleagues compared 70 adult musicians and 70 non-musicians matched for age, sex, and level of education. They found that musicians performed reliably better than non-musicians in Flexibility of Closure (the ability to identify a visual figure or pattern embedded in a complex distracting or disguised visual pattern or array) and Perceptual Speed.

Several studies have also shown a reliable superiority of subjects with high musical ability to subjects with low musical ability in the Hidden pattern Test,[136] which requires detection of concealed figures. White (1954) reported significant positive correlations between performance in detecting hidden tunes (three- to five-note melodies embedded in a more complicated one) and its visual equivalent (embedded figures).[137] It is unclear whether musicians' superior performance reflects non-aural aspects of musical ability or is the result of long-term musical training.

Considering the cognitive demands involved in playing an instrument, it is possible that the abilities of Flexibility of Closure, Perceptual Speed, and Hidden Pattern Identification might represent aspects crucial to the processing of music, namely rapid recognition of musical symbols or structures (e.g., chords, intervals, melodic, or rhythmic patterns).[138] These abilities might be especially helpful for sight-reading, as it depends on the rapid processing of complex visual stimuli and precision of multimodal sensory-motor coupling.[139] Several studies have even determined that these traits are prerequisites to advanced sight-reading.[140] Further studies could measure proficiency in sight-reading abilities along with these traits to see if they are indeed directly related.

In addition to finding a relationship to visuospatial skills, research also cites an indelible link between music and speech. Thompson, Schellenberg, and Husain (2004) also found that music lessons promote sensitivity to emotions conveyed by speech prosody.[141] After hearing semantically neutral utterances spoken with emotional (i.e., happy, sad, fearful, or angry) prosody, or tone sequences that mimicked the prosody of the utterances, musically trained adults outperformed untrained adults in differentiating between different emotions, especially sadness, fear, or neutral emotions.[142] Neuropsychological research indicates that certain aspects of music such as timbre share the same neural resources as speech.[143] These findings offer insight into the possible benefits of musical training in language processing.

The supposition that musical activities lead to a rise in general intelligence has been a subject of recent debate. Some argue that general intelligence supports the development of musical abilities and others suggest that musical ability constitutes a basic aspect of intelligence that is largely independent of other primary mental abilities as suggested by Gardner's (1983) "Theory of Multiple Intelligences."[144]

In their review of more than 50 studies published from the year 1924 to 1979 on the relationship between musical ability and general intelligence, Shuter-Dyson and Gabriel (1981) found that nearly all of the correlation coefficients were positive but low, typically around .30.[145] However, these findings have not been consistently replicated, and the subject requires a great deal more attention before definitive conclusions can be reached.

Although many of the findings for the positive effects of musical training are controversial, an interesting insight is that no study has found that music has a negative impact on the development of any other skill or ability. In fact, Kvet (1985) found that there were no differences in sixth-grade reading, language, and mathematics achievement between students who were excused from regular classroom activities for the study of instrumental music and students not studying instrumental music who remained in class.[146] These findings suggest that, while the positive effects of musical training may be difficult to replicate, participation in musical activities has no negative impact on academic achievement, even if the participation in music leads to exclusion from school-related activities.

While the claim that musical experience has a positive effect on a number of non-musical traits is debatable, it does seem to lead to changes in processing. In pitch-memory tasks, musicians show more right temporal and supramarginal gyrus activation while non-musicians had more right primary and left secondary auditory cortex activation.[147] The authors argue that musical training leads to processing differences, with non-musicians relying solely on brain regions responsible for pitch discrimination. Musicians, however, also use brain regions specialized in short-term memory and recall to perform well in pitch memory tasks. These differences demonstrate that musicians recruit portions of the brain that are normally involved in non-musical tasks for musical discrimination.

In another study, a dichotic listening task involving violin melodies was given to musicians and non-musicians, with musicians demonstrating right ear superiority, and the non-musicians performing better with the left ear. Interestingly, right ear scores distinguished between the groups, but left ear scores did not.[148] These results indicate that musicians mainly use the left hemisphere to process musical stimuli, while non-musicians use the right, suggesting that as a person becomes more musically adept, increasing use is made of a left hemisphere sequential analytic mechanism.

In a three-stage longitudinal study with children at the beginning of puberty, Hassler and Birbaumer (1986) found differences between male musicians and male non-musicians in Witelson's Dichaptic Stimulation Test.[149] Evidence indicated a gradual shift from right-hemisphere superiority for spatial processing to left-hemisphere superiority, which only occurred in musicians.[150] These results indicate that the cortical organization of the male musician is less lateralized than that of the non-musician.

Gender effects have been found in many studies, with females generally relying on less lateralized processing strategies than males. In a study by Gaab and colleagues, male subjects had greater lateralized activations (left > right) in anterior and posterior perisylvian regions during the "perceptual" as well as during the "memory" phases of a pitch memory task. Males also had more cerebellar activation than females, and females showed more prominently posterior cingulated/retrosplenial cortex activation compared to males.

Lee, Chen, and Schlaug (2003) among others have found that male musicians develop greater interhemispheric connectivity and increased hemispheric symmetry between motor areas and other frontal brain regions due to musical experience.[151] Interestingly, although activation pattern differed significantly, there were no significant differences in the behavioral performance between genders.[152] These results indicate that, while males generally have a more lateralized processing strategy, male musicians, like female musicians and non-musicians, tend to process musical stimuli more symmetrically.

Hormonal differences have also been found between musicians and non-musicians. For example, testosterone has consistently shown to be correlated with creative musical behavior. Hassler (1991) finds that an optimal testosterone range may exist for musical expression. This range seems to be at the bottom of normal male testosterone range and at the top of normal female testosterone range.[153] Hassler (1992) also found that these musicians in the optimal testosterone range attained significantly higher spatial test scores than non-musicians in an 8-year period of adolescent development and in adulthood.[154] However, the objective measurement of "creative musical behavior" remains elusive, as creativity is difficult to quantify.

Recent research into the cognitive benefits of passive music listening, often known as the Mozart Effect, has been the subject of a great deal of controversy. The Mozart Effect most specifically claims the result that even passive listening to music composed by Mozart is followed by increases in intelligence scores. Although a number of studies have shown slight effects in tasks that range from paper-folding to spatial awareness,[155] many more have found the Mozart effect impossible to replicate.[156] Many effects that have been found can be attributed fluctuations in arousal and mood generated by different testing conditions,[157] rather than Mozart's music itself.

While the validity of the Mozart Effect is debatable, participation in musical activities has consistently shown to increase self-esteem. This effect may account for the widespread use of music as a therapeutic treatment in clinical settings with groups characterized by low self-esteem.

Costa-Giomi (2004) studied the effects of three years of piano instruction on children's self-esteem. The sample consisted of 117 fourth-grade children attending public schools in Montreal who had never participated in formal music instruction, did not have a piano at home, and had an income of below $40,000. Children in the experimental group received individual piano lessons weekly for three years and were given an acoustic piano at no cost to their families. Children in a control group received no such instruction.

After three years, the results indicated that piano instruction had a positive effect on children's self-esteem as well as school music marks, but did not affect their academic achievement in math and language as measured by standardized tests and school report cards. The children, their parents, and their piano teachers believed that the piano instruction improved the students' lives in many ways by making them feel more assertive, better about themselves, and happy.[158]

In addition to behavioral effects, a number of studies have found structural brain differences between musicians and non-musicians in numerous areas of the brain including the temporal lobe, motor cortex, corpus callosum, cerebellum, visual cortex, Heschl's gyrus, temporal gyrus, Broca's area, and the Planum Temporale. While some authors consider these differences innate, many have found that they are correlated with a measure of musicianship, suggesting they may result from musical experience.

The morphometry of the corpus callosum is of particular interest for studies that examine brain asymmetry and interhemispheric exchange because it plays an important role in interhemispheric integration and communication. Male musicians have a significantly larger anterior corpus callosum than non-musicians. These results are compatible with plastic changes of components of the corpus callosum during a maturation period within the first decade of human life, similar to those observed in animal studies.[159] Females do not show a significant effect, which may be due to a tendency for a more symmetric brain organization than males.

Interestingly, a study by Amunts and colleagues replicated the finding of a larger anterior corpus callosum in musicians, but also found that the effect was more pronounced in musicians with an early commencement of musical training (before age 7) compared to musicians starting later.[160] The authors argue that this might represent a structural cerebral adaptation (e.g. thicker myleninated transcallosal fibers or a greater amount of transcallosal fibers), which were triggered by a requirement for continuously practicing complicated bimanual finger movements.[161]

In other words, the corpus callosum may have undergone an adaptation in the young brain, which coincided with the late mylination of the corpus callosum. Since musicians starting after the age of 7 did not demonstrate this effect and, in fact, did not differ significantly from the nonmusician control group, a selectional hypothesis (e.g., a larger anterior corpus callosum would endow a child to become skilled at playing a musical instrument at a young age) is an unlikely explanation for these anatomical differences.[162]

Several studies have implicated the cerebellum in music processing along with finding significant structural differences between musicians and non-musicians.[163]

Hutchinson and colleagues found that male musicians had a larger cerebellar volume than non-musicians, as well as a correlation between the age of commencement of musical training and the degree of functional or structural difference that was found between musicians and non-musicians.[164]

In a study by Gaser and Schlaug (2003), Musicians showed a higher volume of gray matter in the left Heschl's gyrus, a portion of the auditory cortex that is involved in musical processing, which was associated with neurophysiological source activity differences between professional musicians, amateur musicians, and non-musicians while listening to tones.[165]

Another study by Schneider and colleagues finds that both the morphology and neurophysiology of Heschl's gyrus have an essential impact on musical aptitude.[166] While Schneider and colleagues argue that there must be a great influence of genetics, repeated flexing of the brain by practicing a musical instrument could account for the increased amount of gray matter in the auditory cortex.

A study by Gaser and Schlaug (2003) finds that there is a strong increase in gray matter volume related to musician status in the inferior temporal gyrus, most probably including anatomical regions involved in the ventral visual stream.[167] They suggest that learning related increases in functional activity in the inferotemporal cortex and associated increases in the ventral prefrontal cortex, into which the inferotemporal cortex projects when subjects learn to choose actions prompted by visual stimuli, a process in which musicians are continuously engaged while playing their instrument.[168] These activities could result in an increase in gray matter volumes.

Differences between musicians and non-musicians have also been found in areas relating to the processing of language. Broca's area is acknowledged to be involved in spoken language and various musically relevant abilities, such as visuospatial and audiospatial localization.[169] As a possible correlate to reading and language, sight-reading is a visuospatial analysis task that is specific to and practiced by musicians, and this type of spatial ability is known to be amenable to training effects. A study by Sluming and colleagues (2002) suggests that orchestral musical performance promotes use-dependent retention, and possibly expansion, of gray matter involving Broca's area.[170] Additionally, this offers further support for shared neural substrates underpinning expressive output in music and language.

Differences have been found between musicians and non-musicians in overall gray matter densities. Using a voxel-by-voxel morphometric technique, Gaser and Schlaug (2003) found gray matter volume differences in motor, auditory, and visual-spatial regions of the brain when comparing professional musicians with a matched group of amateur musicians and non-musicians, which contributed to higher overall gray matter volumes in musicians.[171] The authors believe that these multiregional differences are not due to innate predisposition, but instead represent structural adaptations in response to long-term skill acquisition as well as the repetitive rehearsal of those skills. The strong association between structural differences, musician status, and practice intensity supports this assumption.

Most researchers agree that the differences are not exclusively attributable to innate predisposition, but are in some part due to adaptations in response to musical experience. Adaptations could include a combination of a strengthening of existing synapses, the formation of new synapses, and the recruitment of cortical tissue into the activated cortex that was previously not recruited by changing the local balance of excitation and inhibition.[172]

The unique training and motor experiences of musicians provides an ideal experimental design to investigate brain plasticity. The term plasticity is broad and can mean an adjustment or adaptation of a sensory or motor system to environmental stimuli or performance requirements or a compensation of some cerebral structures for others that are impaired due to injury.[173]

A common finding across most skill acquisition studies is the functional enlargement of the representative area that underlies that particular skill.[174] As a demonstration of plasticity affected by a music-related task, Pascual-Leone and colleagues showed that as subjects learned a five-finger exercise on the piano over the course of five days, the cortical representation area targeting the long finger flexor and extensor muscles enlarged.[175]

Karni and colleagues also showed that a few minutes of daily practice of a sequential finger opposition task induced large, incremental performance gains over several weeks of training, which, in turn, was suggested to result in changes in cortical movement representation within the primary motor cortex.[176]

Schlaug also found persistent representational changes in response to the early acquisition of fine sensorimotor skills such as having a larger sensory finger representation in the left hand of string players.[177] This evidence refutes

Schellenberg's theory that musical aptitude and technical ability are no longer plastic after age nine. Musicians form an ideal subject pool in which one can investigate possible cortical changes in response to meeting the unique requirements of skilled performances as well as cerebral correlates of unique musical abilities such as Absolute Pitch.[178]

The ability to identify or sing pitches without an external reference, known as Absolute Pitch (AP), has been a recent focus of music research and offers a prime example of the manner in which abilities are developed through the interaction between genes and environment. Many scientists agree that this ability is apparently neither inherited nor completely teachable. Chin (2003) offers that the reason why some musicians have AP and others do not depends on both the developmental age at which musical instruction began and individual differences in cognitive style, with children who had a particular type of music training before the ages of 5 to 7 years and who have a more analytical cognitive style are most likely to develop AP (see figure 4).[179] Some researchers believe in a genetic explanation for AP and are searching for a single 'Absolute Pitch Gene.'[180] Most, however, believe that the ability comes from a combination of both nature and nurture.

The ability of AP may be linked to one structure in the human brain, the planum temporale, which is preferentially activated in musicians who have absolute pitch during tone tasks. Schlaug (2001) and others suggest that it may undergo some form of functional plasticity that is possible only during a critical period of brain development, as musicians who possess early-onset AP have been shown to have an increased left-sided asymmetry of the planum temporale (see figure 4).[181] Renninger, Granot, and Donchin (2003) found that there are various levels of AP ability,[182] and, if developed later, AP may rely on other brain regions.

Taking these differences between musicians and non-musicians into account, an interesting question emerges; are there prerequisites for musical talent? Waterhouse (1998) attempted to elucidate structure and the basis of special talents, namely in music, arts, mathematics, poetry, and memory. She hypothesized that all of these talents were based on the same global set of cognitive skills that involve "the acutely accurate and extremely extensive representation of visual images and sounds, and the rapid recognition and facile manipulation of patterns involving those visual and auditory representations."[183]

Concerning the differences in the cortical organizations of musicians and non-musicians, it has been suggested that the special anatomy is a prerequisite for musical skill acquisition rather than its consequence.[184] If these structural differences are indeed innate, individuals who possess them might be drawn to becoming musicians and also face fewer obstacles in mastering a musical instrument because they are equipped with the necessary brain anatomy.[185] However, the strong relationship between structural differences and age of commencement of musical activity and amount of practice (see figures 2,3), as well as the wealth of data that supports brain plasticity, an exclusive self-selection for musicianship by individuals with innate brain structural differences is unlikely. Instead, these volumetric structural differences should be seen as adaptations to long-term musical training.

Ericsson and colleagues suggest that many characteristics once believed to reflect innate talent are actually the result of extensive practice for a minimum of 10 years,[186] which is known as the expertise theory. An influential approach in expertise theory is known as deliberate practice, which focuses on the quality and structure of effective practice activity. The deliberate practice approach emphasizes the fact that it is not only the amount of time an individual is engaged in practice activities that is a valid and sufficient predictor of later achievement, but also the amount of intentional and well planned training.[187]

Vitouch finds that the best musicians have the most accumulated hours of practice, with less accomplished musicians having less amounts of practice. He suggests that this is evidence for the fact that innate ability or talent has a limited effect on achievement, and it is rather the amount of practice that is most important. However, one could argue that the musicians who possess an innate predisposition for success in music would enjoy practicing more, which would result in a higher level of achievement.

A major problem with most studies that examine the relationship between musical ability and cognitive abilities is the fact that musical ability can hardly be investigated independently from musical training.[188] Longitudinal studies are required to definitively establish causal relationships between function and structural change. Future studies also should continue to investigate the question of whether musicians' perceptual superiority reflects an innate nonaural component of musical ability rather than representing a beneficial side effect of early, continuous musical training.

While some researchers stress the exclusive importance of genes or environment over the other, it is likely that the truth lies somewhere in between, with both nature and nurture having a significant influence on musical ability. Whether differences in cortical structure and processing are the cause or a consequence of extended participation or success in music remains unclear, although most studies conclude that it is the combination of genes and environment that make musicians so fundamentally different from non-musicians.

Coda

"It got to a point where I had to get a haircut or a violin."

- F.D. Roosevelt, 1938

Since I carried out the extensive research required for this work, my approach to understanding music has shifted considerably. When I wrote this review of literature, I forced myself to consider music as a researcher and a scientist. After traveling the world performing as a professional musician for well over 10 years, however, I see music through a different lens. Music is far more art than science.

While additional research that advances our knowledge in the field is welcomed, I believe we've known quite enough all along: Music is good for the brain, heart, and soul. Regardless its origins, music is a gift to be enjoyed.

As Samuel Pepys said, "Music is the thing of the world that I love most."

Keep playing and live well.

Abel James

P.S. – If you'd like to stay up-to-date with research, books, and other work about music, come visit at **AbelJames.com**.

Figures

Figure 1. From John Hawkins, *A General History of the Science and Practice of Music*, as cited by Head (1997).

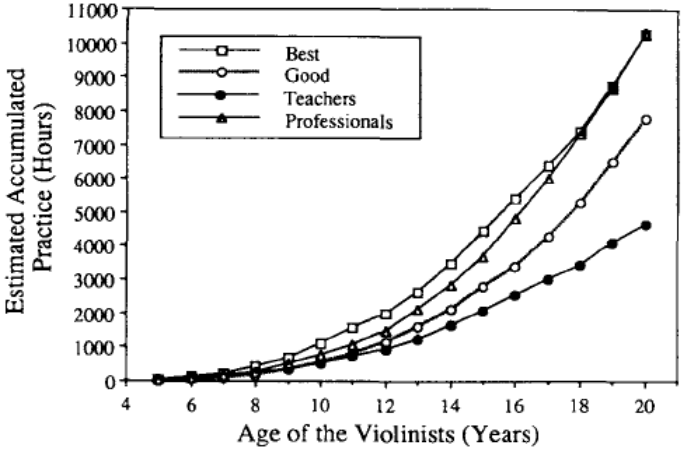

Figure 2. Accumulated amount of practice alone (on the basis of estimates of weekly practice) as a function of age for the middle-aged violinists, the best violinists, the good violinists, and the music teachers (Ericsson, Krampe, Tesch-Romer, 1993, p. 364).

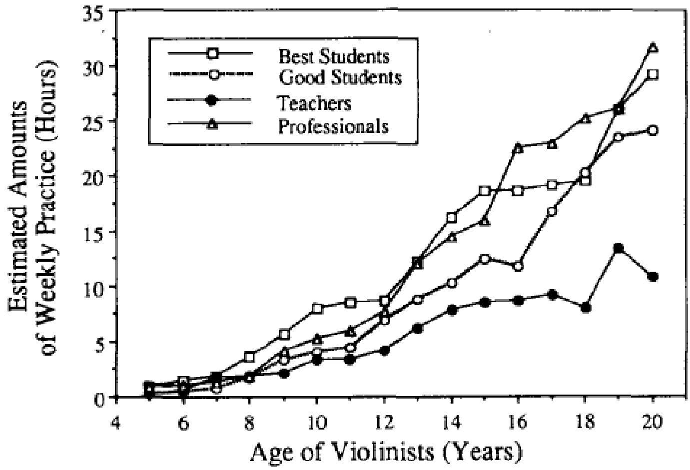

Figure 3. Estimated amount of time for practice alone with the violin as a function of age for the middle-aged (professional) violinists, the best violinists, the good violinists, and the music teachers (Ericsson, Krampe, Tesch-Romer, 1993, p. 365).

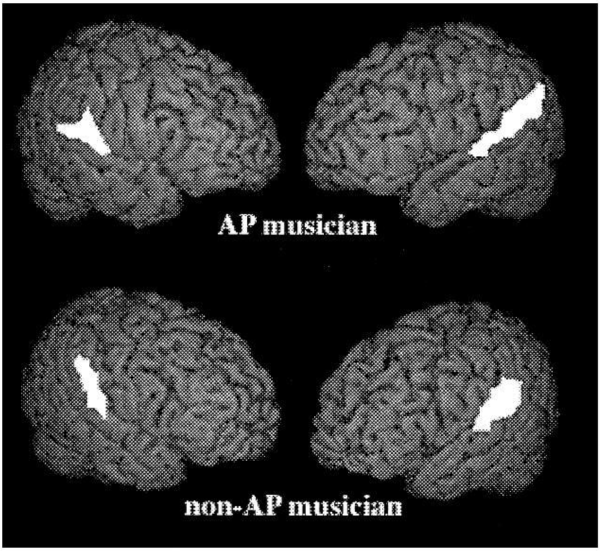

Figure 4. Significantly greater leftward asymmetry of the planum temporale of AP musicians when compared to non-AP musicians (Schlaug, 2001, p. 292).

Bibliography

Amunts, K., Schlaug, G., Jancke, L., Steinmetz, H., Schleicher, A., Dabringhaus, A., Zilles, K. (1997). Motor Cortex and Hand Motor Skills: Structural Compliance in the Human Brain. *Human Brain Mapping* 5, 206-215.

Ashley, E. (2003). An empirical investigation of the anxiolytic and pain reducing effects of music, *Psychology of Music* 31(2), 187-203.

Austin, W. (1953). The Idea of Evolution in the Music of the 20th Century. *The Musical Quarterly*, 39(1), 26-36.

Bailey, B. and Davidson, J. (2005). Effects of group singing and performance for marginalized and middle-class singers. *Psychology of Music,* 33(3), 269-303.

Bamberger, J. (2003). The development of intuitive musical understanding: a natural experiment. *Psychology of Music* 31(1), 7-36.

Baumeister, R. and Leary, M. (1997). Writing Narrative Literature Reviews. *Review of General Psychology* 1(3), 311-320.

Besson, M. and Faita, F. (1995). An Event-Related Potential (ERP) Study of Musical Expectancy: Comparison of Musicians with Nonmusicians. *Journal of Experimental Psychology: Human Perception and Performance*, 1278-1296.

Bigand, E. (1997). Perceiving Musical Stability: The Effect of Tonal Structure, Rhythm, and Musical Expertise. *Journal of Experimental Psychology: Human Perception and Performance*, 23(3), 808-822.

Blacking, J. (1969). The Value of Music in Human Experience. *Yearbook of the International Folk Music Council*, 1, 33-71.

Brandler, S. and Rammsayer, T. (2003). Differences in mental abilities between musicians and non-musicians. *Psychology of Music* 31(2), 123-138.

Burkholder, J. (1993). Music Theory and Musicology. *The Journal of Musicology*, 11(1), 11-23.

Chin, C. (2003). The development of absolute pitch: a theory concerning the roles of music training at an early developmental age and individual cognitive style. *Psychology of Music* 31(2), 155-171.

Chomsky, N. (1986). Knowledge of Language: Its Nature, Origin, and Use. New York: Praeger.

Costa-Giomi, E. (2004). Effects of three years of piano instruction on children's academic achievement, school performance and self-esteem, *Psychology of Music* 32(2), 139-152.

Crawley, E., Acker-Mills, B., Pastore, R. and Weil, S. (2002). Change Detection in Multi-Voice Music: The Role of Musical Structure, Musical training, and Task Demands. *Journal of Experimental Psychology: Human Perception and Performance*, 28(2), 367-378.

Darwin, C. (1871). The Descent of Man and Selection in Relation to Sex. London: John Murray.

Deschenes, B. (1991). Music and the New Scientific Theories. *International Review of the Aesthetics and Sociology of Music,* 22(2), 193-202.

Deschenes, B. (1998). Toward an Anthropology of Music Listening. *International Review of the Aesthetics and Sociology of Music*, 29(2), 135-153.
DeWitt, L. and Samuel, A. (1990). The Role of Knowledge-Based Expectations in Music Perception: Evidence from Musical Restoration. *Journal of Experimental Psychology: General*, 199(2), 123-144.
Gaab, N., Keenan, J., Schlaug, G. (2003). The Effects of Gender on the Neural Substrates of Pitch Memory. *Journal of Cognitive Neuroscience* 15(6), 1-11.
Gabb, N., Schlaug, G. (2003). The effect of musicianship on pitch memory in performance matched groups. *NeuroReport* 14(18), 2291-2295.
Gaser, C., and Schlaug, G. (2003). Brain Structures Differ between Musicians and Non-Musicians. *The Journal of Neuroscience,* 23(27), 9240-9245.
Grew, E. (1928). Herbert Spencer and Music. *The Musical Quarterly*, 14(1), 127-142.
Ericsson, K., Krampe, R., Tesch-Romer, C. (1993). The Role of Deliberate Practice in the Acquisition of Expert Performance. *Psychological Review* 100(3), 363-406.
Hassler, M. (1992). Creative musical behavior and sex hormones: musical talent and spatial ability in the two sexes. *Psychoneuroendocrinology* 17(1), 55-70.
Hassler, M. (1991). Testosterone and Musical Talent. *Exp Clin Endocrinol* 98(2), 89-98.
Hassler, M., Birbaumer, N. (1986). Witelson's dichaptic stimulation test and children with different levels of musical talent. *Neuropsychologia* 24(3), 435-40.
Hauser, M. and McDermott, J. (2003). The evolution of the music faculty: a comparative perspective. *Nature: Neuroscience*. ONLINE.
Head, M. (1997). Birdsong and the Origins of Music. *Journal of the Royal Musical Association* 122(1), 1-23.
Helmbold, N., Rammsayer, T., Altenmuller, E. (2005). Differences in Primary Mental Abilities Between Musicians and Nonmusicians. *Journal of Individual Differences* 26(2), 74-85.
Herzog, G. (1936). Primitive Music. *Bulletin of the American Musicological Society,* 1, 3-4.
Hutchinson, S., Hui-Lin Lee, L., Gaab, N., Schlaug, G. Cerebellar Volume in Musicians, 1-27.
Jackson, C. and Tlauka, M. (2004). Route-learning and the Mozart effect. *Psychology of Music,* 32(2), 213-220.
Jancke, L., Schluag, G., Steinmetz, H. (1997). Hand Skill Asymmetry in Professional Musicians. *Brain and Cognition* 34, 424-432.
Juslin, P. (2003). Five facets of musical expression: a psychologist's perspective on music performance. *Psychology of Music,* 31(3), 273-302.
Juslin, P. and Laukka, P. (2003). Communication of Emotions in Vocal Expression and Music Performance: Different Channels, Same Code? *Psychological Bulletin* 129(5), 770-814.

Juslin, P. (2000). Cue Utilization in Communication of Emotion in Music Performance: Relating Performance to Perception. *Journal of Experimental Psychology: Human Perception and Performance,* 26(6), 1797-1813.
Lee, D., Chen, Y., Schlaug, G. (2003). Corpus callosum: musician and gender effects. *NeuroReport* 14(2) 205-209.
Lesuik, T. (2005). The effect of music listening on work performance. *Psychology of Music* 33(2), 173-191.
Kaemmer, J. (1980). Between the Event and the Tradition: A New Look at Music in ociocultural Systems. *Ethnomusicology*, 24(1), 61-74.
Kivy, P. (1959). Charles Darwin on Music. *Journal of the American Musicological Society* 12(1), 42-48.
Mark, D. (1983). Pop and Folk as a Going Concern for Sociological Research. *International Review of the Aesthetics and Sociology of Music*, 14(1), 93-98.
Maultsby, P. (1995). A Map of the Music. *African American Review*, 29(2), 183-184. Music. (1982). *Oxford American Dictionary*. New York: Avon.
Nadel, S. and Baker, T. (1930). The Origins of Music. *The Musical Quarterly* 16(4), 531-546.
Nawrot, E. (2003). The perception of emotional expression in music: evidence from infants, children and adults. *Psychology of Music* 31(1), 75-92.
Nayak, S., Wheeler, B., Shiflett, S. and Agostinelli, S. (2000). Effect of Music Therapy on Mood and Social Interaction Among Individuals with Acute Traumatic Brain Injury and Stroke. *Rehabilitation Psychology*, 45(3), 274-283.
Nketia, J. (1982). Developing Conteporary Idioms out of Traditional Music. *Studia Musicologica Academiae Scientiarum Hungaricae,* 24, 81-97.
Offer, J. (1983). An Examination of Spencer's Sociology of Music and Its Impact on Music Historiography in Britain. *International Review of the Aesthetics and Sociology of Music*, 14(1), 33-52.
Putman, D. (1985). Music and the Metaphor of Touch. *The Journal of Aesthetics and Art Criticism,* 44(1), 59-66.
Raymond, A., MacDonald, R., Mitchell, L., Dillon, T., Serpell, M., Davies, J. and Ashley, E. (2003). An empirical investigation of the anxiolytic and pain reducing effects of music, *Psychology of Music* 31(2), 187-203.
Rickard, N. (2004). Intense emotional responses to music: a test of the physiological arousal hypothesis. *Psychology of Music,* 32(4), 371-388.
Sacks, Oliver. (1995). Musical Ability. *Science* 268, 621.
Saffran, J. and Griepentrog, G. (2001). Absolute Pitch in Infant Auditory Learning: Evidence for Developmental Regorganization. *Developmental Psychology*, 37(1), 74-85.
Scalero, R. and Baker, T. (1926). On the Origins of Music. *The Musical Quarterly* 12(3), 334-339.

Schellenberg, E., Adachi, M., Purdy, K. and McKinnon, M. (2002). Expectancy in Melody: Tests of Children and Adults. *Journal of Experimental Psychology: General,* 131(4), 511-537.
Schlaug, G. (2001). The Brain of Musicians: A Model for Functional and Structural Adaptation. 281- 299.
Schlaug, G., Jancke, L., Huang, Y., Staiger, J., Steinmetz, H. (1995). Increased Corpus Callosum Size in Musicians. *Neuropsychologia* 33(8) 1047-1055.
Shenfield, T., Trehub, S. and Nakata, T. (2003). Maternal singing modulates infant arousal. *Psychology of Music,* 31(4), 365-375.
Sluming V., Barrick T., Howard M., Cezayirrli E., Mayes A., Roberts N. (2002). Voxel-based morphometry reveals increased gray matter density in Broca's area in male symphony orchestra musicians. *Neuroimage* 17(3), 1613-22.
Smith, N. and Schmuckler, M. (2004). The Perception of Tonal Structure Through the Differentiation and Organization of Pitches. *Journal of Experimental Psychology: Human Perception and Performance,* 30(2), 268-286.
Spencer, H. (1858). The Origin and Function of Music. *Essays, Scientific, Political, and Speculative*.
Supicic, I. (1969). Science on Music and Values in Music. *The Journal of Aesthetics and Art Criticism*, 28(1), 71-77.
Taylor, D.B. (1973). Subject Responses to Precategorized Stimulative and Sedative Music. *Journal of Music Therapy,* 10(2), 86-94.
Thompson, W., Schellenberg, E. and Husain, G. (2004). Decoding Speech Prosody: Do Music Lessons Help? *Emotion*, 4(1), 46-64.
Thompson, W. and Cuddy, L. (1997). Music Performance and the Perception of Key. *Journal of Experimental Psychology: Human Perception and Performance,* 23(1), 116-135.
Tillmann, B. and Bharucha, J. (2000). Implicit Learning of Tonality: A Self-Organizing Approach. *Psychological Review*, 107(4), 885-913.
Tillmann, B., Janata, P., Birk, J. and Bharucha, J. (2003). The Costs and Benefits of Tonal Centers for Chord Processing. *Journal of Experimental Psychology: Human Perception and Performance*, 29(2), 470-482.
Trainor, L. and Trehub, S. (1992). A Comparison of Infants' and Adults' Sensitivity to Western Musical Structure. *Journal of Experimental Psychology: Human Perception and Performance*, 18(2), 394-402.
Trehub, S., Cohen, A., Thorpe, L. and Morrongiello, B. (1986). Development of the Perception of Musical Relations: Semitone and Diatonic Structure. *Journal of Experimental Psychology: Human Perception and Performance*, 12(3), 295-301.
Trehub, S., Schellenberg, E. and Kamenetsky, S. (1999). Infants' and Adults' Perception of Scale Structure. *Journal of Experimental Psychology:; Human Perception and Performance*, 25(4), 965-975).
Walker, R. (2004). Cultural memes, innate proclivities and musical behaviour: a case study of the western traditions. *Psychology of Music* 32(2), 153-190.

Wright, A., Rivera, J., Hulse, S., Shyan, M. and Neiworth, J. (2000). Music Perception and Octave Generalization in Rhesus Monkeys. *Journal of Experimental Psychology: General*, 129(3), 291-307.

Notes

[1] Hauser & McDermott, 2003, p. 1
[2] Darwin, 1871
[3] Spencer, 1858
[4] Juslin, 2003
[5] Hauser & McDermott, 2003, p. 2
[6] Brown, 2000; Levman, 2000; Scherere, 1995; Storr, 1992, Chap. 1; Zucker, 1946, as cited in Juslin, 2003
[7] Hauser & McDermott, 2003, p. 2
[8] p. 573
[9] Kivy, 1959, p. 43
[10] Kivy, 1959, p. 45
[11] As cited in Darwin, 1871, p. 572
[12] Kivy, 1959, p. 48
[13] Kivy, 1959, p. 48
[14] These characteristics, as we will see later in the review, are similar to the those of music.
[15] p. 400
[16] Juslin & Laukka, 2003, p. 775
[17] Eggebrecht, 1983, as cited by Juslin, 2003
[18] Eible-Eibesfeldt, 1989, as cited by Juslin, 2003
[19] Juslin & Laukka, 2003, p. 775
[20] Hauser & McDermott, 2003, p. 1
[21] Hauser & McDermott, 2003, p. 3
[22] Hauser & McDermott, 2003, p. 3
[23] Hauser & McDermott, 2003, p. 3
[24] Wright, Rivera, Hulse, Shyan, & Neiworth, J, 2000
[25] Wright et al., 2000, p. 304
[26] Walker, 2004, p. 154; Hauser & McDermott, 2003, p. 3
[27] Hauser & McDermott, 2003, p. 3-4
[28] Hauser & McDermott, 2003, p. 3-4
[29] Wright, 2000, p. 291

[30] Fishman, 2001, as cited by Hauser & McDermott, 2003
[31] Hauser & McDermott, 2003, p. 4
[32] Hauser & McDermott, 2003, p. 5
[33] Hauser & McDermott, 2003, p. 5
[34] See Figure 1., as cited by Head, 1997
[35] Head, 1997
[36] Dowling & Harwood, 1986; Handel, 1989
[37] Trehub, Schellenberg, & Kamenetsky, 1999, p. 965
[38] Hauser & McDermott, 2003, p. 2
[39] Deschenes, 1998, p. 142
[40] Cuddy, Cohen, & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979, as cited by Trainor & Trehub, 1992
[41] Cuddy et. al, 1992, p. 395
[42] Trehub, Cohen, Thorpe, & Morrongiello, 1986, p. 295
[43] Trehub et. al, 1999, 965-6
[44] Lerdahl, 1988; Meyer, 1994, as cited by Trehub et al., 1999
[45] Dowling & Harwood, 1986, as cited by Schellenberg, 2002
[46] Schellenberg, Adachi, Purdy, & McKinnon, 2002, p. 532
[47] Trehub et al., 1999, p. 966
[48] Trehub et al., 1999, p. 972
[49] Best, 1994; Polka, 1995, as cited by Trehub, 1999
[50] Trainor & Trehub, 1992, 399
[51] Trehub et al., 1999, p. 972
[52] Fernald, 1991, 1993; Fernald & Kuhl, as cited by Trehub et al., 1999
[53] Olsho, 1984; Olsho, Schoon, Sakai, Turpin, & Sperduto, 1982, as cited by Trehub et al., 1986
[54] Badertscher, 1985; Krumhansl & Keil, 1982; Speer & Adams, 1985, as cited by Trehub et al., 1986
[55] Krumhansl & Keil, 1982, as cited by Trehub et al., 1986
[56] Zanatti 1969, as cited by Trehub et al., 1986
[57] Trehub et al., 296
[58] Schellenberg, Adachi, Purdy, & McKinnon, 2002, p. 531
[59] Schellenberg et al., 2002, p. 531

[60] Fernald & Simon, 1984; Fernald et al., 1989; Grieser & Kuhl, 1988, as cited by Schellenberg et al., 2002
[61] Fernald & Simon, 1984; Fernald, Taeschner, Dunn, Papousek, deDoysson-Bardies, & Fukui, 1989; Grieser & Kuhl, 1988; Jacobson, Boersma, Fields, & Olson, 1983; Papousek & Papousek, 1981, 1987; Papousek, Papousek, & Bornstein, 1985; Stern, Spieker, Barnett, & MacKain, 1983, as cited by Trainor & Trehub, 1992
[62] Garnica, 1977; Snow, 1972; Stern, Spieker, Barnett, & MacKain, 1983; Warren-Leubecker & Bohannon, 1984, as cited by Schellenberg et al., 2002
[63] Trainor et al., 2000, as cited by Schellenberg et al., 2002
[64] Hirsh-Pasek et al., 1987, as cited by Schellenberg et al., 2002
[65] Jusczyk & Krumhansl, 1993, as cited by Schellenberg et al., 2002
[66] Shenfield, Trehub, & Nakata, 2003, p. 365
[67] Schellenberg and Trehub, 1996; Trehub et al., 1987, 1999; Trehub and Schellenberg, 1995; Trehub and Trainor, 1993, as cited by Nawrot, 2003
[68] Helmholtz, 1863/1954; Kivy, 1980; Rousseau, 1761/1986; Scherer, 1995; Spencer, 1857; Sundberg, 1982, as cited by Juslin & Laukka, 2003
[69] p. 371, as cited by Juslin & Laukka, 2003
[70] Watson, 1991, p. 2, as cited by Juslin & Laukka, 2003
[71] As cited in D. Watson, 1991, p. 2, as cited by Juslin & Laukka, 2003
[72] As cited by Juslin & Laukka, 2003
[73] Juslin & Laukka, 2003, p. 803
[74] Juslin & Laukka, 2003, p. 803
[75] Schellenberg et al., 2002, p. 534
[76] Hauser & McDermott, 2003, p. 1
[77] Hauser & McDermott, 2003, p. 1
[78] Hauser & McDermott, 2003, p. 1

[79] Schellenberg et al., 2002
[80] Thompson, Schellenberg, & Husain, 2004
[81] Brandler & Rammsayer, 2003, p. 123
[82] As cited by Hauser & McDermott, 2003
[83] Thompson, & Cuddy, 1997, p. 135
[84] Thompson, & Cuddy, 1997, p. 135
[85] Hauser & McDermott, 2003
[86] Patel & Peretz, 1997, as cited in Juslin & Laukka, 2003
[87] Budd, 1985; S. Davies, 2001; Gabrielsson & Juslin, 2003, as cited in Juslin & Laukka, 2003
[88] Schellenberg et al., 2002, p. 511
[89] Thompson, Schellenberg, & Husain, 2004, p. 47
[90] Meyer, 1956; Gaver & Mandler, 1987, as cited in Thompson et al., 2004
[91] Hauser & McDermott, 2003, p. 4
[92] Hauser & McDermott, 2003, p. 4
[93] Hauser & McDermott, 2003, p. 4
[94] Hauser & McDermott, 2003, p. 4
[95] Hauser & McDermott, 2003, 4
[96] Goldstein, 1980; Krumhansl, 1997; Panksepp, 1995; Sloboda, 1991, 1992; Thayer & Levenson, 1983, as cited in Thompson et al., 2004
[97] Sloboda, 1992, as cited in Thompson et al., 2004
[98] Juslin & Laukka, 2003; Sherer, 1995, as cited by Thompson et al., 2004
[99] Patel, Peretz, Tramo, & Labrecque, 1998, as cited by Thompson et al., 2004
[100] Thompson et al., 2004, p. 48
[101] Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991; Narmour, 1990, as cited in Thompson et al., 2004
[102] Hish-Pasek et al., 1987; Jusczyk & Krumhansl, 1993, as cited by Thompson et al., 2004

[103] E.g., McKinnon & Schellenberg, 1997; Peretz, 2001; Snow, 2000; Van Lancker & Sidtis, 1992, as cited in Thompson et al., 2004
[104] Patel, 2003, as cited by Thompson et al., 2004
[105] Chin, 2003, p. 155
[106] Baharloo et al., 2000; Gergersen et al., 2000; Profita and Bidder, 1988, as cited by Chin, 2003
[107] Baharloo et al., 1998, 2000; Gregersen et al., 1999, 2000; Profita and Bidder, 1988, as cited by Chin, 2003
[108] Chin, 2003, p. 158
[109] Chin, 2003, 164
[110] E.g., Welsch, 1988; Heaton, Hermelin, & Pring, 1998; Mottron, Peretz, Belleville, & Rouleau, 1999, as cited in Saffran et al., 2001
[111] Saffran & Griepentrog, 2001, p. 83

[112] Saffran, Griepentrog, 2001, p. 83
[113] Saffran & Griepentrog, 2001, p. 74
[114] Takeuchi & Hulse, 1993, as cited in Saffran et al., 2001
[115] Hauser & McDermott, 2003, p. 3
[116] Hauser & McDermott, 2003, p. 5
[117] Hauser & McDermott, 2003, 5
[118] Deschenes, 1998, 151
[119] Hauser & McDermott, 2003
[120] Trehub et al., 1999, p. 973
[121] Meyer, 1977; Schlaug et al., 1995a,b; Amunts et al., 1997; Zatorre et al., 1998, as cited in Hutchinson, p. 4
[122] E.g., Barwick, Valentine, West, & Wilding, 1989, as cited in Helmbold, Rammsayer, Altenmuller, 2005, p. 74
[123] Helmbold et al., 2005, p. 75
[124] Huttenlocher, 2002, as cited by Helmbold et al., 2005, p. 75
[125] Schlaug, p. 282
[126] Gaser & Schlaug, 2003, p. 9240

[127] Gaser & Schlaug, 2003, p. 9240
[128] Amunts, 1997; Hund-Georgiadis and Von Cramon, 1999; Altenmuller, 1986; Besson et al., 1994; Pantev et al., 1998; Zatorre et al., 1998; Keenan et al., 2001; Ohnishi et al., 2001; Hetland, 2002; Munte et al., 2001; Chan et al., 1998, as cited by Gaser & Schlaug, 2003, p. 9240
[129] Elbert et al., 1995; Pantev et al., 1998; Schlaug, 2001, as cited by Gaser & Schlaug, 2003, p. 9240
[130] E.g., Altenmüller, 1986; Besson, Faita, & Requin, 1994; Bever & Chiarello, 1974; Bhattacharya & Petsche, 2001; Bhattacharya, Petsche, & Pereda, 2001; Johnson, Petsche, Richter, & von Stein, 1996, as cited by Helmbold et al., 2005, p. 75
[131] E.g., Cooley, 1961; Hermelin & O'Connor, 1980; Münzer, Berti, & Pechmann, 2002,Whellams, 1970, Barrett & Barker, 1973; Brochard, Dufour, & Després, 2004; Geng & Mehl, 1969; Hassler, 1992; Hassler, Birbaumer, & Feil, 1985, 1987, as cited by Helmbold et al., 2005, p. 75
[132] As cited by Helmbold et al., 2005, p. 82
[133] Jancke, Schlaug, & Steinmetz, 1997, p. 424
[134] Jancke et al., 1997, p. 424
[135] Aggleton et al., 1994, Gilbert & Wysocki, 1992; Perelle & Ehrman, 1994, as cited by Jancke et al., 1997, p. 430
[136] Ekstrom, French, Harman & Demen, 1976, as cited by Helmbold et al., 2005, p. 80
[137] Helmbold et al., 2005, p. 80
[138] Helmbold et al., 2005, p. 70
[139] Gabrielson, 1999, as cited by Helmbold et al., 2005, p. 80
[140] Bean, 1938, Lannert & Ullmann, 1945, as cited by Helmbold et al., 2005, p. 80
[141] Thompson, Schellenberg, & Husain, 2004, p. 46
[142] Thompson, Schellenberg, & Husain, 2004, p. 46
[143] Juslin & Laukka, 2003, p. 774

[144] E.g., Rodocy & Boyle, 1979; Shuter-Dyson & Gabriel, 1981, as cited by Helmbold et al., 2005, p. 74
[145] As cited by Helmbold et al., 2005, p. 74
[146] Costa-Giomi, 2004, p. 141
[147] Gabb & Schlaug, 2003, p. 2291
[148] Johnson, 2002, p. 43
[149] Hassler & Birbaumer, 1986, p. 435
[150] Hassler & Birbaumer, 1986, p. 435
[151] Lee, Chen & Schlaug, 2003, p. 208
[152] Gaab, Keenan, Schlaug, 2003, p. 1
[153] Hassler, 1992, p. 55
[154] Hassler, 1992, p. 55
[155] E.g., Hetland, 2000b; Rauscher, Shaw, & Ky, 1995; Rideout, Dougherty, &
Wernert, 1998; Rideout & Laubach, 1996; Rideout & Taylor, 1997, as cited by Helmbold et al., 2005, p. 76
[156] E.g., Carstens, Huskins, & Hounshell, 1995; Kenealy & Monsef, 1994; McCutcheon, 2000; McKelvie & Low, 2002; Newman et al., 1995; Steele, 2003; Steele, Bass, & Crook, 1999; Steele et al., 1999; Stough, Kerkin, Bates, & Mangan, 1994; for a meta-analysis based on 16 studies see Chabris, 1999, as cited by Helmbold et al., 2005, 76
[157] Husain, Thompson, & Schellenberg, 2002; Nantais & Schellenberg, 1999; Steele, 2000; Thompson, Schellenberg, & Husain, 2001, as cited by Helmbold et al., 2005, p. 76
[158] Costa-Giomi, 2004, p. 142
[159] Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995, p. 1047
[160] Amunts, Schlaug, Jancke, Steinmetz, Schleicher, Dabringhaus, & Ziles, 1997, p. 207
[161] Amunts et al., 1997, p. 207
[162] Amunts et al., 1997, p. 207

[163] Griffiths et al., 1999, Parsons, 2001, Gaab et al., 2003, as cited by Gaser & Schlaug, 2003, p. 9243
[164] Hutchinson, Hui-Lin Lee, Gaab, Schlaug, 2003, p. 12
[165] Gaser & Schlaug, 2003, p. 9243
[166] Schneider, Scherg, Dosch, Specht, Gutschalk, & Rupp, 2002, p. 688
[167] Gaser & Schlaug, 2003, p. 9243
[168] Gaser & Schlaug, 2003, p. 9243
[169] Sluming, Barrick, Howard, Cezayirrli, Mayes, & Roberts, 2002, p. 1623
[170] Sluming et al., 2002, p. 1623
[171] Gaser & Schlaug, 2003, p. 9240
[172] Schlaug, 2001, p. 283
[173] Schlaug, 2001, p. 282
[174] Schlaug et al., 1994, Karni et al., 1995, Pascual-Leone et al., 1995, Toni et al., 1998, as cited by Gaser & Schlaug, 2003, p. 9240
[175] As cited by Schlaug, 2001, p. 283
[176] As cited by Schlaug, 2001, p. 283
[177] Schlaug, 2001, p. 283
[178] Schlaug, p. 281
[179] Chin, 2003, p. 155
[180] Baharloo et al., 2000; Gergersen et al., 2000; Profita and Bidder, 1988, as cited by Chin, 2003
[181] Schlaug, 2001, p. 292
[182] Renninger, Granot, & Donchin, 2003, p. 357
[183] Waterhouse, 1988, p. 495, as cited by Helmbold et al., 2005, p. 81
[184] Gaser & Schlaug, 2003, p. 9244
[185] Gaser & Schlaug, 2003, p. 9244
[186] Ericsson, Krampe, Tesch-Romer, 1993, p. 363
[187] Vitouch, 2005, as cited by Helmbold et al., 2005, p. 82
[188] Helmbold et al., 2005, p. 82

About the Author

A modern-day Renaissance man, Abel James is a #1 bestselling author, top 10 app developer, award-winning talk show host, musician, and serial entrepreneur. His work has been featured in WIRED Magazine, Paleo Living, and hundreds of media outlets in business, technology, psychology, and health.

As host of the wildly-popular Fat-Burning Man Show, Abel brings Paleo, ancestral, and real food principles to the mainstream. Within its first year, his show rose to the #1 most popular health podcast in the United States and United Kingdom and went on to top the charts across the world.

Also a singer-songwriter and multi-instrumentalist, Abel James has toured North America and Europe as the bandleader of multiple award-winning musical groups.

A tireless researcher, Abel completed high school and college in a total of just six years. Distinguished as Valedictorian at New Hampton School, Abel graduated as a Senior Fellow with Honors at Dartmouth College with a concentration in Psychological and Brain Sciences.

Hailing from the frosty backwoods of New Hampshire, Abel James lives with his rambunctious yellow lab, Bailey, in Austin, Texas.

Read more from Abel at **FatBurningMan.com** and **AbelJames.com**.