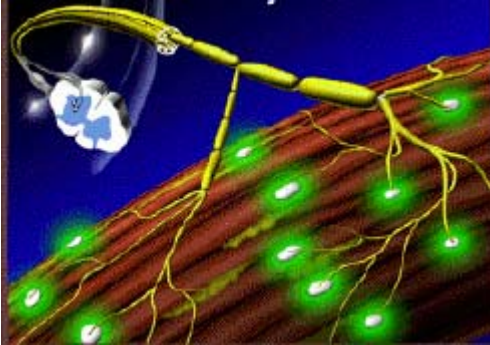


A Psycho Somatic Approach to the Initiation of Hypertrophic Stimuli



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Abstract

The nervous system coordinates and controls the initiation and inhibition of muscular contraction. Further, the recruitment pattern of motor neuronal pools is an intricate process, which plays a vital role in the stimulation of muscular hypertrophy.

To gain insight into such mechanisms, a clear picture of neurological structure and function must be presented. Organic regions discussed include the “smart cord,” cortex, basal ganglia, cerebellum, limbic system, and further regulatory structures. Also included are motor pathways directly associated with the control of human movement. These include the gamma and pyramidal motor systems arising out of the motor cortex, and extra pyramidal pathways arising subcortically in regions such as the red nucleus and reticular formation.

A clear discussion on reflexes will be presented and will include an informative look at the myotactic, reverse myotactic, and reciprocal innervation reflexes.

Information will be very much hierarchical, beginning with the nervous system’s most fundamental unit, the neuron and its mechanism of electrical conduction, and will continue to the integration centers in the central nervous system. Pivotal to the paper is the Psycho Somatic Model of Physiological Reactions, which will introduce the reader to interventions capable of immediate impact on muscle building performance.

*Jesus said unto him, Thou shalt love the Lord thy God with all thy heart, and with all thy soul, and with **all thy mind**.*

The central nervous system comprises two percent of an individual’s bodyweight, and yet receives 15 percent of its blood supply. Moreover, the brain consumes 20 percent of inhaled oxygen, and 50 percent glucose stores at rest (German, 2002). The consumption rate is clearly enormous. The reader is cautioned to realize what

they are dealing with when a subject such as this is addressed. The famous scholar Isaac Asimov once said that the brain was, "the most complex and orderly organization of matter in the universe." Indeed, within you is a form of machinery beyond comprehension, and wholly at your disposal. Study and research of neurological control and adaptive mechanisms involved in tasks ballistic in nature are of vital importance to individuals whose primary goal is the stimulation of increased cross sectional area. The following paper is the first of an entire future section of papers which will be contained on this site that are dedicated to the sensory motor and psychological aspects of bodybuilding. Endless hours of meticulous research will be partitioned for this subject. However, the reader must first understand several fundamental issues before neurological adaptations involving strength, self-regulation, and override strategies can be fully introduced. Therefore, the following pages examine the structure and overall function of the Nervous System. In short, you will be presented with core information meant to serve as a vehicle for the exploration of neurological avenues of mind-boggling proportions.

The Neuron

The following will review the neuron and how information is transmitted throughout the Nervous System.

The neuron is the functional unit of the nervous system. It serves to transmit information to other neurons, as well as effector organs in the periphery (outside the nervous system). An effector organ is an organ which is stimulated to respond to the arrival of a specific signal. The signal can be electrical, chemical, or mechanical. Neurons utilize both electrical and chemical means.

Neurons can be grossly divided into a cell body (soma), an axon, and dendrites. The **cell body** contains the nucleus (control center of the cell) as well as organelles, such as ribosomes, responsible for protein synthesis. **Dendrites** are branches which stem from the cell body. Their main function is to receive information. The connection between two neurons is known as a **synapse**. Information is transmitted from a **presynaptic neuron**. The neuron receiving the information is known as the **postsynaptic neuron**. An additional branch known as the **axon** stems from the cell body. Its function is to transmit information. Branching off of the axon are processes known as **collaterals**, which serve to communicate with numerous other cells.

Communication between neurons is extensive, as the neuron synapses with thousands of like cells. To compound the complexity of the situation, there is an estimated 100 billion of these cells in the nervous system, which is why in all of our exploration, the Nervous System is known as the most complex form of organized matter in the universe. The ends of the collaterals are known as **axon terminals**. Axon terminals contain specialized vesicles (storage containers), which carry chemical messengers known as **neurotransmitters**. Upon stimulation, neurotransmitters are secreted (released) to the postsynaptic cell. Information is then received, processed, and appropriate action is initiated. Still another

specialized structure lies where the axon begins. The site is known as the axon hillock, and is designed specifically to initiate a large electrical signal known as the [Action Potential](#).

The function of the neuron varies. These cells can be classified as afferent neurons, efferent neurons, and interneurons. Afferent neurons receive information (i.e. pressure, pain, stretch, sense of position in space) from the periphery and transmit it toward the executive, or central nervous system, which then interprets the information and takes appropriate action. A detailed discussion regarding the role these receptors play in ballistic movements (i.e. bench press) will be provided further in the paper.

Efferent neurons carry information from the executive to the periphery. Muscular contraction is initiated via efferent stimuli. Efferent neurons are divided into autonomic neurons, which stimulate the myocardium (heart muscle), smooth muscle of the digestive track, vasculature, glands not under our direct control (though they are influenced cognitively, which will be discussed in the Psycho Somatic Model below), and motor neurons, which project to skeletal muscle. Interneurons reside solely in the central nervous system and function as receivers of information, as well as transmitters. Thought, emotion, and interpretation of stimuli all involve complex interactions between these specialized cells.

How Neurons Transmit Electrical Impulses

Electrical impulse conduction via neuronal cells is a complex process. A reductionist approach will need to be adopted to grasp its execution. The first concept to understand is [simple diffusion](#). Atoms have what is known as random thermal motion (they are in constant random motion). The probability of atom X moving in direction A is just as likely as the probability of it moving in direction B. Cells have a complex boundary known as a membrane. If the membrane is permeable (allows the atom to pass through), then molecules will enter or leave based on their concentration gradient. For example, if you have 100 oxygen atoms to the left and only 20 on the right, there is a higher probability of a greater number of oxygen atoms moving to the right than there is of atoms moving to the left. Since the overall probability of an individual atom moving left or right is equal, the quantity of atoms on either side will determine the direction of flow. This process is classified as net flow or net flux, as it does not look at individual atoms, but the relative gradient or number of atoms from one zone to the next. For current purposes, the zones addressed are extracellular fluid (ECF), and intracellular fluid (ICF). Atoms therefore move down their concentration gradient. Moreover, the force with which they move is known as a chemical force. The greater the concentration gradient, the more rapid the net flux down the gradient will be (or greater the chemical force is).

The second concept to understand is the [membrane potential](#). The membrane potential can be defined as the difference in voltage that exists on the inside of the

cell relative to the outside (note that membrane potentials are always viewed this way). Thus, if the inside of a cell is positive relative to the outside of a cell in charge, then a positive membrane potential exists. An ion is a positively or negatively charged atom. Of prime importance are sodium (Na^+) and Potassium (K^+). Both have a positive charge of +1 and both carry their charge as they move. A current can be defined as the movement of charge. Thus, ions are utilized by the body to carry electrical currents. An electrical force is either attractive or repulsive. Cations, or positively charged ions, repel other cations. Anions, or negatively charged ions, repel anions. However, cations attract anions, due to opposite charges. Thus, if a negative membrane potential exists, it will attract positively charged ions into the cell and repel negatively charged ions.

As with a concentration gradient, the strength of the electrical force depends on the severity of the separation of charge. That is, a resting membrane potential of -40 millivolts will have a stronger electrical force than one with a membrane potential of -20 millivolts. Neurons spend a great deal of their energy setting up a negative membrane potential of -70 mv (Marriab, 2001). Moreover, a concentration gradient of sodium ions in the ECF exists. Therefore, sodium is attracted to the inside of the cell due to both concentration gradient and membrane potential. A description of why this occurs follows.

From the information thus far stated, the reader should realize that the magnitude of the concentration gradient and membrane potential affect the speed as well as direction that ions will move. The electrical impulses sent by neurons are really rapid changes in membrane potential. However, other factors also intervene, such as the permeability of the neuron's membrane.

Membranes are composed mainly of phospholipids, and are mainly non-polar. Non-polar simply means that the molecule is not charged. They are therefore not permeable (do not permit) to charged ions. The concept of resistance describes the degree to which a substance allows a current to pass through. Cell membranes have a high resistance to the flow of ions. According to Ohm's law, the rate of a current is equal to the difference, polarity, or separation of charge divided by the resistance. If the separation of charge increases, the rate of current flow will increase. Likewise, if resistance decreases, the rate of current flow will increase.

Simple diffusion will eventually cause equilibrium to be reached. Therefore, a neuron must actively transport sodium outside of the ICF in order to create a concentration gradient. The cell has machinery known as Sodium/Potassium Pumps. These pumps harness the power of ATP to pump three sodium ions out of the cell, and two potassium ions into the cell. Both are positive; however, more positive charge is being pumped out than is entering in. For permeability, the cell has sodium and potassium channels or pores. There are more pores for potassium than there are for sodium (note that the pores are specific in nature), therefore the cell is more permeable to K^+ than Na^+ at rest. Because K^+ is being pumped into the cell, a concentration gradient is produced, and it therefore leaks out of the cell via K^+ pores. Finally, negatively charged proteins are synthesized inside of the cell. Overall, we find that:

1. A concentration gradient is set up such that sodium is higher in concentration in the ECF than the ICF. Potassium is higher in the ICF than

the ECF.

2. More positive charge is leaving the cell than entering, which attracts sodium into the cell. The cell, however, is not very permeable to Na^+ at rest.
3. If you could somehow rapidly increase the permeability of the cell for sodium, it would come flying into the cell at a rapid rate.
4. At rest, due to the pumps and negatively charged proteins, the cell is -70 millivolts relative to the outside of the cell. This is called polarization.
5. If Na^+ came into the cell due to the rapid increase in permeability mentioned, the cell would lose its polarity. This is called depolarization. Moreover, the inside of the cell would become more positive in charge.
6. This is exactly what occurs, as will be explained.

Gated channels are the avenues by which ion permeability enhances. Gated channels for both Na^+ and K^+ exist. Moreover, they can be divided into ligand and voltage gated channels. A ligand is a molecule that can bind and unbind to a protein. A ligand-gated channel has a binding site for a ligand or neurotransmitter. When the ligand binds, a conformational change in the gate takes place, which is known as an allosteric reaction. This reaction causes the gate to open, thereby increasing the permeability to Na^+ or K^+ , depending on the transmitter. Voltage gated channels are charged. If a voltage gated channel is positively charged, then a negative charge will open the gate, as it is attracted toward the charge. Na^+ gates, which face the extracellular environment, are positively charged. Therefore, the concentration of sodium keeps the gates closed as these cations repel the gate.

An action potential is a rapid reversal in the membrane potential. The signal is so strong that it is carried along the entire axon and then to the axon terminal at which point a neurotransmitter is released. The following will describe how action potentials are initiated via neurotransmitters. In this case, a presynaptic neuron secretes a neurotransmitter, which binds to a dendrite or cell body of the postsynaptic neuron. The reader should note that an action potential is all or none.

That is, the change in membrane potential either is high enough to reach threshold, or it is not. In the case of a neuron, the reversal in charge will change the resting potential of -70 mv by a positive $10-15$ mv. If it does not reach the threshold, the current generated will be too weak to travel down the axon, and the axon terminals will not be stimulated to release their chemical messengers. If a ligand binds to a sodium-gated channel, it causes an excitatory graded potential in which depolarization takes place, and the opposite occurs when a ligand opens a K^+ gated channel (this causes more positive charge to leave the cell, which makes it have a greater negative charge). Graded potentials are too small to hit threshold. However, when graded potentials are summed together, their collective effects cause the cell to hit threshold. Thus, step one is binding of excitatory ligands. When bound, they open Na^+ gated channels. At this point sodium shoots into the cell at a rapid rate. Moreover, the area where the Na^+ moved into the cell becomes negative in the ECF and positive in the ICF. At the axon hillock lie voltage-gated channels. Recall that positives are attracted to negatives; therefore, sodium near the axon hillock travels to the adjacent negative region, making it positive again. However, the region near the axon hillock is now negative because the positive sodium ions are gone. The negative charge attracts the voltage gated channels to swing open, which then attracts sodium to it, causing the area vacated of Na^+ to become negative, in turn opening their voltage gated channels. This occurs again and again down the axon. Therefore, the action potential travels across the cell in a propagating fashion as illustrated below.

Repolarization of the cell occurs after depolarization. In this case, the change in membrane potential from negative to positive stimulates potassium voltage gated channels which reside in the cell to open. As the permeability to potassium increases, a rapid flow of positive charge leaves the cell, creating a negative

potential again. The K^+ channels are slow to close, and therefore in the graph above it is important to note that the cell actually becomes more negative than it originally was. This is known as hyperpolarization, and means that the cell will have to wait for a period of time before conducting another action potential (called the refractory period). Of course the Na^+/K^+ pumps and leak channels never stopped working, and they soon return the cell to its resting potential.

These same principles apply to the triggering effect of the cell's neurotransmitter. Simply put, along the neuron are various gated channels. Sodium and Potassium channels are in high concentration along the axon. However, in the axon terminal is a very high concentration of Calcium or Ca^{++} channels. When the action potential reaches the axon terminal, calcium gated channels are stimulated to open, as the Na^+ were. Calcium is higher in the ECF from similar mechanisms used to initiate sodium's concentration gradient. Due to its charge, Ca^{++} rushes into the cell. Vesicles or packages reside in the Axon Terminal, which contains the cell's neurotransmitters. When calcium binds to the vesicles, they can bind to the cell membrane and be released. Calcium acts as a literal key. Therefore, if calcium is not bound to the vesicle, they are stuck inside the cell. There are numerous neurotransmitters secreted. Many of their actions are discussed in *Endocrine Insanity* (King, 2003), as well as in the paper *Acute & Chronic Endocrine Responses to Exercise Induced Disruptions in Homeostasis Part One - Exercise Endocrinology Principles and Catecholamines* (Wilson, 2004).

In summary, a neuron is composed of a cell body or soma, which contains the nucleus, as well as organelles. The axon serves to transmit information, whereas dendrites act to receive information. A synapse is a connection between two neurons, in which the cell sending a signal is called the pre synaptic neuron, and the cell receiving information is called the post synaptic neuron. The axon hillock functions as an integration center. Thousands of neurons can communicate with a single neuron. The axon hillock integrates the signals from these various neurons and either propagates or does not propagate an action potential. There are both inhibitory and excitatory graded potentials (for example, you can inhibit a thought or excite muscular contraction). Finally, neurons transmit information via electrical signals, which then serve to stimulate a chemical response in the form of a neurotransmitter.

Organization of the Nervous System

The nervous system is often divided by its anatomical location and function. The Central Nervous System (CNS) comprises the structures held within the skull and vertebral column. These include the brain and spinal cord, respectively. The Peripheral Nervous System (PNS) includes the cranial and spinal nerves which exit the skull and vertebrae. Functionally, the system is divided into afferent (sensory) and efferent (motor) divisions. Still further, the afferent is divided into somatic afferent and visceral afferent divisions. Somatic means of the body, and visceral refers to the internal organs. Finally, afferent may be defined as toward a central structure. Thus, somatic afferent carries sensory information from the periphery, toward the central nervous system. The motor system is divided into autonomic and somatic divisions. The autonomic is outside of our conscious control and refers to

the sympathetic (flight or fight) and parasympathetic (rest and digest) divisions. The somatic efferent, or somatic motor, innervate skeletal muscle.

There are several key terms that the reader must be familiar with. These include nerves, tracts, gray matter, white matter, ganglia, and nuclei. In the PNS, a collection of axons is known as a nerve. Nerves are mixed, in that they can have axons carrying afferent information, as well as efferent information. When axons are contained within the central nervous system and are headed in the same direction, they are known as tracts. Cell bodies, dendrites, and axon terminals appear gray in the CNS. Therefore, gray matter denotes areas with a high concentration of these structures. The Cerebral Cortex (where all voluntary movement begins) is composed of gray matter. The axons in the CNS appear white, and therefore an area with numerous tracts is called white matter. Tracts allow communication between different areas of gray matter. Nuclei are a collection of like cell bodies in the CNS, and are not to be confused with cellular nuclei. A ganglion is a collection of cell bodies in the PNS.

The Psycho Somatic Model of Physiological Reactions

The brain can grossly be divided into the cortex (where cognitive appraisal takes place), the limbic system (where emotions take place), the regulatory structures, and the brain stem (initiates physiological responses such as where we direct our attention, arousal levels, and heart rate). In Sports Psychology, these structures are viewed in subsequent order. That is, the cortex influences emotion, which drives the regulatory structures, which in turn drives the brain stem to initiate physiological effects. This is known as the Psycho Somatic Model (Fava & Sonino 2000, Oken 2000, Rees 1983), and is a very basic framework for how psycho-physiological interactions occur. There are numerous models, however, and they will be discussed in future articles. The point is to provide an illustration of how the neural processes influence physical reactions before discussing structure in greater detail.

By way of explanation, a stimulus is introduced into the environment. The stimulus may be in the form of a posing routine which must be performed during a competition. Secondly, the individual brings the stimulus into the body (has perception of it). Sensory receptors are involved in this process, such as exteroceptors involved in sight and the perception of sound. Cognitive Appraisal (CA) is a stepwise process. After perception of the stimulus, you compare the stimulus to past experiences and then select out a response, and benefit from the experience. CA occurs in the cortex. If you appraise the situation as being negative, then your emotional response will most likely be high cognitive anxiety, which is a negative emotional state (Gould, Weinberg 2003). This emotional state would pass through the regulatory structures, which would then drive the brain stem to initiate a fight or flight response. Your attentional scale will be narrowed, and your entire focus may be narrowed in on one judge, and not the crowd. Moreover, your posing routine may be less fluent because of impaired muscular control.

Note, however, that several interventions have been placed next to the processes outlined. The athlete can intervene at any stage and produce amazing results. During stress inoculation training the athlete is exposed progressively toward a stress until they become immune to its effects. The process occurs in three stages (Gould & Weinberg, 2003). In the first, the individual is educated on the effect that positive or negative appraisal can have on a situation. Secondly, the athlete utilizes imagery to rehearse the situation over and over, thus immunizing oneself to the situation. In this stage, the event is to be viewed as positive. The participant should smile every time they think of posing on stage. Stage three would involve applying stress inoculation to real life situations. For example, the individual might pose in front of friends or training partners. Some athletes, when preparing for a large event, will simply attend numerous small events to immunize themselves before the large event.

Mace and Carrol (1986) had 18 female participants perform a simple gymnastics bench sequence. Self-reported distress, as well as heart rates, was measured prior to the performance. Further, the participants were video taped and scored by judges, which is similar to a bodybuilding situation. After this process, participants were assigned to a stress inoculation group, or a control group. The SI group *"received seven sessions of training in relaxation, imagery and making self-statements in order to develop a set of coping skills. The control group subjects also received seven training sessions during which they practiced a series of coordination exercises, but no psychological stress management training was given to this group."* The stress inoculation group had reported significantly lower stress levels, and scored higher than the control group. Such a result has been confirmed by numerous studies (Mace & Carrol, 1986, Sarason, Johnson, Berberich, & Siegel, 1979, Ross & Berger, 1996).

Cognitive restructuring would involve the athlete identifying negative thought processes and either eliminating them, such as in thought stopping, or learning to view them in a different manner. For example, when walking on stage, the participant may have a high heartbeat. This is somatic activation. An individual's interpretation of an increased heart rate is another discussion. This may be viewed as energizing and exciting, in which case cognitive anxiety would be lowered and the athlete's attentional field would not narrow, in turn allowing them to focus on working the crowd from one end to the other. Therefore, viewing increased heart rate positively would restructure the Cognitive Appraisal process. Michelson et al. (1990) had participants with clinical panic distress perform cognitive reappraisal techniques, in which they viewed somatic excitation in a positive manner. They also worked on breathing rate control for a 12-week period. Tremendous improvement was made in each participant, such that *"All subjects were free of spontaneous (uncued) panic attacks at post-treatment, and all met operationalized criteria for high end state functioning."*

Utilizing imagery to recreate emotional states was also mentioned. Gould and Weinberg (2003) discussed a case study in which a hockey player would lose his temper due to officiating calls. The player used imagery to simulate bad calls and then restructure his emotional response to the calls. Breathing control and Progressive Relaxation will be discussed in future articles dealing with arousal regulation and anxiety.

The Psychosomatic model is but a taste of how understanding neural psychological / physiological response mechanisms can improve athletic performance. There is much, much more. For example, a notable amount research has gone into a process whereby an individual places oneself into a flow state (alerted state of consciousness) that is powerful enough to literally sky rocket performance in the gym. Moreover, numerous techniques exist which enhance neural drive and increase muscle fiber recruitment rates.

Overview of Structure and Function of the Brain

- As the title suggests, this is an overview of the brain. Certain aspects of this overview will be evaluated in great detail as the paper progresses.

The largest aspect of the brain is the cerebrum (the large convoluted region above), which is divided into left and right hemispheres. Both hemispheres communicate with each other through a tract called the corpus callosum. Recall that a tract is a bundle of axons traveling in the same direction.

The hemispheres also contain fluid filled ventricles, which bathe the nervous system with proper nutrients. The outer shell of the cerebrum is composed of numerous nuclei, and is therefore a layer of gray matter. This is known as the cortex, and can be divided into four lobes.

From a very gross perspective, the frontal lobe is concerned with voluntary movement (flexing the quadriceps), the parietal lobe is concerned with processing sensory information from the body such as touch, pain, and pressure, the occipital

lobe processes visual information, and the temporal lobe is concerned with auditory stimuli (Latesh, 1998, Marriab, 2003). The limbic system is also contained within the temporal lobes and is associated with both emotions and memory. Most of the information processes in the limbic system are relayed to the hypothalamus and the reticular activating system, as well as other areas of the brain stem; it therefore influences the physiological response discussed.

Deep to the cortex lies an extensive region of white matter, which includes the already discussed corpus callosum. Other forms of white matter include projection tracts. Projection tracts carry information from the spinal cord to the sensory cortex and from the motor cortex to the spinal cord (discussed shortly). The basal ganglia are a collection of nuclei (cell bodies) deep to the white matter of the cerebral cortex and are part of the regulatory structures. Sadly, much of our knowledge of basal ganglia function has come from patients with Parkinson's disease (Delwaide, Sabbatino, & Delwaide, 1986). These nuclei are associated with the initiation of movement, the control of slow tracking movements, and to the capacity of augmenting or inhibiting motor units, which facilitate action (O'Driscoll et. al, 2000, Delwaide, Sabbatino, & Delwaide, 1986, Rubchinsky, Kopell, Sigvardt 2003). Rubchinsky, Kopell, Sigvardt (2003) believe that many of these effects are motor program oriented. They actually constructed a model in which evidence is provided that *"the BG are involved in facilitation of the desired motor program and inhibition of competing motor programs (N)."* Contreras agrees: *"Parkinson's disease...is used as a window to examine basal ganglia function. Simulations of dopamine depletion produce motor impairments consistent with motor deficits observed in PD that suggest the basal ganglia play a role in motor initiation and execution, and sequencing of motor programs (P)."* This subject will be discussed in detail in future articles, and is one of the most exciting areas in motor control. The motor program has absolutely everything to do with ballistic movements such as the bench press!

Situated deep in the midbrain lies a structure known as the thalamus.

The thalamus is part of the regulatory structures, and it functions as a relay center to the brain (Sommer 2003, Sherman & Guillery, 1996). Almost everything that reaches or leaves the cortex must pass through this structure. It relays, processes, and edits information. The editing of information has to do with what we perceive as irrelevant at the time, through our actions or what we choose to pay attention to. The hypothalamus lies below the thalamus and is the control center of the autonomic nervous system (fight or flight, etc.). It also regulates body temperature, hunger, thirst, as well as the endocrine system (King, 2004)! As stated, much limbic system output is relayed to the hypothalamus, which supports the psycho somatic model.

The cerebellum is the densest aspect of the brain, and it is situated dorsal to the brain stem. This structure is associated with ballistic (explosive and fast) movements. Lamarre (1978) had monkeys perform a fast ballistic flexion or extension of the elbow in response to a sound cue. The reaction time was about 250 msec in the normal monkey. Reaction time can be defined as the time taken from the introduction of a stimulus to the onset of a response (Schmidt, 1999). They then tested reaction time with monkeys with impaired cerebellums and found that *"the reaction time was consistently longer, being, on the average, 400 msec. This was associated with an equal retardation in the onset of neural changes in the motor cortex. These results are interpreted as evidence for the involvement of the cerebellum in the initiation of some fast ballistic movements."*

The brain stem is composed of the midbrain, pons, and medulla. The midbrain is the initial region of the brainstem and is associated with the sympathetic division of the nervous system. According to Marriab (2001), when an individual has a fear response, the midbrain *"elicits a terror induced increase in heart rate and skyrockets blood pressure, with wild fleeing or defensive freezing, the flexing of the spine (as in rolling into a ball for protection), and the suppression of pain."* The second region of the midbrain is the pons, and is associated with cranial nerves as well as respiration (Latesh, 1998). The medulla oblongata is the third region and has a cardiac center, a blood pressure center, and a breathing or respiratory center. The limbic system will affect each of these areas. It should be clear now why the brain stem is thought of in the psychosomatic model as the structure responsible for regulating homeostatic function.

One of the more exciting subjects concerns the reticular activating system. This structure is located where the spinal cord thickens in its junction with the brain stem. It is responsible for arousal levels and alertness. Think of this as your narrowing scope. In a related issue, Wilson (2004) discussed attentional focus and the ability to narrow in on certain stimuli (See The Psychological Refractory Period Paradigm & Attentional Mechanisms Involved in Information Processing). The RAS is responsible for this function. Once again, a massive dissertation will be relayed to the readers on arousal levels. There are numerous theories which are of vital importance to this subject, and it is an area that the HYPERplasia staff has dedicated much research to in the background. Strategies which activate the RAS will be analyzed, as well as a discussion on what levels of activation are optimal for the sport of bodybuilding.

The Spinal ("Smart") Cord

For a long time the spinal cord had been thought of as a simple conduit which transferred information to and from the periphery. This, however, is no longer the case. It is now postulated that the spinal cord may actually be more complex than the brain itself. Schmidt (1999), considered to be one of the world's experts on motor control, refers to the structure as the "*Smart Cord*." Much knowledge in this area can be accredited to Sherrington, who in the early 1900s studied human reflexes. He postulated that most human movement was controlled by reflexes (this paradigm has now changed). His research led him to discover concepts such as reciprocal innervation, and the golgi tendon organ. Indeed, he is responsible for the term proprioception. In 1910, Sherrington performed studies on cats, in which he inhibited communication between the spinal cord and the brain. Therefore, no input from conscious centers could be transferred to the limbs. He found that the cats could still execute basic stepping movements. These results were supported by Brown (1911). However, decades would pass before knowledge in this area would truly explode.

Shik, Orlovskii, and Severan have performed several experiments in which the spinal cord is disconnected from the midbrain. After preparation, the cat would be supported on a treadmill, such that its feet were in contact with the treadmill. The experimenters then ran an electric current through the superior aspect of the cord, which resulted in the cat actually producing locomotion. When the current was turned off, the cat still continued to walk, as if the process was self-generating. To compound the complexity of the situation, when the speed of the machine increased, the cat began to increase locomotion, to the point of rhythmic running. Therefore, it could be postulated that once the spinal cord is initiated to begin a movement such as locomotion, it can continue the task without control from upper levels of conscious. The condition becomes more startling, however. In another experiment by Shik et al. the treadmill was started without the initial electrical impulse. The cat's legs would first drag on the machine, and then all of a sudden begin to generate locomotion patterns! Again, as speed increased, the cat's gait frequency increased, as if the spinal cord was aware of the limbs and the situation they were in and controlled movement from there. Lions (2002) summarizes the mechanism by which these processes are controlled as follows:

Today, the existence of networks of nerve cells producing specific, rhythmic movements, without conscious effort and without the aid of peripheral afferent feedback, is indisputable for a large number of vertebrates. These specialized neural circuits are referred to as "neural oscillators" or "central pattern generators" (CPGs)...In addition, the rhythmic activities generated by the circuits are often involved in control of vital functions. Circuits for breathing, chewing, and swallowing are located in the brain stem, whereas those for locomotive functions are contained in the spinal cord.

It appears that these "spinal generators" are able to rhythmically activate flexors, followed by extensors, and rotate back and forth in such a fashion as would be required in the locomotion experiments discussed. It is postulated that self-generating neurons are interconnected, such that initiation of a certain set of neurons in a generator activates a second set of neurons, which then activates another set, which in turn reactivates the first set of neurons. A diagram would look like this (Latesh 1998, Schmitdt, 1999):

Higher motor neurons from brain stem → Activates Neuron Set one which activates flexors → Neuron Set one activates an interneuron → The interneuron activates a third

set of neurons which activates extensor muscles à the third set of neurons activates an interneuron à which then activates the flexors again.

However, this is only a simple illustration of what amounts to a tremendously more complex system. Forssberg, Grillner, and Rossignol (1977) had *spinal cats walk with their hind limbs on a treadmill belt, while a tactile stimulus was applied to the dorsum of the paw during various phases of the step cycle. They found that stimulation during the swing phase evoked a flexion response with a concomitant crossed extension, whereas in stance it induced an increased ipsilateral extension.*

The point is that reflexes have been thought to be more or less stagnant. That is, if you stimulate the back of your foot, you would expect a similar reflex every time. However, this was not the case. Instead, the reflex was a flexion response when the leg was swinging in the air, as if the cat was trying to avoid an obstacle! When the leg was on the ground, it induced extension of the leg, perhaps bracing itself. The researchers believe that the generators not only supply rhythmic movement, but also prepare relevant reflexes for the movement being performed! This paradigm is known as reflex reversal and has been demonstrated in humans as well (Schmidt, 1999).

The surface has only been scratched at the complexity of these generators. Carter et al. (1986) attached tape to the hind leg of spinalized cats, and found that they rapidly shook the tape, even without feedback to the brain. They then attached the tape, and had the cats walk on a treadmill, and found that they walked and during the swing phase shook the leg with the tape! The cord was able to coordinate multiple movements at once without feedback! According to Schmidt, evidence from other experiments points to the observation that the Smart Cord literally knows where limbs are based on sensory feedback. Much evidence has been found that humans also have spinal generators (Dimitrijevic, Gerasimenko, & Pinter 1998, Shapkova & Schomburg 2001). Both Dimitrijevec et al. (1998), and Shapkova and Schomburg (2001) found that locomotive stepping which was rhythmic in nature could be stimulated in human paraplegic participants. Moreover, Shapkova and Schomburg found that the frequency of *"locomotor stepping could be independent from the stimulus frequency and that stepping was continuing after the end of stimulation for several cycles (Z)."*

Spinal Cord Organization

When viewed in cross section, the spinal cord can be divided into gray and white matter. The gray matter to the front is known as the ventral horn, and contains motor neuronal bodies, which innervate skeletal and smooth muscle. The rear aspect of gray matter is known as the dorsal horn, and contains cell bodies of interneurons. These neurons receive sensory information from nerves in the periphery and transmit it to higher centers, such as are located in the parietal lobe. The white matter is composed of the axons of interneurons. Thus, the white matter is made up of ascending (carrying sensory information) and descending (carries motor instructions from the brain) tracts. Note that laterally there lies the spinal nerve, which contains both sensory and motor information. However, to the rear you will notice a ganglion (bulb shaped structure), which is a collection of cell bodies outside of the CNS. Sensory neurons have their cell bodies outside of the nervous system. Their extensions move into the CNS to communicate with the interneuron cell bodies in the dorsal root. Note that anterior to the dorsal root is another canal. That canal is known as the ventral root and carries the axons of motor neurons. Again, as these two merge they form the spinal nerve.

The spinal cord begins when the skull ends in the neck region, and ends in the lower back or lumbar region of the body (L1). Spinal nerves, however, continue to travel out of the spinal cord through the length of the vertebral column. The spinal cord is divided into regions corresponding to the vertebrae in which it is housed. For example, a region of the cord which lies in the neck or cervical region of the vertebrae contains the aspect of the cord which receives sensory information from this region (or close to it). There are 31 spinal nerves, and they form various branches or plexuses. The cervical plexus innervates the neck region, the brachial plexus innervates the upper extremities, the lumbar plexus innervates the anterior and medial thigh, and the sacral plexus innervates the posterior thigh and leg.

Ascending and Descending Pathways

A gyrus represents the large convolutions seen in the cortex, whereas the valleys between the gyri are known as sulci. The gyri increase surface area of the brain drastically. The central sulcus can be seen in the illustration above and divides the frontal lobe from the parietal lobe. The large convolution in front of the central sulcus is known as the pre central gyrus, or more commonly the primary motor cortex. This region has the whole body mapped out in it. This region, combined with the large pre motor area, is concerned with voluntary movement. The post-central gyrus or somatosensory cortex, along with the sensory association area, receives information of senses such as touch and proprioception.

What is of particular concern is how information is brought to and from the brain. The ascending pathways are involved in carrying sensory information to the brain, while the descending pathways are involved in sending out motor orders. The pathways begin in one side of the CNS and cross over to the other. Therefore, the right side of the brain controls the left side of the body and vice versa. Secondly, pathways carry information through interneurons, which are connected in series. The order of these neurons starting superiorly is known as first order, second order and, in cases, third order neurons. Ascending pathways receive information from the periphery of the cord, and carry the information upwards to different aspects of the brain (normally converging in the sensory cortex) through linked interneurons.

The descending pathways are made up of pyramidal tracts and extrapyramidal tracts. Combined, they are known as the Alpha Motor System. Pyramidal pathways arise out of the motor cortex, terminate in the anterior horn, and can be divided into the lateral and anterior corticospinal tracts. Both the lateral and anterior tracts transmit impulses from the motor cortex to spinal cord motor neurons, which then activate skeletal muscles on the opposite side of the body. Four primary extrapyramidal tracts originate in subcortical structures of the brain and terminate in the anterior horn. The pyramidal tracts are more concerned with voluntary movement, whereas the extrapyramidal tracts are concerned with unconscious movement, tracking movements, and posture. For example, the current writer attended the San Francisco Grand Prix bodybuilding contest. When viewing Milos Scarvey, his head literally turned and tracked one of the hugest beasts at the show. Milos' back literally looked like a barn door! Interestingly enough, the Tectospinal

tract, which is part of the extrapyramidal tracts, coordinates movements of the head and eyes toward visual targets.

Other extrapyramidal pathways include the Vestibulospinal tract, which transmits impulses that maintain tone and activates ipsilateral (same side) limb and trunk extensor muscles, as well as muscles that move the head. The Rubrospinal tract is concerned with muscle tone of the distal limb muscles on the opposite side of the body. The reticulospinal tract transmits impulses concerned with muscle tone, visceral motor functions, and control of unskilled movements.

Reflexes

Reflex can be defined as "automatic and often inborn response to a stimulus that involves a nerve impulse passing inward from a receptor to a nerve center and thence outward to an effector (as a muscle or gland) without reaching the level of consciousness (Webster's)." A reflex arc in its most basic form consists of a sensory neuron, the executive or processing center (brain or spinal cord), and an efferent neuron, which initiates a response in the effector. The most complex reflex arcs are polysynaptic, in that the afferent neuron relays information through several interneurons before reaching the effector cell. An oligosynaptic reflex arc contains two to three synapses, while a monosynaptic arc involves the afferent neuron and the efferent neuron. That is, the afferent connects or synapses directly with the efferent, which effects muscular contraction.

The reader must be familiar with two terms that are vital to the control for human movement. These are feedforward and feedback signaling. Feedforward signaling involves information sent to an effector without knowledge of how the movement will turn out (Latesh, 1998). For example, before a barbell curl, an individual will send the signal to execute the movement without knowledge of how the rep was executed (though they may have a good idea from past experiences). However, as the set progresses, they may make adjustments in form based on feedback (i.e. tightening the abs or back). Feedback is provided by receptors. Proprioceptors provide intrinsic information, such as where your limb is in space, and exteroceptors provide information external to the individual. Proprioception provides information of where the body is in space that does not require attention. Your CNS is aware of where your limbs are as you read this, but that information does not require conscious processing. However, if you were to attempt to walk with your eyes closed, it would require attention. This is known as kinesthesia, or conscious control of limbs without visual feedback.

Proprioceptors are neurons whose endings can turn specified stimuli into electrical impulses. Muscle Spindles, for example, turn mechanical stimuli (stretch) into an electrical impulse. The Soma or cell body of these neurons lies in the dorsal root ganglion (as do other sensory neurons), and its extension travels through the dorsal root and synapses on a neuron(s) in the CNS.

Muscle Spindles and the M1 Reflex

Muscle spindles are special sensory organs which are cigar shaped. That is, they have a thick mid section known as the "equatorial" region, with tapering ends denoted as "polar regions." The spindle is comprised of a connective tissue capsule, which houses two species of intrafusal muscle fibers. Within a muscle, the normal muscle fibers are called extrafusal muscle fibers, and are under your voluntary control. The intrafusal fibers have non contractile components in the equatorial region. However, the polar region is made up of actin and myosin filaments, which allows the fibers to contract. These intrafusal fibers are called nuclear bag fibers and nuclear chain fibers. The names are due to how the nuclei are grouped on each fiber. Nuclear bag fibers are thicker in the mid region, and the nuclei are arranged centrally or are "bagged" or clustered together. The chain fibers are thinner and their nuclei are in series, or linked in succession like a chain. Both fibers are attached to the extrafusal muscle fibers at their polar regions. Further, they are innervated by both afferent and efferent fibers, the main of which are afferent 1a (also known as annulospiral fibers), afferent Iib (whose receptors or endings are known as flower spray endings), and Gamma efferent fibers.

Afferent 1a or annulospiral fibers are sensitive to both the magnitude of stretch in a muscle (overall length), as well as the velocity of length change (the rate at which the fiber changes length). When the muscle changes length, the afferent 1a fibers increase their rates of depolarization, the greater the rate, the more frequent the firing rate, and the more afferent fibers that get excited to threshold. Moreover, the faster the rate of length change, the greater the excitation rate. They decrease in firing rate when the muscle shortens. This is where the monosynaptic stretch reflex comes into play. When the afferent fiber is stimulated to emit an action potential, it carries the information to the spinal cord through the dorsal root, and then synapses directly onto an alpha motor neuron, which causes the muscle fibers it innervates to contract. We see then that the rate of length change affects the number of muscle fibers recruited during an exercise. The reflex is called mono, due to the fact that it only has one synapse involved; it is called the phasic stretch reflex for obvious reasons. Phasic refers to a sudden contraction (Wilson 2002) due to a sudden length

change. Because contraction causes the afferent fiber to lower in its rate of firing, the system is based on negative feedback. That is, the stimulus causes a reaction, which lowers what stimulated it in the first place.

The monosynaptic stretch reflex occurs in approximately 30-40 ms. However, studies show (Schmidt, 1999) that after the m1 reflex is initiated, a second burst of muscular activity takes place 50-80 ms after the original burst that is greater in magnitude. This is known as the functional stretch reflex, and involves interneurons, which carry the information to higher centers in the spine and brain for a greater response.

Group II afferents are sensitive to overall length and not the rate of length change. They are responsible for the tonic stretch reflex. This is a fascinating reflex, and is polysynaptic in nature, and not as well understood as the monosynaptic reflex (Latesh, 1998) as far as how the nervous system organizes and processes feedback. However, the effects of the reflex have been the subject of much discussion in the world of motor control. When a muscle lengthens slowly, the tonic stretch reflex maintains tension in the muscle through steady contraction rates. As the length increases, the amount of motor units recruited increases, and with it, the stiffness of the muscle. Muscles can be thought of as springs (Darling & Cooke). The stiffness of a spring can be defined as the rate of length change caused in response to a given amount of tension placed on the muscle. A spring, when stretched, stores potential energy which can be used to do work. Giancoli states that, "the force needed to stretch a spring increases with the amount of stretch and at any point is proportional to the displacement from the normal equilibrium position." This is known as Hooke's law, and again explains that the tension in a spring increases as the length increases.

This function is applied to postural control mechanisms. In order to maintain upright posture, the musculature on both sides of an individual's body needs to exert proper tensions. If the flexors exert more tension than the extensors, then posture will be imbalanced (think of two wires holding a tent up; if one is stronger than the other, the tent will be slanted to that direction). However, if the tension on each muscle is adjusted to equilibrium, then a disturbance of the system will cause automatic self-correction to the posture (when wind blows a tent at night, it automatically rebounds to its normal shape due to equal springiness of the wires supporting the structure). The nervous system can adjust the tension of each muscle before any disturbances and after disturbances. Think of it this way: Muscle A as a flexor and Muscle B is an extensor. If Muscle B is stretched, then it will have more tension in it due to its spring-like properties than muscle A, and will therefore naturally pull itself back to the original position, similar to other elastic materials. Thus, the system maintains posture rather nicely. The tension in the musculature, or the relative stiffness, is maintained much in part by the tonic stretch reflex, and also by the monosynaptic reflex. The contribution of the two depends on length and rate changes. Tension in a muscle can be adjusted without actual length changes in the muscle; the key is to change the length of the equatorial region of the muscle spindle itself.

Note: Recall that muscle spindles also provide proprioceptive feedback to the brain. This is accomplished by a further branch, which ascends to the brain and synapses on interneurons in that region. Such information is used to make further adjustments to the environment. Therefore, when a muscle is suddenly stretched, the myotactic reflex (or m1 or mono synaptic) is activated, along with reciprocal

innervation (discussed shortly), and finally the information is carried to higher centers of the executive. An amazing combination.

Gamma System

This brings the paper to the next subject, which is concerned with the Gamma Motor system. The gamma motor system is very much responsible for enhancing or decreasing the sensitivity of the tonic and phasic reflexes, and is based very much on feedforward signaling.

The polar ends of muscle spindles are innervated by gamma motor neurons. These neurons are influenced consciously, in that they originate in the motor area of the cortex. Ultimately, it is when the equatorial region of a muscle spindle is stretched or mechanically deformed that afferent Ia and afferent II receptors are stimulated to threshold. When the muscle endings of the intrafusal fibers contract, they can stretch the equatorial region without a change in muscle length. Consequently, by feedforward signaling, the gamma motor neurons increase the firing rate of the spindles. This has the effect of calling into play further muscle fibers, which increases the tension in the musculature. When you tense up and prepare for an all out exertion, much of that tension is due to the gamma motor system working. Anticipation, in and of itself, is a fascinating topic, and a big issue in bodybuilding and indeed exercise science as a whole. Further, it appears that when alpha motor neurons are activated, gamma fibers are activated with them. That is, when an individual voluntarily contracts a muscle, the length shortens. The spindle fibers need to adjust to this length in case a rapid disturbance occurs to the system. Therefore, the Alpha-Gamma-Co-Activation system allows the spindles to adapt to length changes, as they almost always are active together. A point the reader should not miss is this: the gamma motor system can be influenced psychologically!

Reciprocal Inhibition

When the knee extensors contract, the knee flexors are turned off so that the flexors do not interfere with the extensors; this is known as Reciprocal Inhibition. Afferent neurons carry information to the dorsal root and branch when they hit the spinal cord, such that one of its branches connects to an inhibitory interneuron, which itself controls the antagonist musculature. This is an oligosynaptic reflex.

Golgi Tendon Organ

The Golgi Tendon organ is comprised of a connective tissue capsule, which houses sensory receptors from neurons. It is in series, and intertwined in the junction between the tendon and the muscle. During muscular contraction, tension in the junction between the tendon and muscle increases, and this causes the receptors of the afferent fibers to increase their rate of firing. The greater the tension in the muscle or the greater the contraction used to overcome a load, the higher the firing rate. The information is carried to the spinal cord, in which the afferent fiber connects with an interneuron, which inhibits muscular contraction of the muscle causing tension in the tendon and also branches and connects with an excitatory neuron, thereby augmenting muscular contraction of the antagonist muscle group. This is known as the reverse stretch reflex.

The action of the golgi tendon organ serves a plethora of functions. The first is that it inhibits an individual from handling loads great enough to rip the tendon from the musculature. The tendon also provides for smooth contraction of the musculature involved in the production of torque. That is, it turns off unnecessary muscle fibers and makes sure that only those needed to produce the proper amount of tension are initiated.

Proprioceptive Neuromuscular Facilitation – A Review

Knowlden (2004) discussed the properties involved in Proprioceptive Neuromuscular Facilitation. In review, he issued the fact that this technique is based on properties involved in both the muscle spindles and the golgi tendon organ. Here is a quote from the paper:

PNF was first developed by physical therapists and is now widely accepted as a helpful method of increasing range of motion. The PNF method involves slowly placing the muscle or joint in a static stretch while keeping the muscle relaxed.

Subsequent to this static stretch, the muscle is briefly contracted isometrically against a selected, external force, acting in the same direction as the stretch. This force should be resistant enough to avert any movement in the joint. The muscle or joint is taken out of the stretched position momentarily and a second stretch is completed, potentially resulting in a greater stretch.

The isometric contraction will effect the stimulation of the particular Golgi tendon organs, which may help maintain low muscle tension during the terminal stretching maneuver, allowing for connective tissue to further lengthen and increase, resulting in increased ROM.

Note how Knowlden (2003) discussed using the reverse stretch reflex. Numerous studies support the neurological responses to such a technique. Moore and Kukulka (1991) investigated the rationale underlying proprioceptive neuromuscular facilitation relaxation techniques. Sixteen females were asked to isometrically contract the plantar flexors of the leg. The time response depression of the Hoffman Reflex was then tested. The H-reflex involves stimulating the nerve innervating the musculature, and measuring the amplitude of electrical stimulation needed to activate the target region. If the neurons are inhibited, then it will take a greater stimulus to initiate the response. It was found that the Hoffman reflex was depressed for 10.5 seconds after the isometric contraction. That is, the alpha motor

neurons were experiencing inhibition from the reverse stretch reflex. In another study, Enoka, Hutton, and Eldred (1980) found that "the H-wave on successive trials over a 50 sec period following contraction for the most part demonstrated a depression."

An interesting PNF technique is one which utilizes reciprocal inhibition. When a muscle contracts it also inhibits the antagonist muscle from contracting. Thus, the rationale is to actually contract the agonist muscle while the antagonist is being stretched, which may inhibit that muscle further. This means that you would contract the biceps when the triceps were being stretched. The techniques can also be combined. In this case you would perform the same protocol, with the addition of contraction of the agonist while the antagonist was being stretched. It is important, however, to take care, as this may cause injury if you do not take the proper precautions which are laid out in the Knowlden (2004) paper.

Conclusion

A gateway has been opened and where it leads is future breakthrough issues of The Journal of HYPERplasia Research. Issues, which can travel toward endless avenues of information yielding processes.

Dr. Werner Gitt, considered the worlds leading expert in the Information Theory has this comment on the complexity of the human body

'Without a doubt, the most complex information-processing system in existence is the human body. If we take all human information processes together, i.e. conscious ones (language, information-controlled, deliberate voluntary movements) and unconscious ones (information-controlled functions of the organs, hormone system), this involves the processing of 10^{24} bits daily. This astronomically high figure is higher by a factor of 1,000,000 [i.e., is a million times greater] than the total human knowledge of 10^{18} bits stored in all the world's libraries.'

Dr Werner Gitt, in *Information: The Third Fundamental Quantity*, (reprint from) *Siemens Review*, **56**(6), November/December 1989.

As we ponder the complexity of the brain, and the body it is essential to give credit to the one who designed it.

Psalms 139: 14 I will praise thee; for I am fearfully and wonderfully made

Jacob Wilson

President Abcbodbuilding / Co-Editor of The Journal of HYPERplasia Research

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