The Effects of Musical Training on Cognitive Ability

Abstract

Musical ability has long been shown to correlate with other measures of intelligence that extend to traditional academic performance. However, in much of the literature, it is unclear whether this correlation is due to a self-selection process derived from pre-existing, innate abilities, or whether musical education is to be credited. This paper will reveal that musical education is responsible for increases in cognitive ability, though there are also some self-selection factors as well. Among researchers who have demonstrated that exposure to music improves cognitive ability, there is disagreement as to which abilities are improved upon and how. Some researchers claim that verbal abilities are related to music cognition, and that this is mediated in the left planum temporale. Others state that spatial ability is related to music training, and that this is mediated in the right parietal lobe and in whole-brain networks that fire similarly to music and spatial tasks. This paper will review these possibilities and suggest that perhaps both accounts are right – music cognition is complex and draws upon several different cognitive capabilities that relate separately to pitch, rhythm, listening, and production. The paper then calls for future research to be performed using converging methods and experimental designs that elucidate the verbal/spatial debate and apply this information to cognitive development in children.

Introduction

When a parent makes the decision as to whether to enroll her child in expensive and time-intensive music lessons, a common question on her mind is "Will these lessons make my child smarter?" A number of researchers have demonstrated that professional musicians have superior cognitive skills to non-musicians (Brandler & Rammsayer, 2003; Chan *et al.*, 1998; Hassler *et al.*, 1985; Helmbold *et al.*, 2005; Hobbs, 1985; Jakobson *et al.*, 2003; Phillips, 1976), but such comparisons do not differentiate whether musical education is what causes the enhancement in cognition, or whether more intelligent people in general are drawn to or stick with musical training. Relatedly, children from higher socio-economic classes may be more encouraged and able to take music lessons than children from lower socio-economic classes, and socio-economic class has been shown to be correlated with IQ. (Mercy & Steelman, 1982)

Assuming musical training does improve cognitive skills related to academic performance, which cognitive skills are affected? In the studies showing cognitive improvement with musical training, some researchers believe spatial abilities are enhanced with musical training, whereas others believe music is related to language and that verbal memory is improved with music training.

These questions are important to the concerned parent as well as the education policy-maker. It is of integral interest to determine the degree to which musical training affects cognitive development as it has implications for arts training in the curriculum.

By reviewing training studies and studies using neuroimaging methods, I will attempt to prove that indeed musical exposure is responsible for some of the cognitive enhancement we observe in musicians. Additionally, I will explain the differences in the spatial vs. verbal debate by thoroughly examining the behavioral and neuroscience literature and demonstrating that music cognition is highly complex and multi-faceted. Finally, I will recommend future directions for research in this area, using converging methods.

The Mozart Effect

Probably the most commonly discussed phenomena in music cognition is the Mozart Effect. Rauscher and colleagues first documented the effect in their 1993 Nature paper (1993). After just 10 minutes of listening to a Mozart sonata, subjects performed better on three separate spatial IQ tasks as compared to controls who were listening to a relaxation tape or silence in the same 10 minute period. What is so appealing about this finding is that it appears to be a quick-fix for improving cognitive ability. One can enhance his spatial processing in just 10 minutes. However, they also found that the effect was temporary – after just 15 minutes, the enhancement period would wear off.

Since this discovery, researchers have performed follow-up studies that have drawn the original findings into question. Nantais and Schellenberg performed a study that used an additional control group that listened to a narrated story (1999). Not only did the subjects in the story condition perform as well as the Mozart-listeners, but performance in both conditions correlated with the listener's preference (music vs. story.) Another study showed that listening to an upbeat Mozart sonata enhances performance on a subsequent cognitive task as compared to listening to a slow Albinoni adagio, however, this enhancement disappears when ratings of mood and arousal are taken into account (Thompson *et al.*, 2001). A third study demonstrated the Mozart effect in children aged 10-12, but concluded the nature of the music (whether it was pleasant and calming vs. unpleasant and aggressive) differentially affected performance and that effects were likely due more to mood than to music listening. (Hallam *et al.*, 2002)

A number of other researchers have both replicated the effect and performed similar studies to the ones above that demonstrate the effect is not due to Mozart per se. A 1999 meta-analysis of papers concerning the Mozart Effect, also published in Nature, shows for good that the effect is not due to what the researchers originally speculated; rather, arousal and mood are repsonsible (Chabris *et al.*, 1999).

The good news is that the finding itself is still replicable – increasing one's mood or arousal before performing a cognitive task will improve performance. Unfortunately, the current evidence is such that Mozart and music in general are not special in this regard.

Comparison Studies of Expertise

If the Mozart Effect doesn't exist, what does this mean for music education? Is music exposure beneficial to cognitive development in any way? Fortunately, the evidence points in this direction when considering prolonged instruction and interaction with music (as opposed to a mere 10 minutes of passive listening). A large number of studies have demonstrated superior cognitive ability in musicians with years of training as compared to novices with similar levels of education but no musical training.

Most of these comparison studies show that musical experience correlates best with verbal ability as opposed to other tasks. Jakobsen found a positive correlation between years of musical training and verbal working memory during a list-learning task using 60 adults with a range of musical training. (Jakobson et al., 2003) Temporal-ordering processing was what mediated this difference. The authors suggested that musical training may have enhanced auditory temporal processing skills, allowing for fine discriminations between rapidly changing acoustic events. Another behavioral study with 60 adult subjects compared skilled musicians with at least 6 years of training to controls with no musical training. Again, better verbal working memory skills were found for the musicians than for the non-musicians. (Chan et al., 1998) Brandler and Rammsayer provide an even stronger account for a positive correlation between musicality and verbal skills, as verbal memory was the only cognitive test from an entire battery that showed a difference between musicians and non-musicians. (2003) However, a follow-up study performed by the same research group using many more subjects, perceptual speed of processing was the only test that showed a difference between musicians and non-musicians. (Helmbold et al., 2005)

Only one comparison study, using children as subjects, demonstrates a correlation between musical training and visual-spatial skills. In a study measuring 140 children aged 9-12 with varying degrees of musical training, ability, and creativity (measured by composition and ability to improvise), those who were the most creative also performed best on a visual-spatial task. The non-musicians performed worst. Spatial ability is considered to differ from verbal ability, and is usually considered to be related too math, science, and logic. It is important to determine which aspects of general cognition are most related to musical training.

Training Studies

While comparison studies are informative, they lack the benefit of experimental manipulation. There are number of explanations for why musicians have superior cognitive abilities to non-musician controls. First, it is possible that only the more intellectually rigorous people continue with music training once they have been exposed to it. Practicing a musical instrument takes a tremendous amount of discipline. Individuals who are willing to work that hard may also work hard in academic settings, thus improving their cognitive abilities.

Secondly, socio-economic class could be playing a role. In a study comparing scholastic aptitude among musicians and non-musicians, Philips found a difference in the two groups, but once socio-economic class was taken into account the difference nearly disappeared (Phillips, 1976). It is possible that the differences between musicians and non-musicians is actually innate or caused by something not musically related in the environment. Finally, another problem with comparing professional musicians to adult controls is that we don't get to see how music affects cognitive development in young children. Indeed, there is evidence that children and adults process music differently. (Overy *et al.*, 2004b; Schlaug *et al.*, 1995)

For these reasons, a number of researchers have performed time-intensive training studies, usually on children of various ages. In these studies, researchers have consistently found that musical training improves cognitive development in far transfer areas. In a comprehensive study involving 144 6-yr olds, Schellenberg demonstrated that children exposed to one school year of musical training had a greater increase in IQ score as compared to children who were in control conditions. (Schellenberg, 2004) The two music groups received either keyboard or voice lessons. In order to demonstrate that music training is special above and beyond arts lessons, one of the control groups received drama lessons while the other received no lessons. While all groups significantly improved in IQ due to starting their first year of formal schooling, the music lesson groups improved their IQ scores by an additional 3 points as compared to the drama and no lessons groups. The increase in IQ was distributed across different sub-tests, indicating that music causes general improvement across all of cognition.

Other training studies have shown more localized improvement in cognitive skills, much as the adult studies previously discussed. Ho and others (2003) showed that musical training improves verbal but not visual memory skills, using a hybrid cross-sectional and longitudinal design involving 90 children aged 6-15 yrs, each having 1-5 yrs of musical training. In the cross-sectional part of the study, the researchers tested children at differing stages in their chronological and musical development on both verbal and visual memory tasks. Musical training correlated with verbal, but not visual memory. The longitudinal aspect of the study followed these children as well as new ones who had just started music lessons and tested them one year later. Three groups formed: those with experience who continued lessons, those with musical training who discontinued their lessons, and those who were new to musical training. At pre-test, the beginners performed worse than the musically experienced groups on a verbal memory task, but at post-test, they had caught up to the children who had discontinued lessons. The experienced children who continued lessons rose above the other groups. In the visual memory tasks, all children improved equally, though there was a trend toward lessons making a positive difference. This training aspect of the study shows that verbal but not visual-spatial memory is improved with musical training.

In spite of these findings, several researchers have published conflicting results from training studies. Bilhartz trained 71 4-6 yr olds from diverse economic and ethnic backgrounds on the keyboard in weekly lessons for 30 weeks. (Bilhartz *et al.*, 1999) Researchers administered the Stanford-Binet intelligence test prior to and after training. Out of all of the subtests including ones measuring both verbal and visual skills, the only test to show a significant difference (with the musically trained group performing better) was the bead memory task, which is a visual-spatial task involving remembering the temporal order of objects. Other visual-spatial tasks that did not involve ordering did not show significant effects, and neither did any verbal task. Rauscher and Zupan performed a similar study training 62 kindergarteners on the keyboard for 8 months of semi-weekly lessons. After just four months of training, the experimental group performed better at spatial tasks, and the difference was even larger after 8 months. A control test on pictorial memory (visual, but not spatial task) did not yield a difference between the groups. The researchers made an important distinction between spatial recognition tasks that are more visual in nature versus spatial-temporal tasks that require abstract manipulation of objects, and combining separate elements into a whole. They theorized that this is the skill that is relevant to math and science ability. In a third keyboard training study, Costa-Giomi targeted children aged 9-12 from low-income families to participate for 3 years of lessons (1999). Her impetus was that most studies of music cognition have focused on the typical upper-middle-class musician, whereas it is unclear whether the results would apply to lower-income children. The experimental group showed a larger increase in spatial reasoning skills, but there were no differences found in verbal or quantitative skills. Also, surprisingly, the spatial ability difference was much larger in the 2^{nd} year of training than it was in the 3^{rd} year. The author explained this result by suggesting that the participants did not keep up with their practicing and focus during their last year. Also, many of them entered adolescence, encountering new changes.

While the adult comparison studies pointed more toward a difference in verbal ability between musicians and non-musicians, the child training studies overall seem to suggest that spatial skills are enhanced with musical training. Taken together, these studies paint a puzzling picture. However, it is possible that careful analysis of each study may reveal an explanation for the differences in findings.

Evidence from Neuroscience Methods

It is now clear that musical training improves cognitive abilities in a wide range of areas. However, the results are uncertain as to which areas of cognition are improved and why. In recent years some researchers have used neuroscientific methods such as functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS) to study cognition in trained musicians as compared to controls subjects. These studies add evidence to the spatial-temporal vs. verbal debate, but they do not provide definitive answers.

Neuroimaging studies have used both comparative and training methods in both adults and children. As with previously described adult comparison studies, one such study looking at differences in the cortical organization of musicians and non-musicians showed evidence linking musical expertise to verbal areas. (Ohnishi *et al.*, 2001) Specifically, the authors found differences in the planum temporale (PT) and left dorso-lateral prefrontal cortex (DLPFC). The left PT is also known as Wernicke's area, which is associated with language comprehension. Additionally, the authors found that the degree of activation in the PT was correlated with the age at which the subject started musical training. Also, the PT is associated with absolute pitch (AP) ability. People with AP are able to correctly name any note they hear, without hearing a reference. Thus, it is not surprising that this ability is related to language as it is a form of note labeling. Schlaug and colleagues (1995) found similar results when comparing structural images of musicians and non-musicians' brains. Specifically, they discovered that there was more PT asymmetry (with larger on the left side) in musicians than in non-musicians, changes in the brain related to language and pitch processing. The difference was even bigger for individuals with AP. These neuroimaging studies that point toward a relationship between music and verbal ability also argue for left hemisphere dominance in musical structures.

A similar adult comparison study of musicians and non-musicians yields differences found in motor, auditory, and visual-spatial brain regions with focuses on the superior parietal region (usually involved in spatial cognition) and the inferior temporal lobe (thought of as part of the ventral visual stream, used in identifying objects.) (Gaser & Schlaug, 2003) The authors also found increased grey matter throughout the cortex as compared to controls. While the structural differences could have been innate, the authors suggest that musical training helped shape the developing brain.

Probably the most exciting studies are those that involve training and neuroimaging methods. A recent study performed by Kim and colleagues compared 8 adult novices to themselves both before and after a 6 month training period on string instruments. (2004) Before and after training, fMRI and TMS results were collected. The fMRI results localized motor and sensory areas by observing activations while the subject either performed a finger tapping task or touched a string with his or her finger. The TMS results verified the details of these motor and sensory maps. At post-test, the finger on the trained hand showed a very different response to sensory and motor areas (parietal lobule, premotor area, left precuneus, right anterior temporal gyrus, posterior middle temporal gyrus) as compared to the untrained finger on the other hand. Structurally speaking, the brain had developed new maps to accommodate training.

Only a small number of studies to date have used neuroscience methods to study music cognition in children. fMRI methods require the subject to stay completely still for sometimes more than an hour while in an enclosed space. Children often have difficulties with these requirements. Nonetheless, researchers are beginning to make progress on this front. Norton and colleagues (2005) recently published results comparing beginning musicians aged 5-7 to their non-musician peers to determine whether there were any pre-existing neural correlates to musical ability. No differences were found between the groups. The study was part of a longer within-subjects longitudinal study that is still in progress, determining whether and how musical training changes the structures of these children's minds. The same research group has already shown that 6 year old children process rhythm and melody differently than adults do. (Overy et al., 2004b) Specifically, adults tend to show right-hemisphere dominance for melody processing and left-hemisphere dominance for rhythm processing (Samson *et al.*, 2001; Zatorre, 2001). The children, on the other hand, showed bilateral activity for both kinds of processing. Moreover, after one year of training, these children demonstrated a shift towards more left-hemispheric processing of pitch discrimination (Overy *et al.*, 2004a). It is likely that musical training leads to more lateralization and specialization of these processes.

Music Cognition is Complex – Reconciling the Spatial and Verbal Accounts

From the literature reviewed thus far, it is clear that musical training is beneficial to cognitive ability. While socio-economics play a role in the differences between musicians and non-musicians, (Phillips, 1976) controlled training studies show that music enhances cognition (Schellenberg, 2005). What is less clear is exactly which cognitive abilities are enhanced by musical training and how.

According to the spatial-temporal account, music is arranged through space and time using precise and complex patterns of rules. Skills required for remembering and producing musical sequences are thought to be related to math, logic, and science skills, especially when the tasks involve combining separate elements into a single whole, or the temporal ordering of different objects. Researchers who take this position are careful to distinguish between spatial-temporal reasoning and visual-spatial memory that does not involve manipulation. (Bilhartz et al., 1999; Hassler et al., 1985; Rauscher *et al.*, 1995; Rauscher & Zupan, 2000) Indeed, several of these studies used a control visual or visual-spatial task operating on a different type of spatial skill and showed that the experimental group showed no difference on this task. (Bilhartz et al., 1999; Rauscher & Zupan, 2000)

Leng has come up with a neurological account for how musical training is related to spatial-temporal processing. (Leng *et al.*, 1990) According to his trion model, a network in the cerebral cortex fires according to different spatial-temporal patterns, and the strengths of the connections are modified using a Hebbian learning rule. The relationship between music and other spatial processing tasks is in that these networks fire and modify themselves similarly. Leng also hypothesized that because children's brains are so plastic, training on musical tasks may strengthen the pathways in this network, thus helping to improve spatial-temporal skills that are relevant to other areas of cognition and scholastic aptitude. (Rakic, 1997)

The verbal account takes a different approach. According to these researchers, music cognition is related to language due to their reliance on the auditory cortex and related areas. Specifically, there are frequent reports of either an increased size in the planum temporale (PT), greater lateralization (with the left size being larger), or more activation during a listening task. This area is also known as "Wernicke's area," which is one of the two major speech centers in the brain (the other being Broca's area.) Wernicke's area is responsible for language comprehension and semantics. Thus, it is not surprising that this area would be related to absolute pitch (AP) ability, wherein musicians with this skill have the ability to label any pitch they hear. (Schlaug *et al.*, 1995)

There problem with this debate is that these arguments do not take into account the complex nature of music cognition. It is possible and even likely that different aspects of listening to and performing music draw upon different skills and brain areas. For example, evidence suggests that adults have a left-hemisphere dominance for rhythm processing (Samson *et al.*, 2001) and a right-hemisphere dominance for pitch processing (Zatorre, 2001).

In each of the reviewed studies in this paper, musical training was studied broadly either by enlisting well-rounded trained musicians or by offering similarly well-rounded lessons to children. Musicians are skilled in pitch perception including processing of melody, harmony, and timbre. They are also skilled in temporal processing of rhythm and meter. In addition to listening skills, musicians have built complex motor programs for performance and are very skilled in hand-eye coordination as well as breathing, depending on the instrument. Different musical instruments require different levels of skill for each of these traits. For example, a drummer requires an impeccable sense of time and superior motor co-ordination of both arms and legs, but does not require any pitch or melody processing ability. A pianist also does not require the ability to self-produce pitches on her own, as the piano is a percussive instrument, but keyboard ability is highly complex with including the coordination of both hands and usually several different lines of music. Vocalists require no hand-eye coordination, but must have an excellent sense of pitch as well as coordinated breathing. The same is true for brass players who have to adjust their speed of breathing depending on the pitch they wish to produce. In addition to these skilled performers, there are skilled listeners who study music theory and have the ability to analyze the chord progressions of musical pieces. No motor coordination is required for this task, but complex perceptual and cognitive skills are needed. In their paper on the neural basis of music perception, Koelsch and Siebel (2005) describe a complicated model for listening to and understanding music, involving multiple modules located in separate regions of the brain. Because the experiments published thus far have only touched on "music listening" or "musical ability" as a whole, they have no way of differentiating these multiple aspects of cognition.

My hypothesis is that the different findings based on either verbal memory or spatial-temporal processing improvements due to musical training are largely due to different specifics either in the training program, the population tested, or the "verbal" and "spatial" tasks themselves. As mentioned previously, the spatial account is sensitive to two different kinds of spatial processing; one is enhanced by musical training and the other is not. It is possible that the visual-spatial memory task used in the Ho et al study (2003) was more similar to the visual tasks from the Rauscher studies that did not show an improvement (Rauscher et al., 1993; Rauscher & Zupan, 2000). Likewise, one of the verbal processing findings depended on temporal sequencing, which is related to spatial ability. (Jakobson et al., 2003)

Another explanation is possible for the differences in findings. One pattern that emerges from the aforementioned articles is that adult comparison studies using highly skilled musicians with multiple years of prior training tend to show that musicians have better verbal memory, whereas the results from training studies lasting about a year with children demonstrate improvement in spatial ability for the experimental group. It is possible that over time and through musical training, the brain becomes more lateralized and shifts occur towards integrating language areas in music processing. It may be the case that in the first year or two of learning with musical training, the positive effects are in the spatial-temporal domain.

Implications for Future Research

While I have presented two possibilities for the differences in the findings between the spatial-temporal and verbal accounts of music cognition, these hypotheses need to be tested. The best way to test the first possibility would be to embark upon a series of experiments manipulating single musical variables. As a first pass, existing musicians of different specialties could be tested, for example, drumming, vocal, composition, string, brass, listening, performing, etc.) A more thorough series of experiments would implement different types of musical training programs to children, focusing on single aspects of musical processing. As for the second account, training studies using adults as subjects would help us to determine whether the structural differences observed between children and adults while processing music have more to do with general development, changes during music training at a young age specifically, or changes during training at any age. It is important to explore more fully the transformations in brain plasticity among children to determine when is the best time to educate children in music in order for there to be transfer effects to other areas of cognition.

Another outstanding question in music education is how the age at inception of training matters. Cognitive neuroscientists have already shown that young brains are highly plastic (Rakic, 1997). Human minds are usually most malleable at the youngest ages, but sometimes there are also critical periods of plasticity depending on the particular task. For example, children who are exposed to multiple languages before the age of 6 usually learn them without much effort, whereas adults require years of training and still appear to be imposters. (Johnson & Newport, 1989) Some researchers believe that people can only obtain perfect pitch ability with exposure to music at an early age.

Indeed, Saffran demonstrates that infants have absolute pitch from birth, but lose it in favor of learning relative pitch, which is more useful to language. (Saffran & Griepentrog, 2001) Schlaug's fMRI study comparing musicians to non-musicians shows that the amount of laterality in the planum temporale, an area thought to be related to absolute pitch, correlates with the age at which the musician started training. (1995) Future studies on the cognitive plasticity for music in children should take on two foci: 1) More studies need to be performed in non-AP areas of music cognition. As described previously, music cognition is extraordinarily complex. 2) Future studies will need to determine more definitively an ideal period for starting musical education for the maximum cognitive benefit across different aspects of music cognition.

In addition to this proposed set of studies, it is important to take a converging methods approach. Structural and functional MRI images have already shown us that musical experience leads to restructuring in the brain and different strategies for completing tasks (Gaser & Schlaug, 2003; Koelsch & Siebel, 2005; Leng et al., 1990; Samson et al., 2001; Schlaug et al., 1995; Zatorre, 2001). However, more methods should be used to explore the cognitively beneficial effects of musical training. Event-related potentials (ERPs) have been used widely in music cognition research. Usually the studies measure differences in attentive processes between musicians and non-musicians. The findings are commonly that musicians are more accurate and fast at perceiving differences or oddities in auditory stimuli. (Koelsch *et al.*, 1999) This method could be extended to investigate whether these attentive properties transfer to other attention-related tasks. As compared to fMRI, ERPs have quite low spatial resolution, so it can be difficult to know the precise location of an event, however, they are temporally quite precise, especially in comparison to fMRI. Because music is arranged through time, ERP recordings could be a key method for studying the effects of musical training as we can measure online processing of music perception. Within fMRI, new methods are emerging such as functional connectivity and perfusion imaging. Functional connectivity measures the connectedness of different areas of the brain, thus this method would be ideal for further exploring the spatial-temporal hypothesis and Leng's trion model. Perfusion imaging measures slow changes in cognitive activity over time, which regular BOLD fMRI methods are unable to do. This method is a fine choice for measuring how musicians' and non-musicians' strategies differ over a task that takes several minutes to complete.

Funding for research on music cognition is often difficult to come by, which could explain why the studies I propose here have not already been tested by other researchers, and why there is still a debate concerning whether music training improves spatial or verbal abilities. However, due to music's remarkable power to improve cognitive ability, it is integral that we continue to study its effects on cognition. While most of the studies described in this paper are on basic research, a handful implemented applied methods, working in a school setting. In each case, these projects yielded positive results for improving music cognition. More applied work should be done to test the ideal curriculum for implementing music education in the classroom, as it has clearly been shown to have positive benefits.

Conclusions

Through a thorough review of the literature I have shown that music training improves non-musically related cognitive abilities such as memory, spatial, and verbal cognition. It is likely children are most sensitive to cognitive improvements when exposed to musical training. What is still unclear is exactly which aspects of cognition are improved under what conditions, and what the mechanisms are for the improvements. Future studies should use converging methods from neuroscience and more simple training plans focusing on singular aspects of music cognition to determine which parts of musical training are responsible for which cognitive enhancements. Finally, these results should be applied to research in the classroom in order to establish an ideal curriculum incorporating musical education at an early age.

Box I

This summary table, while certainly not comprehensive, demonstrates the variety of methods used to test the effects of musical training on cognitive ability, as well as the wide range of findings that are often at odds with each other.
Key: *Method* can either be Comparison, contrasting musicians to non-musicians; Training, taking equally music-novice subjects and assigning some to an experimental musical training group; Neuroimaging, using fMRI or TMS methods in conjunction with one of the prior behavioral methods; or Exposure, involving subjects in the experimental group passively listening to music for a short period of time. *Population* describes how many subjects were in the experiment and how old they were. *Findings* compare the experimental (music-exposed or musician group) to the control group(s).

Study	**Method**	**Population**	**Findings for experimental condition**
(Jakobson *et al.*, 2003)	Comparison	60 adults	Better verbal sequencing memory
(Chan *et al.*, 1998)	Comparison	60 adults	Better verbal memory
(Hassler *et al.*, 1985)	Comparison	120 children 9-14 yrs	Visual-spatial skills correlate with musicality and creativity
(Helmbold *et al.*, 2005)	Comparison	140 adults	Better speed of processing; no difference in visual or verbal memory
(Brandler & Rammsayer, 2003)	Comparison	35 adults	Better verbal memory
(Hobbs, 1985)	Comparison	72 children 6-8 yrs	Academic achievement correlates with musical experience
(Phillips, 1976)	Comparison	60 children 8-9 yrs	Academic achievement correlates with musicality, but this is driven by socio-economic status
(Schellenberg, 2004)	Training	144 children 6 yrs	Overall IQ increase
(Bilhartz *et al.*, 1999)	Training	71 children 4-6 yrs	Improved visual memory and sequencing (no verbal improvement)
(Costa-Giomi, 1999)	Training	117 children 9-12 yrs	Improved spatial but not verbal or quantitative skills
(Ho *et al.*, 2003)	Training	90 children 6-15 yrs	Improved verbal memory (not visual)
(Rauscher & Zupan, 2000)	Training	62 children 5-6 yrs	Improved spatial-temporal skills; not other visual skills
(Ohnishi *et al.*, 2001)	Neuroimaging: Comparison	28 adults	Age of inception to music correlated with left PT activation
(Norton *et al.*, 2005)	Neuroimaging: Comparison	70 children 5-7 yrs	Different brain structures activated and better ability on visual tasks
(Gaser & Schlaug, 2003)	Neuroimgaging: Comparison	80 adults	Cortical differences in visual-spatial, motor, and auditory areas
(Kim *et al.*, 2004)	Neuroimgaging: Training	8 adults	Modified motor and sensory maps in the trained finger
(Rauscher *et al.*, 1995)	Exposure	36 adults	Improved spatial-temporal reasoning
(Nantais & Schellenberg, 1999)	Exposure	46 adults	No difference compared to control "story-telling" condition
(Hallam *et al.*, 2002)	Exposure	31 children 10-11 yrs	calming music improved arithmetic

Box II: Theoretical issues
In the study of the effects of music on transfer to other cognitive abilities, there exists some agreement and some disagreement. While researchers tend to agree that regular musical training over a period of several months leads to cognitive enhancement, they disagree as to which areas of cognition are most benefited by this sort of training.

Researchers disagree on which aspects of cognition are related to musical training

	Visual/Spatial-Temporal	Verbal
Position Summary	Musical performance involves complicated manipulation of sequences through space and time. Musical training enhances the skills we use for performing spatial-temporal tasks, and sometimes visual-spatial tasks as well.	Verbal skills, particularly memory, are enhanced by exposure to music due to the auditory relationship and the fact that music draws on similar brain areas.
Behavioral Findings	Spatial reasoning is improved with training in music. Also, musicians have better spatial reasoning. Sometimes regular visual memory tasks are not improved upon.	Verbal memory, usually in the form of list recall, is enhanced after musical training. Additionally, musicians have superior verbal working memory than non-musicians.
Neuroscience Findings	When listening to music, a network in the cortex fires in the same way that it does when completing spatial or mathematical tasks. The right parietal lobe is also implicated.	Language areas are active while making musical judgments. In skilled musicians and people with perfect pitch, the left planum temporale (Wernicke's area) is larger and active when listening to music.
Key Papers	(Bilhartz et al., 1999), (Costa-Giomi, 1999; Drake & Palmer, 2000), (Gaser & Schlaug, 2003), (Hassler et al., 1985), (Leng *et al.*, 1990; Rauscher & Zupan, 2000), (Rauscher et al., 1995)	(Brandler & Rammsayer, 2003), (Chan et al., 1998), (Helmbold et al., 2005), (Ho et al., 2003), (Ohnishi et al., 2001), (Schlaug *et al.*, 1995)

Researchers tend to agree on the following issues

The Mozart Effect is an artifact of arousal and mood
The exciting "Mozart Effect" finding of increased cognitive ability immediately after passive listening (Rauscher *et al.*, 1993) has been shown to be an artifact of arousal (Schellenberg, 2005) and preference (Nantais & Schellenberg, 1999). A meta-analysis by Chabris (1999) also shows the effect to be an artifact of non-music factors.

Extended musical training is cognitively beneficial
Many researchers have confirmed through studies that musical training benefits non-musical cognitive abilities. (Bilhartz et al., 1999; Chan et al., 1998; Costa-Giomi, 1999; Hassler et al., 1985; Ho et al., 2003; Kim et al., 2004; Meister *et al.*, 2005; Rauscher et al., 1995; Rauscher & Zupan, 2000; Schellenberg, 2004, 2003) Schellenberg reviews some of the findings and agrees that this position is widely held. (2005)

Box III – Future Directions

Research on the effects of musical training on cognitive development is currently incomplete. I make the following recommendations for research in the area:

1. Perform more studies to tease apart the issues surrounding the visual/spatial-temporal vs. verbal debate in far transfer of music ability.
2. There are undoubtedly several different mechanisms responsible for "musical ability" (such as rhythm, pitch, harmony, etc). Perhaps these different areas of music translate into improvements in different areas of cognition. More studies should be performed that test one area of music rather than lumping "musical ability" as one unitary cognitive module.
3. More research needs to be done in this area using neuroscientific methods.
    a. Functional connectivity analysis may demonstrate how musical areas of the brain are connected to and integrated with areas of the brain specific to cognitive abilities such as memory, language, and spatial reasoning. This method would be particularly useful in testing the spatial-temporal network hypothesis.
    b. In addition to localizing areas of the brain specific to musical processing, fMRI methods can tell us how trained musicians may differ in strategy and brain activations from controls when performing cognitive tasks.
    c. Event-related potentials, which are sensitive to millisecond timecourses, should be recorded to measure differences in attentive processing and timing for musicians and non-musicians.
    d. Transcranial magnetic stimulation can help verify music areas of the brain discovered in other studies by demonstrating what types of cognition fail when a brain area is temporarily disabled.
4. There is evidence that training children in music has a different and probably more profound impact than training adults. More work should be done to determine how truthful this claim is, and at what age(s) children are most susceptible to positive returns on musical training. Specifically, when does a critical plasticity stage end?
5. While most of the studies in this area are on basic research, some of the applied studies have demonstrated that musical training has positive benefits in classroom education. More studies should be done in this area to determine ideal ways to add musical education to the curriculum.

References

Bilhartz, T. D., Bruhn, R. A., & Olson, J. E. (1999). The effect of early music training on child cognitive development. *Journal of Applied Developmental Psychology, 20*(4), 615-636.

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

Chabris, C. F., Steele, K. M., & Bella, S. D. (1999). Prelude or requiem for the 'mozart effect'? *Nature, 400*(6747), 826-828.

Chan, A. S., Ho, Y.-C., & Cheung, M.-C. (1998). Music training improves verbal memory. *Nature, 396*(6707), 128.

Costa-Giomi, E. (1999). The effects of three years of piano instruction on children's cognitive development. *Journal of Research in Music Education, 47*(3), 198-212.

Drake, C., & Palmer, C. (2000). Skill acquisition in music performance: Relations between planning and temporal control. *Cognition, 74*(1), 1-32.

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *Journal of Neuroscience, 23*(27), 9240-9245.

Hallam, S., Price, J., & Katsarou, G. (2002). The effects of background music on primary school pupils' task performance. *Educational Studies, 28*(2), 111-122.

Hassler, M., Birbaumer, N., & Feil, A. (1985). Musical talent and visual-spatial abilities: A longitudinal study. *Psychology of Music, 13*(2), 99-113.

Helmbold, N., Rammsayer, T., & Altenmüller, E. (2005). Differences in primary mental abilities between musicians and nonmusicians. *Journal of Individual Differences, 26*(2), 74-85.

Ho, Y.-C., Cheung, M.-C., & Chan, A. S. (2003). Music training improves verbal but not visual memory: Cross-sectional and longitudinal explorations in children. *Neuropsychology, 17*(3), 439-450.

Hobbs, C. (1985). A comparison of the music aptitude, scholastic aptitude, and academic achievement of young children. *Psychology of Music, 13*(2), 93-98.

Jakobson, L. S., Cuddy, L. L., & Kilgour, A. R. (2003). Time tagging: A key to musicians' superior memory. *Music Perception, 20*(3), 307-313.

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in 2nd laguage-learning: The influence of maturational state on the acquisition of english as a 2nd language. *Cognitive Psychology, 21*(1), 60-99.

Kim, D.-E., Shin, M.-J., Lee, K.-M., Chu, K., Woo, S. H., Kim, Y. R., et al. (2004). Musical training-induced functional reorganization of the adult brain: Functional magnetic resonance imaging and transcranial magnetic stimulation study on amateur string players. *Human Brain Mapping, 23*(4), 188-199.

Koelsch, S., Schröger, E., & Tervaniemi, M. (1999). Superior pre-attentive auditory processing in musicians. *Neuroreport: For Rapid Communication of Neuroscience Research, 10*(6), 1309-1313.

Koelsch, S., & Siebel, W. A. (2005). Towards a neural basis of music perception. *Trends in Cognitive Science, 9*(12), 578-584.

Leng, X. D., Shaw, G. L., & Wright, E. L. (1990). Coding of musical structure and the trion model. *Music Perception, 8*(1), 49-62.

Meister, I., Krings, T., Foltys, H., Boroojerdi, B., Müller, M., Töpper, R., et al. (2005). Effects of long-term practice and task complexity in musicians and nonmusicians performing simple and complex motor tasks: Implications for cortical motor organization. *Human Brain Mapping, 25*(3), 345-352.

Mercy, J. A., & Steelman, L. C. (1982). Familial influence on the intellectual attainment of children. *American Sociological Review, 47*(4), 532-542.

Nantais, K. M., & Schellenberg, E. G. (1999). The mozart effect: An artifact of preference. *Psychological Science, 10*(4), 370-373.

Norton, A., Winner, E., Cronin, K., Overy, K., Lee, D. J., & Schlaug, G. (2005). Are there pre-existing neural, cognitive, or motoric markers for musical ability? *Brain and Cognition, 59*(2), 124-134.

Ohnishi, T., Matsuda, H., Asada, T., Aruga, M., Hirakata, M., Nishikawa, M., et al. (2001). Functional anatomy of musical perception in musicians. *Cerebral Cortex, 11*, 754-760.

Overy, K., Norton, A., Cronin, K., Gaab, N., Alsop, D. C. W., Ellen, & Schlaug, G. (2004a). *After one year of musical training, young children show a left-*

hemispheric shift for melody processing. Paper presented at the Organization for Human Brain Mapping Conference.

Overy, K., Norton, A. C., Cronin, K. T., Gaab, N., Alsop, D. C., Winner, E., et al. (2004b). Imaging melody and rhythm processing in young children. *NeuroReport, 15*(11), 1723-1726.

Phillips, D. (1976). An investigation of the relationship between musicality and intelligence. *Psychology of Music, 4*(2), 16-31.

Rakic, P. (1997). Corticogenesis in human and nonhuman primates. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 127-145). Cambridge, MA: MIT Press.

Rauscher, F. H., Shaw, G. L., & Ky, K. N. (1993). Music and spatial task performance. *Nature, 365*(6447), 611.

Rauscher, F. H., Shaw, G. L., & Ky, K. N. (1995). Listening to mozart enhances spatial-temporal reasoning: Towards a neurophysiological basis. *Neuroscience Letters, 185*(1), 44-47.

Rauscher, F. H., & Zupan, M. A. (2000). Classroom keyboard instruction improves kindergarten children's spatial-temporal performance: A field experiment. *Early Childhood Research Quarterly, 15*(2), 215-228.

Saffran, J. R., & Griepentrog, G. J. (2001). Absolute pitch in infant auditory learning: Evidence for development reorganization. *Developmental Psychology, 37*(1), 74-85.

Samson, S., N, E., & M, B. (2001). Cerebral substrates for musical temporal processes. In R. J. Zatorre & I. Peretz (Eds.), *The biological foundations of music* (pp. 166-178). New York: NY Academy of Science.

Schellenberg, E. G. (2004). Music lessons enhance iq. *Psychological Science, 15*(8), 511-514.

Schellenberg, E. G. (2005). Music and cognitive abilities. *Current Directions in Psychological Science, 14*(6), 317-320.

Schellenberg, E. G. (Ed.). (2003). *Does exposure to music have beneficial side effects?* New York, NY,US: Oxford University Press.

Schlaug, G., Jancke, L., Huang, Y., & Steinmetz, H. (1995). In vivo evidence of structural brain asymmetry in musicians. *Science*(267), 699-701.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the mozart effect. *Psychological Science, 12*(3), 248-251.

Zatorre, R. J. (2001). Neural specializations for tonal processing. In R. J. Zatorre & I. Peretz (Eds.), *The biological foundations of music* (pp. 193-210). New York: NY Academy of Science.