ABSTRACT

Music and the Mind: How the Brain is Affected by Song

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Music is often thought of as a nonverbal language, capable of communicating emotional messages. Areas of the brain have been identified that, when damaged, affect only musical skills. At the same time, while the initial sensation of the sounds that make up music is a predominantly auditory experience, the neural basis of music perception lies in several different areas of the brain and overlaps with those used in language, emotion, and motor tasks. Thus music is a complex experience that utilizes seemingly divergent abilities of the brain. This thesis will describe the systems level processing of music perception and implications for music therapy.

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MUSIC AND THE MIND: HOW THE BRAIN IS AFFECTED BY SONG

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By

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To my parents,

for always pushing me to be better,

but not in a “crazy Asian parent” sort of way

Also, to Jacky,

whose creative abilities far surpass my own

CHAPTER ONE

General Introduction to Music

Music plays an integral part in our everyday lives. It is nearly impossible to go a whole day without hearing some snippet of music somewhere along the way. As far as research has found, music is also a uniquely human trait (McDermott & Hauser, 2005). While other animals may have song, none of them purposefully make music for the sole enjoyment of it. These songs have mating, communicating, or territorial purposes. So why do humans continue to make music, if it is only for the sake of doing so? This thesis will explore the effects that music has on the brain, especially in its overlap with language, emotion, and motor skills.

The Evolution of Music

Music is universal. Every known human culture in the world has been found to have some element of music. Music is used in a variety of social events, from weddings to funerals. It plays a major role in media, especially movies and commercial advertisements. Yet, the exact origins of music remain unknown, lost in prehistoric time. To complicate things further, music has no direct, obvious adaptive function (McDermott & Hauser, 2005). That is, despite what some people say about how they would die without music, humans gain no direct survival benefits from making or listening to music. This makes it harder to determine how music originated by working backwards. There are many theories of music evolution, but three main ones will be explored: sexual selection, social cohesion, and simple side effect. These are not mutually exclusive, and it may well be that these three theories all explain some aspect of music evolution.

Sexual Selection

Sexual selection occurs when an evolutionary adaptation serves no other purpose but courtship. A common example is the male peacock's dazzling tail. While it has no functions in survival – and in fact may shorten the peacock's lifespan as the colorful tail attracts predators – the tail has evolved to be colorful to promote sexual attraction. Females are attracted to the brightest, most vibrant tails. Males with more drab tails may not be as successful in mate attraction as those with more colorful tails. Thus, there is a natural selection for bright tails. In the same way, music may have evolved in human culture along the same premises. Just like vibrant plumage may indicate health and virility to female peacocks, ability to make music may signal high levels of cognition and mental capacity to humans. In the way, the ability to make music may have helped attract the opposite sex and thus evolved for this reason (Miller, 2001).

Social Cohesion

Another theory of music evolution holds that music evolved as a coalition signaling system. Hagen and Bryant (2003) argue that sexual selection cannot account for why humans often make music in groups (such as in choruses and orchestras). They propose that group music signals a sort of social cohesion, indicating the strength of a coalition. Among the primates, humans are uniquely able to form groups and alliances that are not predicated on a blood relationship. Hagen and Bryant (2003) claim that the formation of non-consanguineous social groups is predicated on group activities such as song and dance. Thus music, which is also a uniquely human ability, evolved with this ability to cooperate with one another. This social cohesion theory explains how music is used in many social settings in which people come together in groups and are able to relate to one another. Sporting events are a prime example. The fact that many school sports teams have their own fight song that all the students can rally to provides strength for this theory that music is used to promote social cohesion.

Auditory Side Effect

The last theory we look at holds that music evolved as a simple side effect of having an auditory system. In 1997, Pinker claimed that music is the result of humans harboring neural circuits for language. Thus, music is simply a byproduct of language. He called it "auditory cheesecake," with no adaptational value at all besides incidental enjoyment.

Elements of Music

Music contains eight perceptual attributes that can be individually manipulated and, though often analyzed separately, must be merged to make up the experience of music. These are pitch, rhythm, timbre, tempo, meter, contour, loudness, and spatial location. Each of these attributes will be explored in detail in chapter three.

A Brief History of Western Music

While the exact origin of music may be a mystery, it is likely that the first instrument was the voice. Singing and rhythmic chants may have marked the advent of music (Clendenin, 1974). Later, primitive man began making instruments: drums, rattles, and flutes made of carved bone, all quite similar to ones still used now. The oldest known musical instrument is a bone flue found in a Neanderthal campsite dated to the middle Paleolithic age, about 50,000 years ago. On a replica, researchers were able to produce notes along the contemporary diatonic scale (Kunej & Turk, 2000).

Most of the studies detailed later will utilize Western music. This is why only Western music will be explored here as opposed to the Eastern, oriental styles of music. Eastern music is so vastly different from Western music, even using a different scale, that it would take an entire thesis just to give an exposition.

The Bible documents the use of music in ancient Jewish culture. There are many instances of singing throughout the Old Testament, and the entire book of Psalms is filled with instructions as to what instruments should be played with certain psalms. Unfortunately, the exact notes of all these songs were never recorded so they cannot be heard now. For the Ancient Greeks, music was an integral part of theater, almost as important as the acting itself. They also developed an intricate music theory. On the other hand, not much is known about the music of Ancient Rome, though the Romans were most likely heavily influenced by the Greeks and the Etruscans (Clendenin, 1974).

In the Middle Ages, music and the Church were inextricably intertwined. Most notated music still in existence from this time are sacred hymns, with few examples of secular music. The Gregorian Chant was developed during this time and became the customary form of liturgy. A four-lined staff, used in a somewhat similar fashion as the five-bar staff today, was established to allow for easier reading of music. Prior to this, the pitch was indicated by written text near the lyrics. It was also during this time that music theory began to be studied, with the emphasis first being on intervals (Clendenin, 1974).

During the Renaissance, emphasis shifted from the Church to the individual man. Knowledge was sought for its own sake, and music was created for the sake of creating music. The Renaissance is the first time we see composers writing their names on their manuscripts, allowing the songs to be attributed to them. Before this, music was usually made to glorify God, and thus composers remained anonymous to glorify God rather than themselves. The Renaissance saw the increased separation of church and state as focus was transferred from God and the eternal hereafter to humans and life on earth. It was also in this time that the five-bar staff used today was developed and became the common form of music notation (Clendenin, 1974).

Following the Renaissance was the Baroque period. Music written during this time became more dissonant, more dramatic. Alongside this increase in drama is, appropriately, the advent of opera. Interest in the revival of Greek theater influenced the development of opera. The first full opera was written in 1600, called *Euridice*. Three of the more well-known composers of this period are Antonio Vivaldi, George Frederick Handel, and Johann Sebastian Bach (Clendenin, 1974).

The deaths of Bach and Handel marked the end of the Baroque period, which was then followed by the Classical period. While the term "classical music" is used now for any music that is not contemporary, true Classical music only refers to those written from around 1750 to 1800. A revival of Ancient Greek and Roman ideals flourished, as people began once again turning to reason and balance. The string quartet and the symphony orchestra became established and standardized. This period saw the rise of perhaps the most famous composers of all time: Franz Joseph Haydn, Wolfgang Amadeus Mozart, and Ludwig van Beethoven (Clendenin, 1974).

The response to the Classical period was the Romantic period. In reaction to the emphasis on reason and order, the Romantic period shifted the focus to nature and imagination. Any constraints on music composition were lifted and the imagination was allowed to run free. Melodies became much less structured and formulaic, and syncopated rhythms became the norm. This is the period of Richard Wagner, Franz Liszt, and Frederic Chopin. The music of the Romantic period set the stage for the variety seen now in contemporary music (Clendenin, 1974).

Finally, we reach modern music. There is no one particular style that pervades contemporary music composition. Explorations of sounds, both natural and electronic, mark this modern time. Modern composers span the genres, from melodies that sound like they could be from the 1600s to futuristic sounds that almost lack any melody at all. In fact, new music is composed sometimes for the sake of being strange and novel (Clendenin, 1974). It is in this contemporary time that scientists also begin to study the underlying reason for our intrinsic enjoyment of music, and music psychology research abounds.

CHAPTER TWO

Music Sensation

A discussion of the perception of music cannot be complete without at least a cursory introduction of music and sound sensation. Before music can be perceived and enjoyed, something must first be picked up by a sensory organ and registered by the lower processes of the brain before the higher order processes can occur.

The Basic Physics of Sound

A sound wave is generated by vibrations mechanically pushing air molecules. When a violin bow is pulled across the strings, the strings vibrate; and, like a ripple effect in water when an object disturbs the surface, there is a sort of ripple effect in the air molecules around the strings caused by the mechanical disturbance of the vibrations. As the air molecules are pushed away from the string, they collide with adjacent molecules, perpetuating the wave. This results in areas of compression – high pressure areas where molecules are close together – and areas of rarefaction – low pressure areas where the molecules are relatively further apart. This wave pattern is called a longitudinal wave and can be visualized in the motions of a Slinky toy (Brownell, 1997).

Certain characteristics of the wave form the attributes of sound: wavelength and amplitude. The wavelength is an entire cycle of one complete compression and one complete rarefaction. It determines the frequency of the wave, which in turn determines pitch, how high or low a sound is perceived to be. Amplitude gives the intensity, which is perceived as volume. Wavelength and frequency are related by the equation: $wavelength(m) = \frac{velocity(m/s)}{frequency(Hz)}$, where velocity is the speed of sound through a specific medium, which is constant as long as the wave remains in the same medium (Rosenberg, 1982). Frequency is directly related to pitch, thus the larger the frequency, the higher the pitch and vice versa. It follows then, that since wavelength is inversely related to frequency, it is also inversely related to pitch. For example, middle C (C_4) on the piano has a frequency of 261.63 Hz and a wavelength of 1.32 m, whereas high C (C_5), which is one octave higher, has a frequency of 523.25 Hz and a wavelength of 0.66 m (Suits, 1998). The average human ear can detect sounds ranging from 16 to 15000 Hz.

The Ear

The ear is where sound sensation begins, as the mechanical disturbances that are sound waves are detected by hair cells that can then relay the information to the brain. The ear is divided into three main sections: the outer ear, the middle ear, and the inner ear.

Outer ear

The outer ear consists of the pinna, the concha, and the ear canal and serves to mainly direct sound waves into the middle and inner ear. The pinna is the outer visible portion of the ear and only channels sound waves into the ear, while the concha and the ear canal also slightly amplify certain frequencies of sound. However, flattening the ridges of the pinna impairs sound localization, demonstrating that the pinna plays a role in auditory perception. One mechanism of sound localization involves inter-aural timing differences. Sounds directly in front of the ear (and therefore beside the person) reach the eardrum faster, while other sounds must first be reflected from the ridges of the pinna, causing a slight delay. The brain can then interpret these time differences directionally (Hood, 1977).

To measure amplification in the outer ear, Rosenberg (1982) describes a method using two tiny microphones, one placed outside the ear and the other at the end of the ear canal right next to the ear drum. It was shown that the ear amplifies those sound waves with frequencies in the range of 2000-7000 Hz, with two peaks at 2500 Hz and 6000 Hz where amplification is maximized. This is significant in that this is the ideal range of amplification for speech perception.

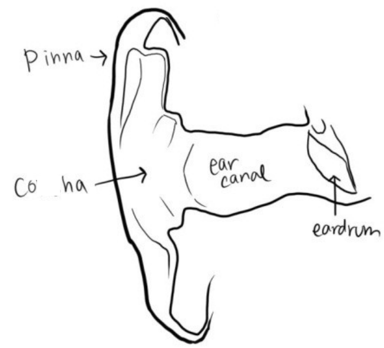

Fig 1: the outer ear (adapted from Rosenberg, 1982)

Middle ear

The middle ear begins with the ear drum and contains the three smallest bones in the body: the malleus, incus, and stapes, more commonly known as the hammer, anvil, and stirrup, respectively. These three bones are also known collectively as the ossicular chain. Sound waves travel down the ear canal and literally hit the ear drum, which begins a mechanical chain reaction, as the malleus is attached on one end to the eardrum and on the other to the incus. As the eardrum is pushed by the pressure from the wave, the malleus acts as a pivot and pulls the incus, which is in turn attached to the stapes, pushing it forward. The stapes is attached to the oval window. Together with the round window, the oval window connects the middle ear with the cochlea of the inner ear. When the oval window is pushed or pulled, it exerts pressure on the fluids inside the cochlea, causing displacement.

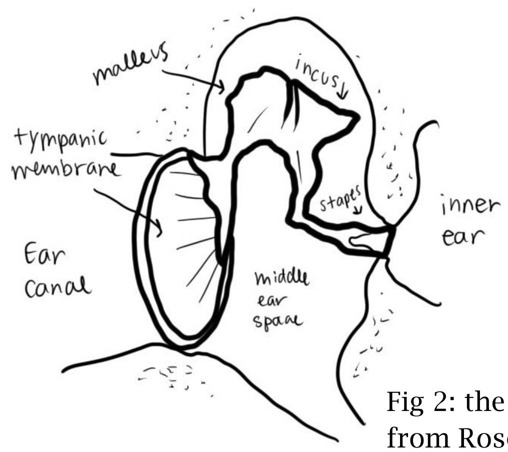

Fig 2: the middle ear (adapted from Rosenberg, 1982)

The inner ear is impermeable to the pressure changes caused by the sound waves themselves. Thus, the ossicular chain plays a fundamental role in hearing. Damage or malfunction in the middle ear can cause deafness.

The middle ear also contains muscles that control the joints between the elements of the ossicular chain. The stapedius muscle prevents damage to the ear as a result of sudden loud noises by reacting almost instantaneously to decrease the intensity with which the stapes vibrates against the oval window. Change in head position or posture is also compensated for using one of these middle ear muscles, the tensor tympani (Rosenberg, 1982).

Inner ear

The inner ear consists of the cochlea and the semicircular canals, which have important roles hearing and balance, respectively. These are housed deep in the temporal bone of the skull and are actually made up of the hollow, fluid-filled tunnels in the skull itself. The spiral cochlea is both the tiniest and perhaps most complex organ in the human body. The oval window connects the cochlea to the middle ear mechanically and is sealed by the stapes. Thus, when the stapes vibrates, it exerts pressure on the fluids in the cochlea, perpetuating the waves originally from the air molecules. In order to prevent unnecessary pressure build-up, the seal of the round window is a flexible diaphragm that vibrates in harmony with the stapes.

The basilar membrane spans the length of the cochlea, if it were to be “rolled out” of its spiral shape. It divides the cochlea into two compartments except for a small opening at the apex of the cochlear spirals, called the helicotrema, through which fluids can flow to prevent pressure differences from accumulating. But perhaps most importantly, the basilar membrane also holds the hair cells that are the sensory receptors that actually detect the vibrations. The hair cells are divided into two groups: inner hair cells, which are individually innervated, and outer hair cells, which consist of up to about ten cells per nerve. They are covered in rows of stereocilia which are anchored to the cell membranes by actin filaments that run through the core of each stereocilia. The lengths of the stereocilia in each row increase as they approach the front of the cells. Also, adjacent stereocilia seem to be connected, as side to side movement of longer stereocilia causes movement of shorter ones (Rosenberg, 1982).

It is this horizontal movement of stereocilia that causes a nerve impulse that may then be relayed to the brain, though the actual physiological mechanism of this has only been theorized. One theory proposes that while the membranes of stereocilia are permeable to the ions dissolved in the cochlear fluid (called endolymph), the amount of surface area exposed to the fluids are significantly less when stereocilia are completely still and vertical. Stereocilia are pushed sideways when sound entering the ear cause fluid displacement as the stapes contacts the oval window. The sideways movement increases the surface area of the stereocilia in contact with endolymph and increases ion flow to create a nerve impulse. Each individually innervated hair cell is specific for a certain frequency. Thus, pitch processing begins in the cochlea (Rosenberg, 1982).

The Brain

Once a nerve impulse has been created, it travels up the central auditory pathway to the cochlear nucleus in the pons of the brainstem. From here, a portion of the nerves in this pathway cross the midline, allowing impulses created at one ear to be represented bilaterally in the brain. This is adaptive in that damage to the brainstem above the nucleus will not cause deafness if it is isolated to one side. Further, even if an entire hemisphere of the cortex is removed or damaged, no hearing impairment should appear at either ear, since the nerve impulses from both ears will continue to travel to the other hemisphere (Hood, 1977). The cochlear nucleus itself plays a role in differentiating speech from non-speech sounds and assists in sound localization. Auditory input is relayed to the thalamus, which parses the signal, relaying relevant signals to the primary auditory cortex. In a study performed by Frith and Friston (1996), the mid-thalamus was the only area of the brain found to have any significant change in levels of activation, as measured by PET scans, with differing rates of attention to the sound stimulus. Also, abnormalities in the thalamus have been found to be associated with auditory hallucinations in patients with schizophrenia (Martinez-Granados et al, 2008).

Once the impulse reaches the cortex, it is actually still unclear exactly how sounds are processed in the temporal cortex. Each nerve is specific for a certain frequency, beginning at different locations along the cochlea. This arrangement then remains constant throughout the central auditory pathway, allowing for easier recognition in the brain (Hood, 1977). Also, different aspects of sound perception occur in different areas of the brain. In 2004, the American Speech and Hearing Association filed a technical report citing several independent mechanisms of auditory processing: localization and lateralization, discrimination, pattern recognition, temporal aspects (such as masking, ordering, and resolution), auditory performance changes with competing stimuli, and performance changes with degraded stimuli. The analysis of these aspects of hearing is localized to different areas of the brain.

For example, Tardif, Murray, Meylin, Spierer, and Clarke (2006) found that sound localization, coded by inter-aural timing and intensity differences, is largely analyzed by specific areas in the temporal, parietal, and inferior frontal cortices, especially in the right hemisphere.

Additionally, Diekhof, Biedermann, Ruebsamen, and Gruber (2009) used fMRI to detect which areas of the brain were activated during an exercise of discrimination in which participants were asked to identify a deviant tone in a melody. The left superior temporal sulcus was activated in trials in which the deviant tone was not identified, indicating its role in subliminal processing. On the other hand, when the deviant tone was correctly identified, the putamen, the left middle temporal gyrus, and the anterior cingulate cortex were differentially activated. These same areas were not stimulated when the participant indicated hearing a deviant tone where none were presented, signifying that these brain areas are important in successful discrimination.

This is a cursory discussion of the mechanisms of sound sensation, presenting some prerequisite knowledge that may help in understanding higher levels of music processing and perception.

CHAPTER THREE

Music Perception

This chapter will focus on specific areas of the brain associated with music processing. It will also explore how brain damage may affect musical skills.

Analysis of the Eight Perceptual Attributes of Music

As noted in chapter one, there are eight traits in music that each contribute to the perception of music as a whole. These characteristics are largely analyzed independently in different areas of the brain before being synthesized into the experience of music as a whole. Of these characteristics, pitch and rhythm are the most salient and seem to play the biggest roles in the perception of music.

Pitch

Pitch is how high or low a note sounds. It is determined by the frequency of the sound wave and is thus absolute as opposed to relative (see Chapter 2). Each hair cell in the cochlea is specific for a single frequency, and this continues up the entire length of the auditory pathway. The primary auditory cortex contains a tonotopic map of pitch that parallels the organization of cochlear nerve endings. The lateral region of the anterior auditory cortex plays a key role in pitch processing, as lesions in this area have been found to cause pitch perception deficits (Bendor & Wang, 2005). While pitch itself is absolute, human music perception relies heavily on the relativity of pitch between adjacent notes. These musical intervals are largely processed by the temporal cortex, especially the superior temporal gyrus (Liegeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998).

On the other hand, in people who have perfect pitch – that is, they are able to determine the absolute pitch of a note without reference to a relative note – experimenters found left posterior dorsolateral frontal cortex activation upon presentation of a tone (Zatorre, Perry, Beckett, Westbury, & Evans, 1998). This area was not activated in participants who have only relative pitch until they were asked to make relative pitch judgments of intervals (i.e. whether they were major or minor). During this task, the relative pitch participants also showed activation of the right inferior frontal cortex, which was not seen with the absolute pitch group. Those with perfect pitch were also found to have larger left planum temporale than participants with relative pitch ability. Since this area is involved in verbal memory, this finding suggests a relationship between verbal memory and perfect pitch ability (Zatorre et al., 1998).

Rhythm

Rhythm can be described as the underlying pulse of the music. It is made up of either regular or irregular beats. Rhythm processing utilizes areas of the cerebellum, basal ganglia, premotor cortex and supplemental motor area, revealing a strong relationship with movement (Janata & Grafton, 2003; Lotze et al., 1999). Lesion studies have also shown that the left temporoparietal cortex is vital to rhythm discrimination (Phillips-Silver et al., 2011). More on rhythm can be found in the motor skills section of chapter 4.

Timbre

Timbre is what makes instruments sound different even when they are playing the same note. Differences in timbre, or complexity of sound waves, make it possible to tell that a sound is from a trumpet, or a flute, or a piano as opposed to a violin. Most instruments do not create a perfect sine wave when a note is played, but rather a more complex wave made up of multiple sine waves. While the ear detects these complexities in the sound wave, the brain analyzes the timbre separate from the overall pitch of the note. Damage to regions in an individual's non-dominant posterior superior temporal lobe has been shown to selectively impair perception of timbre (Kohlmetz, Muller, Nager, Munte, & Altenmuller, 2003).

Timbre also affects the analysis of the emotional aspect of music (Hailstone, Omar, Henley, Frost, Kenward, & Warren, 2009). Participants were presented with novel melodies intended to convey one of four emotions: happiness, sadness, anger, or fear. These melodies were played on one of four instruments: piano, violin, trumpet, or electronic synthesizer. Participants were then asked to select which emotion was conveyed in the melody. The participants were separated into two age groups: younger (age 18-30) and older (age 58-75). When the experimenters calculated the number of incorrect responses – that is, those that did not match the intended emotion – they found significant differences in average percentages of error for the different emotions dependent upon the instrument on which the melodies were played. For example, in both groups, happiness was harder to identify when played on the violin. Similarly, participants also had high error rate when sadness was presented by playing melodies on the synthesizer. On the other hand, while the younger group had the highest accuracy in identifying fear when it was played on the piano, this was the hardest instrument for the older group to identify fear (Hailstone et al., 2009).

Tempo

Tempo describes how fast or slow a piece is played. Unlike rhythm, it is usually held constant throughout a song, with any changes gradually transitioned into or used to signify a new movement. Tempo affects the emotional aspect in a piece of music, with slower tempos strongly correlated with songs that are more often rated as sad (Balkwill & Thompson, 1999). Neural processing of tempo involves the cerebellum, and is very similar to meter processing.

Meter

Meter, also known as the beat, is very similar to rhythm as well, but, like tempo, it is regular throughout. In musical notation, the meter is written as a fraction with the number of beats per measure in the numerator and the note length that comprises one beat in the denominator. For example, 3/4 time indicates three beats per measure, with a quarter note equaling one beat. Meter is processed in the right temporal cortex, as lesions in this area have been found to affect a patient's ability to follow a beat or maintain a steady tapping, but had no effect on his or her ability to follow an irregular rhythm (Wilson, Pressing, & Wales, 2002). Furthermore, Ibbotson and Morton (1981) found that participants were able to tap a rhythmic pattern with their right hand better than their left, and vice versa for the beat, indicating right brain dominance for meter.

Contour

The way a melody is shaped is called the contour. This is defined by the perceived curve of the pitches of different notes as the song progresses. Contour also applies to language in the intonations of speech, especially in the tonal languages. The right superior temporal gyrus plays a major role in contour analysis, as seen when patients with excisions in these regions have difficulty identifying the direction of contour in a musical excerpt (Patterson, Uppenkamp, Johnsrude, & Griffiths, 2002).

Loudness

The loudness of a particular sound is determined by the amplitude of the sound wave. Varying degrees of loudness, called dynamics, contribute to the emotional processing of music.

Brain Structure Differences between Musicians and Non-musicians

Several anatomical differences have been found by functional and structural brain imaging of musicians and non-musicians. For example, musicians have significantly larger corpus callosum than non-musicians. This may be due to the need for faster communication between the two hemispheres of the brain in order to coordinate the precise movements of the left and right hands (Schlaug et al., 1995). Understandably, the anterior-medial region of the primary auditory cortex and inferior temporal lobe, both associated with auditory processing, are also reportedly larger in musicians (Schneider, et al., 2002; Luders et al., 2004). Similar structural differences are found in the inferior frontal gyrus, the primary motor cortex, the cerebellum, and the planum temporale, all in which these areas are larger in musicians than in non-musicians (Luders et al., 2004; Hutchinson et al., 2003; Amunts, 1997).

Amusia

Amusia occurs when an individual has an inability to process or perceive music. It can be congenital or result from an injury to the brain. It is interesting in that the deficit is highly specific to music. Often, no other auditory or language dysfunctions are evident in the amusic individual. One form of congenital amusia involves a pitch processing deficiency. This leads to what is commonly known as tone-deafness. But beyond simply being unable to carry a tune, people with amusia often have trouble remembering and recognizing a melody as well. They usually report that they do not particularly enjoy listening to music; some even report that it is downright unpleasant and try to avoid music. Surprisingly, it is not just a simple pitch processing defect that causes amusia. When asked to determine whether two spoken sentences, manipulated to vary only with respect to intonation, were identical or different, participants with amusia did not have significantly more errors than control participants without amusia. Thus, this inability to process pitch is highly selective and affects only music (Ayotte, Peretz, & Hyde, 2002).

Amusia can also affect only a certain aspect of music processing. For example, Phillips-Silver et al. (2011) describe the case of man who was solely "beat deaf." He was able to sing in tune and enjoyed listening to music, but reported that he could never catch the beat of any piece of music. He was able to tap a steady rhythm on his own and with a metronome, but when asked to tap along to a song, even one with very obvious, strong beats, he was unable to do so. On the other hand, he could identify when a dancer was moving in time to the music or not. Dysfunction in the left temporoparietal cortex is implicated in this case as seen below (Phillips-Silver et al., 2011).

While the exact cause of congenital amusia is unknown, those who are affected by it end to have thicker right inferior frontal gyrus and auditory cortices, implicating abnormal connectivity between these two regions (Hyde et al., 2007). On the other hand, the cause of acquired amusia can be pinpointed to a specific moment. Several brain areas in which damage occurs have been found to cause acquired amusia. Lesions in the left fronto-temporal lobe have been found to cause rhythm-related amusia, while lesions in the right hemisphere affect pitch processing (Alcock, Wade, Anslow, & Passingham, 2000). Patients who received surgery to repair a ruptured aneurysm on the middle cerebral artery had an up-regulated frequency of music agnosia after the treatment (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000).

The study of amusia in individuals has elicited a better understanding of which regions of the brain are associated specifically with music processing. Also illuminated are those brain areas that overlap with processing of other skills. This is the focus of the next chapter.

CHAPTER FOUR

Overlap with Other Abilities

This chapter explores the areas of overlap between music processing and that of language, emotion, and motor skills. It will also look at the implications of such relationships for music therapy.

Language

Language is a uniquely human phenomenon. While many animals are indeed able to communicate with one another, only humans are able to use true language complete with grammatical and syntactical rules. Music, too, has been found to be exclusively human, one of the many traits it shares with language. In fact, some theories hold that music and language evolved together, and others hypothesize that music was the predecessor, evolving before language (Merker, 2000).

Studies exploring the differences in the languages and musical styles across nations have often found correlations between a country's spoken language and its music. In 2003, Patel and Daniele used the normalized Pairwise Variability Index, or nPVI, to measure variability in rhythm in several countries' language and music. The nPVI measures variability in the duration of elements like syllables in speech, giving a value from 0 to 200, with 0 meaning each element is the exact same in length and 200 indicating great variability in syllable length. Different languages have significantly different nPVI values. Patel and Daniele calculated the nPVI values for music by British and French composers and found that the differences corresponded to those in the English and French languages, with English having a higher nPVI in both language and music. This finding has since been replicated and expanded upon by Huron and Ollen (2003), who differentiated between "stress-timed" and "syllable-timed" languages, in which the former relies on stress with irregular syllable length and the latter contains more regular syllable timing. For example, German and English are stress-timed languages, while Chinese, French, and Spanish are all syllable-timed. The researchers found that, in general, those countries that had syllable-timed languages also had lower nPVI values for their music, indicating more regularity in rhythm. These two studies indicate some relationship between music and language, but this is a shallow one. The next studies will show a surprisingly deep relationship that holds great implications in the use of music therapy for language disabilities such as dyslexia.

In 2007, Besson, Schon, Moeno, Santos, and Magne explored the differences in pitch processing in those with and without musical training. All speech requires the ability to differentiate pitch for full understanding. Many languages, including Chinese, Vietnamese, and most sub-Saharan African languages, are tonal in nature. A difference in pitch can change the entire meaning of a word or phrase. Thus, pitch processing is a vital aspect in both music and language.

In the first experiment, they presented the musicians and non-musicians with musical excerpts and linguistic phrases that either ended typically or had the last note or word increased by 20% or 50% of a tonal step, the latter they deemed weak and strong incongruities, respectively. The participants were asked to identify whether or not there was a pitch violation in each excerpt or phrase heard. The experimenters found that, while both groups were able to accurately identify strong pitch violations, the musicians had a significantly higher accuracy in detecting the weak incongruities. Also, using electroencephalography, the experimenters recorded participants' event-related potentials (ERPs) during the course of the study and found clearer bilateral distribution in musicians during strong pitch violations, but no significant differences otherwise. On the other hand, during weak pitch violations in both language and music, musicians had significantly larger responses than non-musicians, showing increased sensitivity to pitch that encompassed language as well as music. A negative component at 300 milliseconds (N300) appeared in response to weak incongruities only in the musicians. Also, a positive component peaking at 600 milliseconds (P600) in response to weak pitch violations in speech was significantly greater in musicians than in non-musicians.

The experimenters then set to determine whether this heightened sensitivity to pitch was a result of musical training or a predisposition that allowed these musicians to become such. In a second, longitudinal experiment, two groups of children were given eight months of either painting training or music training. The children were then subjected to the same pitch violation test used in the first experiment.

After eight weeks of training, there were still no significant differences in the children's abilities to distinguish pitch violations. But when looking at the ERPs, the experimenters found that strong violations elicited less P600 response in the music training group. This may indicate that pitch processing has become more automatic in this group.

After six months, the experimenters found that the children who underwent musical training were now better at detecting the weak violations in both music and language than before their training, while the children in the painting training group had no such improvement. Also, the ERP responses in the musically trained children showed significant differences as well: the amplitudes of both N300 and P600 increased significantly in their response to weak incongruities. These two experiments show the transfer of music training skill to language.

Beyond a simple transfer of skills, Slevc, Rosenberg, and Patel (2009) argue that music and language share processing resources in the brain as proposed in the shared syntactic integration resource hypothesis. To test this, simple sentences were paired with chord progressions in which a syntactic or semantic manipulation in the sentence was paired with a chord that was either in key or out of key. Syntax is the study of how sentences are constructed and is related to grammar; an example of a syntactical violation is “the dog brought the ball back to *she*.” On the other hand, semantics is the meaning of words, and an example of a semantic violation is “the *umbrella* brought the ball back to me.” There were six possibilities for combinations in the experiment: syntactic violation with in key chord, syntactic violation with off key chord, semantic violation with in key chord, semantic violation with off key chord, and no violation with both on key and off key chords.

Only one or two words would appear on the screen at a time, and participants were asked to read the sentences, pressing a button to continue to the next word and chord. After the entire sentence was presented, a yes or no comprehension question was presented that the participants had to answer. The participants were told that the chords would play but that they were not relevant to the task at hand. The response times for the participants to move on to the next part of the sentence after the manipulated word was presented were recorded and averaged.

As expected, response times following either semantic or syntactic violations were slower than those following no violations. But, while response times were significantly slower for syntactic violations when they were presented with an off key chord than an on key chord, no such differences were found with chord variations accompanying semantic violations. The experimenters concluded that, for this task, the syntactic processing of language is indeed shared with harmonic processing of music, as evidenced in the slower response times signaling the additive nature of concurrent processing of the two aspects. On the other hand, harmonic processing did not affect that of semantics. This could be due to the semantic violations being so salient that the participants did not pay attention to the chord violations that they were already told were irrelevant to the task. Or, the surprise of the semantic violation overshadowed the harmonic processing.

In 2008, Steinbeis and Koelsch conducted an experiment also using paired chord progression/semantics and chord progression/syntax violations, along with electroencephalography data. In contrast to the Slevc et al. (2009) experiment, participants were told to identify chords played on a specific instrument and respond by pressing a button, as well as answer simple questions about the sentences presented. The EEG data showed two major ERPs in response to chord violations that were significantly reduced when the chords were presented together with language violations. The early right anterior negativity (ERAN) was decreased by the simultaneous presentation of a syntactic violation but not a semantic violation, while the N500 was reduced with a semantic violation but not a syntactic one. This again shows a sharing of processing resources for language and music.

Finally, while rhythm has often been associated with motor area activation in the brain, Vuust, Wallentin, Mouridsen, Ostergaard, and Roepstorff (2011) found that, when musicians were asked to tap polyrhythms, Brodmann area 47, associated with language processing, was also activated. Polyrhythms occur in music when two different meters are combined at the same time, a main meter and a counter meter. For example, Chopin's *Fantasie-Impromptu* requires the pianist to play sextets in the left hand with thirty-second notes in the right hand. In other words, the pianist must evenly play six notes per beat in the left hand and eight notes per beat in the right hand at the same time. Contemporary jazz music often utilizes polyrhythms to create rhythmic tension, destabilizing the listener's precept of metrical background/ foreground relations (Vuust et al., 2011).

The participants in Vuust et al.'s study were 18 professional musicians. They were instructed to listen to an excerpt of three measures from Sting's *The Lazarus Heart*, which is written at a steady tempo of 120 beats per minute. The excerpt was repeated four times during which the musicians were asked to alternate between six measures of listening, three measures of tapping along at 120 bpm (tapM) with their right index finger, and then three measures of tapping at 160 bpm (tapC), also with the right index finger. The tapC scenario creates a 3 to 4 ratio in which the musician must tap 4 even beats in the time of three beats of the stimulus. The participants underwent fMRI scanning throughout the duration of the task. As expected, in both tapping scenarios, the left premotor and primary motor cortices were activated, along with the thalamus, right cerebellum and vermis. But in comparing scans taken during tapM and tapC, tapC scans showed activation of the left inferior frontal gyrus (IFG), especially in Brodmann's area 47, and the anterior cingulate cortex. While the anterior cingulate cortex has been implicated in the processing of conflict and error (Holroyd & Coles, 2002) and thus follows logically to be activated during such a task as tapping polyrhythms, Brodmann's area 47 is associated with language, especially syntactic processing. In fact, the left IFG is associated with integrative processing of the different aspects that comprise language comprehension. The fact that this area was activated in response to polyrhythm but not regular meter implicates the inferior frontal gyrus' role in processing discrepancies not only in language, but in music, and perhaps other communicative forms as well.

With the intimate relationship between music and language in the brain, music therapy can be incredibly beneficial for patients with language deficiencies. Numerous studies have found that patients with aphasia due to injury, stroke, or dementia have greatly improved speech fluency and content and increased spontaneity of speech following as little as three months of music therapy sessions (Brotons & Koger, 2000; Hartley, Turry, & Raghavan, 2010; Sparks, Helm, & Albert, 1974).

Dyslexic children have been found to have significantly higher error rates in pitch discrimination of speech, even in strong pitch violations. Following eight weeks of music training, along with the traditional phonological training already in progress, the dyslexic children had error rates equal to that of a control group of non-dyslexic children who were given eight weeks of painting training (Santos, Joly-Pottuz, Moreno, Habib, & Besson, 2007). Although more research needs to be conducted on the direct relationship between music therapy and reading skills for dyslexic children, this study shows a relationship between dyslexia and pitch discrimination that can be remediated by music.

Emotion

Music is often said to be an art of emotional communication, a nonverbal language with the ability to convey pure feelings. This is what makes it such a central part of movies and advertisements, as producers try to induce emotions according to the scene or that would make the advertised product more desirable.

The ability to perceive emotion in music is universal. In 1999, Balkwill and Thompson conducted a study in which thirty Western participants were asked to rate twelve Hindustani raga pieces on the degree to which they felt four emotions from the piece: joy, sadness, anger, and peace. A raga is a piece of Hindustani classical music written purposefully to convey a feeling or emotion. Even though the participants were completely unfamiliar with any sort of Hindustani music, they were able to accurately identify the intended emotion of most of the pieces.

Even people with autism are able to identify emotion in music, even though one of the characteristics of autism is a deficiency in emotional processing. When Quintin, Bhatara, Poissant, Fombonne, and Levitin (2012) presented autistic adolescents with a similar task as the one described above, they were able to identify the emotion portrayed in each excerpt with the same accuracy as the control group. This has great implications for the use of music therapy with children who have an autism spectrum disorder, especially in the use of conveying emotions.

Beyond being able to simply identify emotion, participants have reported changes in affect following exposure to music. In a study conducted by Ilie and Thompson (2011), participants were asked to listen to seven minutes of various Mozart pieces and then report on their emotional experience. They rated their affect on three dimensions: valence, energy, and tension. The experimenters found significant direct correlations between pitch and valence, tempo and energy, and tempo and tension. More specifically, in regards to pitch, higher ratings of valence were reported for high pitched music only when the music was soft. This same effect was not found with loud music. Also, tempo and tension levels had a significant relationship only when the piece was also low-pitched, but not when it was high. The effects of music are also greater when the song is familiar as opposed to completely novel (Pereira, Teixeira, Figueiredo, Xavier, Castro, & Brattico, 2011).

Physically, music can raise an individual's heart rate, with those performing the music themselves experiencing greater heart rate increase than those simply listening (Nakahara, Furuya, Obata, Masuko, & Kinoshita, 2009). On the other hand, it can also lower anxiety. Pregnant mothers undergoing a fetal non-stress test often report elevated levels of anxiety. While this in itself has not been shown to be directly related to the later health of the baby, chronic anxiety in the mother is associated with premature birth and lower Apgar scores upon birth. Thus, it is important that pregnant women not be overly anxious or that they have something that will give an anxiolytic effect. Music has this effect. Kafali, Derbent, Keskin, Simavli, & Gozdemir (2011) studied the effect of music on pregnant women as they underwent a fetal non-stress test. After the test, the women were asked to complete an anxiety inventory interview. The results revealed that the women who were allowed to listen to music throughout the test did, in fact, have significantly lower anxiety levels than the control group, who did not listen to music.

A great number of people also report getting "chills" when listening to a particularly striking or beautiful piece of music. Blood and Zatorre (2001) found that activation in the left ventral striatum, right dorsomedial midbrain, right thalamus, left anterior cingulate, right orbifrontal cortex, right supplementary motor area, insula, and cerebellum was associated with the onset of these chills. On the other hand, activation in the left hippocampus, the amygdala, medial prefrontal cortex, right cuneus, and the precuneus correlated with the subsiding of chills. Thus, these areas all seem to be involved in emotional processing, but for varying degrees of such.

Interestingly enough, in affecting mood, music can also in turn affect visual processing. Jolij and Meurs (2011) conducted a study in which participants were asked to identify a whether a faint schematic face that appeared on the computer screen for a split second was smiling or frowning, or whether a face appeared at all. During the task, the participants were assigned to listen to either happy music, sad music, or no music at all. The content of music deemed happy or sad was determined by the participants themselves before the study began. The results showed that participants who listened to music were slightly better at detecting the appearance of the face than those in the no music group. Also, those who listened to happy music were more likely to accurately detect the happy faces, with the opposite true for sad music. In fact, those who listened to happy or sad music were more likely to report a happy or sad face, respectively, regardless of whether there was one or not. Through the route of emotion, even vision can be affected by music.

Mirror neurons are thought to be partly responsible for these effects of music on emotion. The mirror neuron mechanism is proposed to allow individuals to process the meaning of a communicative signal by creating a sort of mirror representation of it in that individual's brain. These mirror neurons can be found in a network that includes the posterior frontal gyrus, the ventral premotor cortex, and the inferior parietal lobule. These neurons have been found to be stimulated both when an action is performed and when an individual sees a similar action being performed. Since music can be perceived as a communicative signal, it follows then that the mirror neurons might be activated so as to mirror the conveyed emotion from the song, thus inducing the emotion in the listener (Molnar-Szakacs & Overy, 2006).

Music therapy has already been shown to have positive, albeit short term, effects on patients with dementia by reducing anxiety and agitation, improving mood, and increasing socialization (Ledger & Baker, 2007; Ziv, Granot, Hai, Dassa, & Haimov, 2007; Lesta & Petocz, 2006). It also has a promising future in treating affective disorders, such as depression, in its ability to both decrease negative emotions and increase positive ones (Koelsch, Offermanns, & Franzke, 2010).

Motor Skills

Music cannot exist without motion. The physical production of sound relies on movements and vibrations. It is very likely that in ancient times, music and dance were so intertwined that one never occurred without the other. Many people find it exceedingly difficult to stay perfectly still while listening to music, oftentimes they cannot help but nod their head or tap their feet to the beat of the song. Even simply thinking about a song may elicit a corresponding foot tap or head nod. Like with emotion, mirror neurons have been implicated in this phenomenon. It has been proposed that listening to a song may cause the mirror neurons to fire in regards to the movements required to make that piece of music. This then leads to the urge to move (Molnar-Szakacs & Overy, 2006).

As mentioned in the previous chapter, musical timing has the most direct relationship to motion, as rhythm processing activates areas of the brain commonly associated with movement. Foot tapping and head nodding tend to follow the beat, not the melody of the music. When fMRI scans were taken of participants while they tapped an even, regular rhythm, the left premotor area and right cerebellum showed the most activation. On the other hand, when they were asked to tap a more complex rhythm, the right premotor area was activated, as well as bilateral areas in the cerebellum (Popescu, Otsuka, & Ioannides, 2004).

Pianists show activation of motor areas in the brain when listening to a familiar piece of music, even without any actual movement on their part. This involuntary activation was evidenced in a study by Haueisen and Knosche (2001) in which experienced pianists were scanned by fMRI as they listened to a well-practiced piece of music. EMGs of hand muscles were also recorded in order to exclude data in which they unintentionally made actual movements. They found that the music did indeed evoke activity in the left primary motor cortex, especially in areas known to be associated with the hand, even in the absence of actual movement. Furthermore, using the brain surface current density method, the experimenters were able to determine when areas associated with either the thumb or the pinky finger were more activated at certain times. In comparing this with the music score, it was revealed that the activity correlated with when a certain note would usually be played with the respective fingers. Only the thumb and pinky were chosen to be looked at because they are the furthest apart and thus clearest to differentiate.

In the case of movement and music, the effect is not a one-way street. Movement may also affect music perception, or at least preference. Phillips-Silver and Trainor (2005) found that babies who were bounced to a particular rhythm later listened longer to that same rhythm than to a different one, indicating greater interest or preference. The same experimenters then discovered that this effect occurs in adults as well. Participants were trained to bend their knees to either a 2/4 march-like or 3/4 waltz-like rhythm while listening to a piece of music. This music was identical for the two groups. Later, when presented with both a march-like and a waltz-like piece and asked to determine which one is more similar to the original piece, participants were much more likely to choose the one with the same rhythm that they had to bounce their knees to earlier (Phillips-Silver & Trainor, 2007).

The deep relationship between music and movement holds great implications for the use of music therapy with patients with motor dysfunctions. For example, while listening to stimulating music, patients with Parkinson's disease experienced a short term effect of enhanced motor coordination. They were able to walk with a steadier gait than before, taking longer, faster strides. Fine motor coordination of the hands and fingers also improved during this time. More research has yet to be conducted on what aspects of the music produce peak improvement (Bernatzky, Bernatzky, Hesse, Staffen, & Ladurner, 2004).

While music therapy may never become the sole treatment for recovery of motor skills, it has become increasingly evident that it can have a synergistic effect with conventional physical therapy. A study conducted with stroke patients revealed that when music was incorporated into the motor training sessions, improvements in motor skills, especially fine motor skills, were significantly greater than exclusively conventional therapy. For three weeks, patients learned to play simple melodies on an electric piano. In that time, they already showed significant improvement on a motor skills test, whereas the group that was undergoing only conventional therapy showed no improvement. This difference may be attributed to better mood and increased motivation to learn this new skill of playing piano. Also, the patients are able to receive immediate feedback and reinforcement as they play a tune (Schneider, Munte, Rodriguez-Fornells, Sailer, & Altenmuller, 2010). In any case, this shows the impact music can have on the healing process.

Conclusion

Though some may say that it is only “auditory cheesecake” (Pinker, 1997), it cannot be denied that music has a very tangible effect on the brain, as evidenced by the differences found between the brains of musicians and non-musicians. While music psychology has experienced an increase in attention and study, the entire range of mechanisms and effects of music on cognition is far from understood. Further research into the use of music therapy may shed light on new treatments to be used for various conditions, taking advantage of the vast amount of overlap music has with other processes in the brain. Music is already an integral part of our culture in itself, but now it holds implications for other aspects of our daily lives. Our brains are constantly being affected by the music around us, from movie soundtracks to radio hits blasting from car speakers to tinkling elevator tunes.

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