Neuroanatomy of a Kick

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Introduction

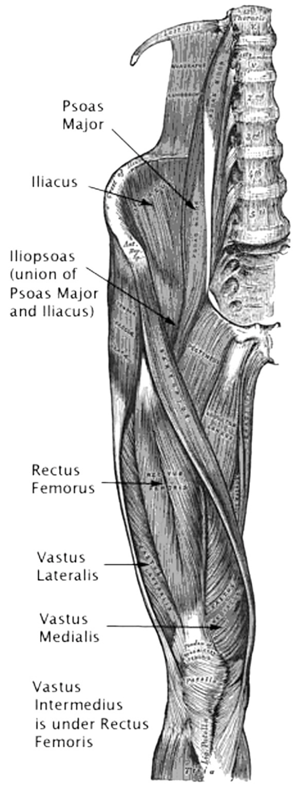
A kick is a staple fighting technique that is included in many martial arts. A kick may vary in appearance from a straightforward front kick to a complicated jump spin heel kick, but each is a composition of separate muscle movements ultimately coordinated by our brain. A kick may appear simple on execution, but is in reality immensely complicated on the neurological level. The brain is able to coordinate various components of any given movement without being actively aware of each component. Practice and repetition generates more connections in the brain and allows fine-tuning and controlled motion to take place with less thought. This paper examines the events that occur in the body and brain during execution of a kick, with particular attention to the neural processes involved in three distinct kicking situations: a beginner's kick, a veteran's kick, and a kick in a sparring situation.

The physical complexity of a movement has little bearing on the total number of neural processes involved in executing that movement. For this reason I have chosen to analyze one of the simplest kicks: the front snap kick. As it is a linear kick, the number of muscles involved when initiating the kick and stabilizing the body afterwards is kept to a minimum. According to Master Hee Il Cho, founder of the Action

International Martial Arts Association (AIMAA) and author of *The Complete Master's Kick*, the (right) front snap kick is executed from a fighting stance with the left foot forward. The balance is shifted onto the left leg while the right knee is brought up. The right leg is extended as the toes curl back and the ankle is locked forward. Following completion of the kick, the foot can either be placed down in front (resulting in right-foot-forward fighting stance) or re-cocked in preparation for another kick (from left-foot-forward fighting stance).[1] These are the conscious movements required to execute the kick; subconsciously, the body must balance itself by contracting and relaxing the correct muscles in the proper order so that a kick can be thrown without falling over. Fortunately, the brain takes care of most of the details. To fully appreciate the processing power of the brain, I will first discuss the pathways leading up to the brain including the spine, peripheral nerves, muscles, and the cellular activities of each of these tissues.

Gross Anatomy of a Kick

The front snap kick is a simple linear kick with little complexity; however, several different muscles are used to execute the kick. The process of execution of the front snap kick can be divided into three main segments: the chambering or raising of the knee, the extending of the leg, and retraction of the leg. The knee is raised primarily by the contraction of the iliopsoas, which is attached to the pelvic girdle, the lumbar vertebrae and the proximal part of the femur (see Figure 1).



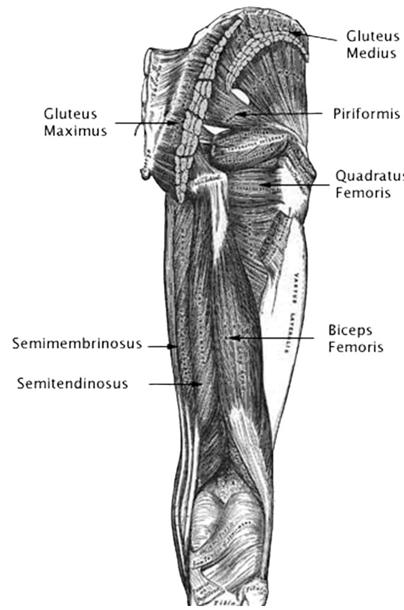
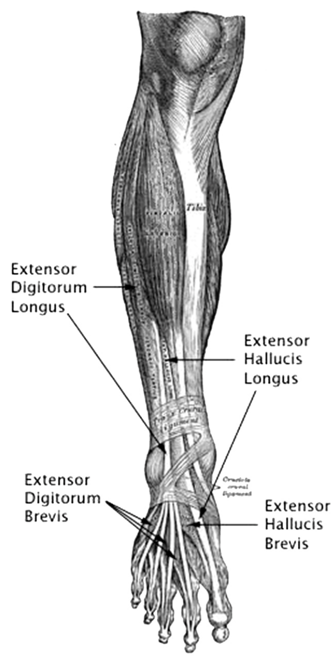


Figure 1: Musculature of the Upper Leg, front view (left).[2]

Figure 2: Musculature of the Upper Leg, rear view (right).[3]

At the same time, the gastrocnemius and soleus muscles, attached to the heel of the foot, the femur, and the tibia, contract to plantar flex the foot (see Figure 4). Extensor hallucis longus and brevis pull back the big toe while extensor digitorum longus and brevis pull back the rest of the toes (see Figure 3). Extension of the leg is achieved by contracting the rectus femoris and the three vastus muscles, which are attached to the hip, femur and the patella (see Figure 1). As the leg extends, lateral rotators (eight muscles total) attached to the femur and hip such as piriformis and quadratus femoris (see Figure 2), serve to keep the kick linear as the hips rotate naturally. After the kick is executed, the hamstrings (biceps femoris, semitendinous, and semimembranous) contract to rechamber the leg and the gluteus maximus and medius (see Figure 4) will extend the hip thus bringing the leg back into a ready position.[4] The muscles described above comprise only the primary subset of muscles actually used in executing the kick. Many more muscles are used for the proper placement of the arms and head, stabilization of each joint and for balance. These actions are secondary to the actual kick and most of them are subconscious or reflexive.



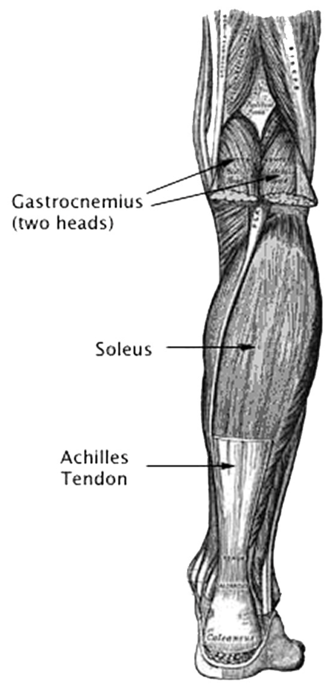


Figure 3 Musculature of the Lower Leg, front view (left).[5]
Figure 4 Musculature of the Lower Leg, rear view (right).[6]

Muscle and Nerve Physiology

In order for the body to execute a controlled movement, every cell in a muscle must contract simultaneously. To do this reliably, a muscle is divided into components that function in synchrony. The entire muscle is surrounded by a connective tissue layer called the epimysium and is divided into multiple fascicles, each of which is enclosed by its own perimysium. Each fascicle contains multiple cells or muscle fibers, and each fiber is encased by endomysium (see Figure 5). Each cell contains numerous myofibrils (*not shown*) that contain the paired proteins actin and myosin along with many other proteins in repeated units called sarcomeres. The intimate interaction of actin and myosin within each sarcomere is responsible for the lengthening and contracting of the entire muscle.[7]

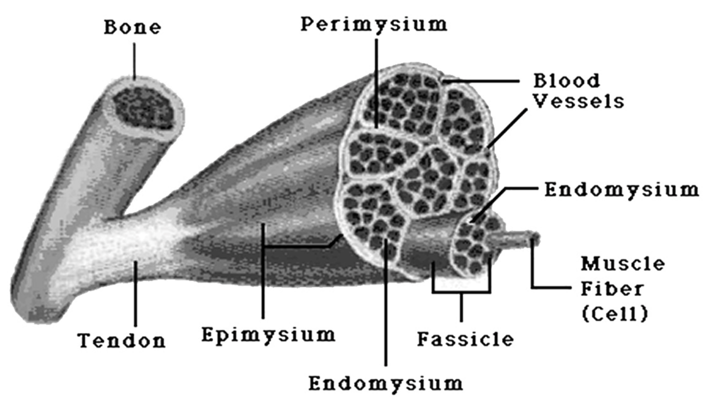


Figure 5: Cross-section of a representative muscle.[8]

Actin and myosin contraction is regulated by adenosine triphosphate (ATP), and by calcium ions (Ca^{2+}). One ATP molecule provides the energy for one myosin head to move forward one subunit of actin. In order for any functional movement to occur, millions of sarcomeres must contract requiring very large amounts of ATP. Normally muscles collect their energy aerobically (with oxygen), but when the muscle is under strenuous activity, it will tend to get its ATP anaerobically (without oxygen). This occurs because the blood cannot bring oxygen to the cell quickly enough. As a result, a lactic acid byproduct builds up causing pain that can inhibit muscle function until sufficient oxygen is conveyed to the cell and lactic acid levels decline.

Calcium ions are stored in the sarcoplasmic reticulum, a large sac inside the muscle cell that is sensitive to nerve firing. Actin and myosin interaction is normally inhibited, but upon exposure to Ca^{2+}, the interaction occurs and the muscle can contract. Calcium is released from the sarcoplasmic reticulum whenever an attached nerve ending fires. This union of the nervous and muscular system is the basis of controlling muscle contraction. Each muscle fiber is connected or innervated by a single nerve ending which branches off a larger nerve. The firing of the larger nerve subsequently causes all of the sarcomeres, muscle fibers, and the entire muscle to contract at the same time.[9]

The signals for muscles to contract are received from the brain and travel to the muscle via the spinal cord and peripheral nerves. For example, the nerve that innervates the iliopsoas is the femoral nerve, originating from spinal nerves L2-L4 of the lumbar spinal cord. The cell body of the motor neuron is found inside the spinal cord and it receives information from other nerves through synapses from the brain or other peripheral nerves which affect whether or not it will fire. Sensory neurons carrying information about pressure or pain will synapse directly on motor neurons as part of reflex action, allowing the necessary muscles to contract quickly when pain is felt, independent from specific input from the brain. At the same time, the same sensory neuron would send information to an inhibitory interneuron in the spinal cord, which would inhibit contraction in the antagonistic muscle. Another reflex involves special sensory organs called muscle spindles found within the muscle, which carry information about how long the muscle is and how much strain it is experiencing. If the muscle gets too long or the strain becomes too great, then the muscle will either contract or relax accordingly by reflex in order to protect itself. This can happen when a doctor uses the knee-jerk reflex to see if the quadriceps contract while the hamstrings simultaneously relax. The same reflex is activated to a greater degree when a leg gets hyperextented or feels pain from stretch. This can protect the muscle from serious damage. The last major input to a lower motor neuron originates from the brain as an upper motor neuron, which will be discussed later.

The Brain of the Beginner

Brain Inputs and Local Organization

Until this point, the physiology for the beginner, the veteran, and the person sparring has been essentially the same. However, as the brain increases its role, the pathways become increasingly more complicated and divergent. The brain control involved for the beginner is the simplest and is present for the veteran and in sparring application as well. The beginner learning the front snap kick for the first time will be slow and methodical, focusing on technique before considering application or style. He or she essentially controls the contraction of each muscle individually while consciously trying to maintain balance and body placement. As we will see later, the veteran does not have to be so methodical.

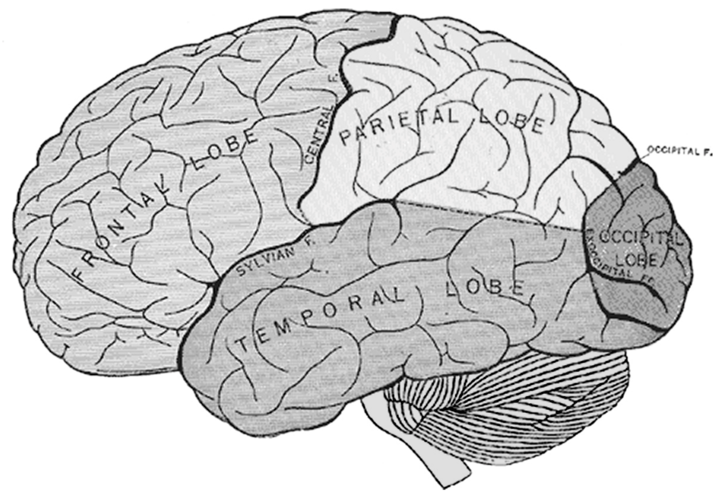


Figure 6: Major lobes of the brain.[10]

The command to initiate movement originates from the prefrontal cortex found in the anterior part of the frontal lobe (see Figure 6). This is the area of the brain where conscious thought occurs, and where the executive decisions for voluntary movement are made. The prefrontal cortex receives information from many areas of the brain in order to plan out which movements to make.[11] In a beginner, the main inputs will initially be auditory and visual. The student must first hear a description and then see the technique demonstrated before attempting it. Sound from the instructor's voice is first received by the student's ear, projected through the three small bones of the middle ear, and then received in the inner ear where the processed sound waves reach an organ called the cochlea. This organ resonates according to the frequency of the sound it receives and reports the information to the auditory cortex via the eighth cranial nerves.[12] The auditory cortex in the temporal lobe processes the information through various language centers of the brain and the interpreted information is sent to the prefrontal cortex. The instructions are then stored in short-term memory, to be recalled when the student executes the kick.

The student assesses visual input (of the instructor's demonstration) in a similar fashion. Light entering the eye is gathered and organized by the retina, which sends visual information to the visual cortex of the occipital lobe via the optic nerve and the visual tract. There is a part of the visual cortex that is responsible for detecting every aspect of what we see and recognize, including: color, edges, motion, even a happy face. Once the cortices compile an image together, the information is passed to the prefrontal cortex for conscious perception of the object. Visual information is also relayed to the cerebellum (see Figure 8) in order to maintain balance and body orientation. The typical beginner relies completely on visual input to organize his/her body in space; closing of the eyes will most likely lead to loss of balance during a kick.

Once the beginner knows what a front snap kick is and what it looks like, the prefrontal cortex then sends a signal to the basal ganglia instructing it to initiate movement. The basal ganglia is responsible for initiating anything controlled by the brain including thoughts, emotions, and most importantly: voluntary movement. The basal ganglia project to the thalamus, a central structure in the brain that relays information to all parts of the brain. The importance of the basal ganglia can be demonstrated in movement disorders such as Parkinson's or Huntington's diseases, which represent hypo and hyper kinetic movement disorders respectively.[13] The motor cortex is part of the frontal lobe and also receives information from the cerebellum regarding which muscles should contract to maintain balance. In turn, the cerebellum receives information from the prefrontal cortex and the peripheral nervous system which helps dictate muscle movements.[14]

Brain Outputs

Once the motor cortex has received all of the necessary information from the prefrontal cortex, the thalamus, and the cerebellum, then the appropriate motor neurons are fired. These upper motor neurons descend from the motor cortex, cross at the medulla, enter the spinal cord, and terminate in all spinal levels (see Figure 7) where lower motor neurons are awaiting the signal to contract or relax.[15] Once the appropriate lower motor neurons receive the signal to fire then the corresponding muscles will contract or relax and the kick will be executed. The front snap kick of the beginner will be uncoordinated and rough since the body and brain have not yet performed many front snap kicks. As the beginner practices the kick, new neural connections will be formed in tandem with all the previously mentioned pathways. As the beginner becomes a veteran, the kick becomes more familiar and it will be easier to properly execute the kick.

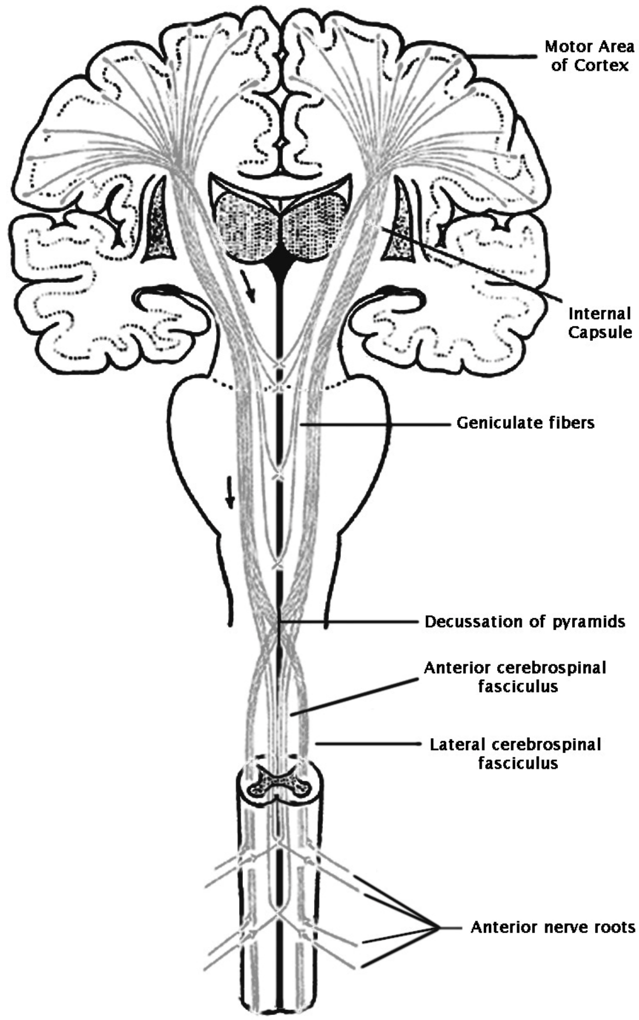


Figure 7: Descending fibers from the motor cortex to the spinal cord.[16]

The Brain of the Veteran

The source of struggle for the beginner arises for several reasons. First, because the beginner lacks a detailed knowledge of what the snap kick entails; the representation of this action stored in his or her memory is necessarily sparse compared to that of a martial arts veteran. Secondly, lack of experience in executing these kicks means that the cerebellum has not yet learned to coordinate and order the firing of appropriate motor neurons. The veteran will have detailed memories of the front snap kick so that auditory and visual instruction would be less necessary. Unlike the beginner, the veteran will be more familiar with his/her body orientation. This is partially due to increased connections in the parietal lobe (see Figure 6), which is responsible for determining where things are in space. The parietal lobe also sends information to the cerebellum which allows the veteran to close their eyes, execute the kick, and still maintain balance.

Once a veteran martial artist has decided to execute the kick, the same pathways are utilized from the basal ganglia to the motor cortex as in the beginner. A veteran martial artist will have more motor cortex inputs from the cerebellum allowing more precise timing and coordination of muscle contractions, which is also known as muscle memory. The cerebellum will also be able to use information from experience to control the body's balance while executing the kick through involuntary reflexes.[17]

In a Sparring Situation

In a sparring situation, the martial artist's brain receives and processes much more information than if he or she were just kicking in the air or against a bag. Assuming that the person sparring is a veteran martial artist, then he or she would have the memory of many kicks, strikes, and defenses running in his or her mind all at once. Auditory and visual input would again become important so that one can perceive the opponent in space, and gauge how to organize the body accordingly. In this situation, the prefrontal cortex also takes into account how the opponent is standing, their facial expression, and their overall demeanor. If the martial artist has worked with this opponent in the past, then memories of their fighting style or tendencies will also factor into the brain's decisions.

Autonomic Brain Functions

In a fighting situation, the brain activates the instinctual "fight or flight" or sympathetic autonomic system (this is opposed to the rest and recover instinct of the parasympathetic nervous system). Activation of the sympathetic nervous system is controlled by the hypothalamus (see Figure 8), which can regulate the body's functionality via hormones or direct neural connections. The hypothalamus is responsible for: increasing a fighter's heart and breathing rates; dilating the pupils; and increasing blood flow to muscles and skin while decreasing blood flow to the digestive system and kidneys. The hypothalamus also has direct neural connections to the adrenal gland, which secretes adrenaline, a hormone that makes the body stronger and more alert. Memory of a fighting situation will have direct connections to the amygdala (see Figure 8), or emotion center of the brain, causing the fighter to be excited or fearful. These emotions will affect the brain's decision in whether to be more aggressive or more passive when attacking. The body will also relay information concerning its level of fatigue while the prefrontal cortex decides whether a font snap kick is appropriate or even possible given the body's physical state.

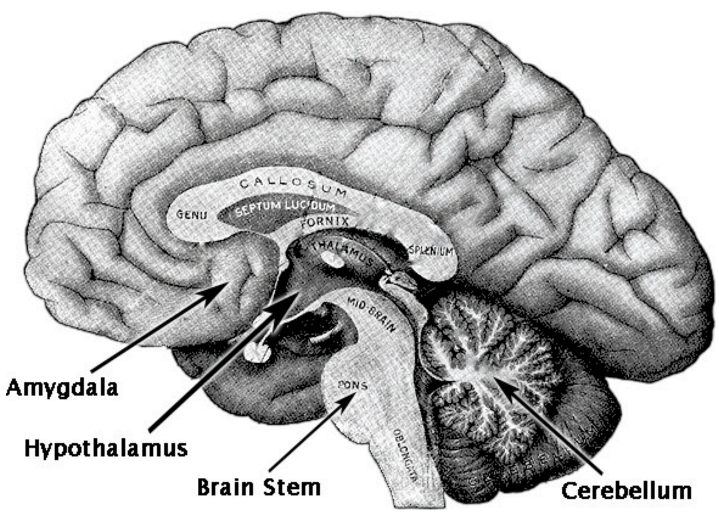


Figure 8: Median Sagittal Section of the Brain[18]

Applications of the Front Snap Kick

A front snap kick can be used to attack the face, solar plexus, or the groin, because the body's balance can easily be shifted to the opposite leg.[19] A veteran fighter would know this and would be watching his or her opponent until an opportunity arises where the kick can be executed and would make contact without being blocked. In this case, the front snap kick would be executed as a reflex. The brain is able to associate a certain stance or position of the opponent to be good or bad for the front snap kick, and will initiate movement without thought. These reflexes are also partially a result of new connections made in the spinal cord. After executing many front snap kicks, the spinal cord would begin to associate the specific contractions and relaxations of one muscle with the other so that less brain power is needed, resulting in quicker movements overall.[20] Just like the knee-jerk reflex, the body can learn the reflex of throwing a proper front snap kick.

All nerves and muscles can be trained to perform better together. Through repeated training, muscles will gain control and strength. Repeated training also causes nerves to grow and make new connections, making movement smoother and more controlled. This principle of repetition is common to martial arts training programs (as well as sports training in general) and is applicable to every technique. Each kick, defense, strike, or throw, et cetera, has a process-list of muscles that need to be contracted in a precise order in order to for the technique to be executed properly. The beginner's execution will be a little rough and less controlled, but with adequate training, he or she will soon acquire memories of each technique and reflexes that will help smooth out a kick while adding strength. In application, the experienced fighter will know what to look for in the opponent in order to effectively execute any technique. However, the only way to become experienced is to train and to teach the muscles to work together to achieve the desired results.

Conclusion

It is now apparent how complicated it is to initiate a "simple" front snap kick or any voluntary action. Fortunately, these complications typically move through the brain without intervention by conscious thought. If active thought were given to each nerve firing, then the brain would be so occupied with breathing, regulating the heartbeat, and overseeing other necessary functions, that performance of higher brain functions would be impossible. The fact that the brain is able to function so quickly and efficiently often lends it to be taken for granted. However, if one just takes a step back to examine all the things that must occur to execute an action, something as simple as a front snap kick becomes more than just a complex series of processes, it becomes its own art form. I do not recommend pondering the front snap kick when sparring; however, after your victory, perhaps your brain deserves a brief sign of appreciation.

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Endnotes

1. Cho, pp. 145-146.
2. Gray, illustration 430.
   High resolution color versions of these graphics are available on the web at http://www.funfolks.net/UCMAP_M6/da_Costa/
3. *Ibidem*, illustration 434.
4. Marieb and Mallatt, pp. 276-289.
5. Gray, illustration 437.
6. *Ibidem*, illustration 438.
7. Marieb and Mallatt, p. 219.
8. This illustration came from http://tinyurl.com/4bg9x. Last update: unknown. Accessed July 29, 2004.
9. Bear, et al, pp. 356-352.
10. Gray, illustration 728.

[11] Bear, et al, pp. 375-376.

[12] Bear, et al, pp. 279-280

[13] Bear, et al, pp. 186-390.

[14] Bear et al, pp. 396-399.

[15] Marieb and Mallatt, pp. 384-385.

[16] Gray, illustration 764.

[17] Bear, et al, pp. 396-399.

[18] Gray, illustration 715.

[19] Cho, p. 144.

[20] Bear, et al, p. 369-372.