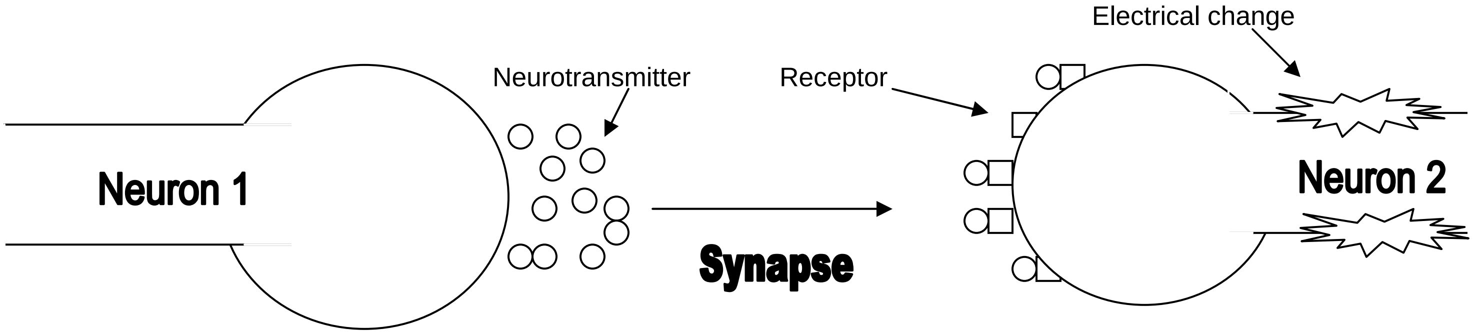
# What Musicians Can Learn about Practicing from Current Brain Research

**By Molly Gebrian**

As musicians, we spend a large portion of our lives practicing our instruments and learning how to do very complicated things with our hands, arms, mouths, and feet. Neuroscientists are becoming very interested in us because the complexity of what we do and the practicing regimen we follow is very unique, so they can learn a lot about how the brain works by studying us. But we can also learn a lot from what they have found in their experiments on both musicians and non-musicians (or even rats!). By knowing how the brain works, we can find ways to make our practicing more efficient and effective, as well as what to do when we have too much music and not enough time to learn it. After first explaining what happens when you learn something new and how our brains are different from a non-musician's brain, surprising discoveries about the importance of sleep and mental practicing will be discussed.

## Some Basic Information on Brains

Our brains are composed of hundreds of thousands of neurons that communicate with each other to makes us do (or not do) something. The way neurons talk to each other is largely through synapses, which are tiny gaps between individual neurons. Basically, when one neuron wants to send a message to another one, it releases neurotransmitter (a chemical signal) into the synapse. Receptors on the other neuron pick up this chemical signal, which causes an electrical change in that neuron so it can pass on the message (or stop the message dead in its tracks).



Our brains are also made up of different areas whose neurons are specialized for one type of information. Two very important areas for learning and executing motor skills are the primary motor cortex and the cerebellum. The primary motor cortex is activated whenever you move voluntarily, whether it's a skilled action like playing the Tchaikovsky violin concerto, or a not-so-skilled action like dragging yourself out of bed in the morning. The cerebellum is important for coordinating actions and it also serves as an error detector. As you learn a new piece of music or a new playing technique (such as circular breathing), the synapses in these two brain areas change. In the motor cortex, the synapses that relay the information on how to play something correctly get strengthened, while those that send erroneous or irrelevant messages get weakened. To understand how this works, think of a garden hose that someone has punched a bunch of big holes in. Some of the water will go through the hose and out the nozzle, but a lot of it will run out of the holes. This is what your brain is like when you first start learning something new: the water running out the holes is all the wrong and irrelevant messages your brain is sending to your fingers. But when you plug up the holes in the hose, all of the water goes out the nozzle; in your brain, this is analogous to the synapses relaying the right messages being much stronger than those sending the wrong message. The brain accomplishes this through changing the number of receptors on the receiving neuron and/or the amount of neurotransmitter released by the sending neuron. The more receptors or neurotransmitter, the more likely the next neuron will get the message and pass it on, or vice versa.

In the cerebellum, something different happens. Cerebellar synapses are designed to detect movement errors using three different messengers: Purkinje cells (a special name for neurons in the cerebellum), parallel fibers, and climbing fibers. When a parallel fiber and a climbing fiber both send messages that repeatedly arrive at a Purkinje cell simultaneously, this indicates an error in movement execution. The result is that the Purkinje cell decreases the number of receptors that receive messages from the parallel fiber (because these are erroneous messages), restructuring the synapse in a way that minimizes errors. Without the message from the climbing fiber, the Purkinje cell would pass on the message from the parallel fiber, sort of like when you play “Telephone” and the wrong message comes out at the end. The message from the climbing fiber is like a phone call coming in on the other line just in time to tell you not to pass on the message from the parallel fiber.

So what all of this means is that every time you practice or learn something new, you’re actually changing your brain. If you learn something wrong, to use the hose analogy, it would be as if you made one of the holes in the hose so big that most of the water was going out of the hole, rather than the nozzle. So in order to correct the mistake, you have to first close the hole before you can get the water going in the right direction. In brain terms, you have to strengthen one group of synapses while *also* weakening another, rather than just strengthening a message. That’s twice as much work! It’s obvious that it pays to learn something right the first time, but reinforcing mistakes by just playing through without addressing problems is just as bad as learning it wrong in the first place. The more times you do something wrong, whether or nor you know it’s not right, the stronger you make those messages and the weaker the correct message becomes.

These changes are just the beginning, and since they occur on such a microscopic level, they are relatively easily undone. As you continue learning something, not only do the synapses involved in what you’re doing get strengthened, but new synapses are formed between neurons that weren’t connected before. This takes about a week to happen. At the same time as this is happening, groups of neurons (called neuronal ensembles) become more and more streamlined in their behavior. At first, as an ensemble, they send a lot of random messages and do strange things (neuroscientists call this “noise”). It’s a lot like an orchestra rehearsing a newly composed piece for the first time – there are a lot of individual mistakes, and it sort of sounds like the piece, but not really. As the neuronal ensemble gets better at working together, just like an orchestra, individual mistake may still happen here and there, but what comes out is much more cohesive and intelligible. In fact, if a neuroscientist looks at the activity of a refined neuronal ensemble, she can predict pretty accurately what movement will result before it even happens (Laubach et.al., 2000).

## Musicians v. Non-Musicians

Most of these studies on changes in neuronal activity only last a week or two at the most. It's not logistically feasible to have people coming into the lab for weeks or months on end to have their brains looked at, so some neuroscientists think musicians are an ideal population to find out what happens when you practice a motor task repeatedly for years and years. One of the most obvious changes is that, especially in string players and keyboard players, the portion of the motor cortex devoted to the fingers is *much* bigger. At the same time, the neurons in this cortical network are much more efficient. These two things happen because, presumably, over time, lots and lots of neurons get connected by synapses that wouldn't normally be connected, and the neuronal ensembles that result from these new connections get much better at what they do because they get to practice everyday. A musician's brain is so efficient at things like scales and other simple patterns that are automatic to us that entire brain areas don't get engaged in a musician's brain that are very active in a non-musician or amateur's brain. Two of these areas are the pre-motor cortex and the supplementary motor area. These are involved in planning complex movements and coordinating timing, but when musicians play scales or simple rhythm patterns, these areas barely do anything at all. The only other complex motor tasks that show this lack of activation are overlearned skills such as writing. What this means is that our basic set of tools and skills as musicians are so automatic that our brain barely has to do anything to execute them. But what this also means is that when you learn a new skill, especially something like the extended techniques used in contemporary music, there is a necessary period of days or weeks that your brain needs to rewire itself and for new neuronal ensembles and circuits to form.

The other amazing thing that happens in musicians' brains as new synapses form is that our motor cortex gets connected to our auditory cortex. Think about how strange that is. For most people, what they hear doesn't cause them to have automatic associations with movement, and moving certainly doesn't cause them to hear things in their heads. But if a musician listens to a recording of a piece they know and play well, not only does their auditory cortex light up on a brain scan (called an fMRI), but the portion of their motor cortex devoted to their fingers does too. Furthermore, neuroscientists have shown that the motor cortex isn't just lighting up as a whole unit – the areas that control the individual fingers light up in the order and timing they would to execute the correct fingering (Bangert and Altenmuller, 2003). (When these kinds of studies are done, measures are taken to make sure the musicians aren't actually moving their fingers.) The opposite happens too: if you tell a pianist to play a piece silently on a tabletop, their auditory cortex lights up as it would if they were actually playing (and hearing) the piece. These finding just serve to highlight how important it is to always keep singing in your head as you play and to be really clear about what you want to hear. It affects what comes out of your fingers and arms and mouth, not in some strange metaphysical way, but because your auditory cortex is *connected* to your motor cortex. If you aren't clear on what you want to hear, the auditory cortex has a very limited message to send to your fingers.

## The Role of Sleep in Learning

If all of these changes have to take place in your brain before you can play something fluidly and competently, is there anything you can do to speed up the process? The answer depends on how much you want to speed it up, because it turns out that a very important component of motor (and auditory) learning is sleep. Matthew Walker and his colleagues here in Boston have done a number of experiments on motor learning during sleep (Walker, et al, 2002, 2003, 2005). Their basic experimental paradigm involves three groups of people. The first group gets taught a finger tapping task (4-1-2-3-4 where 4 is the pinky finger and 1 is the index finger) at 10am, which they then practice and are tested on multiple times throughout the day. The second group gets taught and practices the same task at 10am, but they don't get tested on it again until 10pm. Then, they are sent home to sleep and tested the next morning at 10am. The final group is trained on the task at 10pm and has their first retest at 10am the next morning. What they found is astonishing. The first group gets gradually better throughout the day at a rate that you can predict. The second group shows the same linear increase during the day, but when you test them the next morning, there is a huge jump in their performance (measured by faster sequence execution without loss of accuracy). The same goes for the group that was trained at 10pm and then retested for the first time the next day – they got *much* better overnight, even though all they were doing was sleeping! (Everyone was instructed not to practice when they went home.) Even more surprising, there is absolutely no relationship between how much better a person got during daytime practicing and how much better they got after sleeping.

How is this possible and what does it mean? Researchers have concluded that the last result means that practice-dependent learning and sleep-dependent learning are independent processes. This doesn't mean, of course, that if you don't practice, you'll get better just by sleeping. But it does mean that you shouldn't underestimate the importance of sleep in learning, especially when it's brand new. Knowing this can help you use your practice time much more efficiently. Say, for instance, you have a lot of music to learn for orchestra and not a lot of time to practice it. You will be *much* better off practicing your orchestra music for 15 minutes a day until the concert, rather than "wood-shedding" the day before the concert. Why? Because you'll have all those nights of sleep for your brain to process the new music. So ultimately, you'll be able to play the music better with fewer hours of actual practice.

When you're learning a new piece that you have ample time to practice, keeping the role of sleep in mind can also help you practice more efficiently. The primary thing that improved with sleep for the people in these studies was speed (at least that's what the experimenters were measuring). Since the amount of daytime improvement and learning after sleep aren't related, spending hours and hours on a really tricky fast passage on the first few days of practicing isn't as efficient as getting it fluent at a slower tempo and then just leaving it until the next day. The next day, not only will you be able to play it faster, but you'll spend much less time getting it to a faster tempo than you would've the day before.

No one probably would've guessed that just sleeping would make you better at playing your instrument, but researchers have shown that it does, over and over again. The effects of sleep are really hard to study, but in this case, researchers think they know how it works. Sleep is divided into two broad types: REM sleep and non-REM sleep (or NREM sleep). REM sleep is when you have dreams. During what is called Stage 2 NREM sleep, however, electrical brain events occur that are called sleep spindles. During a sleep spindle, there is a huge burst of electrical activity in a population of neurons that causes massive amounts of calcium to enter those cells. Calcium is what causes all the changes discussed earlier, from strengthening and weakening synapses, to making new synapses, to synchronizing the firing of neuronal ensembles. Sleep spindles reach peak intensity late in the night and have been shown to increase following motor learning during the day. The study by Matthew Walker and his colleagues at Harvard Medical School also found that the percentage of improvement after sleeping strongly correlated with the amount of time the person spent in Stage 2 NREM sleep in the final quarter of the night, precisely when sleep spindle activity is at its peak. This finding also highlights the importance of getting enough sleep while you're learning something new. A full night of sleep was defined as 8 hours in this study, and it was only the last two hours that were really important for learning. Getting a full night's sleep may be even more important that we realize.

## Mental Practice

Another surprising finding is how much you can accomplish by practicing mentally. Alvaro Pascual-Leone and his colleagues at the NIH (National Institutes of Health) did a study in which they looked at the effects of mental practicing, resulting in very exciting conclusions. In their study, they had two groups of people (all non-musicians) learn to play a five-note scale (do-re-mi-fa-sol-fa-mi-re-do or C-D-E-F-G-F-E-D-C) on the piano in 16th notes at quarter note equals 60 (or four notes per second). Both groups practiced for two hours a day for five days (a total of 10 hours), but one group was only allowed to practice mentally. They were not even allowed to move their fingers. Everyday at the end of the practice session, everyone was tested to see how well they could play the scale. This is the only time the mental practice group got to actually play the keyboard. As easy as this would be for any trained musician, regardless of instrument, it is quite difficult for people with no musical training. At the end of the first day of practicing, both groups had a very hard time playing steadily and they would often play their fingers in the wrong order. After having practiced for five days, however, the group that got to practice on the piano everyday could play the scale perfectly. After five days, the group that only practiced mentally could play it at the same level as the physical practice group achieved after three days. The mental practice group was then allowed to practice at the keyboard for two hours, after which they could play it perfectly! This is amazing if you think about it. Nobody in the mental practice group had ever played piano before, but after only two hours of actual practicing preceded by mental practice, they could play a scale perfectly and steadily, something the physical practice group could only do after practicing for 10 hours!

The researchers also found something else in this study that is even more astounding. At the end of each day, in addition to testing how well they could play the scale, the researchers measured the size of everyone's motor cortex using a technology called transcranial magnetic stimulation (TMS). As you would expect, they found that in the group that practiced on the piano everyday, the portion of the motor cortex corresponding to the fingers progressively got larger. They also found, however, that the portion of the motor cortex corresponding to the fingers in the mental practice group got larger as well, to an almost identical extent. This means that not only did the mental group learn a totally new task just by thinking about doing it, they actually changed their brains!

This finding obviously has major implications for how we as musicians think about practicing.  The authors of this study concluded that

> Mental practicing may accelerate the acquisition of a new
> motor skill by providing a well-suited cognitive model of
> the demanded motor act in advance of any physical practice.
> [It] seems to place the subjects *at an advantage for further*
> *skill learning with minimal physical practice*.  The
> combination of mental and physical practice leads to *greater*
> *performance improvement than physical practice alone* (my emphasis).

Often we are faced with the problem of not being able to practice as much as we want or need to, either due to injury or because we don't have access to an instrument or a place to practice (i.e. during travel).  At these times, especially, practicing mentally could be considered essential.  As a supplement to normal physical practicing, mental practicing can help us improve much more quickly than we would if we only practiced on our instruments.  Remember also from the study discussed earlier that when a violinist plays "air violin," for instance, her auditory cortex will also be activated and that when a pianist listens to a recording of something he is working on and knows well, his motor cortex will be activated.  Listening, singing, and moving, as well as just *thinking* about our music away from our instruments will help us to improve.  Once we do actually play what we have practiced mentally, it will take far less time to get it to the level we want than if we had only practiced physically.  This isn't magic - it works because when you think about playing, you are actually changing your brain.

Our brains are changing all the time, especially when we do something on a daily basis as complicated and demanding as playing an instrument.  Hopefully, knowing this and knowing the ways in which our brains must change before we can play something successfully will help in organizing and planning practice time.  Just as important as this, however, is remembering what happens when we're not playing: the changes that occur during sleep, as well as the benefits of mental practice.  Practicing is an art, just as much as performing is, and practicing intelligently and in ways that derive the maximum benefit from our brains' natural abilities will only serve to enhance our artistry as musicians.