Sensitive Periods in Musical Development

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Honors Thesis
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The focus of my thesis comes primarily from a passion for music, combined with an enlightening Child Development course taken at Washington State University and flavored with an interest in the nature of sensitive periods in human development. I sing privately and publicly as frequently as possible, and continually cultivate my own musical interests, abilities and understanding. I grew up in a home where personal and performance music was encouraged and shared openly within the family, among friends and in our church congregation. This eventually combined with my study of Psychology while at WSU to raise the question as to how much influence an environment rich in musical experiences has on the musical growth of young people.

Critical and sensitive periods have waxed and waned as a topic of interest in general psychology several times since their initial discovery and definition early in the 20th century, but the field of human development has been the most consistent locus of research into the ideas. Even before I began my undergraduate studies of Biology and Psychology at WSU, I had heard of sensitive periods while learning about feral children raised with little or no human interaction. These children were drastically different from socialized children, with the clearest difference being that after maturing past a certain age, it was difficult, if not impossible, for these children to acquire normal language skills. The idea fascinated me. How is it that the interaction between a capable and adaptive human mind and their environment has such a permanent effect on development of a structural and functional characteristic like language?

Later I learned that research into the presence and influence of such sensitive periods goes far beyond language acquisition. Ultimately, I learned that evidence of sensitive periods
appears in nearly every aspect of human development. I was excited to find that recent improvements in the investigation of neurological functioning have encouraged researchers to combine behavioral studies and observational data to form a better picture of potential influences; namely that sensitive and critical periods may impact specific behaviors of human musical development. After reviewing much of the literature related to sensitive periods and musical development, I present my reasoning for the argument that much of the current neurobiological and psychological evidence supports the presence of sensitive periods for musical development.

To analyze the idea, I first provide an overview of the history of sensitive and critical periods, and the differences between these two terms. Secondly, I discuss current scientific understandings of music as a behavior and a neurological process and describe the difficulties faced in examining such a complex and differentiated behavior. Third, I demonstrate support for the presence of sensitive periods in several different aspects of musical development with research published in peer-reviewed journals and literature. Finally, I review the current position of musical development in the research field and discuss possibilities for future study.
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Introduction

The human brain demonstrates an impressive ability to grow and adapt, and the more one learns about it the more fascinating and surprising it becomes. Perhaps the most important and least thoroughly understood aspect of the human body, the brain processes an individual’s experiences with the world and houses most of the tools used to interact with that world. Studying the brain is one of the most interesting parts of psychology, and one of the most mysterious as well; we understand much of the structure and function of the brain, but we are limited in our knowledge about the human mind (Wolfe & Brandt 1998). Catching a glimpse of how an individual mind accumulates human behavior became an interest of mine while taking a basic Human Development course at Washington State University several years ago, and that interest continues to this day.

About one year ago, I read a book that eventually merged this interest in human development with my personal musical interests to produce the basis for this paper. *This is your brain on music* by Daniel Levitin is a broadly discursive work with a briskly paced focus on the way that our brains perceive, process and react to music. One of the topics touched upon is how early experiences with music effect our later tastes and development. Levitin posits that “basic structural elements are incorporated in the very wiring of our brains when we listen to music early in our lives”, and continues, saying that taking music lessons as a child is extremely important in creating efficient neural pathways for music (Levitin 2006, p. 109). This reminded me strongly of the critical period hypothesis as discussed in the psychological sciences, and encouraged me to explore the issue further by asking the question: are early-life musical
experiences so important that they can determine our future musical abilities? Further exploration revealed that though it was possible to locate well-focused studies, research results and theories concerning the subject of musical development, a lack of a summary on the specific topic of the influences of musical experiences early in life on later ability encouraged me to gain an overview of the topic of sensitive periods in early musical development.

To explore this topic, we must engage knowledge from several fields of study. Psychology helps explain how the maturing brain understands and reacts to stimuli and the exchange between our environment and ourselves. Neuroscience aids in understanding the structure of our brains and the physical changes encouraged through learning and experience. An understanding of music as an art and a language helps us link the two sciences together. Overall, examining the relationship between our development and our environment through the lens of sensitive periods helps us more accurately describe part of the picture of human development, predict possible outcomes of different teaching and learning situations, and addresses important questions in the long-term debate of whether nature or nurture is the more important factor in human development.

Research Question

Does current research in human development, cognition and neuroscience indicate a sensitive period for the acquisition of musical skills?
Methodology

To examine this question, I utilized literature from the primary fields of Human Development and Neuroscience, and some literature from the fields of Music Teaching and Learning Theories. Experimental research undertaken in the last 15 years was sought due to changes in research possibilities as explained in the Results and Discussion section. However, many of the theories and research presented have a longer history than just the last 15 years. Though the topic of sensitive periods and their effects on human development is actively present in popular literature and culture as shown in magazines such as TIME (Sayre 2007) and Newsweek (Wingert & Kantrowitz 1997), the vast majority of my resources come from peer-reviewed journals and the extension of these ideas as published in professional literature. Wherever possible, I use sources that demonstrate evidence-based scientific research, minimal personal bias and well-designed experimental conditions; suggestions of where and how experimental conditions and design might be improved are included in the Future Research section of this paper.

I also attempt to utilize research presenting minimal bias as demonstrated by the mention and explanation of opposing viewpoints, and where I find such bias to be present, it is mentioned in the Future Research section. Finally, I will use these resources to outline and investigate the possibility of a sensitive period for musical development, and to examine the history and future possibilities of this intriguing field.
Several of the terms used in this paper require operational definitions to help avoid confusion. The operational definition of critical and sensitive periods will be explained and defined in the next section. In this section I will define musical ability and human development.

The term musical ability has broad definitions, and an understanding of different viewpoints helps to clarify some of the abstract nature of the term, which is used widely throughout the literature. Essentially a combination of the attributes and actions of a person's musical perceptions, nature, environment and performance, musical ability is defined by Seashore as a set of fundamental sensory skills, related by a common genetic basis and thus unchangeable over time (Hallam & Prince 2003). Gordon understood musical ability as the influence of three aspects of an individual's conception: tonal imagery (harmony and melody), rhythmic imagery (tempo and meter), and sensitivity to musical elements such as phrasing and style (1987). Radocy and Boyle defined ability as being able to do something, regardless of how a person acquires the knowledge, skills or experience involved (2003). They then explained musical abilities as an interplay between attitude, interest, appreciation, taste, preference (involves choices and indicating them to others, rather than agreement with experts about quality or excellence, as does taste) and sensitivity to musical stimuli (Radocy & Boyle 2003). Musical ability is therefore clearly a broadly defined term, but for this paper it will represent the tendencies, both learned and unlearned, that an individual uses to relate to and understand their musical world, primarily their perceptions, skills and sensitivities.

Human development is the study of the systematic changes that an individual undergoes between conception and maturity, and musical development is an extension of this
concept to the specific area of musical behaviors (Kemp & Mills 2002). These changes may include, as noted by Eliot (1971), biological, psychological and social aspects, and continue throughout an individual’s lifetime (Bornstein 1987). Radocy and Boyle explain that people develop from the earliest awareness of sound to more complex interactions with music and occasionally reach a form of music literacy, although most people never extend past the stage of musical recognition and basic singing (2003).

Literature Review

Musical Behavior and Human Development

Musical behavior is among the most complex of human actions. By combining physicality, energy, storytelling, emotion and memory with sound and timing, we produce works of astounding depth and power, which are communicated through interplay of our environments, our senses, and our brains to create a musical experience. The impact of music is made more impressive when we consider that music is universal to all known human cultures (Trehub 2001). Though the preferences, methods and standards vary between societies, all have some identifiable form of musical expression, and this fact raises an army of questions about the origins and purpose of music: Is there a singular definition of music? Why is music important enough that all cultures have it? Why and how does music differ from culture to culture? Is music a necessary element of human culture, or a passionate oddity? Though these questions are all interesting, this paper focuses on the question of whether there are sensitive periods in developing music ability.
Internal and External Influences on Development

The question of how individuals obtain their own musical abilities and how the interaction of their personal nature with external influences affects their musical development stands out as a central area for psychological research. Many aspects of human development stem from mixtures of genetics and environment, wherein some aspects are inherited and some are shaped by external influences experienced during growth (Korenman & Peynircloglu 2007; Colombo 1982). An example of this is language acquisition: humans inherit the ability to learn language, but timing and quality of their exposure to certain languages largely determines their linguistic acquisition (Robertson 2001). Though genetics and environment are the two primary influences on human development, their impacts are extremely difficult to separate and measure; there are simply too many unknown factors in each area to understand accurately (Gordon 1987; Ceci 1990). By testing for differences and analyzing emergent patterns between individuals, researchers are more able to isolate the proportions of environment or genetics that accompany a specific attribute. However, even with precise and inspired experimental design, the combination of numerous individual characteristics like motivation or tonal perceptive ability into an intricate behavior like music creates such a dense behavior that the prospect of dividing environment from genetic predisposition may soon bloom out of reason. Thus, we must continually ensure that we are looking at specific elements of musical behavior and adding them to our understanding.

Even with the historically challenging “nature or nurture” debate, some research indicates that a stimulating environment is the most important factor influencing the particular
behavior of musical achievement. A study published in 1996 demonstrates that a supportive and encouraging environment combined with a stable practice structure were more important to musical achievement than perceived differences between high and low achievers (Sloboda et al.) Additionally, Sloane supports an encouraging environment, defined as one where musical expression is permitted and reinforced by parents, peers or teachers, as being of utmost importance to the maturing musical mind (1985).

Even with this evidence that environment plays a major role in musical development, achieving a direct view of such a complex behavior is difficult. For example, much of the environment experienced by the children Sloane observed was directly linked to involvement from parents, at least on the level of supporting the musical expressions of the children (Sloane 1985). Such environmental influence may be attributable to the genetic predispositions of the parents, of which part may be passed on to the children, as shown by Ceci in 1990. This example of how deeply interrelated genetics and environment can become shows that only by distinctly separating the unique parts of a behavior like musical ability into more achievable pieces are researchers able to glean theories that may act like small pieces in the puzzle of a larger idea.

Sensitive Periods

Researching sensitive periods in musical development appears to be just such a puzzle, requiring individuation of elements to gain a picture of the whole. By focusing on research into specific behaviors, neurological changes, and developmental thresholds, we are able to
understand and substantiate patterns; by crossing-referencing these behaviors with an understanding of musical attributes and cognition, we form a large-scale picture of the current consensus in human musical development. In the case of musical development, many specific, focused theories can be combined to reveal a larger movement supporting the presence of sensitive periods for the development of human musical behavior.

Sensitive periods are phases during an organism’s development when specific structures and functions have enhanced sensitivity to the presence or absence of experiences, such that the structure or function is significantly affected in a way that it will not be affected at any other point in development (Fisher & Lerner 2005; Bailey, Bruer, Symons & Lichtman 2001). Many researchers support theories that exposure to particular stimuli during sensitive periods may highly influence, and in some cases predict, abilities of the exposed individual at a later stage (Thomas & Johnson 2008; Zhang, Bao & Merzenich 2002; Robertson 2001). There are well-supported sensitive period theories for language acquisition, healthy organ growth and sensory functioning, among others (Robertson 2001; Hubel & Wiesel 1970). Often, a singular reason a sensitive period exists is not well understood, but the theory itself still stands due to repeatedly observable differences between individuals (Bornstein 1987; Hubel & Wiesel 1970).

Some historians claim the concept can be traced back to ancient records, but the first true usage of the term “sensitive period” was in a 1921 paper concerning organ growth written by the embryologist Charles Stockard (Colombo 1982). Stockard noted that during periods in which a specific organ was studied, disruption of certain developmental processes with interference chemicals would harm the specific organ but not the organism as a whole, and
would not harm the specified organ if introduced at other, less crucial times. This demonstrated that there were sensitive periods during the growth of that particular organ which left it much more susceptible to influence than at any other period, and that the experiences of that period had a lasting effect.

Specifically speaking of musical experiences, theories supporting sensitive periods in human development extend deep into the canon of the psychological sciences, and many of the current theories regarding human development stem from the experiments of animal behaviorists. As early as 1937, Konrad Lorenz proposed the idea of imprinting, where certain species of birds would demonstrate inextinguishable attachment behavior toward a suitable object introduced in their immediate environment during a period closely following birth. Once the fledglings were attached to a specific object, Lorenz demonstrated they were unable to change or even modify the object of their attention. In the wild this object is usually the fledgling’s parent, though Lorenz discovered that the object could vary, as long as it satisfied several basic requirements. Lorenz showed the strength of this attachment by famously imprinting himself on a group of young birds, which then responded to him and followed him as though he were their parent. Most interestingly to the study of sensitive periods, the birds were unable to form such an attachment if an object was not presented before the sensitive period closed, and would thereafter consistently experience developmental difficulties and abnormal socialization (Lorenz 1970, 1981). This example fits the description of a sensitive period very closely, with the features and effects of the sensitive period demonstrating lasting effects on the subject’s maturation and abilities. Results of animal research do not necessarily
predict or mirror outcomes in humans, but nonetheless, these results shed encourage
research into sensitive periods in human development.

Differences between Critical and Sensitive Periods

Though the terms sensitive period and critical period are often used interchangeably, the consensus in the psychological literature is that the term critical period refers to sharply defined, highly predictable periods of susceptibility to influence whose effects are nearly immutable. Sensitive periods refer to longer, less rigidly delineated intervals which have a number of elements of varying predictability, and whose effects can sometimes be "modifiable or reversible with subsequent experience" (Gardner 1973). Thus, if one thinks of a window "opening and slamming shut" the case probably concerns a critical period, but if the periods of influence are more gradual, can be sustained over a longer time or lead to effects which may be changed by later experiences, the case would be a sensitive period (Bailey et al. 2001). Critical periods tend to relate more with very specific traits, whereas sensitive periods are usually associated with broader behaviors, often resulting from the combination of influences from several traits (Altenmüller & Gruhn 2002). Although the terms differ, the essential idea shared between the two is that experience at one stage or point in development has a different impact than the same experience at any other point (Bornstein 1987).

Because of the enormous variability of situations in which humans live and the large amount of time required for our intricate brains to develop, the terminology of sensitive, rather
than critical, is most often used when describing such periods in human development, as Howard Gardner stated in 1973:

While many animals have critical periods during which specific experiences must occur if certain capacities are to evolve, the human infant seems characterized rather by “sensitive periods,” whose temporal and spatial limits are not so rigidly demarcated and whose alternative courses are more numerous. (p. 91)

As noted by Farran, this aspect of the complex differentiation of human development encourages awareness that sensitive periods are flexible and that the influences experienced during sensitive periods can even occasionally be reversed or overcome (2001).

One of the primary reasons it is difficult to say with absolute certainty that a sensitive period has begun or ended lies in this variable complexity of the subject at hand. For example, with the group of young birds studied by Lorenz, the imprinting process can be confined to a narrow band of time with a highly predictable starting point and a moderately predictable ending point, which evidences a critical period (Lorenz 1970). With musical behavior however, the increasing volume of crucial factors encourages the issue of when such periods of increased susceptibility open and/or close to become more complicated. In view of these considerations, musical development is best thought of in terms of sensitive periods, as it results from the interaction of a spectrum of different perceptive and cognitive traits.

**Musical Abilities**

Heiner Gembris stated that musical abilities “have to be understood in inclusive fashion as an amalgamate of many factors, including instrumental and vocal abilities, music-specific
cognitive processes, emotional experiences, musical experiences, motivation, musical preferences, attitudes and interests” (2002, p. 488). Musical ability cannot be simply looked upon as a one-dimensional aspect of human characteristics or an innate and inflexible behavior, though for the scope of this present study the focus is on musical abilities and sensitive periods as they most clearly effect neurological development. This paper focuses on perceptive abilities, music-specific cognitive processes, musical experiences and how influences on those subjects effect their growth.

Most areas of musical cognition and performance are examples of high-level neurological activity (Huttenlocher 2002). These types of activity require processed and refined information from several unique low-level sensory systems, which must be combined to create a larger, more complete idea of the mental task. This reliance on cumulative inputs from several cognitive areas means these higher neurological functions are often constrained by a low ability in only one portion of the inputting functions that creates a bottleneck for the other functions (Huttenlocher 2002). Even if all the components are functioning adequately, the inherent complexity of the pathways creates problems when designing experiments to test each function’s influence. One example of such processing is the combination of a vocalized melody with phonological and syntactic systems to create a lyrical song. This example involves input from a least three different perceptive and cognitive systems, and is therefore only a moderately difficult trait to study. Extend that example to the varied rhythm and instrumentation of an opera with a full orchestra and watch the complexity drastically increase (Butler 1992).
Another difficulty is the consideration that many of the learning systems used to understand music and build musical knowledge are not aligned only with musical development, but are also involved with general learning. Using the previous example of a simple lyrical melody, the syntactic system that allows us to understand musical lyrics shares many functions with the system that processes the spoken words used in language. Thus, a change in one part of the system, for example an increasing ability to understand sung words, may lead to a change in the other part of the system dealing with speech, and vice versa (Altenmüller & Gruhn 2002). It is complicated to separate two parts of a general system for specific study, but rigorous experimental designs are invaluable.

These challenges to accurately studying a complex behavior like musical development may seem overwhelming. However, therein lies the reward: a deeper understanding of musical development must be achieved through examination of many parts of human development in general. Combining these differences between abilities, motivation, cognitive processing and temporal perception creates the intriguing and sometimes beguiling area of study we call musical development (Gembris 2002).

**Research Trends**

Research in the field of musical development has recently blossomed. Within the last 15 years, there has been an explosion of research on the perception and cognition of music, largely due to advances in the field of functional brain imaging, which includes electroencephalography (EEG), magnetoencephalography (MEG), positron emission
tomography (PET), and functional magnetic resonance imaging (fMRI) (Gruhn & Rauscher 2002). Researchers usually match the type of scan they use with the type of information they hope to gain. EEG and MEG directly monitor the electrical activity of the brain, which permits precise temporal resolution and therefore immediate observation of rapid changes, but at the cost of accurately determined locations of said changes. PET and fMRI monitor metabolic changes and blood flow respectively, which enable excellent three-dimensional resolution and therefore the special location of specific brain structures linked with certain actions, but have less precision due to the time delay necessary for movement of blood (Altenmüller & Gruhn 2002). Of these scanning technologies, all but EEG have been historically limited in availability, precision, scale and affordability. The recent explosion of their usage, in musical development as well as general brain research, is due largely to the increased efficiency of computer processing and the decreasing size of the necessary hardware (Bremner 2005). The increased affordability and availability of these imaging scans allows researchers to accumulate important data by testing a larger experimental population more regularly and thoroughly, and to more directly and immediately investigate how experience effects brain growth and organization. The results have been exciting; research and theories previously based on small sample populations, non-generalizable case studies and self-reported or correlational data can now draw upon a increasing pool of detailed and extensive imaging, which shows how the brain is functioning rather than what the subject reports thinking. These technological advances have increased the ability to generalize findings in developing theories, which foster further interest in the field and in turn promote additional research.
Knowing the challenges of studying such a complex behavior and the numerous advantages of recent technology, we are able to approach music development from a clearer perspective. How do these psychological and neurological realities combine to flesh out the picture of musical development? To understand that, we must first understand how our brains process and organize our musical world.

**Music Cognition and Processing**

The resources of a variety of brain structures and neurological centers come into play with even a simple piece of music, because listening to music and creating music are the most "complex auditory functions" our brains experience on a normal basis (Altenmüller 2001, p. 275). A normally functioning brain uses both hemispheres to analyze musical information. Depending on the task, certain activities are concentrated in one or the other hemisphere. The left hemisphere tends to process information in a serial or piece-by-piece manner. The processing of music on a holistic and compositional level tends to be concentrated in the right hemisphere, though each person creates an individually unique neuronal network which uses both hemispheres (Bever & Chiarello 1974). For example the melody is processed by the right hemisphere as an entire shape; the left hemisphere identifies individual notes which make up that melody (Altenmüller 2001). They interact via the corpus callosum, explained below, to produce a holistic picture of the musical information at hand.

As we focus on different aspects of musical processing, the areas of the brain involved become progressively more specific and isolated, and only a general understanding is needed
for this discussion. The perception of music and the initial processing take place in the primary and secondary auditory association areas in both temporal lobes, as shown in Figure 1. Musical information arrives here from the thalamus, which receives input from the ear structure. The primary auditory area is most closely associated with loudness and pitch perception and the initial division of music into spectral and temporal aspects as explained below. Part of this division is shown in the inset of Figure 1, where a certain frequency is processed mainly in one particular band of the primary auditory cortex. Temporal information related to timing is processed chiefly in the left temporal lobe, and spectral processing occurs primarily in the right temporal lobe. Information then shifts from the primary auditory area to the secondary area, also shown in Figure 1, where it moves up in specificity to analyze particular aspects such as timbre (Altenmüller & Gruhn 2002; Levitin 2006). Musical semantics, wherein meaning and language are applied to a certain piece or melody, are concentrated in Wernicke’s area in the back of the temporal lobes on either hemisphere of the brain. Processing the structure of music, such as the relationships between notes and the rules that govern the music with which the listener is most comfortable, is concentrated in the frontal lobes (Peretz 2002).
Development Theories and Sensitive Periods

Though evidence of sensitive periods exists, in human development theories there is currently no universally accepted explanation for their presence (Hubel & Wiesel 1970; Robertson 2001). Several theories do attempt to deal with the topic of why sensitive periods open and close when they do, and how the experiences during that period may benefit the individual’s skill acquisition. Many theories of musical development do not directly deal with the evidence of sensitive periods at all because they are more focused on defining skill sets than individual abilities, but are important to understanding the relationship between the data and the present theories nonetheless.

Theories dealing with the opening of sensitive periods tend to refer to how the vast neurological potential of the human brain during infancy and young childhood determines which functions arise most quickly, as in the case with Johnson’s theory of interactive
specialization explained below. Research shows us that the human brain is born with billions of possible neural connections, but that as an individual matures, the possibility of connections forming between any two neurons decreases, eventually all but disappearing without proper stimulation (Joseph 1999). The lower level behaviors or brain functions most beneficial to the child, such as attention to novel stimuli or recognition of facial characteristics, are established first. Other higher level functions, such as the ability to focus attention on an object amidst distractions or reacting to changes in another’s facial expression, occur later (Wolfe & Brandt 1998). Usually this is linked to the idea that brain functions are becoming more efficient and more specialized for a particular function. Most researchers do not deal directly with the opening of sensitive periods. Those who do rely heavily on transition from low-level to high-level functioning as a demonstration that certain abilities must be in place before other, more complex abilities can begin to appear.

The developmental stages theorized by Jean Piaget arose repeatedly in the literature as an example of the cognitive theoretical basis for talking about musical development. Essentially, Piaget, Vygostsky and Gestalt psychologists such as Wertheimer and Koffka support the idea that a child learns by thinking about their world, relying on insight rather than trial-and-error (Bower & Hilgard 1981). Piaget’s theory of Cognitive Development was referred to consistently in the literature. Piaget theorized that child development consists of four transitional stages from infancy to adulthood, with general, readily identifiable cognitive trends in each stage. In the sensorimotor stage, usually from birth until two years of age, children experience their world through their five senses and their movements within that world. They
begin to create schemas, or cognitive patterns that they use to filter experiences; an example of a schema is object permanence, where the child realizes that an object continues to exist even if it can no longer be seen. The preoperational stage is next, with the two to seven-year-old child beginning to understand parts of the world in terms of symbols. As in the first stage, the child has difficulty in understanding things from the perspective of another person. Also, there are still large gaps in logical ability; although the child will be able to answer questions correctly, they may not understand why or how they know the answers. From age seven to eleven, the concrete operational stage takes place, with children acquiring the abilities to classify and sort objects, use advanced logic to reason out problems, consider the viewpoints of others relatively accurately, and understand that quantities and aspects of an object or an idea retain their characteristics even when they are changed. The fourth and final stage of Piaget's theory is the formal operational stage from 12 years into adulthood, wherein the child can use logic and pieces of information to draw conclusions, and where abstract thinking blossoms (Radocy & Boyle 2003).

The theory of interactive specialization presents another interesting approach to the issue of the opening and closing of sensitive periods. Essentially, the theory explains that maturation of the human brain proceeds as one of "increasing specialization, or fine-tuning, of response properties" (Thomas & Johnson 2008, p. 1). This means that as particular pathways from the many possible neural routes are increasingly used for a certain function, the brain reduces the number of potential pathways. Thus, repetitious interaction with a particular
function leads to a reduction in the total number of possible pathways for that function as a primary pathway is realized.

**Brain Structure and Efficiency**

A number of studies propose that musical training may have significant impacts on brain structure and efficiency. Research from Bengtsson et al. (2005), Schlaug (2001) and Chin (2003) studied the structure of the brain and how exposure to music effects readily measurable changes upon it. Bengtsson et al. studied differences in the corpus callosum, the web of neurons that links the right and left-brain hemispheres, between musicians and non-musicians (2005). Schlaug examined the total cerebellar volume between young musicians exposed to musical training lessons and children who were not taking lessons (2001). In a study published in 2003 which focused on the increased occurrence of absolute pitch in individuals who experienced early musical training, Chin observed differences in the relative size of the each hemisphere’s planum temporale between musicians and non-musicians.

Structural elements of music perception have demonstrated evidence of sensitive periods as well. Temporal processing, difficult to accurately study, has been demonstrated by Pouthas in 1996 to undergo a period of rapid change during middle childhood, and other researchers, including Altenmüller and Gruhn (2002) and Gardner (1973, 2004) support the concept as well. However there are conflicting viewpoints to this issue, as demonstrated by the research of Gerard and Auxiette, whose findings directly contradict those of the aforementioned researchers (1992).
Spectral processing has historically been easier to study than temporal processing, and therefore the research is much richer where this aspect of pitch perception is concerned. By studying the acquisition of musical “keys”, Zenatti (1993, p. 182) was able to present a time period for the stabilization of an individual’s tonal perceptions and preferences, and this research was supported by the work of Dowling in 1999.

Increasing ability to differentiate between timbres is important to understanding how musical perceptions are processed and refined. Schellberg’s research in 1998 looked at growth in this ability, using samples of music featuring several different instruments to assess the differences between young children and those several years older. Another research experiment implemented by Dowling in 1999 aimed to use changes in the ability of an individual to isolate one melody from another melody, even when a melody meant to distract the listener was played simultaneously.

**Structural Elements**

Structural changes in the brain present some of the most solid neurological evidence for sensitive periods for musical development. An infant’s brain has billions of possible neural connections, and as the child grows, learns and adapts to its environment, pathways are formed for specific traits and behaviors that the brain tends to use preferentially and consistently. Research from Zatorre, Evans, Meyer, Schlaug and Chin, among others, suggests that beginning musical training between age six and age ten is important to the creation of optimal neural pathways for musical learning (Zatorre, Evans & Meyer 1993; Schlaug 2001; Chin
2003). "Even just a small exposure to music lessons as a child," states Levitin, "creates neural circuits that are enhanced and more efficient than for those who lack training" (2006, p. 194).

One example of these "enhanced" neural pathways is the corpus callosum. The corpus callosum is the major pathway of communication between the right and left hemispheres of the brain, and is subject to growth throughout childhood. The larger the corpus callosum, the more efficient the communication between the two hemispheres of the brain, and thus the better the brain accomplishes tasks requiring input from both hemispheres (Zatorre, Evans & Meyer 1993). Some musical skills, such as playing an instrument, require coordinating several activities between the two hemispheres of the brain. One example is accurately reading sheet music and synchronizing this information with the fine motor control necessary to sound the correct note when playing a keyboard or a stringed instrument.

In a paper published in 2005, Bengtsson et al. showed that children who experienced early and intensive training and practice on the piano, defined for their study as starting one-on-one lessons with a music teacher before the age of ten, showed increased size of their anterior corpus callosum over those students who started after the age of ten. The researchers hypothesized that this difference is due to the increased demand for interhemispheric communication required by coordinating high-level motor tasks in both hands with advanced music notation reading or memory recall of previously practiced music. This increased size of the corpus callosum was theorized to stem primarily from the closure, at around ten years of age, of a sensitive period for the formation of a myelin sheath that increases fractional anisotropy between nerve cells in the corpus callosum (Bengtsson et al. 2005). Fractional
anisotropy measures mylenation of nerve cells and their efficiency of transmission, and increases in this measurement are indicative of increased mylenation and increased efficiency (Kochunov et al. 2007). The research of Bengtsson and colleagues indicates that without exposure to such training before this sensitive period closes, the structure of the brain is affected so that communication between the two hemispheres of the brain is less efficient. This developmental position, also supported by Altenmüller and Gruhn (2002), may highly impact an individual’s ability to achieve musically later in life.

Overall cerebellar volume is affected by early music training as well, according to research by Schlaug (2001). This longitudinal study shows that in subjects who were matched before the age of 7 for handedness and gender, and additionally tested for motor skill abilities, those who participated in music lessons had a significantly larger cerebellar volume compared with those who did not engage in such training (Schlaug 2001). Prior to starting music lessons, the subjects were matched for overall cerebellar volume, and the results showed no significant previous difference between the subjects who entered training and those who did not experience training. However, as with the corpus callosum, the sensitive period for this cerebellar growth appears to close around on average the age of ten, supporting the theory that musical training during this sensitive period can affect brain structure into adulthood (Schlaug 2001).

The planum temporale is another brain structure that may be affected by exposure to musical experiences early in life. The planum temporale is found on the temporal lobes of both brain hemispheres, and is strongly associated with language and music abilities (Moore 2003).
Differences in the relative sizes of the planum temporale between the two hemispheres is one predictor of absolute pitch, which is the generally desirable musical ability to name or recreate a musical note without the assistance of an outside reference tone (Chin 2003). Absolute pitch is highly correlated with a larger planum temporale in the left hemisphere relative to that found in the right hemisphere (Schlaug et al. 1995). Chin's research indicates that acquisition of true absolute pitch may occur only when a child begins musical lessons before the age of nine (2003). After that time, the likelihood of acquiring absolute pitch may be decreased partially due to the shift in the child's worldview, from an absolute view where objects are viewed as isolated and unique to a relative view where objects are viewed in terms of their relationships with one another (Takeuchi & Hulse 1993). This shift of focus is a common feature of most prominent developmental theories (Hodges 1996). This evidence indicates that to acquire absolute pitch, a child must experience structured musical instruction sometime before their ninth birthday, a viewpoint that is further supported by an increased relative volume of the left planum temporale.

Perception and Elements of Music

In a simplistic sense, music can be divided into two essential perceptive elements. Spectral elements deal with pitch, while temporal elements deal with the timing or rhythmic nature of a piece of music. These two elements vary from culture to culture, but both are necessary for a piece of music to function as a perceptive and cognitive reality (Bernstein 1976). In terms of experimental analysis, spectral processing is significantly easier to study than
temporal processing, at least in young children. Young infants can be reliably tested for their preference to spectral stimuli, based largely on well-supported attention and novel stimuli procedures (Lerdahl & Jackendoff 1983). However, most temporal experiments rely on synchronization of an action with a stimulus or the reproduction of a novel rhythm, but because significant control of motor skills is necessary to reproduce rhythms, very young children often cannot be accurately tested for their preferences or abilities (Pouthas 1996). Without reliable test results or the establishment of developmental thresholds, it is difficult for researchers to demonstrate testable theories as to whether temporal abilities in young children are most affected by age or development itself (Radocy & Boyle 2003). This significant experiment design difference means the majority of available research deals with spectral rather than temporal processing.

**Temporal Processing and Rhythm**

The difficulty with accurately testing temporal aspects of music in young children is an unfortunate situation because many researchers believe temporal processing may be the most structurally important element for music perception (Moore 2003). However, much of the existing evidence, including information from Radocy and Boyle (2003) as well as EEG research from Altenmüller and Gruhn (2002), supports the idea that temporal processing, like many other abilities needed for music cognition, seems especially open to influence during a certain period. In an update on his prominent theory of multiples intelligences, Gardner reinforced the idea he introduced in 1973 of the existence of several sensitive periods for the acquisition of
musical abilities, and concluded that temporal abilities are almost completely developed by the age of ten (Gardner 1973, 2004). This statement is supported by Radocy and Boyle (2003) who theorize that temporal processing ability has largely matured to near adult levels around the age of ten years, and other researchers hypothesize the increasing abilities of children from the age of five to ten years (Pouthas 1996; McPherson & Gabrielsson 2002). Gerard and Auxiette (1992) contradict some of the findings of this age range, stating that children can synchronize their actions with near adult accuracy around the age of five years. This disparity demonstrates the tension in the study of temporal functioning and contradictory findings create a basic issue for researchers.

One of the most thorough experiments that deals with temporal processing in young children was undertaken by Pouthas in 1996 and shows an increase in timing accuracy between the ages of five and seven years old. In this experiment the variable of motor control is at least partially controlled for by allowing children to maintain a rhythm verbally or physically. These children were instructed to match the rhythm of a pulsing light, and the increase in accuracy between five and seven was found to stem mainly from a difference in strategy. The five and six-year-olds mainly used the light as a metronome and attempted to imitate its pulsing, whereas the seven-year-olds employed independent counting to establish their own rhythm matching that of the light (Pouthas 1996). This study also highlighted possible reasons for the difference in temporal accuracy between children and adults, supporting the ideas that children are less efficient at encoding rhythms, that they had a higher tolerance for differences between their action and the stimulus and that they were less accurate in controlling the timing of their
own actions. Although the results do fall within the theorized age range for a musical sensitive period, the conclusions of this study are weakened by the narrow range of ages involved in the experimental sample.

Though Pouthas, Altenmüller and Gruhn, Gardner and others support the existence of a sensitive period for temporal processing between ages six and ten, the disagreement shown by Gerard and Auxiette poses problems to the external and internal validity of some temporal processing research. This demonstrates that still more research is required before the results in this area can be seen as truly significant.

Spectral Elements and Pitch

Tonality presents more experimental evidence of a sensitive period than temporal processing. By comparing the preferences of children between the ages of three and ten between classical compositions utilizing consonance to those of contemporary compositions based mainly on dissonance, researchers were able to demonstrate the stabilization of tonality (Zenatti 1993; Dowling 1999). This is accomplished through the acquisition of a musical “key”, usually the one most commonly found in the child’s dominant culture, which stabilizes as the child ages and is consistently reinforced for a specific key (Barlett and Dowling 1980). Most children demonstrate inconsistent preference for tonal structures and consonant chords before they reach the age of five. Additionally, any preference they do demonstrate is minimal, and can usually be shown to be a reaction to novel stimuli, rather than a distinct preference for tonality. By comparing the self-reported preferences of children between the ages of three and
ten, then monitoring and re-testing those children on a frequent basis, Zenatti was able to
determine that preferences increased from age five to ten for consonance and tonality. The
preferences of the ten-year-olds were consistent with adult responses 95% of the time for
consonance and 90% of the time for tonality (Zenatti 1993). This increase from no distinct
preference to a clear preference for tonality shows a stabilization of the children’s musical key.
This recognition and acceptance of the normative tonality is pointed to by researchers as clear
evidence of a tonal sensitive period.

Timbre is another part of spectral perception that demonstrates an increased period of
susceptibility. Timbre, also known as tone color or tone quality, can be defined as the
distinctive tonal qualities of a particular instrument, or more generally as the individual “voice”
of an instrument that distinguishes it from other instruments (Bernstein 1976, p. 15). Timbre
greatly influences our perceptions of music, and appropriately mixing instruments of different
timbrres, even if they are producing the same note, is generally considered to give music a richer
and fuller sound. As more instruments are added to the mixture, say in a full orchestra, rock
band or vocal choir, the demands on our perceptive systems escalate and it becomes
increasingly difficult to isolate individual instruments. This may affect an individual’s ability to
process, enjoy or experience a particular piece of music. Young children’s perceptive systems in
particular may be overwhelmed by many simultaneous timbres, but as they grow older, their
ability to differentiate timbres increases (Altenmüller & Gruhn 2002). Schellberg (1998)
discovered an “enormous increase” in the ability of four to six-year-olds to differentiate
between timbres of several different orchestral instruments. All of the children had been
exposed to the instruments and presented with images of each instrument while a sample timbre was played. When presented with a recording of a single instrument from a group of potential familiar instruments, four-year-olds were ineffective at identifying which of the instruments was present in the sample, but five and six-year-olds were accurate to nearly an adult level. Also, the older children were able to distinguish which instruments were present in a sample even when the instrument was presented “in combination with other instruments” (Gembris 2002, p. 492).

Additionally, the presence of a sensitive period for tonality is evidence of a subject’s broadening ability to discern a tonal target melody from atonal distracter melodies (Dowling 1999, p. 617). Between the ages of five and seven, children perform only slightly better than chance would predict on recognizing the presence of a target melody in a group of melodies presented simultaneously when the distracter melodies are atonal (Dowling 1999). Tests on seven-year-old children show an increase in accuracy over chance, and by the time the children are nine years of age they demonstrate an accuracy of 70%, only slightly below that of musically untrained adults, but short of the 90% typical of musically trained adults (Dowling 1999). This demonstrates that the ability to accurately discriminate between tonal and atonal melodies is increasing from chance to nearly adult levels between the ages of five and ten years.

An individual need not be rigidly locked in to a single tonal preference however. Most people exposed primarily to Western-influenced music understand a number of keys in both major and minor tonality, and the number of tonal keys a child prefers can increase if the child is consistently exposed to and enjoys disparate tonalities (Davidson, McKernon & Gardner
This is most common when the primary caretaker of the child enjoys listening to music that does not fit all the musical norms of the dominant culture, or when the child is raised in a multicultural environment, where musical standards are dependent upon more than one tonal norm. Additionally, like many aspects of human behavior, this tonal preference is not absolute throughout the life process, as tastes can change between styles of music and between tonal keys. Even with this possibility of change, there is usually a primary, tonic key that an individual finds most preferable (Davidson, McKernon & Gardner 1981).

Discussion and Implications

As mentioned, Piaget’s theory of Cognitive Development is referred to repeatedly by musical development researchers such as Bornstein, Gembris, Dowling, and Radocy and Boyle. “According to Piaget’s theory,” states Gembris, “children start to develop the ability to coordinate several different aspects of perception around the age of 7 years...this implies that children have to reach at least 7 years before they can pay attention to and coordinate rhythm and melody simultaneously” (2002, p. 494). As is common in music research, Piaget’s theory predicts the abilities of children at this stage of development, and researchers extrapolate this general theorem to the specific nature of music development. An inherent weakness when using Piaget’s theories to discuss musical development is that the theories are not designed specifically for musical development, and fail to take into account many of the specific influences that musical experiences have been shown to present to an individual. Also, Piaget’s theories do not address the ending of sensitive periods, and researchers seem to often ignore
this aspect when discussing support for said theories. While it is helpful to utilize Piaget’s theories for a general discussion of human development, as the discussion of a particular behavior becomes more specific as with musical development, the theory of Cognitive Development becomes increasingly unable to explain the reasons behind the actions.

The refinement of the neural pathways inherent in interactive specialization may influence the opening of sensitive periods. As the pathways become more dedicated to one function, the plasticity of that function is reduced, and the function becomes more stable (Huttenlocher 2002). Now the stability of lower-level functions can act as a platform for adding higher-level abilities, which must go through their own periods of interactive specialization. Because higher-level abilities usually require input from several low-level functions, a sensitive period gradually opens up as more low-level abilities stabilize. The result is a gradual period of increased susceptibility to experiences, followed by a period of interactive growth, and eventually closing as the neural pathways specialize to their unique functions and reduce or eliminate the possibility of alternative neural pathways (Johnson 2005). Interactive specialization is a relatively new theory of human development, and its value as applied to the possibility of sensitive periods largely remains to be seen.

Other theories address the issues of how sensitive periods open and close. Farran explains the “timing argument is that children need to learn certain skills early because of the societally imposed requirement of school entry” (2001, p. 242). Simply put, sensitive periods may come to an end because the expectations of standardized ability levels when entering school environments force children to modify their development and behavior patterns without
regard for their potential or actual abilities. This argument for the closure of sensitive periods has not been widely supported; as demonstrated later in the same article, “there is little evidence that later differences in achievement between children rest solely on differences in the ability they have when they enter school” (Farran 2001, p. 242).

Future Research

Future research in musical development is full of possibility and promise. The ease and accessibility of powerful brain imaging technologies is likely to continue, and the effect of recent research offers encouragement to higher education programs to add musical development to their course options, increasing the field’s potential growth.

Analysis of evidence on a potentially divisive topic such as sensitive periods unfortunately lends itself to bias on the part of researchers and theorists. Several times bias surfaced during the review of literature. Most sources that proved to maintain bias were eliminated rather than risk contamination of valid information with overtly partial viewpoints, but as may be the case with all research, it is nearly impossible to completely control for bias in the reporting or analysis of research. Only one included study clearly presented considerable potential bias, on issues not directly used in this discussion of the topic, but for the sake of disclosure it is noted here. On the topic of genetic inheritance of musical abilities, Gardner claims high and low musical abilities to be based so firmly on genetics that this predisposition can rarely be overcome regardless of training (1973). This statement is quite questionable in light of most musical learning research, and therefore excluded from the discussion. For the
most part however, sources were selected for research and theoretical evidence that were as well-designed and controlled as available.

One of the major issues affecting this subject is availability of appropriate study populations. Solid theories rely on reproducible experiments, which usually require a population of suitable subjects. Musically deprived subjects are the most effective comparisons for realizing the influence of music training, but such populations are, for good reason, rare. Most people receive some type of formal or informal musical training while of school age, and this can introduce confounding variables to studies of training effects. Because we cannot ethically create populations of musically deprived children, we must be attuned to designing practical, ethical and accurate studies of populations where they are available (Bailey & Bruer 2001). One possible solution to this dilemma may be presented in longitudinally designed studies of children in different curricula, although the results may not be as conclusive as with a deprived sample population (Hassler 1991; Huttenlocher 2002).

The future looks particularly bright for the use of brain-scan imaging technology in studying sensitive periods. Hopefully, the trend of using brain-imaging technology to monitor and measure neurological differences between subjects exposed to musical stimuli, such as that found in one-on-one music lessons, will continue. Even with the shift toward this type of quantifiable research, much of the support from the current sensitive period research comes from a small pool of neurobiological research. Reproducing, refining and expanding upon the evidence gathered by imaging research can potentially clarify the issue of sensitive periods for gaining musical skills to a much greater degree. Flohr and Hodges suggest several directions for
neuroscience that will particularly impact the study of sensitive periods. They suggest 1) Studying activities that help children learn most efficiently; 2) Continuing focus on music cognition to understand the interrelationships between music and other systems in the brain; 3) Using several types of brain imaging rather than only one method to better validate the locations and functions of systems, and perhaps most importantly; 4) Continually striving for research with the greatest possible external validity (2002).

The possible combined use of brain-scan imaging and genetic analysis to predict or influence a child’s education could lead to some interesting and questionably ethical possibilities for musical development. Proponents of such analysis, including Wolfe, Brandt, Sousa and Levitin have suggested that using these techniques on an individual basis may someday lead to predictions of an individual’s future musical ability and modification of their education (Wolfe and Brandt 1998; Sousa 1998; Levitin 2006). This idea, as with most issues surrounding the possibility of a genetically and medically observed population, carries with it numerous quandaries of a social, ethical and personal nature.

Regardless of the outcome of such a debate, most of the literature addressing theories in musical development recognizes that there must be a balance between science and actual practice. Key to future use of these theories is remembering that clinical theories should not always dictate classroom practice, and that experimental evidence is not the only predictor of future musical ability. It is important to the history and the future study of musical development that teachers and educators look to the methods, both formal and informal, which have helped students learn and grow as musicians and individuals in real world settings.
Structuring musical education only around theoretical principles risks sacrificing the flexibility, individuality and enjoyment of personal musical development to the goal of maximized clinical achievement. As stated in *Music in Childhood*: “The myth that few children are musically endowed is a dangerous one that threatens the right of all to a musical education, and may even endanger a musical culture” (Campbell & Scott-Kassner 1995, p. 8).

Although the research of Schlaug, Gardner, Pouthas, Zenatti and others supports the presence of a sensitive period for musical development between the ages of six and ten, there are still many reasons to challenge the idea that people are absolutely entrenched by the musical experiences they have before they reach their teens. Musical development is continual, a life-long process that is but one part of our ever-materializing persona (Campbell & Scott-Kassner 1995). Though highly affected by the experiences and acquisitions of the sensitive period, musical taste, ability, motivation and achievement are all modified as we age. As Gembris says, “Musical development occurs as part of the general development of an individual over the life span. It does not end—as is often assumed—by the end of adolescence.” (2002, p. 495). The stance of the human brain as a flexible instrument, ever adapting to changing circumstances, echoes throughout sensitive period research and evidence suggests that the auditory system is “particularly adaptive” in response to experience and learning (Altenmüller & Gruhn 2002, p. 72). It is therefore important to remember that adaptability is a principle reason for our successful development, and that our brains are usually somewhat capable of structural and functional change throughout our lives. Even though sensitive periods can strongly affect
our potential abilities, they are but one part of the myriad influences that combine during our musical, and human, development.
References Cited


[Untitled digital image of brain showing auditory cortex and spectral processing distribution].

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