Mind, Muscle and Music

Physiological Clues to Better Teaching
by Frank R. Wilson, M.D.

The relationship between medicine and music is an ancient one: Apollo, the Greek god of light, was also the god of music and healing, and his son Asclepius was the god of medicine. In the temples of Asclepius, music was used to restore health when physical and mental harmony were disturbed. Music therapy has continued to be employed in medicine up to the present time, specifically in the treatment of stroke victims, psychiatric patients and children with learning disorders or retardation. It has also been tried in the treatment of epilepsy.

In the middle ages, there was widespread use of music to treat a variety of symptoms thought to be caused by the bite of the tarantula. The accompanying dance, the tarantella, has remained popular to this day. Philosophers in the 18th century considered that muscle fibers in the body could be either consonant or dissonant and that music, working through the emotions, could retune muscles that were disordered.

By the middle of the 19th century, when Neurology as a clinical branch of medicine had come into being, philosophical speculations about the brain gave way to scientific study as physicians began to examine the brains of their patients after death. A French physician, Paul Broca, made the observation that a small area of the frontal lobe of the brain on the left side had been damaged in a patient who had lost the power of speech. When other patients with the same trouble were found to have damage in precisely the same area of the brain, the foundation was laid for the establishment of a science of brain function. Man's curiosity about his own brain is insatiable and a large number of neurologists, psychiatrists, neurosurgeons, physiologists and psychologists now devote their careers to this search for a clearer understanding of the relationship between brain activity and human behavior.

The focus of medicine is heavily in the direction of abnormality. Consequently, written reports in the medical literature are inclined to deal with people who have had things go wrong. Thus, for example, a great deal has been written about the composer Ravel, who had a brain disease which impaired his powers of speech and certain of his musical abilities and Robert Schumann, whose tragic illness led to a suicide attempt and ultimately death in a mental institution.

But we physicians are not hopelessly morbid in our interests. As a neurologist, I have shared the fascination other have had in the extraordinary mental powers of some musicians—for example, the remarkable memory attributed to certain composers. Both Mozart and Mendelssohn were able to sit through lengthy choral or orchestral works and then produce from memory complete scores of the music they had heard. I have a favorite story about Mendelssohn, who is best known as a composer but who was also an accomplished pianist. The story is that he and Franz Liszt had attended a dinner party together, after which Liszt indulged his personal bent for improvisation by playing eight or nine variations on a Hungarian dance. When he had finished, he ceremoniously insisted that Mendelssohn take his turn at inventing for the audience. After considerable protest, because he was not an improviser, Mendelssohn sat down and played through, from start to finish, the same variations Liszt had just played, throwing in a few hilarious Lisztian flourishes for good measure.

Another source of interest for the person curious about unusual talent is the technical skill som performers have been noted for. Paganini, the best known of the violin virtuosi, finally became androit that he would deliberately break strings during a performance to show the audience that unlike ordinary musicians, he didn't need four strings on a violin. He occasionally would play works on a single string, in fact, which is the basis for another story about him. He charged enormous fees to perform, without apologies, because he felt entitled. One day he was recognized by a hackney driver who was taking him to a concert hall. The driver insisted on raising the fare, claiming he could not otherwise afford the cost of a ticket to a Paganini concert. Paganini laughed at him and refused to pay the higher fare saying, "I'll pay this much when you can drive your fiacre on one wheel."

Well, besides be interested in funny or "gee whiz" stories about musicians, I have become interested as a neurologist in the processes involved in the acquisition of musical skill. What is it about the human brain and muscular systems that permits the musician to develop the degree of control needed to produce music from an instrument? This turns out to be a fascinating study, with a number of important implications for music teachers and it is this subject I would like to review with you now.

I think we should begin by recalling the nature of the device the musician must learn to operate—his musical instrument. Reduced to its basic properties, any instrument is simply a resonant device which the musician must manipulate, or strike, or alter aerodynamically so as to produce some sort of sound. The sounds become music when they are formed into patterns of notes whose pitch, rhythm, dynamics and harmonic quality are controlled by the musician.

The instrument sets conditions on the sound and imposes specific physical demands on the musician—a point illustrated by the seemingly trivial difference between the harpsichord and piano. Although both are keyboard instruments, the harpsichord's plucking mechanism makes it impossible for the player to control its dynamics solely by finger pressure. Around 1709, a harpsichord make named Cristofori invented a mechanism with which the strings were struck rather than plucked, as a result of which the instrument could be played soft or loud according to the touch. Without fully realizing what he was doing Cristofori had created a machine whose subtle physical demands made it an ideal match for the human hand, and the roach was prepared for Chopin, Brahms, Beethoven, Schumann, Debussy and a host of other artists to reveal the expressive capacity of the human hand through a musical instrument.

Before looking at the brain and its inner workings, we need to spend a few moments with the business end of the system, the hand itself, and with the muscles that control its movements. Let's start with the muscle. Muscle is a specialized tissue in the body whose essential function is to change its length. When it is at rest it just sits there; when it is activated, or turned on, it gets shorter. Obviously, the muscle has to be attached to something at both ends to get anything done. In the body, one end of the muscle is usually attached to a bone, and the other end to a second bone, with a joint, or moving surface in between. When the muscle is put to work and it gets shorter, the angle between the two bones changes. There is another shorter muscle on the opposite side of the two bones; that's so that you can put things back the way they were when you started. Although this is the simplest possible arrangement, the principle holds true that bodily movement takes place because of a combination of muscular contractions and relaxations working in cooperation. Obviously, if all the muscles were contracting at one time the only thing that would happen is that you would shrink. In order for our movements to be effective, the brain, or the motor control system, must complete records of which muscles are doing what at every instant and regulate the degree of contraction and relaxation of every muscle participating in a particular move, or precise control would not occur.

Just how does the brain make a muscle shorten or contract? It sends a series of electrical pulses, like Morse code on a telegraph wire, down the spinal cord and then along a nerve attached to the muscle. When the coded message arrives at the end of the nerve, a substance is released which causes a very fast chemical reaction to take place in the muscle and the energy stored in the muscle goes to work causing it to pull together. As a general rule, the more pulses sent to the muscle, the hard the pull. I should point out here that we usually think of a muscle contraction as being a sustained pull against an opposing force, but in fact there is a great range and variety of possible muscle contraction involved in bodily movements and in some cases there are combinations of gentle and forceful and fast and slow contractions occurring simultaneously in the same individual.

In the hand small muscles are arranged with nerves, bones, ligaments and joints into what is an intricate and compact machine engineered to permit an unlimited variety of movements. When the musician is operating his instrument, the external movement visible to his audience may be quite simple, or quite complex, but underneath this fabulous machine is at work producing the final result. By comparison, the Maserati is just a toy. You can read the owner's manual and you know exactly what it can do. The hand, however, because it is operated by the human brain, will continually reshape, refine and improve its own performance depending on the owner's experience, training and goals. There is no manual for the human hand that will tell you its operating characteristics: if there were such a document it would probably contain the simple statement: "Ask the owner."

In calling attention to the special nature of highly skilled use of the hand, I think it is appropriate to comment on the striking similarities found in the situation confronting musicians and another group of specialists in motor system development call athletes. Despite the stereotyped and mutually uncomplimentary notions you might encounter in football locker rooms or recital halls, there is very little to distinguish the serious musician from the serious athlete, apart from this: the musician concentrates on perfecting control of the small muscles of the upper extremities (or the vocal apparatus), tends to be stationary while performing, and monitors his own output largely with their auditory system. By contrast, the athlete develops mainly his trunk, leg and upper arm muscles, has to change his location almost continuously in relation to other people and an inanimate moveable object whose location is of great interest to everyone, and they rely mostly on their visual system to monitor what is happening. In certain sports, most notably gymnastics and ice skating and of course in ballet, the essential similarity of these physical disciplines becomes apparent. Proficiency and success tend to come only after long periods of repetitious training in which country hours are spent on drills and exercises which condition muscles and establish patterns and increasingly complex sequences of movements. These must be learned so well that they can be confidently and smoothly executed whenever needed, automatically. When the necessary moves have been mastered, the athlete or performer moves to start the summit experience—live performance—during which everything must be done flawlessly if the effort is to succeed. During performance, the athlete confronts a live competitor whom he must out-perform if he is to win. The musician confronts the unseen competitor, in the form of another musician who is remembered by the audience as having set a standard for the music being presented. The athlete in competition knows at the end of the contest, whether they have won or lost, but the musician may have to wait until he reads the reviews in the paper the next day.

There probably is one difference between the small muscle and the large muscle athletes that really does count. This has to do with the effect of age. For the most part, musicians can look forward to continued maturation and refinement of the skills well beyond the age at which even the most durable football or tennis player has retired to the sidelines. Rubinstein, for example, claimed that he really did not begin to play as he wanted to play until he was nearly eighty. Still, as the horn players say, you do have to keep your chops in shape!

We now come to the brain. It is divided into two halves, called hemispheres and they are nearly mirror images of one another. In general, the right half of the brain controls the muscles on the left side of the body and the left half of the brain controls the muscles on the right side of the body. The back part of the brain, called the occipital cortex, received information from the eyes; the side part, which looks like the thumb of a boxer's glove, is called the temporal cortex and it contains centers for receiving information from the ears. The temporal lobes of the brain are note quite the same on the two sides because for the majority of people the left temporal lobe has become specialized to regulate language function—to control speech and writing. There is a tendency to refer to the left half of the brain as the "literate" half, or the dominant hemisphere; the right side, by contrast, seems to have a greater capacity for non-verbal skills such as recognizing visual patterns (this is what accounts for the ability to recognize faces, for example) and also for responding to the music characteristics of sound.

Crossing from side to side, approximately in the middle of the brain, is an infolding of the called the central sulcus. A special feature of this region of the brain is that cells which directly activate muscles are lined up just in front of the infolding and cells which receive information about muscles and joint position are lined up just behind the fold. This means that the part of the brain that has final control of the muscle movement will know very quickly whether the intended movement was completed correctly. This area of the brain is one of the few places where you can find a sort of map of the body. Some years ago, a team of neurosurgeons in Montreal, headed by Dr. Wilder Penfield, made recordings showing which specific muscles moved when a very weak electric charge was released over this part of the brain, which we call the "motor strip". What the map shows is extremely interesting when consider what musicians do. It shows that this very important part of the brain's motor control system gives special priority to the small muscles of the body. An anthropologist looking at this map wouldn't giggle at the priorities; he'd say that this is the brain of an animal for whom the muscles of the hand, throat and mouth have become extremely important.

Before going into any greater detail about the way the brain is organized, I think we need to look a little more closely at the method it uses for sending messages around. At the heart of the control system is a very small cell called a neuron. When you look at neurons under a microscope, you find there are a number of sizes and shapes. They all have a center called the cell body and extensions that look like wires that connect them to other neurons.

What is so special about neurons is that they can develop an electric charge and send that charge along one of those little wires (called an axon) to another neuron. When the charge, or impulse, gets to its destination, it will try to do one of two things: either make that cell fire its message off somewhere else, or block that cell from firing. It's almost as though this is a system of traffic lights: at the end of each one of these wires, or axons, there is either a red light or a green light that can be turned off and on. How much effect it has seems to depend on how fast it blinks.

This sounds like a tidy system until you discover that each neuron may get information from thousands of other neurons before deciding whether or not to send its own message, and it goes through this process anywhere from a few to several hundred times each second. When you consider that there are billions of these cells in the brain, each sampling the opinion of thousands of other neurons as often as several hundred times each seconds, you begin to sense the enormous complexity of this system. Another point worth making is that we start out in life with all the neurons we're ever going to have. What changes as we mature is that the connections between cells become more numerous and complex. Both biologic growth and experience are probably involved in determining how many and what kinds of connections are made in the brain as we mature.

Inside the brain there is another area we need to know about. This is a group of structures call the basal ganglia, which are known to have a great deal to do with regulating the cooperative effort of groups of muscles, especially in relation to body posture. To see why this is important, hold your arm out to one side and move your fingers as a violinist might to control the pitch of the violin strings, or a wind player to operate the instrument's valves. Now, not only are there muscles moving your fingers, but another group of muscles is holding your upper arm in a fixed posture, to stabilize the hand. If you were also standing, or walking, or marching, it would still be necessary to control the muscles involved in these other jobs without disturbing what was taking place between the hand and the instrument being played. The basal ganglia seem to be most important in controlling body posture and positioning our arms so that our hands can be used most effectively.

Underneath the brain is a very large and important component of the control system called the cerebellum. Although we are still not completely certain how it works, it seems to be true that the cerebellum works with the motor strip of the brain in regulating the smoothness and the timing of muscular contractions—obviously two qualities extremely important for musicians. It is particularly interesting that in humans nearly ninety percent of the cerebellum assists in regulation of the movements of the arms, hands and fingers.

In order for us to see why it should be necessary to have a very large section of the brain set aside just for assisting with smoothness and timing of muscle contractions, we have to stand back a bit and consider how the system works as a whole. When brain scientists first began working out the details of the motor control system, they reasoned that any movement had to begin with an idea, or the intention to move the body, or a part of the body, in a particular way. The brain, through the motor strip, would then send a series of coded messages through the spinal cord to the nerves connected to particular muscles. This would cause a movement to begin. The eyes, the nerves in the skin, muscles and joints would begin reporting back to the brain immediately how things were going, and adjustments would be made along the way as necessary to complete the move as intended.

It turns out that this scheme is correct, but incomplete. It doesn't explain how the body brings about movement of the kind required to control a musical instrument during fast passages, because there simply isn't time to get information back and forth in the nervous system in order to make corrections if the move isn't exactly on target. So there has to be another way to explain how the brain manages to keep these very fast moves accurate.

The first important clue to understanding these movements was provided by a physiologist named Richer over 110 years ago. In 1895 he took photographs of the thigh muscle during a kicking motion. When he studied these films, he noticed that the muscles were not contracting, or pulling, during the entire course of the movement. The move starts with a single burst of activity in the muscles, which launch the limbs upward. The muscles then relax, while the limb coasts through the rest of the move. Because of the obvious similarity to the way a bullet is fired from a gun, this has been called a "ballistic" move. It is now recognized that all fast movements of the body, including most of the movements used by musicians in fast passages, are of this type. In considering these fast, or ballistic, movements, it is important to understand that before the move begins, the precise details of all control signals must have been worked out in advance. Since there is no chance to correct mistakes after the move has begun, everything has to be absolutely right from the beginning.

It is now believed that the cerebellum assumes the enormous responsibility of regulating the advance programming of command signals to muscles when they must operate in long sequences with precision control, as is the case in musical performance.

There has been a great deal of speculation among physiologists about the exact way the cerebellum works together with the motor strip to coordinate fine mote activity. The most current thinking is that we begin to learn how to make complicated moves rather laboriously—working out the details step-by-step, making corrections when we observe our own mistakes, and consciously and deliberately establishing patterns of movements (sometimes coaching ourselves verbally as we go along) which eventually become less tentative, and finally become smooth and sure. What is happening during this process is that the cerebellum is watching what is happening and keeping track of successes. The time will come when the main motor control center, the motor strip, will say in effect "now I've got it," and will turn the job over to the cerebellum. In the case of musical practice, when the movements have been practiced in such a way that they are completed correctly virtually all the time, the brain shifts to a ballistic strategy. It is as if the conscious mind is saying, "I'm tired or slaving over the details; now let the cerebellum do it. I want to stand back and watch!" And the conscious attention of the musician shifts from the mechanical details of performance to the esthetics. As it turns out, this is a good thing because the cerebellum may have to take orders from the conscious brain, but it is infinitely better at running the muscular system when speed and smoothness are essential. If you don't believe that's true, just ask any musician what happens during a performance when he starts thinking about the details of what he is doing physically. When the conscious brain steps in and tries to take over, everything slows down, tone control becomes erratic, timing irregular and notes tend to appear out of sequence. The musician may become intensely aware that his hands are shaky, perhaps cold and moist and the muscles slow and stiff. That is not his imagination—both the smoothness of the control system and the responsiveness of the muscles are different when the conscious brain over-rides the cerebellum.

I think it would be useful here to quote the Nobel Laureate Physiologist Sir John Eccles, from a paper of this subject which was published in 1977.

> *"We can say that normally our most complex muscle movements are carried out subconsciously and with consummate skill. The more subconscious you are in a golf stroke, the better it is and the same with tennis, skating or any other skill. In all these performances we do not have any appreciation of the complexity of muscle contractions and joint movements. All that we are conscious of is a general directive given by what we may call our voluntary command system. All the finesse and skill seems naturally and automatically to flow from that. It is my thesis that the cerebellum is concerned in this enormously complex organization and control of movement and that throughout life, particularly in the earlier years, we are engaged in an incessant teaching program for the cerebellum. As a consequence, it can carry out all of these remarkable tasks that we set it to do in the whole repertoire of our skilled movements in games, in techniques, in musical performance, in speech, dance and so on."* [1]

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[1] Eccles, J.C. An Instruction—Selection Theory of Learning in the Cerebellar Cortex, *Brain Research* 127: 327-352 (1977).

So far we have seen that muscles are arranged in groups along with bones and joints and that a great variety of movements are possible because of the anatomic arrangement of these structures. We have seen that the muscles contract because electrical impulses travel through the nerves that connect muscles to the spinal cord. In the brain itself there is a blending of messages coming from the eyes, ears, the skin, muscles and joints. The basal ganglia and the cerebellum cooperate with the motor strip to make decisions about which muscles should contract in what order. The command signals also have to specify how much the muscle must contract, how rapidly, with what force and for what length of time. Simultaneously the brain must relax those muscles which would offer resistance to the desired move if they were contracting.

I think you'll agree that's a tall order. But it's not all, mostly with what we have called ballistic movements. You will recall that with this type of movement the instructions have to be worked out in advance, because there was not time to make corrections. Although this sort of advance programming works very effectively, it has one drawback. Steinways are not the same as Baldwins and a key will occasionally stick on the best piano. In other words, we live in a changing world and the amount of muscular contraction required to accomplish a specific task may vary considerably depending on the circumstances to which the job is carried out. Furthermore, the mechanical properties of the muscle itself may change for a variety of reasons. For example, when the hands are cold the muscles become mechanically stiff and do not contract as quickly as when they are warm. If you don't believe that, ask anyone in a marching band who does halftime shows for night-time football game, or a pianist who performs outdoors on a cold night. No matter how carefully the signals have been worked out in advance, it's no good if the instruments doesn't behave as it is supposed to, or the muscles are not responding normally; performance is not going to be quite the same.

Astonishingly, even this sort of problem has been provided for. It is far too technical to explain in detail here, but each muscle contains a minute sensing system, called a muscle spindle, which is capable of making very small last second adjustments in the responsiveness of the muscle to signals sent from the brain, according to the conditions in the muscle at the time the control signal actually arrives, in a very real sense, the spindle systems works exactly as Neil Armstrong's small computer aboard the Eagles worked during the landing on the moon. In the final few seconds of the landing, when the lag in radio transmission time made it impossible for the computers on Earth to solve the final landing problems, this small computer on board the lunar lander was able to handle the job. The same thing happens when a finger playing fast passages hits a key with unexpected resistance—the pressure necessary to correct the touch will be fine-tuned by the spindle through a final adjustment in the muscle force moving the finger to its target.

Having been through all this I think it would be well to suggest how much we take for granted in finished musical performance by showing this single page from Brahms' Second Piano Concerto. Every one of those black dots on the page is in fact a set of instructions to a whole group of muscles in the pianist's arms and hands to press particular keys on the instrument in specified groups and sequences at a particular rate and with individual variations in force and duration. At performance speed, it takes about fifty seconds to get from the top left hand side to the lower right side. And, incidentally, while all this is going on the pianist is also obliged to pay attention to the behavior of a sizeable orchestra and someone waving a stick just to his left. How many times will the artist have played this piece of music before a critic will nod in appreciation and perhaps bestow the modest compliment, "not bad!"

Now that I have shared with you some rudiments of my specialty, I would like to share with you some preliminary conclusions I have reached about yours—music education. First, it seems to me that a close examination of the "tried and true" principles of music teaching shows them to be compatible with what we are now discovering to be the operating characteristics of the human brain and neuromuscular system. Whether or not they actually understand the underlying physiologic or psychologic principles, good teachers have found didactic techniques which optimize the natural learning system built into the human brain. And I can't help believing that a wider appreciation of the operating characteristics of the nervous system will help make teaching systematically better.

Let me give you two small examples of what I mean. Slow practice is the key to rapid technical progress. The cerebellum is a non-judgement part of the brain it assumes that any repetitive activity … is being repeated because the conscious mind is trying to make it automatic. The cerebellum will be just as efficient an automatizer of incorrect sequences of timing as of those that are correct. When practicing takes place at a pace too fast for accurate playing there is very little chance for the material to be mastered and reliable confident performance simply will not occur. On the other hand, it is probably true that practice for speed is seldom necessary. The cerebellum can supply all the speed wanted if patterning is correct during practice.

A second teaching principle which stands on a sound footing has to do with mental preparation. By this I am referring to those aspects of study or preparation which take place away from the instrument or which are used to make rehearsal simulate live performance conditions. Students of the Lhevinne's at Julliard were told to practice their music away from the piano and my association with the teaching staff of the Concord Blue Devils Drum and Bugle Corps made me aware that they use similar techniques in preparation for competition. Serious athletes are now being trained to do the same thing. A technique referred to as Visual Motor Behavioral Rehearsal (Richard Suinn) has been shown to help skiers, runners, weight lifters and others to improve their limits and to discover small technical errors that adversely affect performance. It seems very likely that these techniques work not simply because they help performers cope with stress and anxiety, but because they facilitate programming of the cerebellum.

Third, I think it useful to acknowledge that there are three distinct groups of music students, each with special opportunities and problems, each needing a special approach. The first of these groups comprises children beginning in music. They are being exposed to a rigorous, integrated physical and mental discipline possibly for the first time in their lives, and they will inevitably transfer both positive and negative experiences to subsequent structured learning situation they encounter. So music teachers have an opportunity (and I think responsibility) to provide the child with a model, or a set of protocols, for positive attitudes and strategies in their future education. The second group of students is made up of adults who approach music as a potential long term recreational interest. My suspicion is that many of these students set unrealistically low goals for themselves because they were brought up thinking that music and athletics were the special preserve of people who had unusual gifts or talents.

There are special challenges and opportunities in this group—the opportunities having to do with the incredible lift adults get when they are given a glimpse of their own potential. If you doubt the truth of this notion, you haven't noticed all the people jogging in your neighborhood lately. The third group consists of both adults and children who have a genuine special aptitude for music. These are the people who progress technically at an unusually rapid pace, or whose personal sensitivity and ability to communicate musically mark them as potentially successful performers. They obviously have an extra set of requirements in their training since survival in the competitive musical world demands a carefully developed long term plan and unusual commitment from their teachers. They may also need special personal attention to reduce the risk of early social isolation.

I would like to conclude with this reflection about music and musicians. Man, in all the kingdom, is specially physically because of the exceptional control he has over his hands and because of his powers of communication. Beyond the purely physical realm, we all have dreams and a quality that defies definition, which we call spirit. Musicians have created a discipline and a world in which these unique human qualities can flourish without restraint. It is a world in which the challenges can never be exhausted, because a single individual can never complete master a music instrument, or all the music written for it. So the musician can dreams and reach as far as he or she cares too.

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_ Mind, Muscle and Music. Physioiogicai Cities to Better Teaching by Frank R. Wiison, MD. The relationship between medi...Â Music and the Mind. Dr Lauren Stewart. Dr Daniel MÃ¼llensiefen. (Music, Mind and Brain group,. Goldsmiths, University of London) Storr - Music and the Mind. Music. And the mind. Mind,Muscle,and MusicbyFrankR.Wilson,M.D. Dr. Wilson is assistant clinical professor of neurology, University of California School of Medicine, San Francisco. This article is a typescript of a presentation given at the American Music conferences Board of Directors meeting. automobile is just a toy in comparison to the hand. You can read the owners manual and you will know exactly what the car can do.