Development of quantitative therapeutic tool for motion disorder patients using Hill's equation and neuronal modelling of motor pathways

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DEVELOPMENT OF QUANTITATIVE THERAPEUTIC TOOL FOR MOTION DISORDER PATIENTS USING HILL'S EQUATION AND NEURONAL MODELLING OF MOTOR PATHWAYS HO WEE KIAT DESMOND 2011

NANYANG TECHNOLOGICAL UNIVERSITY

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ABSTRACT

Studying the principles governing human movement can help us understand more about human locomotion which in turn can help to improve existing rehabilitation methods. Currently there is a lack of quantitative method to record improvements of patients with motion disorder undergoing treatment through rehabilitation or drugs intake. This project focused on two main objectives to provide a solution for the above. A close loop reflex system has been developed with the identification of a good mechanical model.

The mechanical model was generated based on Hill's equation and research comprising of theoretical and experimental analyses of interaction between motor and sensory control mechanisms had been carried out to formulate the reflex loop control system. Data and results generated proved that the mechanical model exhibit the actual mechanics and characteristics of muscle movements, thus made it suitable for the proposed reflex loop system.

Doctors and physiotherapists will be able to use this reflex loop control system to quickly quantify physical improvement of patients with motion disorder usually cause by neural disease. The research can be enhanced with clinical trials to further prove the effectiveness of the control system. It is essential to collect more data on the different size of muscles and limbs, store them into a database and create a simple program to feed the data into the reflex loop. This will allow practitioners to work on a wider range of limbs movements.

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Finally the author would like to thank his family for their restless support and encouragement.

TABLE OF CONTENT

TABLE OF CONTENT

Pg

TABLE OF CONTENT

Pg

LIST OF FIGURES

LIST OF FIGURES

Pg

LIST OF FIGURES

Pg

LIST OF TABLES

CHAPTER ONE

Introduction

1.1 BACKGROUND

1.1.1 Structures of the Nervous System

The nervous system is a complex, highly organized network of billions of neurons and even more neuroglia. The structures that make up the nervous system include brain, cranial nerves and their branches, the spinal cord, spinal nerves and their branches, ganglia, enteric plexuses, and sensory receptors. [1] It is unique in the vast complexity of thought processes and control actions it can perform. It receives each minute literally millions if bits of information from the different sensory nerves and sensory organs and then integrates al these to determine responses to be made by the body. [2] These diverse activities can be grouped into three basic functions: sensory, motor and integrative.

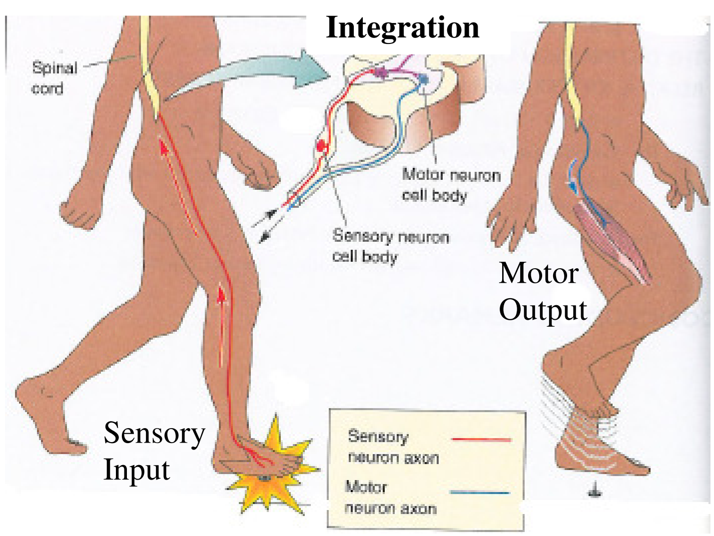


Figure 1.Components of nervous system. [3]

Sensory function: Most of our activities are initiated by sensory experience exciting the sensory receptors. Sensory receptors detect internal stimuli such as an increase in blood acidity, and external stimuli such as something sharp piercing your foot. Sensory information is carried from cranial and spinal nerves into the brain and spinal cord or from a lower to a higher level in the spinal cord and brain by sensory or afferent neurons.

Motor function: The most important eventual role of the nervous system is to control the various bodily activities by contraction of appropriate skeletal muscles throughout the body, contraction of smooth muscle in the internal organs and secretion of active chemical substances. The nervous system's motor function involves responding to integration decisions. The neurons that serve this function are motor or efferent neurons. Motor neurons carry information from the brain toward the spinal cord or out of the brain and spinal cord into cranial or spinal nerves. The cells and organs contacted by motor neurons in cranial and spinal nerves are termed effectors for example the muscle fibers.

Integrative function: The nervous system integrates (processes) sensory information by analyzing and storing some of it and by making decisions for appropriate mental and motor responses. Many of the neurons that participate in integration are interneurons, whose axons extend only for a short distance and contact nearby neurons in the brain, spinal cord or a ganglion. Interneurons comprise the vast majority of neurons in the body.

1.1.2 Reflex Activity

During normal movements, the central nervous system (CNS) uses information from a vast array of sensory receptors to ensure the generation of the correct pattern of muscle activity [4]. Sensory information from muscles, joints, and skin, for example, is essential for regulating movement. This is why the spinal cord is strategically located between the brain and afferent and efferent fibers of the peripheral nervous system; this location enables the spinal cord to fulfill its two primary functions: (a) serving as a link for transmission of information between the brain and the remainder of the body and (b) integrating reflex activity between afferent input and efferent output without involving the brain. This type of reflex activity is known as a spinal reflex [5].

A reflex is a fast, involuntary, unplanned sequence of actions that occurs in response to a particular stimulus [1]. There are two types of reflexes:

Simple or basic, reflexes, which are inborn or unlearned responses, such as pulling your hand away from some burning hot object before you even feel that it is hot.

Acquired or conditioned, reflexes, which are a result of practice and learning. For example, you learn many reflexes while acquiring driving expertise. Slamming on the brakes in an emergency is one example.

Nerves impulses propagating into, through, and out of the CNS follow specific pathways, depending on the kind of information, its origin, and its destination. The pathway followed by nerve impulses that produce a reflex is a reflex arc or reflex circuit. A typical reflex arc includes five basic components, receptor, sensory neuron, integrating center, motor neuron and effector.

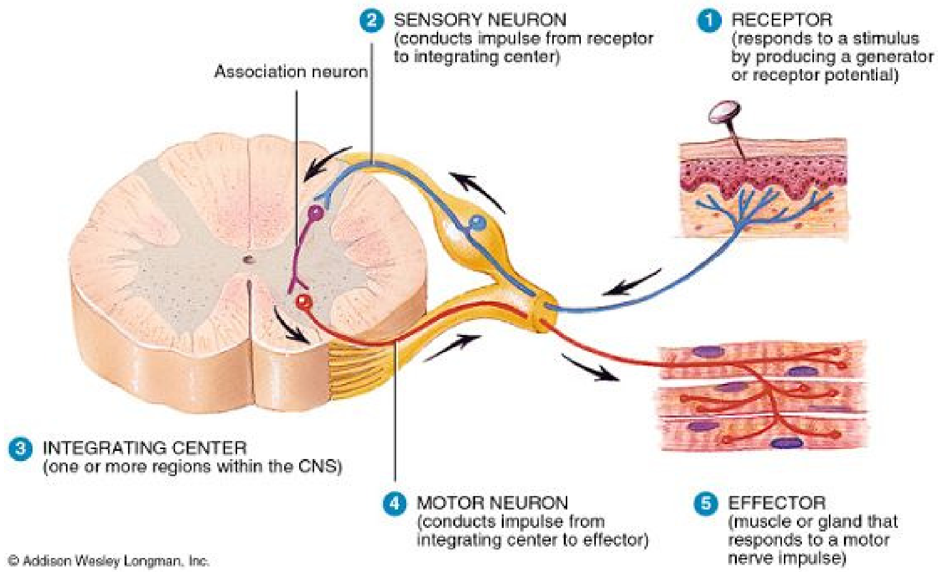


Figure 2.General components of a reflex arc. [6]

Sensory Receptor: The sensory receptor will responds to a specific **stimulus** that is caused by a change in the internal or external environment by producing graded potential. Once the graded potential reaches the threshold level of depolarization, it will trigger nerve impulses in the sensory neuron.

Sensory Neuron: The electrical impulse will propagate from the receptor (dendrite) along the axon of the sensory neuron to the axon terminals. The axon terminals are usually located in the gray matter of our spinal cord or brain stem.

Integrating Center: In most cases, the central nervous system, CNS is the integrating center. The spinal cord and brain stem are responsible for integrating basic reflexes. The integrating center processes all information available to it from this receptor as well as from other inputs. "A decision" will then be made for the adequate response which will be transported out.

Motor Neuron: The motor neuron transport impulses triggered by the integrating center out of it and send the impulse to the part of body that will respond.

Effector: A muscle or gland which carries out the desired response. Unlike conscious behaviour, in which any one of a number of responses is possible, a reflex response is predictable, because the pathway between the receptor and effector is always the same.

1.1.3. Neurological Disorder

Neurological disorder occurs when the nervous system of human is affected. Changes to the electrical and chemical properties of the neurons cause these disorders. Neurological disorder affecting the motor control of the body is most commonly seen. General movements like walking, talking and breathing. One of the most common motor disorder is the Parkinson's disease.

Parkinson's disease occurs when nerve cells, or neurons, in an area of the brain known as the substantia nigra die or become impaired. [7] The true cause of PD is not known yet till present but studies have shown that abnormal nerve firing patterns within the brain that cause impaired movement are the results of decreased stimulation of the motor cortex by the basal ganglia, normally caused by the loss of dopamine. [8]

Not all PD patients will suffer the exact same symptoms of the disease. PD symptoms often begin on one side of the body, and eventually progress to both side. Usually one side of the body will be more affected than the other. The four primary symptoms of PD motor symptoms that affect movement are namely tremor, rigidity or resistance to movement, postural instability and slowing down and loss of spontaneous and automatic movement. There are also other symptoms which are all non-motor related.

Currently there is no cure for PD, but patient can improve from this disease via medication, rehabilitation as well as physiotherapy. Common medications used are Dopamine agonists, Levodopa and MAO-B inhibitors which all in a way or other produces more dopamine in the substantia nigra to aid in improve motor sensory.

1.1.4. Symptom Analysis

Currently the most common way used by physiotherapies or doctors to judge the improvements of motor disorder patients is by pure visual observation. How patient reacts to stimulation or the magnitude of tremor on their limbs when they are asked to perform some movement will be a gauge for their progress during treatment. A better way to quantify patient's improvements during treatment will be through measuring the exact time the patient will take to react to stimulation or how long a body part takes to make a controlled motion from a position to another. From simple muscle and joints modeling coupled with the firing frequency of neuron, we will be able to quantify patient's condition during their treatment with drugs and rehabilitation.

1.2 Objective

The objectives of this report are:

1. Develop a control system to quantify physical improvement of patient with motion disorder caused by neurological disease.
2. Identify a good mechanical model and implement onto the control system.

1.3 Scope

The scope of the project encompasses the understanding of fundamentals of neurological activities, the human spinal reflex, relationship between muscle force and its contraction speed. Lastly the modeling of motor pathway will help to set up a system to quantify data obtained. These can be achieved with the followings;

1. Study of synaptic activities of neurons and effect of drugs on neurological activity with proven mathematical algorithm.
2. Develop a simplified mechanical model of muscle on links to explain the Biomechanics of muscle Reflex.
3. Provide a quantifiable mathematical algorithm to study joint movements using Hill Equation.
4. Form a simplified close loop system to aid in quantitative physiotherapy activity feedback.

CHAPTER TWO

Literature Review

2.1 Cells of the Nervous System

The nervous system is composed primarily of two cells: support cells known as glial cells (glia or neuroglia) and nerves cells (neurons), the basic signaling of the nervous system [5]. The functional unit of the nervous system is the neuron. Most neurons have 3 parts namely, the cell body, dendrites and axon.

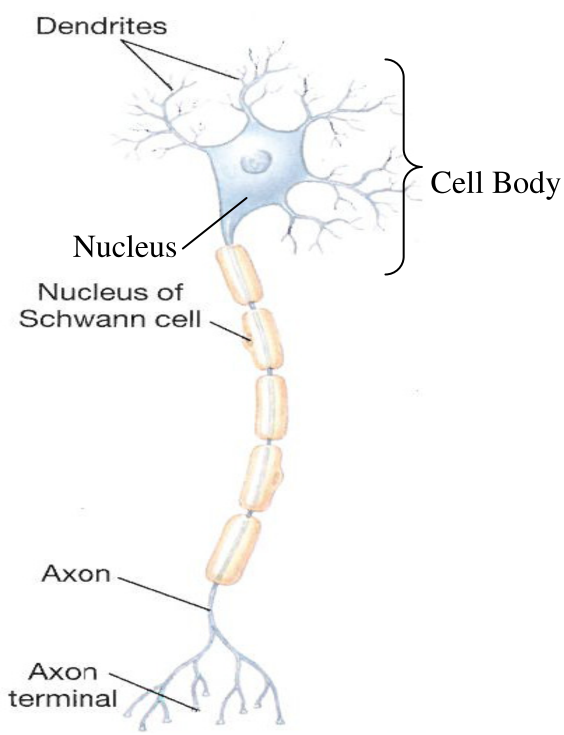


Figure 3. Schematic diagram of biological neuron. [5]

The cell body is the control center of the neuron. The cell body contains a nucleus surrounded by cytoplasm that includes typical organelles such as lysosomes, mitochondria, and a Gogli complex. Protein synthesis sites can also be found inside the cell body.

There are two kinds of processes or extensions emerging form the cell body of a neuron. They are multiple dendrites or a single axon, which are also termed as nerve fiber. Dendrites are receiving or input portions of a neuron. Dendrites increase the surface area of a neuron, allowing it to communicate with multiple other neurons.. They are short, tapering, and highly branched and form a tree-shaped array of processes extending from the cell body.

Axons carry outgoing signals to the target. The single axon of a neuron propagates nerve impulses toward another neuron, a muscle fiber, or a gland cell. An axon is a long, thin, cylindrical projection that often joins the cell body at a cone-shaped elevation called the axon hillock. Impulses arises at the trigger zone (junction of the axon hillock) and conduct along the axon. Axons vary from over a meter in length to only a few micrometers long. They often branch sparsely along their length, forming collateral which ends in a swelling end called the axon terminal. Functionally, axons transmit outgoing electrical signals from the integrating center of the neuron to the end of the axon. At the distal end of the axon, the electrical signal is usually translated into a chemical message: secretion of neurotransmitter or neuromodulators. Neurons that secrete neurotransmitter and neuromodulators terminate near their target cells, which are other neurons, muscles, or glands.

The region where an axon terminal meets its target cell is called a synapse. The neuron that delivers that signal to the synapse is known as the presynaptic cell, and the cell that receives the signal is called the postsynaptic cell. The narrow space between the two cells is called the synaptic cleft.

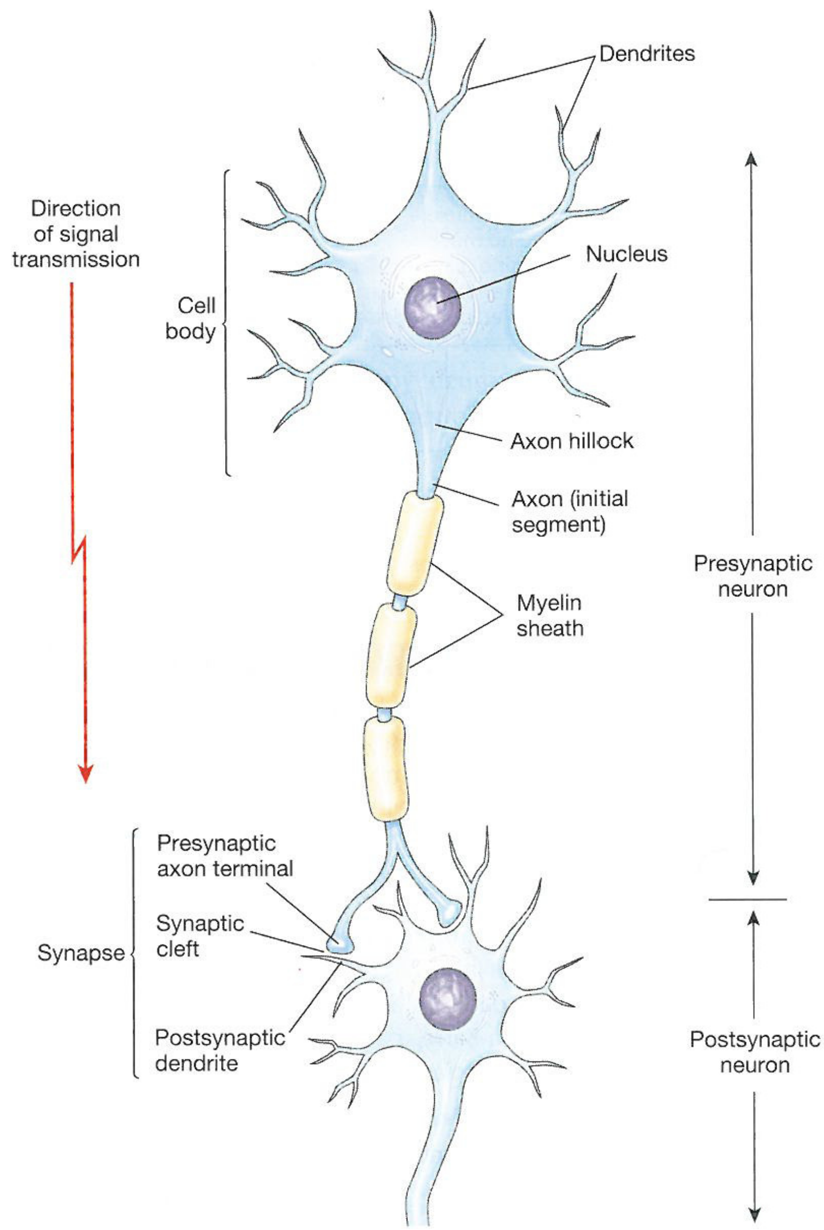


Figure 4. Pre, Postsynaptic signal transmission. [5]

2.2 Neuronal Physiology

All body cells display a membrane potential, which is a separation of positive and negative charges across the membrane. This potential is related to the uneven distribution of Na+, k+, and large intracellular protein anions between the intracellular fluid and extracellular fluid, and to the differential permeability of the plasma membrane to these ions [9]. Both nerve cells and muscle cells have developed a specialized use for this membrane potential. Electric signals are given out when there is fluctuations in potential across their membrane. Cell not displaying rapid change in potential is known to be at its

resting potential typically at -70mV.Both muscle and nerve are considered excitable tissues because when excited they change their resting potential to produce electrical signals. Nerve cells use these electrical signals to receive, process, initiate, and transmit contraction. In muscle cells these electrical signals initiate contraction. We can see that electrical signals play an important role in the function of the nervous system as well as all muscles.

2.2.1 Graded Potential

Graded potential are local changes in membrane potential that occur in varying grades or degrees of magnitude or strength. Graded potential are usually produced by a specific triggering event that causes gated ion channels to open in a specialized region of the excitable cell membrane. Changes in potential can be described by the followings:

- **Polarization**: Changes are separated across the plasma membrane, so that the membrane has potential. So long the membrane potential is not at 0mV, be it in the positive or negative direction, the membrane is in a state of polarization.
- **Depolarization**: A change in potential making it less polarized (less negative) than at resting potential, moving it towards 0mV.
- **Repolarization**: Membrane potential returns to its resting state after being depolarized.
- **Hyperpolarization**: A change in potential making it more polarized (more negative) than at resting potential, moving it even further than 0mV.

Graded potentials are usually spread by passive current flows and die out over a short distances. The passive current flow between active and adjacent inactive areas is similar to the means by which current is carried out through electrical wires. Current is lost across the cell membranes as charge carrying ions leak through the "un-insulated" parts of the membrane, that is, through open channels causing local current to progressively diminish.

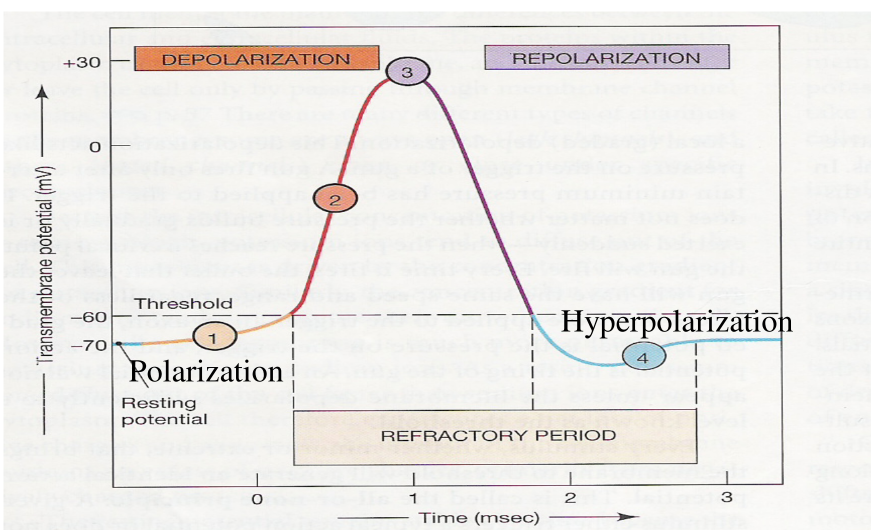


Figure 5. Graded membrane potential. [10]

2.2.2 Action Potential

An action potential or impulse is a sequence of rapidly occurring events that take place in either the depolarizing phase or the repolarizing phase. During an action potential, two types of voltage-gated channels present mainly in the plasma membrane of the axon and axon terminals open and then close. The Na+ channels allow Na+ to rush into the cell causing depolarizing phase to occur. K+ channels then open allowing K+ to flow out; causing repolarizing phase to occur. All this typically happen in about 1ms in a typical neuron. When depolarization reaches a certain level termed threshold potential (-55mV in most neurons), the voltage-gated channels open, and an action potential follows. If the threshold is not reached in response to the depolarizing event, no action potential occurs. All Action potentials are identical and they do not diminish in strength as they travel through the neuron. The mechanism through which action potentials are generated and conducted along the axon allows them to stay constant. Action potential measured at the distal end of an axon is identical to the action potential that started at the trigger zone. This property is essential for the transmission of signals over long distances, such as from a finger tip to the spinal cord.

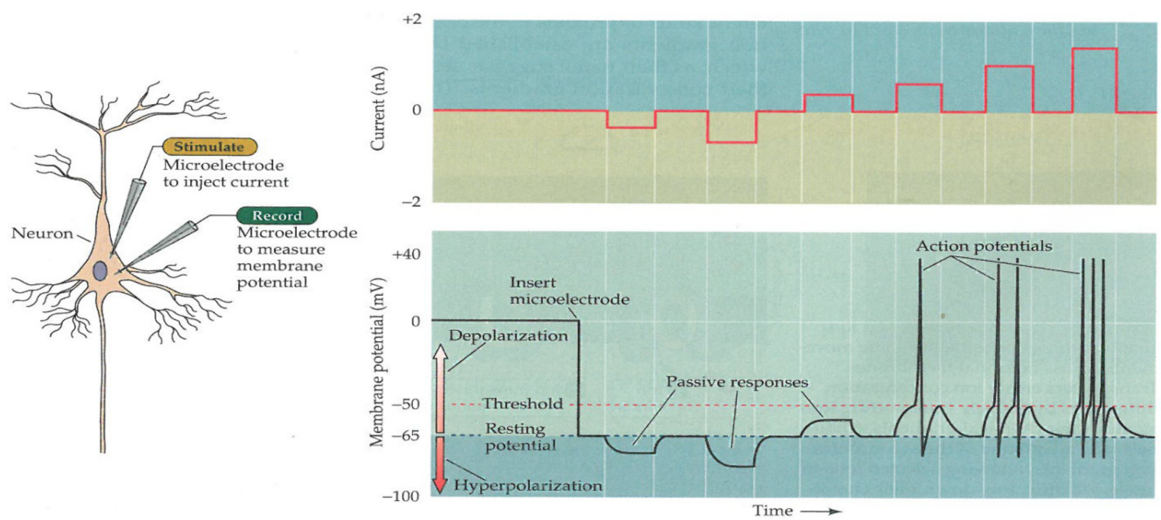


Figure 6. Recording of action potential with injection of current. [12]

Speeds of action potential conduction in mammalian neurons are influenced by two key factors. They are the diameter of the neurons and the resistance of the neuron membrane to leak out of the cell. The larger the diameter of the axon or the more leak-resistant the neuron membrane, the faster an action potential will move. Myelinated axons have greater membrane wall resistant thus better in preventing current from leaking out of the membrane.

Table 1. Characteristic of different axon fibers. [12]

Fiber	dia (μm)	Conduction Speed (m/s)	Myelinated	Description
α	5 - 20	12 - 130	Yes	Sensory neurons that propagate impulses associated with touch, pressure, position of joints, and some thermal sensations. Axons of motor neurons that conduct impulses to skeletal muscles.
β	2 - 3	15	Yes	Conduct Sensory nerve impulses from viscera to the brain and spinal cord. Constitute all the axons of the autonomic motor neurons that extend from brain and spinal cord to the automatic nervous system.
γ	7 - 20	0.5 - 2	No	Unmyelinated axons conducting sensory impulses for pain, touch, pressure, heat and cold from skin, and pain impulses from viscera Automatic motor fibers that extend from autonomic ganglia to stimulate heart, smooth muscle, and glands.

2.3 Synaptic Functions of Neurons

Information is transmitted in the central nervous system mainly in the form of nerve action potentials known as nerve impulses through a succession of neurons, one after another. However, in addition, each impulse may either be blocked in its transmission from one neuron to the next, or it may be changed from a single impulse into repetitive impulses, or it may be integrated with impulses from other neurons to cause highly intricate patterns of impulses in successive neurons. There are two major types of synapses, Chemical synapse and Electrical synapse.

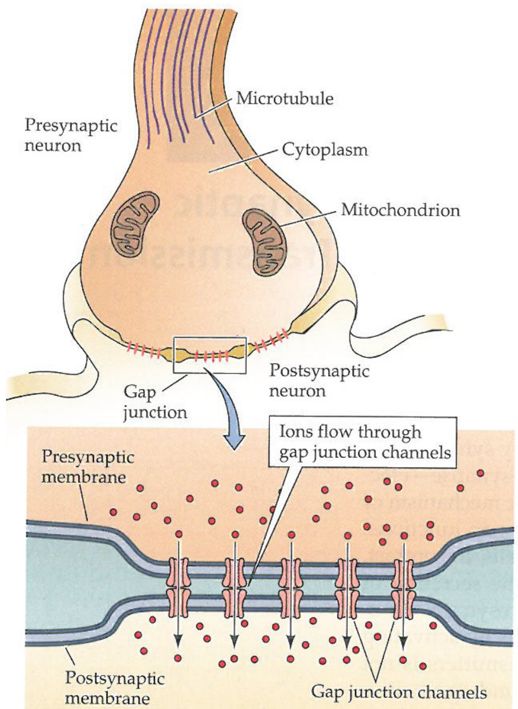


Figure 7. Electrical Synapse. [12]

Electrical synapse are characterised by direct open channels that conduct electricity from one cell to the next. Most of these consist of small protein tubular structures called gap junctions that allow free movement of ions from the interior of one cell to the interior of the next. Only a few examples of gap junctions have been found in the central nervous system. However, it is by way of gap junctions and other similar junctions that action potentials are transmitted from one smooth muscle fibre to the next in visceral smooth muscle and from one cardiac muscle cell to the next in cardiac muscle. The primary advantage of electrical synapses is rapid conduction of signals from cell to cell. Advantages of electrical synapse are faster communications because action potentials conduct directly through gap junctions and electrical synapse can synchronise the activity of a group of neurons or muscle fibers.

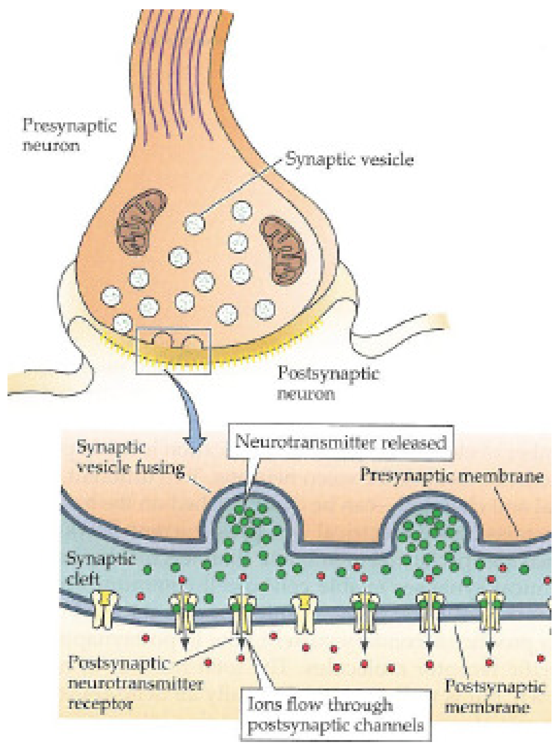


Figure 8. Chemical Synapse. [12]

Chemical synapses are the vast majority of synapses in the nervous system that use neurotransmitters to carry information from one cell to the next. The first neuron secretes at its nerve ending synapse (presynaptic) a chemical substance which is commonly known as neurotransmitter. This transmitter in turn acts on receptor proteins in the membrane of the next neuron's synapse (postsynaptic) producing a postsynaptic potential, to either excite or inhibit it, or modify its sensitivity in some other way. The time required for these processes at a chemical synapse, the synaptic delay is about 0.5 msec. This delay is the reason that chemical synapses relay signals more slowly than electrical synapses. Although the plasma membranes of presynaptic and post synaptic neurons in a chemical synapse are close, they do not touch. The synaptic cleft, a space of 20-50 nm that is filled with interstitial fluid, separates the two neurons.

Chemical synapses have one exceedingly important characteristic that makes them highly desirable for transmitting most nervous system signals: they always transmit the signals in one direction [2]. Think for a moment about the extreme importance of the one-way conduction mechanism. It allows signals to be directed toward specific goals. Indeed it is this specific transmission of signals to discrete and highly focused areas both within the nervous system and at the terminals of the peripheral nerves that allows the nervous system to perform its myriad functions of sensation, motor control, memory, and many others.

2.3.1 Excitatory and Inhibitory Postsynaptic Potentials

A neurotransmitter causes either an excitatory or an inhibitory graded potential. If it depolarizes the post synaptic membrane, it is excitatory as it brings the membrane closer to threshold. A depolarizing postsynaptic potential is called an excitatory postsynaptic potential (EPES). Although a single EPSP normally does not initiate a nerve impulse, the postsynaptic neuron does become more excitable. It is partially polarized and thus more likely to reach threshold when the next EPSP occurs. If a neurotransmitter causes hyperpolarisation of the postsynaptic membrane, it is inhibitory. During hyperpolarisation, generation of a nerve impulse is more difficult than usual. The membrane potential is more negative and thus further away from threshold than it was in its resting state. A hyperpolarizing potential is termed as inhibitory postsynaptic potential (IPSP).

2.3.2 Spatial and Temporal Summation of Postsynaptic Potentials

A typical neuron in the CNS receives input from 1000 to 10000 synapses. Integration of these inputs, is known as summation, occurs at the trigger zone. The greater the summation of EPSPs, the greater the chance that threshold will be reached. At threshold, one or more nerve impulses (action potentials) arise. The postsynaptic neuron can be brought to threshold in two ways: (1) temporal summation and (2) spatial summation. When summation results from buildup of neurotransmitter released by several presynaptic end bulbs, it is called spatial summation. When summation results from buildup of neurotransmitter released by a single presynaptic end bulb two or more times in a rapid succession, it is called temporal summation. Most of the time, spatial and temporal summations are acting together to influence the chance that a neuron fires an impulse. The sum of all the excitatory and inhibitory effects at any given time determines the effect on the post synaptic neuron in the following ways:

- **EPSP.** If the total excitatory effects are greater than the total inhibitory effects are greater than the total inhibitory effects but less than the threshold level of stimulation, the EPSP does not reach threshold. Subsequent stimuli can easily generate an impulse through summation as the neuron is partially depolarized.
- **Nerve impulse(s).** If the total excitatory effects are greater than the total inhibitory effects and threshold level of stimulation is reached or surpassed, the EPSP spreads to the initial segment of the axon and triggers one or more nerve impulses. Impulses continue to be generated as long as the EPSP is above the threshold level.
- **IPSP.** If the total inhibitory effects are greater than the excitatory effects, the membrane hyperpolarizes. The result is inhibition of the postsynaptic neuron and an inability to generate a nerve impulse.

  IPSP is important in human nervous system to help prevent excessive spread of signals and to stabilize neuronal circuits.

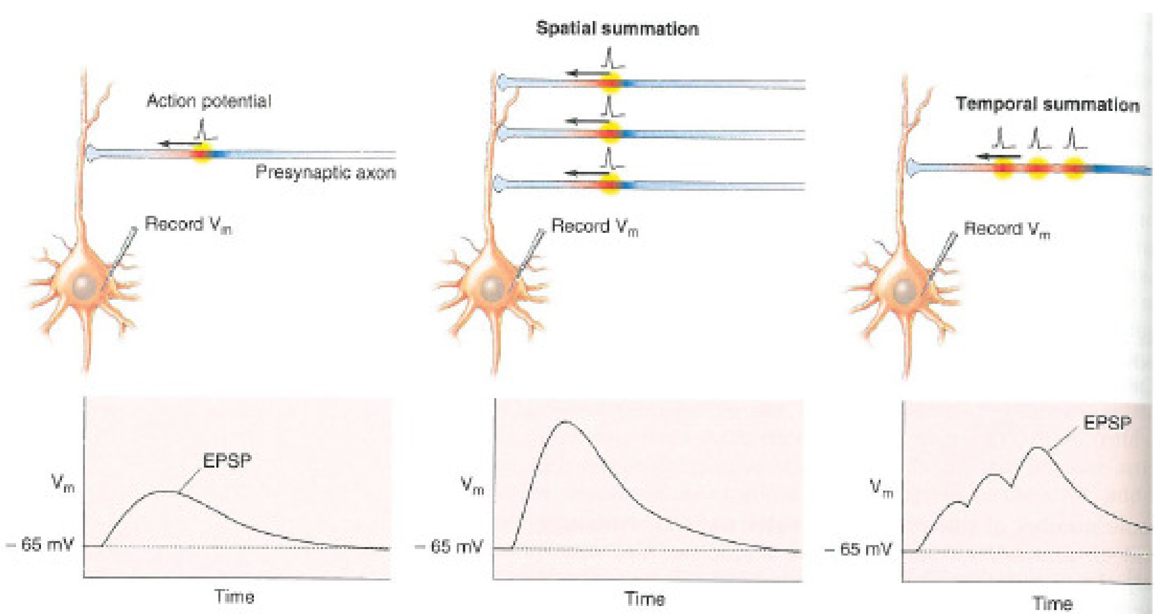


Figure 9. Spatial and temporal summation. [3]

2.4 Muscle Mechanics

From the Introduction, we can see how neurons pass information from one to another to allow muscle contraction to react upon external stimulation. A muscle fiber contracts in response to one or more action potentials propagating along its sarcolemma and through its T tubule system. Muscle action potentials arise at the neuromuscular junction, the region of synaptic contact between a somatic motor neuron and a skeletal muscle fiber.

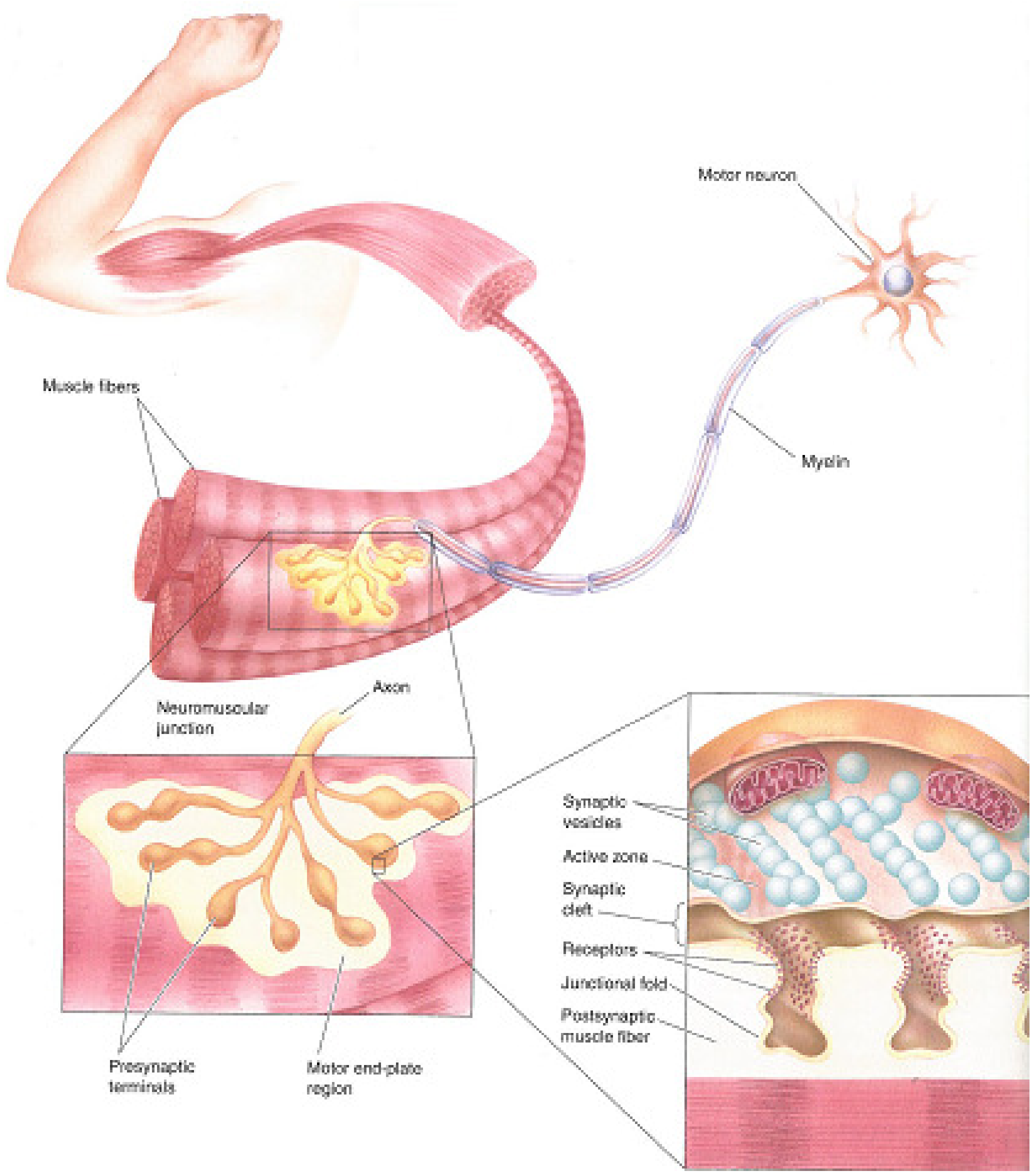


Figure 10. Neuromuscular Junction. [3]

2.4.1 Muscle Tissues

There are three types of muscle tissues namely, skeletal, cardiac and smooth. All three share the some properties but they differ from one another in their anatomy, location and control by nervous and endocrine systems.

Skeletal muscle tissues made up skeletal muscles which are used to move bones of skeleton. Skeletal muscle tissue works mainly in a voluntary manner. Its activity can be consciously controlled by neurons that are part of the somatic division of the nervous system.

Cardiac muscle tissues form most of the heart wall. Cardiac muscle is also striated, but its action is involuntary. An example will be the alternating contraction and relaxation of the heart which is not consciously controlled.

Smooth muscle tissue is located in the walls of hollow internal structures, such as blood vessels, airways, and most organs in the abdominopelvic cavity. The action of smooth muscle is usually involuntary.

Both cardiac muscle and smooth muscle are regulated by neurons that are part of the autonomic division of the nervous system and by hormones released endocrine glands.

Through sustained contraction or alternating contraction relaxation, muscle tissue has four key functions. It produces body movements, stabilizes body positions, stores and move substances within the body, and generates heat.

2.4.2 Sensors in Muscle

Muscle spindles and Gogli tendon organs are the two main types of sensors found in muscle.

Muscle spindles are small encapsulated sensory receptors that have a spindle-like or fusi-form shape located within the fleshy part of muscle. Their main function is to signal changes of length of the muscle within which they reside. Changes in length of muscles are closely associated with changes in the angles of the joints that the muscles cross. Thus, muscle spindles can be used by the central nervous system to sense relative positions of the body segments.

Gogli tendon organs is a proprioceptive sensory receptor organ that sense of the relative position of neighbouring parts of the body. It is located at the insertion of skeletal muscle fibres into the tendons of skeletal muscle. During muscle contraction the strands of collagen are stretched as the muscle shortens. This stretching deforms the terminals of the afferent axon, opening stretch-sensitive cation channels. As a result, the axon is depolarized and fires nerve impulses up to the central nervous system via the spinal cord. The action potential frequency signals the force being developed within the muscle.
In short muscle spindles measure the displacement of a muscle while gogli tendon organs measure the force in the tendon (muscle force).

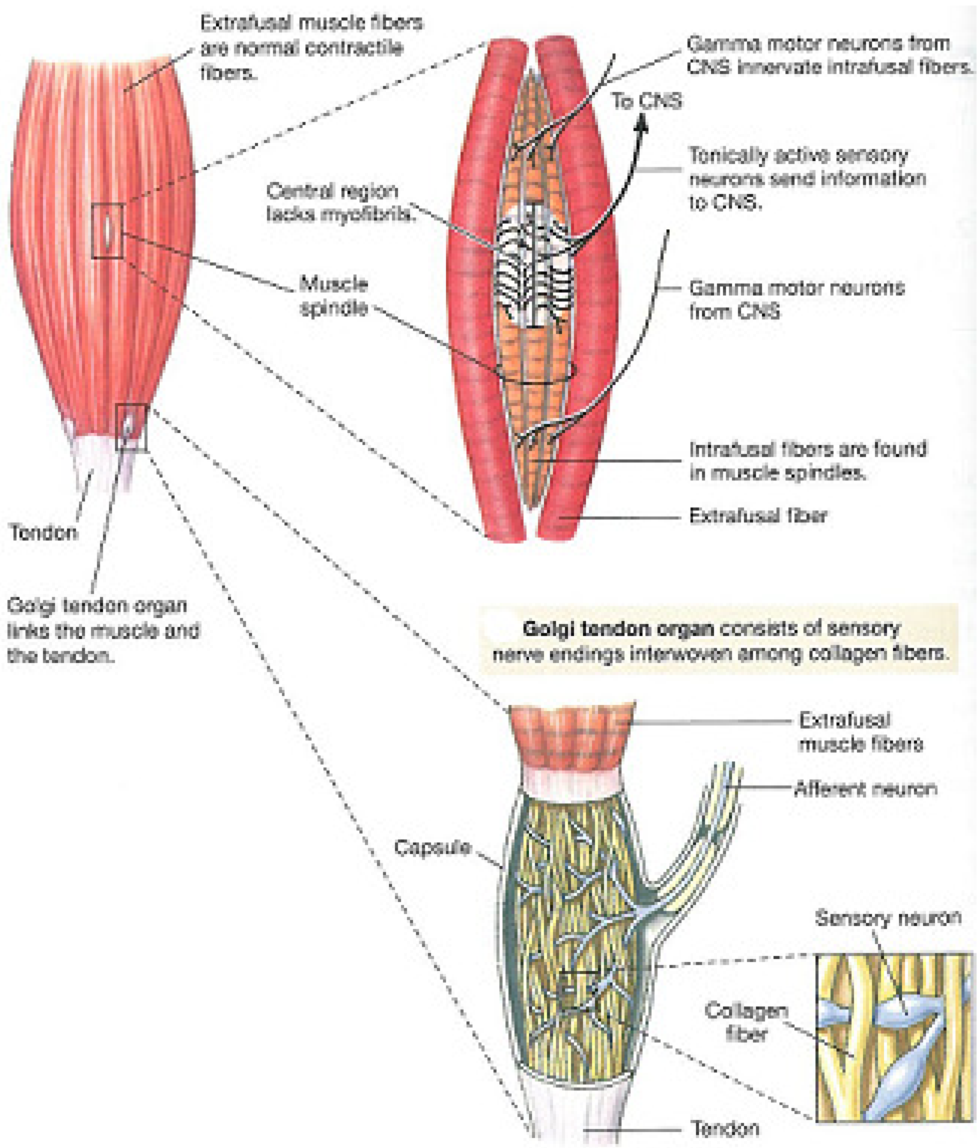


Figure 11. Muscle Spindle and Gogli Tendon Organs. [3]

Table 2. Comparison of Properties of Receptors in Muscle.

Property	Primary Ending	Secondary Ending	Golgi Tendon Organ
1. Location	Mid-equatorial region of bag and chain fibers in spindles	Juxta-equatorial region of chain fibers in spindles	Muscle-tendon junction
2. Afferent fiber	Large, group Ia	Small, group II	Large, group Ib
3. Efferent control	Both static and dynamic fusimotor	Static fusimotor	None known
4. Response to ramp stretch with plateau	Dynamic and static (signals length)	Static (signals length)	Dynamic and static (signals tension)
5. Response to release of stretch	Abrupt silence	Progressive decrease	Abrupt silence
6. Response to tendon tap	Low threshold, vigorous	High threshold, little	High threshold, vigorous if threshold is exceeded
7. Sensitivity to small stretches	High, especially if rapid	Low	Low
8. Response to twitch contractions	Abrupt silence	Abrupt silence	Vigorous discharge
9. Signals	Muscle length and rate of change of length	Muscle length	Muscle tension and rate of change of tension

2.4.3 Muscle Control and Tension

Even though each skeletal muscle fiber has only a single neuromuscular junction, the axon of a motor neuron branches out and forms neuromuscular junctions with many different muscle fibers. A motor unit consists of a somatic motor neuron plus all the skeletal muscle fibers it stimulates. A single motor neuron makes contact with an average of 150 muscle fibers in one motor unit contract in unison. The total strength of a muscle contraction depends on how large the motor units are and how many motor units are activated at the same time.

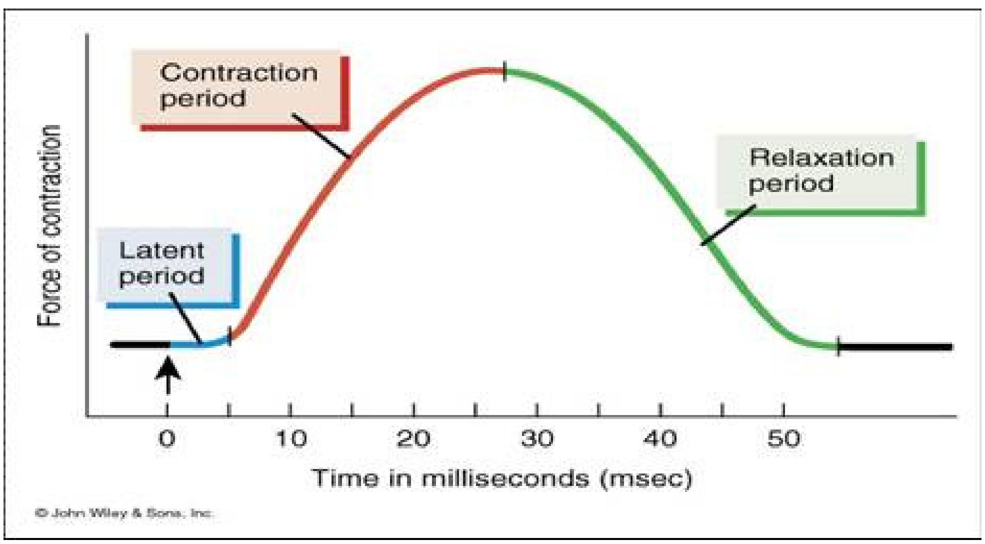


Figure 12. Muscle Twitch Contraction. [1]

All muscle fibers in a motor unit twitch contract in response to a single action potential in its motor neuron. Twitches of skeletal muscle fibers can last from 20 to 200 msec. This duration is very long compared to the brief 1-2 msec duration of an action potential. The contraction begins with a short delay of about 2 msec known as the latent period. Contraction period follows and last about 10-100 msec. The third phase, relaxation period last about 10-100 msec too. Examples of fast and slow twitch muscles are eye muscles (10 msec) and leg moving muscles (100 msec). If two stimuli are applied, one immediately after the other, the muscle will respond to the first stimulus but not the second. When a muscle fiber receives enough stimulation to contract, it temporary loses its excitability and cannot response for a time. This period of lost excitability is known as the refractory period.

2.4.4 Polysynaptic Stretch Reflex Circuitry

In most cases, limb segments are connected by extensor and flexor muscle. Once the extensor is stretched, it will send out a firing frequency. In this case, the subject will have to hold onto the mug while liquid is being poured into it. When the liquid is poured into the mug, load is added. This extra load will be picked up by sensor in the extensor muscle. Only when the extensor has been stretched to a certain length and reaches its threshold of firing frequency, the extensor will fire a signal to the CNS. Figure 13 explains this circuitry.

When the extensor muscle is stretched beyond the limit, sensor in the muscle will fire off a signal to the CNS to stop inhibiting it and send a signal through the motor neuron to activate the muscle spindle which in turn will contract and resist the load of the liquid and mug. At the same time, a signal will be send to inhibit the motor neurons of the flexor muscle to allow the extensor to contract. Stretching a muscle spindle leads to increased activity in Ia afferents and an increase in the activity of α motor neurons that innervate the same muscle. Ia afferents also excite the motor neurons that innervate synergistic muscles, and inhibit the motor neurons that innervate antagonists. The stretch reflex operates as a negative feedback loop to regulate muscle length [11].

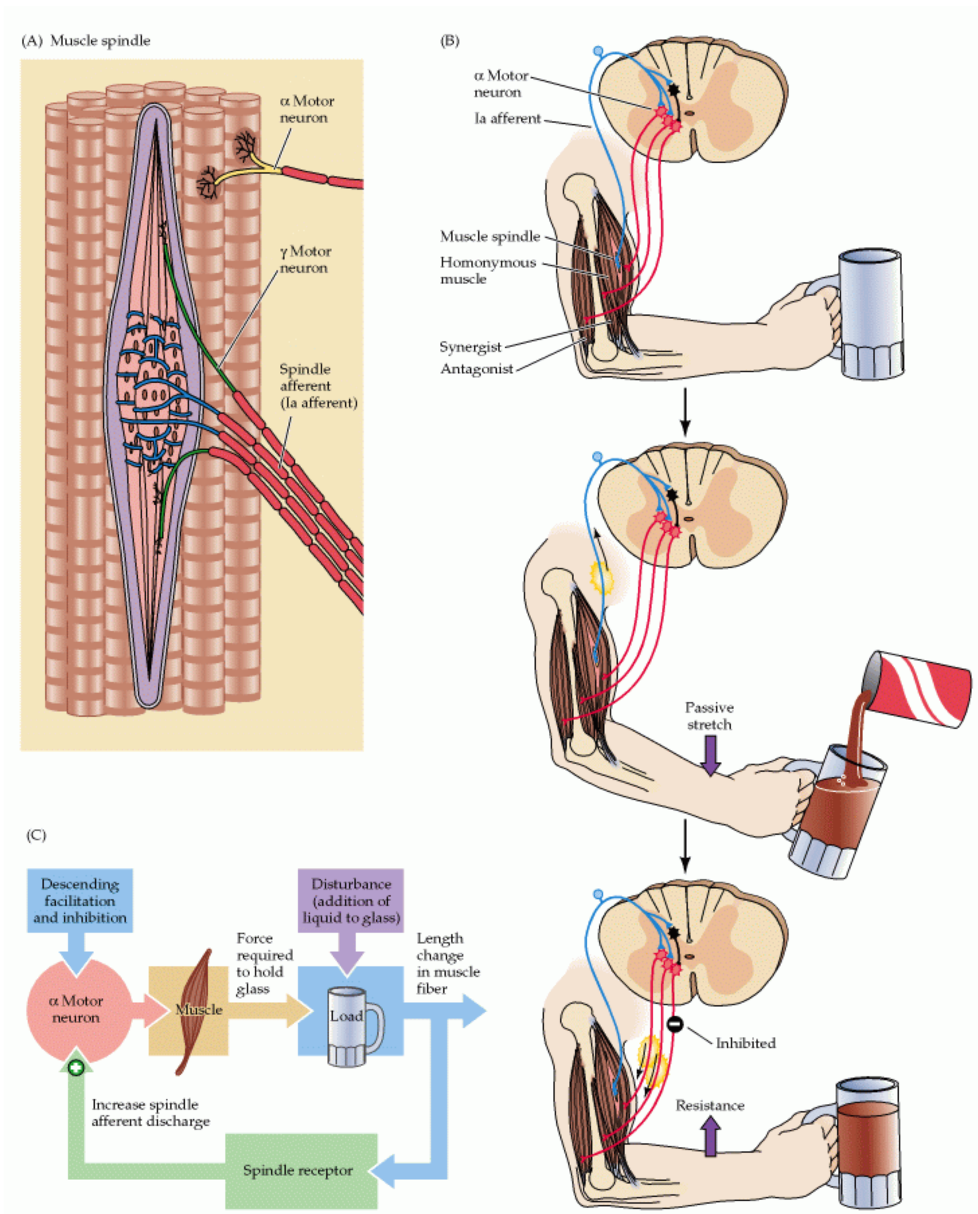


Figure 13. Stretch reflex circuitry. [12]

2.5 Hill's Force-Velocity Relation in Shortening Muscle

The force-velocity relationship of a muscle is one of the most extensively investigated muscle properties. Laulanie was among the first to recognize explicitly that in human muscular movement the efficiency (work/total energy used) varies with the speed [13]. But it was not until Hill came up with another form of force-velocity relation which is used extensively even until now as a reference [14]. Hill's force-velocity curve had empirically almost the same form as Fenn and Marsh [15] but obeyed simpler and more convenient equation.

The equation that governs the force-velocity relationship is:

$$v = b\,(F_0 - F) / (F + a) \qquad (1)$$

F	force (tension) exerted g wt.
F_0	Maximum tension at 0 speed in isometric tetanus, g wt.
v	Velocity of shortening, mm/sec
a, b	Constants of equation.

a and b are constants chosen to give the best fit of the equation to a series of observed values of v and F. The constant b, has the dimensions of velocity, a, the dimensions of force. Constant a, was of interest for many years and it appeared to be the heat of shortening per cm. $(F + a)v$ would be the rate at which the muscle was liberating total energy during shortening, as work and heat together and proportional to $(F_0 - F)$. The maximum velocity of shortening, under zero load, must, if the equation holds over the whole range, be $v_0 = bF_0/a$. A usual value of a/P_0 in a frog sartorius is 0.25, so v_0 would be 4b [16].

Hill also found out that the allowable average values of a/F_0 and b/l_0 to be at 0.25 and 0.3 respectively. Here, l_0 is the standard muscle length.

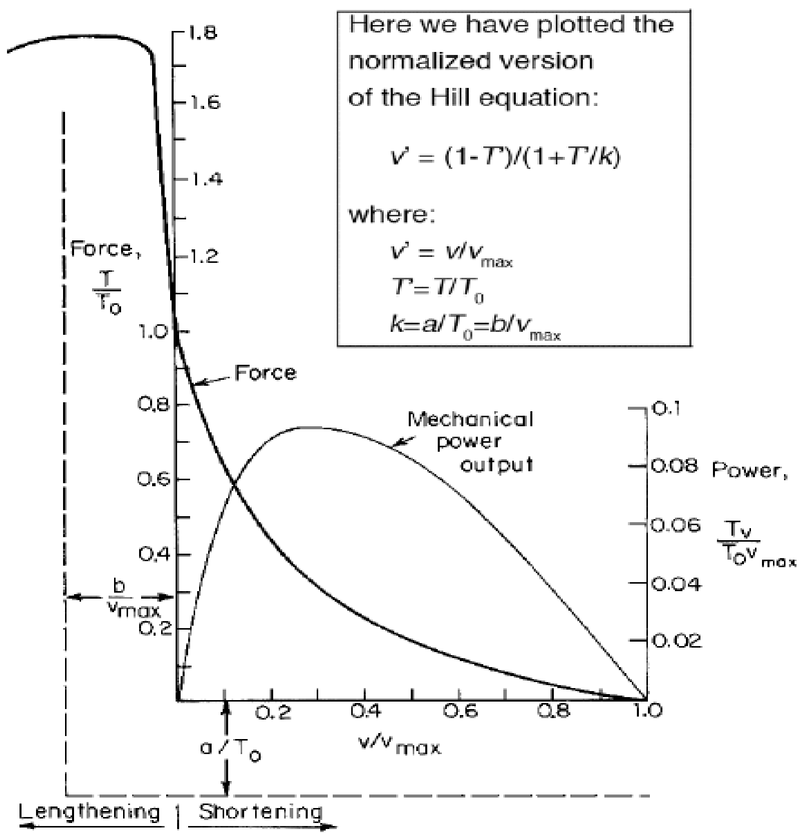


Figure 14. Normalised Hill equation. [17]

2.5.1 Force-velocity Relation of Contractile Component During an Isometric Contraction

The contractile component shortens and stretches the elastic elements in series with it during an isometric contraction. The amount of shortening and stretch can be calculated if the active state of muscle is fully developed and the force-velocity known. If the tension-extension curve of the series elastic component is known and active state of muscle is fully developed, the force-velocity relation can be calculated.

Let x be the length of the contractile component and y that of the series elastic component. Assume muscle has reached its fully active state.

$$dx/dt = (dP/dt) / (dP/dx) \quad (2)$$

Here, $-dx/dt = v$, the velocity of shortening, and $x + y = \text{constant}$ due to isometric contraction,

$$v = (dP/dt) / (dP/dy) \quad (3)$$

dP/dt will be the slope of tension-time curve during isometric contraction

dP/dy is the slope of tension-extension curve.

At any P, we can find v with the two slopes above. Repeating this at various P values we can get the force-velocity relation.

However, the limitation of this method to obtain force-velocity relation is that tension-extension relation of the series elastic component cannot be determined directly except by method of quick release from maximum tension. Furthermore the only way to obtain the relation accurately is by that of a special kind of isometric contraction known as tension redevelopment after release from a high tension to a low but not zero tension.

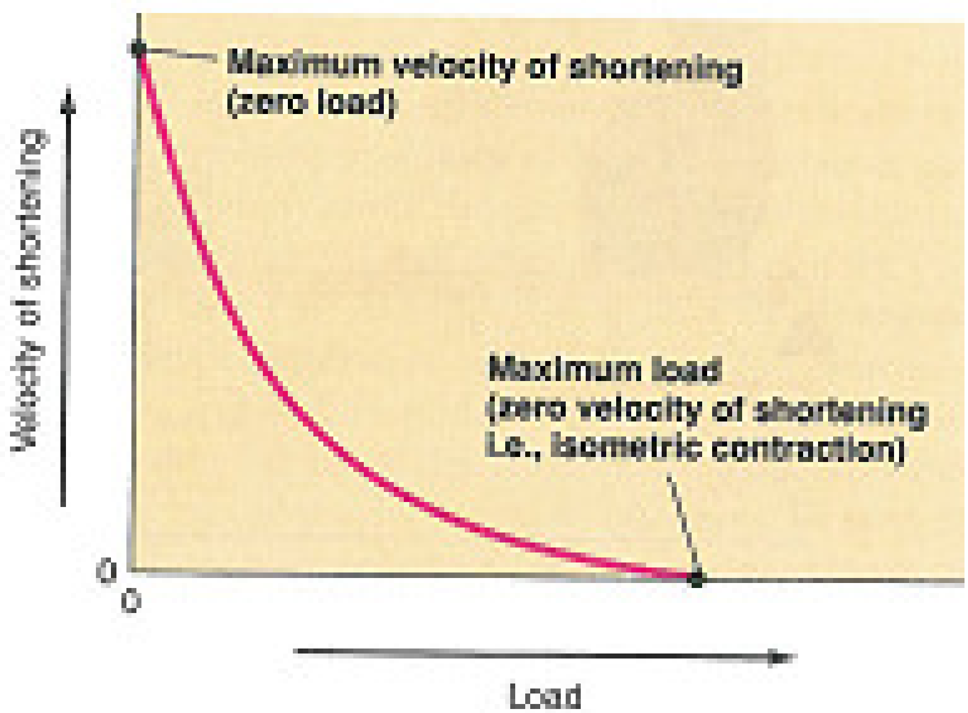


Figure 15. Ideal case of muscle shortening velocity against load. [5]

2.5.2 Experiments to Determine Hill's Model Parameters

The initial muscle length is fixed by using the catch at the end of the level [17]. The muscle is stimulated to produce peak isometric force T_0. Upon reaching the desired T_0, the catch is released instantly. At the point of release, muscle force is reduced to a value T (where $T < T_0$) which is equal to the weight in the pan.

There is an instant change in the length of Kse, stiffness of the series elastic component representing force deflection properties of tendon, following the release. This is followed by a more gradual change in the length of the muscle at Kpe, stiffness of the parallel elastic component representing force deflection properties of sacrolemma, epimysium, perimysium and endomysium. As T increases, there is a decrease in v (obtained from the length-time graph), reflecting that muscle cannot shorten quickly under high loads. The combinations of T and v reflect the force-velocity properties of a given muscle.

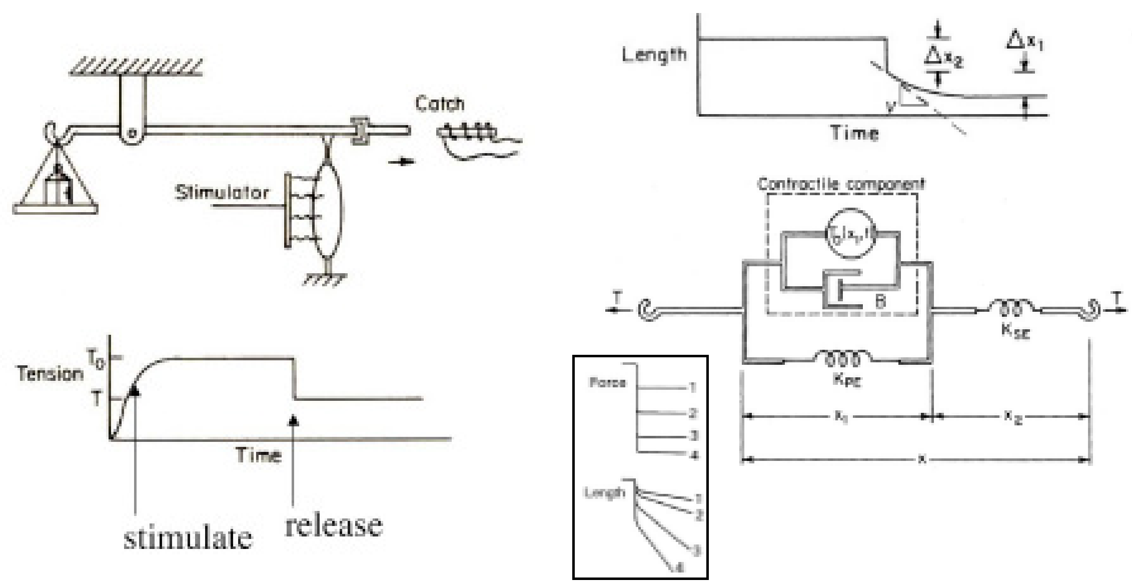


Figure 16. Experiment on Hill's Model. [17]

2.5.3 Argument of Hill's Equation

The force-velocity relation was scrutinized by Caplan [18], based on the methods of irreversible thermodynamics. On certain assumptions about the types of energy converters involved, a force-velocity relation of the usual kind could be deduced with only minimal reference to known properties of muscle. But it is still unknown in which category the applications of irreversible thermodynamics will finally appear in the force-velocity relation. It may well be that the attempted application to muscle may supply an excellent testing of principal themselves of irreversible thermodynamics; the properties of muscle are becoming rather well known and it is the most universal of prime movers.

According to Fuss and Tan [19], the parameters required for Hill's equation are the maximum force and the maximum velocity of the muscle. These parameters can be derived from the physiological cross section of a muscle as well as from ratio of fast and slow twitch fibres and the optimal fascicle length. But these parameters are usually not available and hence the question arises whether the maximal force and velocity can be measured. The maximum force can be calculated from isometric maximum voluntary contraction and moment equilibrium, after measurement of the reaction force. However, it is not sure if the maximum angular velocity of a limb segment measured due to the muscle really shortening at its maximum velocity.

CHAPTER THREE

Methodology

3.1 Modeling of Monosynaptic Reflex Loop

A simplified Monosynaptic model is developed for this project to study the force-velocity relationship of muscle is a simple reflex loop. The model represents a bone joint in a which will produce an "escape reflex" when stimulated like human basic reflex towards boiling hot object. The model is made up of two simple conical shaped linkages, each representing a limb segment (for example finger tip) with a combination of bone and tissue. They are put together via a planar joint at the apex of the conical shaped bone structure. The bottom link is fixed while the top link is able to move in an angular direction. Four red cylindrical rods representing muscle fibers connect the conical linkages. Contraction of the muscle fibers will force the linkages to rotate left and right.

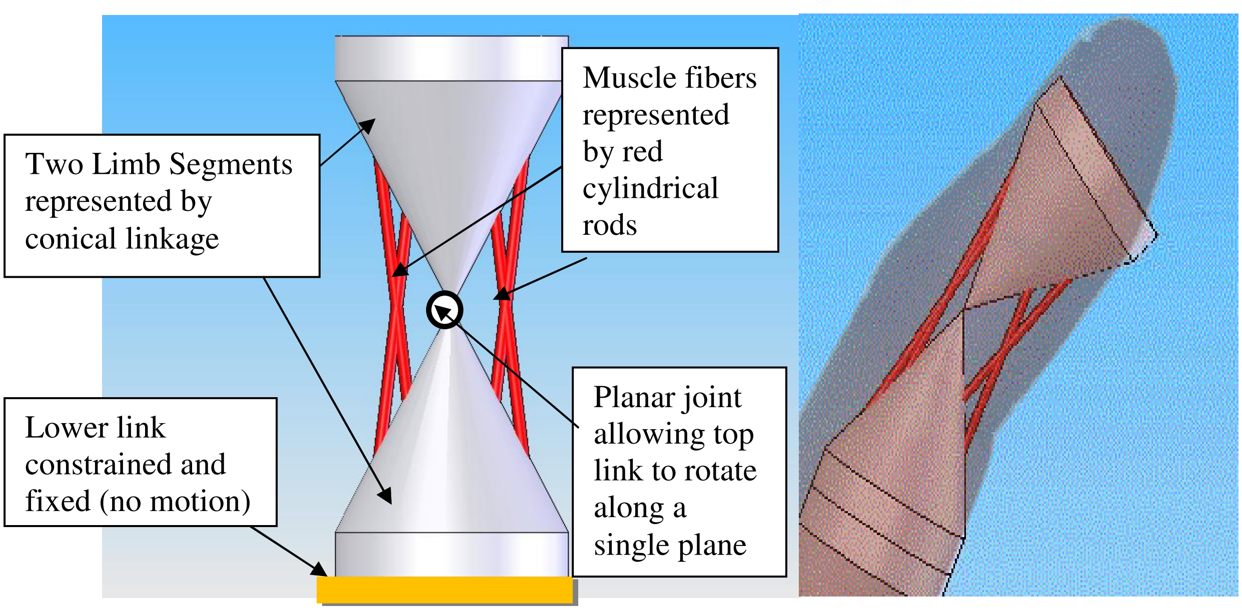


Figure 17. Monosynaptic model and its possible implementation.

The reflex loop of this monosynaptic model will be similar to the reflex loop shown in chapter 1 Introduction. The blue line is the sensory neuron that sends an action potential to the CNS after a signal is received from the receptor on the limb segment represented by the blue circle upon external stimulation [20]. After the signal goes through the inter-neuron, it is then passed through the motor neuron in red. Lastly, the signal is transmitted to the effector, muscle spindles causing the muscle to contract. This results in an angular displacement of the upper conical bone structure.

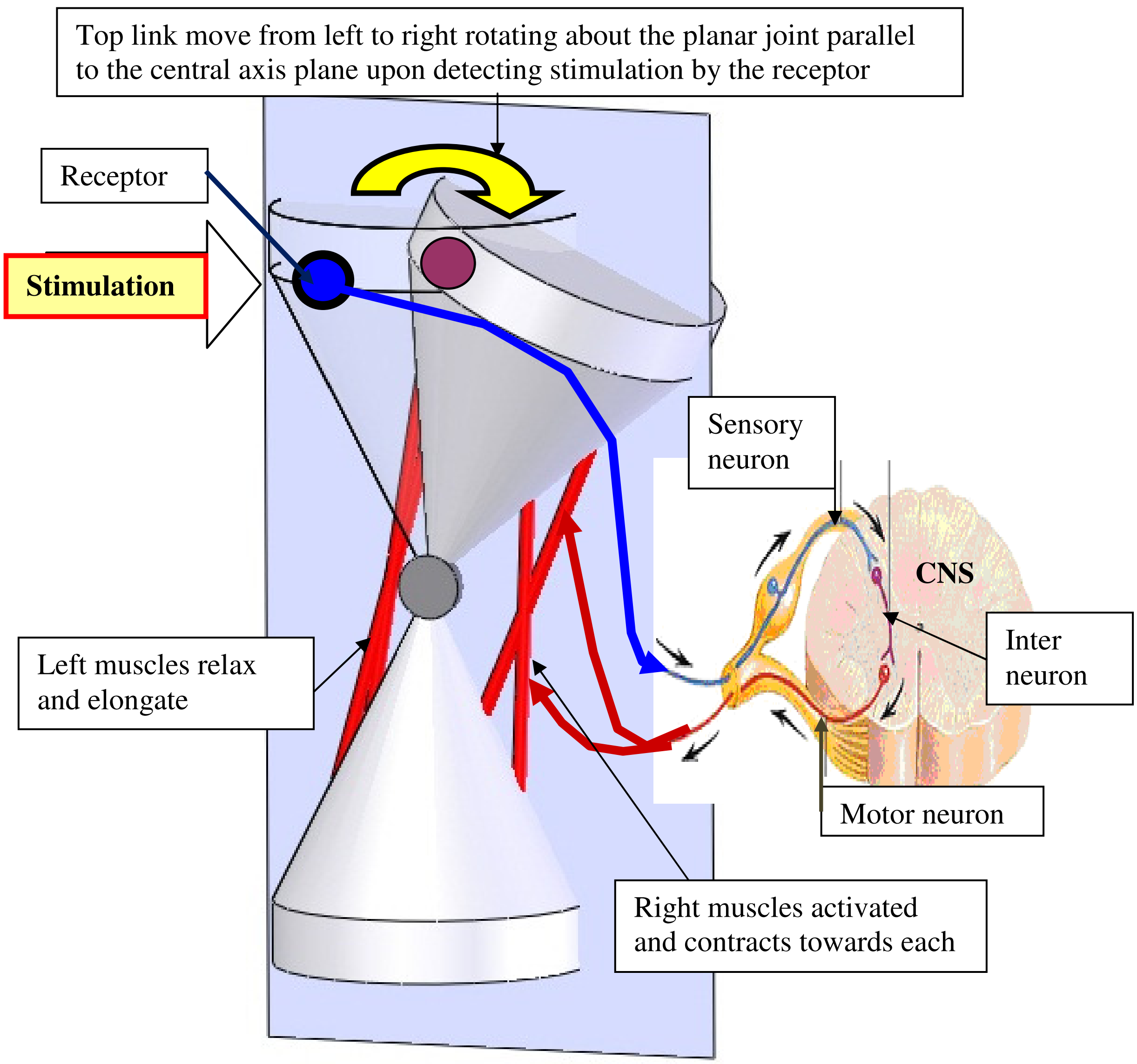


Figure 18. Proposed model reaction to stimulation.

3.2 Mathematical Modeling of Monosynaptic Reflex Model

A mathematical model describes a system by a set of variables and a set of equations that establish relationships between the variables which represent some properties of a system. Having a mathematical model is an important step to present essential aspect of an exiting system which transforms knowlegde of that system into usable form. Often, it helps to improve existing systems, develop better ones, or predict the behavior of certain systems and how things will be in the future.Mathematical models are used widely in the natural sciences and engineering disciplines.

A mathematical model will be generated for the monosynaptic reflex model to study the **neurological synaptic activity** and **kinematics of the limb segment and muscle fiber**, as well as the relationship between important parameters of the whole system.

3.2.1 Assumptions Made

As the model has to be simplified to allow basic observation of the system, we have to make some assumptions.

- Density of the limb segment structure, 1.45g/cm^3 is the average between human bone density, 1.9g/cm^3 [21], [22] and tissue density, 1g/cm^3 [23].
- Properties of muscle fibers and neurons in the model are similar to that of human.
- Cross sectional area of muscle fibers remain constant throughout the whole process.

3.2.2 Modeling of Neuron and Synaptic Action Potential Exchange

Modeling of Axon

We can understand many of the electrical properties of an axon with the aid of a model that resembles an electrical cable covered with defective insulation so that current leaks to the surroundings in many places [11]. More specifically, we assume the axon consists of a cylindrical membrane containing a conducting fluid, the axoplasm. The current can travel along the axon in this fluid and can also leak out through the membrane. We can use the RC circuit to model the axon of the neuron. The electrical properties of the axon are determined by several quantities.

The resistance R of a length of the axon to a current i_{axon} along the axon is proportional to the axoplasm resistivity, $\rho_{a.}$ The resistance of a unit area of membrane to a leakage current i_{leak} is labeled R_m. The membrane also has capacitance, since the charges of opposite siagns accumulate on the two sides of the membrane. The charge per unit area divided by the resulting potential difference is the capacitance of a unit area $C_{m.}$

Thus [24],

$$R = \rho_a l/\pi r^2 \qquad (4)$$

Where ρ_a = axoplasm resistivity

l = length of axon

$A = \pi r^2$ = cross-sectional area of the axon.

Capacitance of the membrane,

$$C = C_m (2\pi rl) \quad (5)$$

Where C_m = capacitance per unit area

$A = 2\pi rl$ = membrane surface area

Table 3, Values of axon parameters [24]

Quantity	Myelinated Axon	Unmyelinated Axon
Axoplasm resistivity, ρ_a	2ohm m	3ohm m
Capacitance per unit area of membrane, C_m	$5x10^{-5}$ Fm^{-2}	10^{-2} Fm^{-2}
Resistance of a unit area of membrane, R_m	40 ohm m^2	0.2 ohm m^2
Radius, R	5 x 10^{-6} m	$5x10^{-6}$m

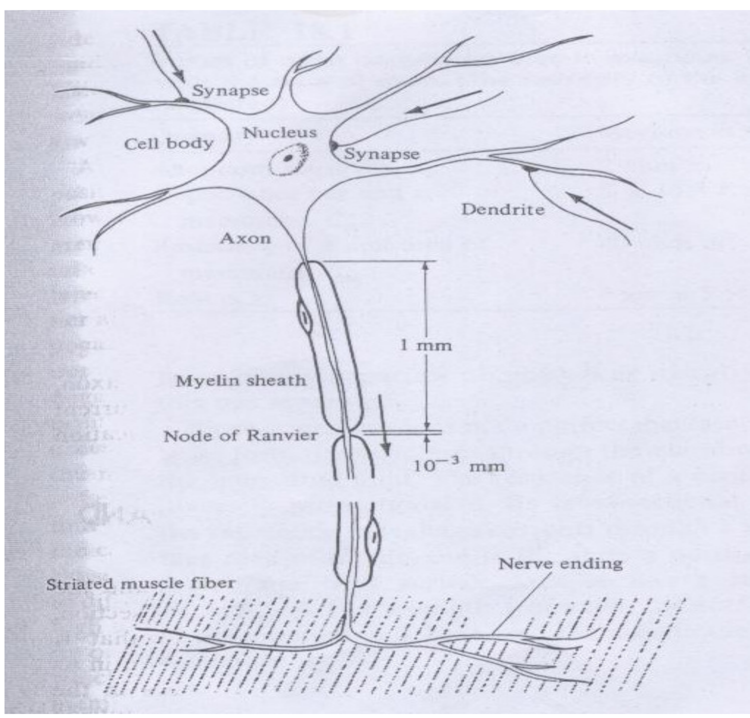
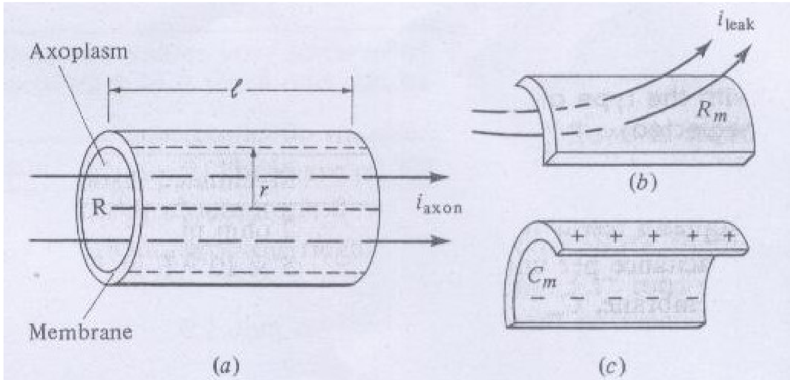


Figure 19. Direction of Nerve Impulse. [24]



(a) The conducting axoplasm has a resistance R to a current i_{axon} along the axon. (b) The resistance of a unit area of membrane to a leakage current i_{leak} is R_m. (c) Charges can accumulate on the two sides of the membrane. The capacitance of a unit area is C_m.

Figure 20. Axoplasm Conductance. [24]

Equilibrium Potential

Neurons are just as other cells enclosed by a membrane which separates the interior of the cell from the extracellular space. Inside the cell the concentration of ions is different from that in the surrounding liquid. The difference in concentration generates an electrical potential which plays an important role in neuronal dynamics. Neuron membrane is a nearly perfect electrical insulator. It is a separation between the intracellular environment and the extracellular environment. Embedded in the membrane are proteins that are transporters of ions across the cell and also act as ion channels. The transportation of ions from one side of the cell to other causes a difference in ion concentrations in each side. The difference in the ion concentration attributes to the difference in potential difference between both sides of the membrane. At equilibrium, the voltage generated by the different ionic density is given by the Nernst equation [25];

$$E_k = \frac{RT}{ZF} \ln \frac{[K^+]_o}{[K^+]_i} \quad (6)$$

$$= 58 \log \frac{[K^+]_o}{[K^+]_i}$$

Where K = represent the type of ions flowing across the membrane (e.g. Na, Cl, K)

E_k = equilibrium potential for the specific ion

R = gas constant =8.31 J/mol K

T = temperature in Kelvin = 293 K

Z = Valence for K+

F = Faraday constant = 96500 C/mol

$[K^+]_o$ = Concentration of K^+ ions outside the cell

$[K^+]_i$ = Concentration of K^+ ions inside the cell

Nerst Equation is typically used to calculate the equilibrium potential across the membrane of the neuron if and only if a single type of ion is allowed to flow across the cell membrane.

Goldman-Hodgkin-Katz Equation

Since more than one type ions cross the cell membrane wall during each excitation, Nernst equation will not be as effective. Instead, Goldman-Hodgkin-Katz equation is used to calculate the equilibrium potential as its equation accommodates more than one type of ions flow across the membrane simultaneously. In the presence on different type of ions, the membrane of the cell depends on the relative permeability of the ions.

Goldman-Hodgkin-Katz Equation

$$E_m = \frac{RT}{F} \ln \frac{P_K [K^+]_o + P_{Na} [Na^+]_o + P_{Cl} [Cl^-]_i}{P_K [K^+]_i + P_{Na} [Na^+]_i + P_{Cl} [Cl^-]_o} \quad (7)$$

Where P_K, P_{Na} and P_{Cl} = permeabilities of K^+, Na^+ and Cl^- respectively

Modeling Axon Based on the Hodgkin-Huxley Model

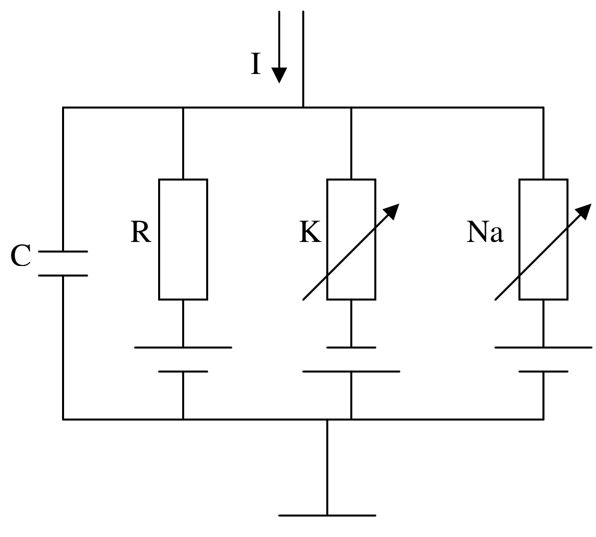


Figure 21. Schematic diagram of Hodgkin-Huxley model.

The Hodgkin-Huxley model [26] corresponds to the electric circuit of a small segment of an axon. Two major components decide the movement of the current flow. The first component is based on different type of ions flowing through the membrane and the other is based on charging of the membrane capacitance. The ionic current is the net sum of 3 distinct types of ions, and they are chloride, sodium and potassium. The sodium and potassium channels are voltage dependent.

$I(t) = I_C(t) + \Sigma I_{ch}(t)$ (8)

Since $I_C = C\,(dV/dt)$

$C\,(dV/dt) = -\Sigma I_{ch}(t) + I(t)$ (9)

Where C = Capacitance of the membrane

V(t) = Membrane potential

I(t) = Sum of the currents of the different branches

ΣI_{ch} = Sum of ionic currents passing through the cell membrane

Parameters of the Hodgkin-Huxley Model

Table 4. Values of concentrations of various ions inside C_i, and outside C_o of a resting axon.

C_o	C_i
Na^+ 145	Na^+ 12
K^+ 4	K^+ 155
Cl^- 120	Cl^- 4

Equilibrium Potential of each channel:

Using the Nernst Equation, Eqn (6),

$E_{Na} = 58 \log (145/12)$

$= 63\text{mV}$

$E_K = 58 \log (4/155)$

$= -92\text{mV}$

$E_{Cl} = -58 \log (120/4)$

$= -86\text{mV}$

Each channel in the cell membrane is characterized by its conductance. The leak conductance is a constant. Sodium and potassium conductance are voltage and time dependent. As each channel is either opening or closing at some point of time, three more variables, m, n and h are added to yield the total current equation.

Conductance of each channel:

$g_{Na} = 120\ mS/cm^2$

$g_K = 36\ mS/cm^2$

$g_{Cl} = 0.3\ mS/cm^2$

$\alpha_m = (2.5 - 0.1V) / [\ \exp(2.5 - 0.1V) - 1]$

$\beta_m = 4 \exp(- V/18)$

$\alpha_h = 0.07 \exp(- V/20)$

$\beta_h = 1 / [\ \exp(3.0 + 0.1V) + 1]$

$\alpha_n = (0.1 - 0.01V) / [\exp(1 - 0.1V) - 1]$

$\beta_n = 0.125 \exp(- V/80)$

Where m = opens the sodium channel and the membrane potential rises

n = opens the potassium channel and the membrane potential decreases

h = closes the sodium channel

α and β = the functions α and β of are empirical equations originated from the adaptations made to fit the experimental data.

Thus,

$$\Sigma I_{ch} = g_{Na} m^3 h (V-E_{Na}) + g_K n^4 (V-E_K) + g_L (V-E_L) \quad (10)$$

$$C (dV/dt) = - [g_{Na} m^3 h (V-E_{Na}) + g_K n^4 (V-E_K) + g_L (V-E_L)] + I(t) \quad (11)$$

The three new variables are given by the following differential equations:

$$dm/dt= \alpha_m (V) (1-m) - \beta_m (V) m$$

$$dn/dt= \alpha_n (V) (1-n) - \beta_n (V) n$$

$$dh/dt = \alpha_h (V) (1-h) - \beta_h (V) h$$

Modeling of Synapse

The change of postsynaptic potential is determined by the synaptic input to the synapse as shown in the synaptic circuitry in figure 21.

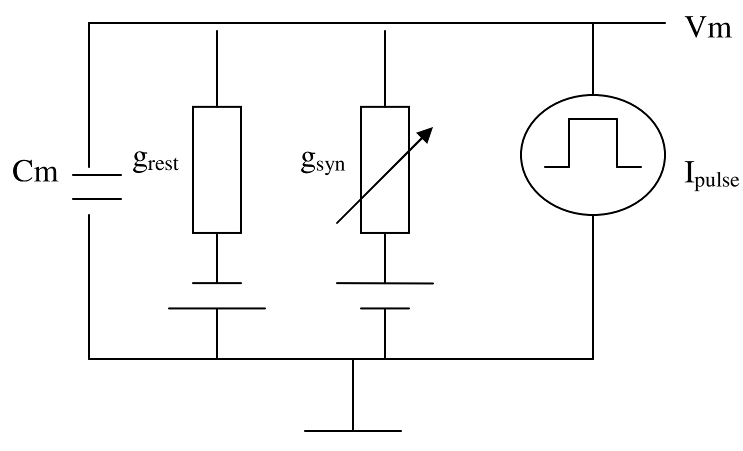


Figure 22. Schematic Diagram of Synaptic Circuitry.

Synaptic Conductance,

The synaptic conductance change causes a linear rise and follows by an exponential decay [27] that is modeled as the alpha function with a single time constant,

$$g_{syn}(t) = g_{max}\, t/\tau\, e^{(1-t/\tau)} \quad (12)$$

Where τ = time constant. Sometimes a dual exponential function is also used.

$$g_{syn}(t) = Ag_{max}/(\tau_1 - \tau_2)\, (e^{-t/\tau 1} - e^{-t/\tau 2}) \quad (13)$$

Where τ_1 = decay time, τ_2 = rise time

$t_{peak} = \tau_1\tau_2 (\ln \tau_1/\tau_2) / [\tau_1 - \tau_2]$

Normalization constant, A = Normalization constant is chosen so that the synaptic conductance reach maximal value of 1

$A = 1/ [e^{-tpeak/\tau 2} - e^{-tpeak/\tau 1}]$

Synaptic Current,

$$I_{syn}(t) = g_{syn}(t)\, [Vm - Esyn] \quad (14)$$

Synaptic Reversal Potential, Esyn,

Using the Nernst Equation (6)

$$E_{syn} = RT/ZF \ln [K]_o/[K]_I \quad (15)$$

Mathematical Formulation of Postsynaptic Potential,

Kirchoff's Law,

$$I_C + I_{rest} + I_{syn} = 0 \tag{16}$$

Membrane equation for a pulsed-shaped conductance,

$$V_{PSP}(t) = g_{syn}/(g_{syn} + g_{rest}) \times E \times (1 - e^{-(gsyn+grest)t/Cm}) \tag{17}$$

Where E = Esyn – Erest

Effects of Drugs

Administrated drugs usually affect the receptor of the membrane and alternate the transmission of signal of neurons. Usually the drugs will bind themselves to the receptor and depending on its nature, it will either excite the postsynaptic potential and formed EPSP or inhibit the postsynaptic potential. Sometime the drugs can also act as a blocking agent by making sure that no ions will flow through the ion channel and no excitatory postsynaptic current (EPSC) is formed [27].

Modeling of Drug-Receptor Interaction

$$\text{Receptor} + \text{Ligand} \rightleftharpoons \text{Receptor} \bullet \text{Ligand}$$

Equilibrium is reached if the rate of new ligand-receptor complex formed equals the rate at which ligand-receptor complex dissociate.

At equilibrium:

$[Ligand]\bullet[Receptor]\bullet k_{on} = [Ligand\bullet Receptor] \bullet k_{off}$

Equilibrium dissociation, k_d,

$$\frac{[Ligand]\bullet[\mathrm{Re}ceptor]}{[Ligand\bullet \mathrm{Re}ceptor]} = \frac{k_{off}}{k_{on}} = k_d \qquad (18)$$

Where $k_{on} = M^{-1}\min^{-1}$ = Association rate constant or on-rate constant

$k_{off} = \min^{-1}$ = Dissociation rate constant or off-rate constant

$k_d = M$ = Equilibrium dissociation constant

Equation of drug bounded to receptor:

$$\frac{[DR]}{[RT]} = \frac{[D]}{([D]+K_d)} \qquad (19)$$

The above equation shows that the binding of drugs to the receptor is dependent on the drug concentration and the equilibrium dissociation constant, K_d.

For drug to take effect, it must first bind to the receptor. An assumption is made to relate the physiological effect or response of drug, E to the amount of drug bound to the receptor.

Assumption:

$$\frac{E}{E_{\max}} \alpha \frac{[DR]}{[RT]} \alpha \frac{[D]}{([D]+K_d)} \tag{20}$$

When drugs are bounded to a receptor, each drug differs in the ability to initiate a change in the physiological activity. We will use the symbol 'e' to define intrinsic activity. Intrinsic activity shows the ability of drug to cause changes in the receptor structure as well as cellular activity.

Therefore the new equation will be,

$$\frac{E}{E_{\max}} = f\,\frac{e[D]}{([D]+K_d)} \tag{21}$$

Drugs that are agonist differ in their capability to stimulate the receptor. Therefore, agonists are categorized as either full or partial agonist. Full agonists are drugs that can give maximal response upon activation. Usually the value of e is 1 for full agonist. However, partial agonists are drugs that can activate the receptor but do not give maximal response to the system. The intrinsic activity, e, is usually less than one for such agonist.

With the equation above, we can plot the dose response curve. Dose-response curve can be used to plot almost anything. The concentration of drugs will be represented in the X-axis. The Y-axis can be response showing the changes in membrane potential, enzyme activity or secretion of hormone.

The dose-response curve can also show the activity of the antagonist at the receptor. Antagonist does not have any intrinsic values since it does not give stimulus response to the receptor. However, the main role of an antagonist is to block the binding between the agonist and the receptor. The new equation to show the relationship between the agonist and antagonist is,

$$\frac{E}{E_{\max}} = \frac{e[D]}{[D] + K_d\left(1 + \frac{[B]}{K_b}\right)} \tag{22}$$

Where [D] = concentration of drug for agonist

K_d *= affinity of agonist*

[B] = concentration of drug for antagonist

K_b *= affinity of antagonist*

3.2.3 Modeling with Hill's Equation

Hill's equation that governs the force-velocity relationship of muscle will be the fundamental equation used for this report from equation 1:

$$v = b\,(F_0 - P) / (F + a)$$

F force (tension) exerted g wt.

F_0 Maximum tension at 0 speed in isometric tetanus, g wt.

v Velocity of shortening, mm/sec

a, b Constants of equation.

a and b which are force and velocity constant respectively, will be denoted as C_a and C_b to avoid any confusing with muscle acceleration denoted by "a". Thus the new equation will be:

$$v = C_b\,(F_0 - P) / (F + C_a) \qquad (23)$$

From this equation the basic relationship between the velocity and force of muscle is that force of the muscle is 0 when velocity is at its maximum, v_0. Velocity is reduced to 0 when force of muscle reaches its maximum, F_0.

Maximum muscle force can also be measured under static conditions using isometric contraction keeping velocity of muscle at 0. The maximum muscle stress of human is a physiological constant of about 0.3MPa [28], [29]. From the above equation ratio of

C_a/F_0 and C_b/v_0 is identical by reducing F to 0. The value of the ratio is set at 0.25 which is common among a variety of species [14].

By rearranging equation (23), force of muscle is [14];

$$F = (F_0 C_b - C_a v) / (C_b + v) \quad (24)$$

From equation 23, the physiological acceleration of muscle can be obtained base on the equilibrium of muscle moment and torque of a limb segment about an axis parallel to the gravitational force.

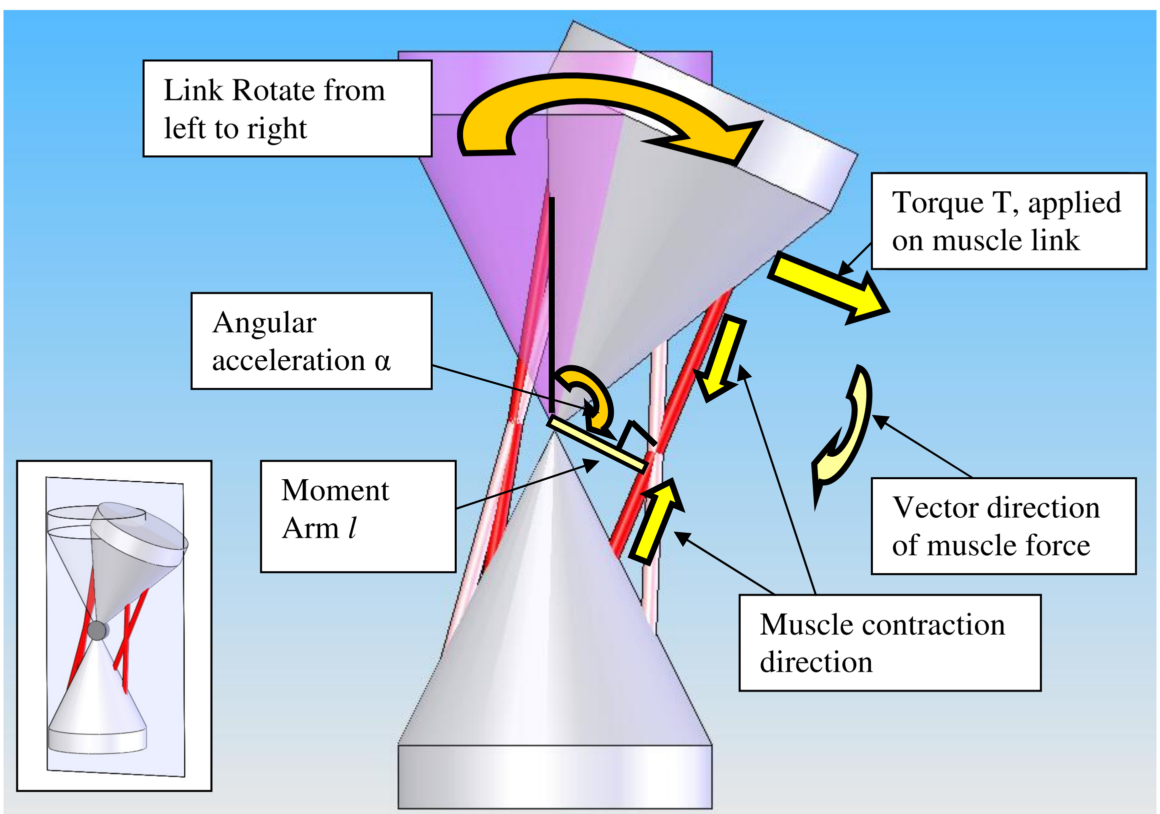


Figure 23. Muscle Torque and Moment.

The torque applied to the limb segment with mass moment of inertia I accelerate the structure at an angular acceleration α;

$$T = I\,\alpha \tag{25}$$

The torque on the limb segment is created by the muscle moment. This will cause a rotational movement to the limb segment about the pivot point of the apex. Muscle moment M, is the cross product of muscle force F and its moment arm *l*.

$$M = Fl \tag{26}$$

Linear acceleration a, of muscle occurs when the muscle shortened. This acceleration can be calculated by multiplying the angular acceleration of the rotating limb segment α and the moment arm of the muscle.

$$a = l\,\alpha \tag{27}$$

The mass moment of inertia of a limb segment I_{ic} about the joint axis instantaneous center is a summation of the limb segment's mass moment of inertia about its center of mass I_{com}, and mass moment of gyration, mr^2 about its instantaneous center where r is the distance of the center of mass of the limb segment to the instantaneous center.

$$I_{ic} = I_{com} + m\,r^2 \tag{28}$$

Where m is the mass of the limb segment

From equation (25) and (28), Torque of limb segment can be express as;

$$T = \alpha\,(I_{com} + m\,r^2) \quad (29)$$

Finally, based on the moment equilibrium (T=M) and solving for the linear acceleration, a of the muscle, we have;

$$a = (F\,l^2) / (I_{com} + m\,r^2) \quad (30)$$

Thus by using equations (24) and (30) and boundary conditions "force of the muscle is 0 when velocity is at its maximum, v_0 and velocity is reduced to 0 when Force of muscle reaches its maximum, F_0", we will be able to formulate a table to study the movement of the limb segment and the muscle velocity-force relationship.

3.3 Computation of Equations

Essential parameters needed for equations synaptic potential of neurons and mechanical properties muscle fibers on limb segments will be calculated based on assumptions made. These parameters will then be used to formulate the table to study the movement of the limb segment and the muscle velocity-force relationship using the Microsoft Excel.

3.4 Close Loop Reflex Model for Quantitative Analysis

From the synaptic activity studies, mechanical muscle reflex model and muscle reflex loop circuitry from literature, a simple close loop of muscle-limb reflex circuitry is derived. We can also view it as a control system [30] that regulates the various parameters of muscle contraction. The essential feature of this type of system is the more-or-less continuous flow of information from the element controlled back to the device that controls it which is also termed as “feedback”. Feedback is essential in a control system to make sure that there is proper regulation of system. The control system for this project will be as below. In the system there are 2 signals that will be sent to the CNS to control the motion of the muscle spindle.

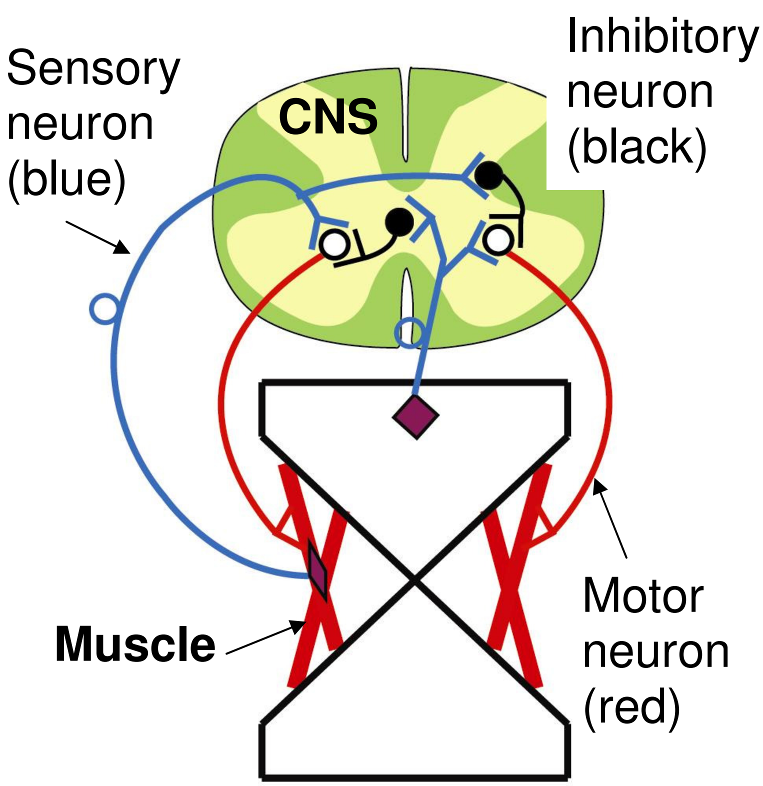


Figure 24. Muscle Reflex and control loop model.

A disturbance will be picked up by sensory neuron on the conical limb segment itself as shown in the diagram. This can be something similar to a knee jerk test practiced by doctor, a person stepping on a nail or touched a very hot object that cause the sensory neurons on the affected area or skin to fire off a signal for the limb to be retracted immediately.

The signal passed into the CNS from the sensory neuron on the limb segment will now send a pulse to activate the motor neuron controlling the right muscle spindle and causing it to contract. At the same time an interneuron before the motor neuron controlling the left muscle will inhibit it to allow the muscle to relax and extend as the muscle on the right contracts. This completes the muscle reflex motion from the initial disturbance.

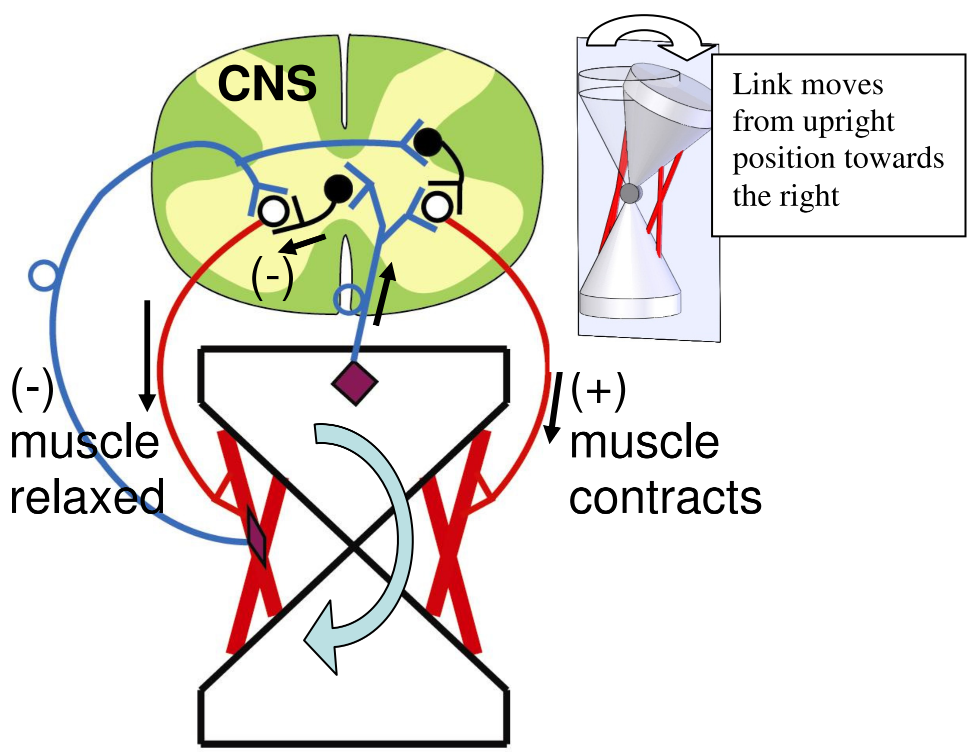


Figure 25. Sensory neuron picks up disturbance and sends a signal to contract right muscle, inhibit left muscle.

As the muscle contracts on the right, muscle on the left will keep on extending. Ia spindle afferent will monitor the activity of the muscle on the left as the limb segment is tilted to the right. Once muscle overstretched is sensed on the left, a signal will be sent to the CNS and this time round, the motor neuron on the left will activate left muscle to contract while the right motor neuron inhibits muscle contraction causing the right muscle to relax totally. This will bring the limb segment back to the normal and balanced position.

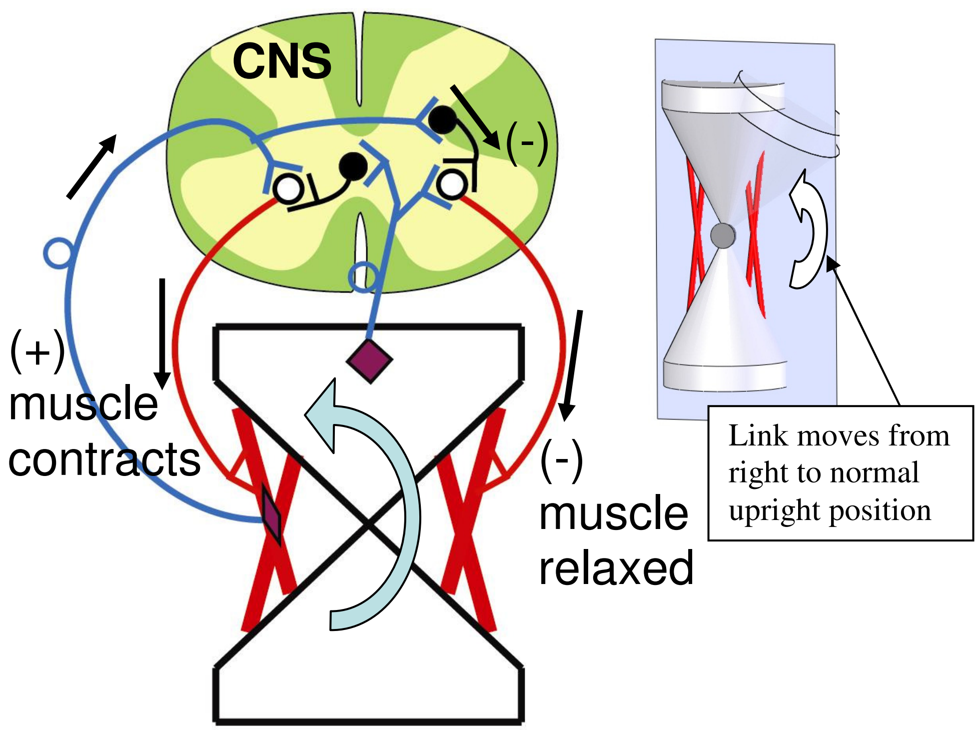


Figure 26. Sensory neuron on muscle picks up over-stretched and sends a signal to contract left muscle, inhibit right muscle

With the above modeling, we can formulate a control system loop that will enable us to understand the working principle of the reflex model.

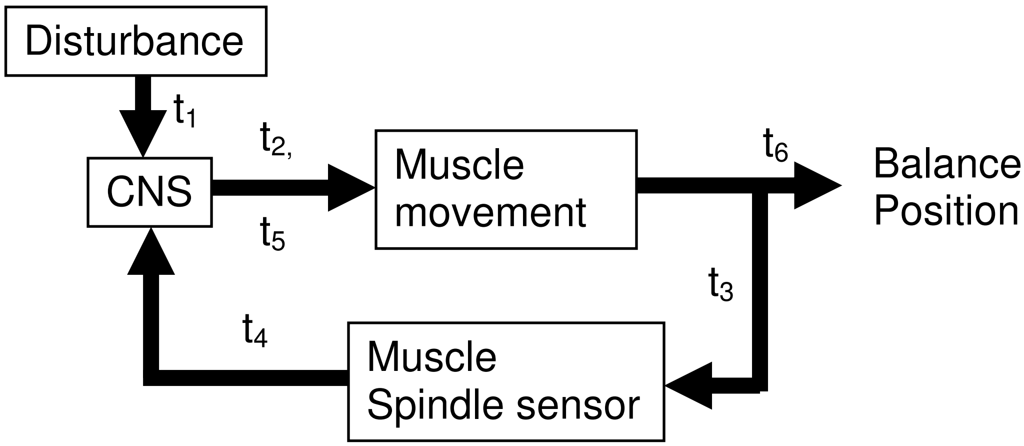


Figure 27. Reflex loop control system with feedback loop.

The reflex loop will start with the disturbance on the conical limb segment. Time taken for the sensory neuron to send the signal to CNS is $t_1$while t_2 is the time taken for the signal to travel through the efferent motor neuron to activate/inhibit the muscle. Time taken for the limb segment to move is t_3. The time taken for movement can easily be extracted from the mechanical model of the limb segment. Time taken for the sensory neuron on the muscle to send a signal back to CNS upon getting signal that the muscle on the left is overstretched will be t_4.

This feedback loop is essential to make sure that the muscle on the left is not over stretched and to bring the limb segment back to the original upright position. t_5 is similar to t_2 which is the time taken for the signal to travel through the efferent motor neuron to activate/inhibit the muscle (to bring the limb segment back to original position). Last but not least t_6 is the times taken by the muscle to move the limb segment to its upright position and this can be easily obtain from the mechanical model. Using this model, the total time taken for the loop of the limb segment model will be used as a benchmark as an estimated time for a patient with motion disorder due to neural disease to complete the exact motion. Figure 28 below gives the summary and flow of the model build up and how we can generate t_3 and t_6 from it.

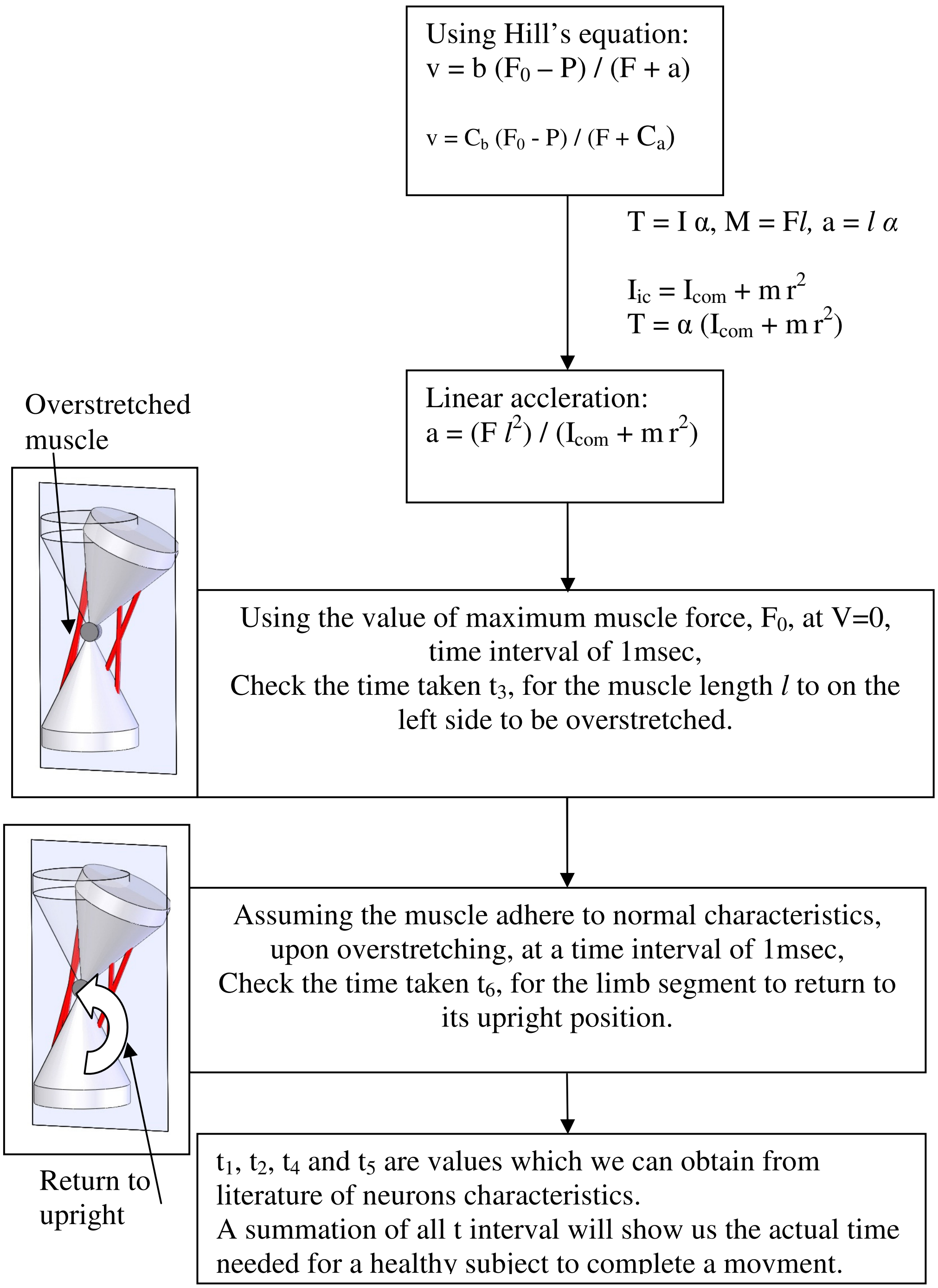


Figure 28. Summary and flowchart of obtaining time variable from model

CHAPTER FOUR

Results & Discussion

4.1 Acquiring Parameters

After obtaining the necessary equations in the previous chapter, some are solved to obtain important parameters to start the generation of data in tables formulated in excel spreadsheet. Results of the mathematical modeling of the neuron cell membrane electrical properties and mechanical properties and relationship of muscle fibers will be evaluated. From the excel spreadsheet, we can generate graphs that shows the relationship between important parameters of the model.

4.2 Pre-synaptic Evaluation

The action potential triggered in the pre-synaptic membrane. An action potential rapidly propagates depolarization at the axonal membrane which leads to the release of neurotransmitter as shown in figure 23. The depolarization of the action potential is caused by the influx of positive Na^+ ions penetrating into the inter-cellular region. The hyperpolarization state of the action potential is caused by the influx of the K^+ ions when the voltage-activated K^+ gates are open at a slower rate than the voltage-activated Na^+

gates and Na+ channels spontaneously close and inactivate after a brief period (~2ms). When an action potential is triggered, neurotransmitter from the vesicles will be release to the synaptic cleft. This causes the signals to be carried to the postsynaptic terminal and generate an EPSP.

Current cause by potassium and sodium ions at the pre-synaptic membrane, can be seen in figure 24, potassium ions produce a negative current while the sodium ions produce a positive current.

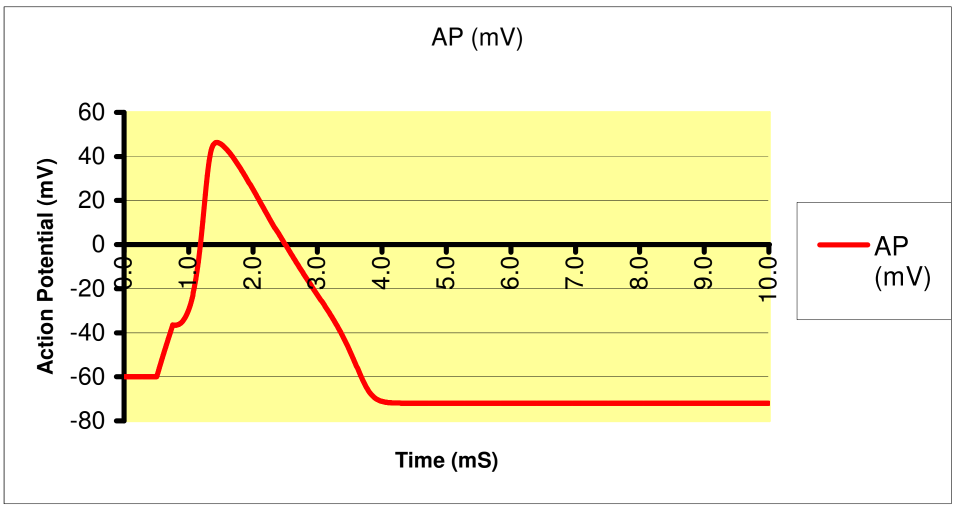


Figure 29. Action potential in the pre-synaptic cell.

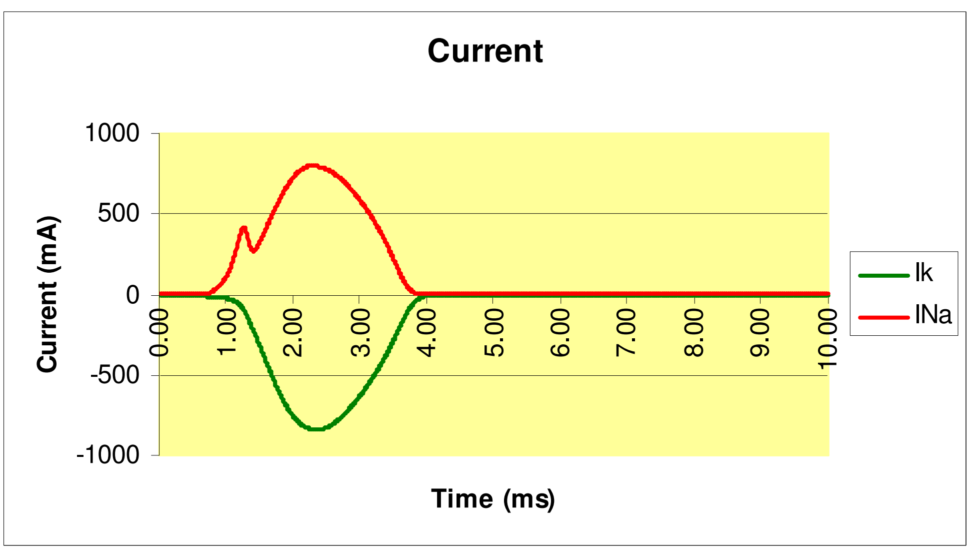


Figure 30. Current of Potassium (k) ions and Sodium (Na) ions.

4.4Post-synaptic Evaluation

Parameters that determined the amplitude of the EPSP and IPSP were varied to illustrate the significant changes occurring to varying synaptic inputs. Figure 25 shows the synaptic current in the excitatory synapse. The parameters varied are the value on the right hand side of the synaptic current equation, Isyn(t) = gsyn(t) [Vm – Esyn]. The synaptic current rises sharply till it reach its peak at around 70mA, before it slowly decays exponentially to zero. The period of the graph is around 0.05 seconds.

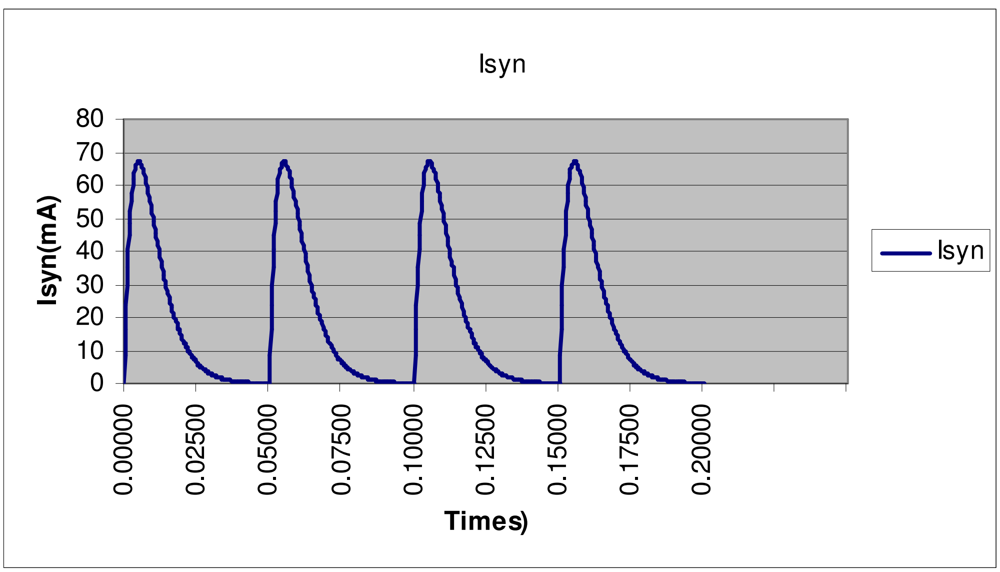


Figure 31. Synaptic current flowing into the membrane.

The following graph shows the synaptic conductance of four identical excitatory synaptic inputs at an interval of 50 msec. Each of these synaptic inputs has a maximum conductance of 1nS. The graph resembles that of the synaptic current flowing into the membrane. The synaptic conductance rises sharply before it decreases exponentially to 0 again.

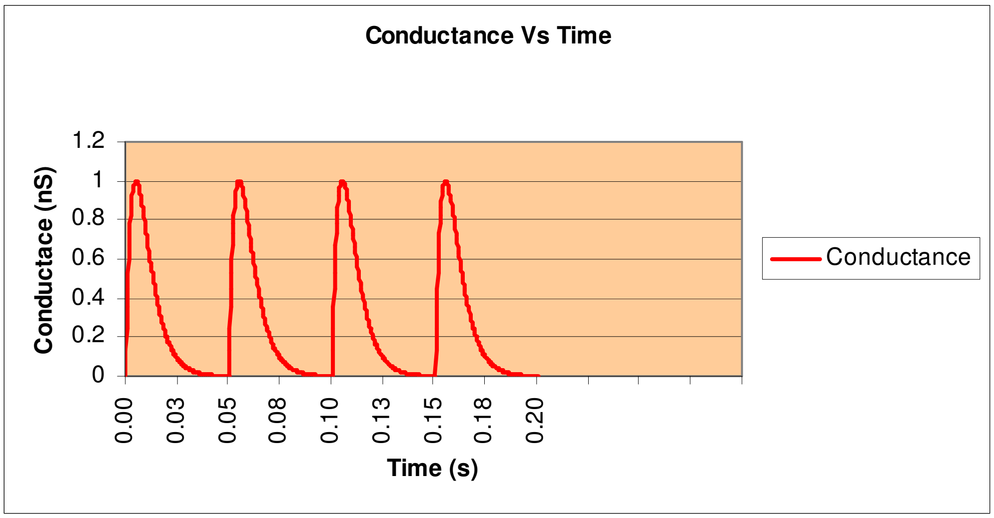


Figure 32. Conductance of the synapse.

Figure 27 shows the response of the cell for a single synapse of excitatory and inhibitory input. The amplitude of the excitatory postsynaptic potential is higher than the amplitude of the inhibitory postsynaptic potential. The excitatory input pushes the potential of the neuron up and if the excitatory input is strong enough, it may fire off an action potential to the activate the next neuron. The inhibitory input on the neuron will have its potential kept below 0mV to prevent any excitation from occurring to fire off an action potential to the next neuron.

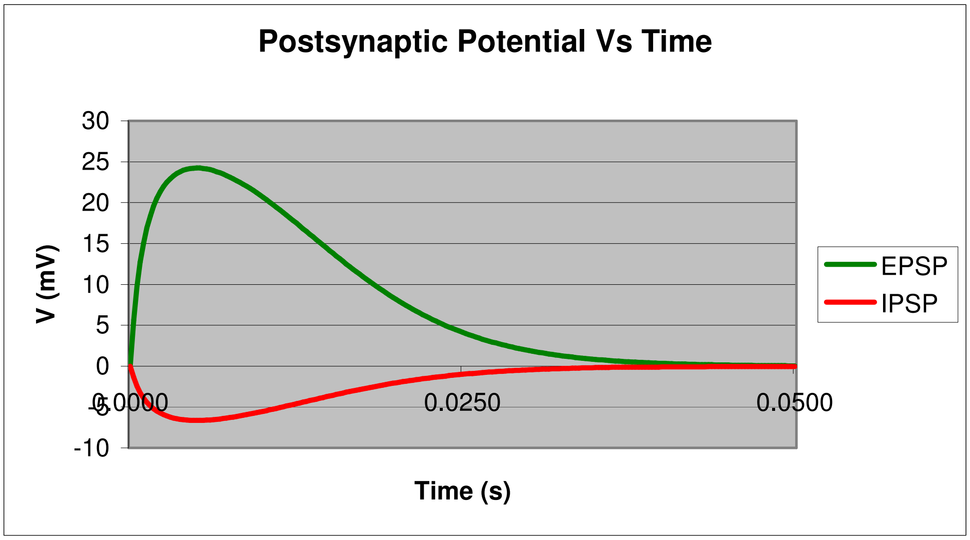


Figure 33. Amplitude of the EPSP and IPSP.

4.3.1 ESPS with Varying Gmax

The change in the EPSP amplitude with varying maximum synaptic conductance, gmax is shown in figure 28. The blue line shows the value of gmax set to 1nS. The yellow line shows the EPSP when gmax is set to 0.5nS and the pink line shows the EPSP when gmax is 5nS. From the figure, with increasing gmax, the amplitude of the will also increase. However the rate that it reaches the peak amplitude is the same. The other significant change is rate that it decays exponentially. With increasing gmax, the EPSP takes a longer time to decay exponentially. Therefore, for the summation of EPSPs to reach threshold in a faster rate, EPSPs that have a larger gmax will reach threshold value faster than EPSPs that have a smaller gmax for the same frequency of firing at the synapse.

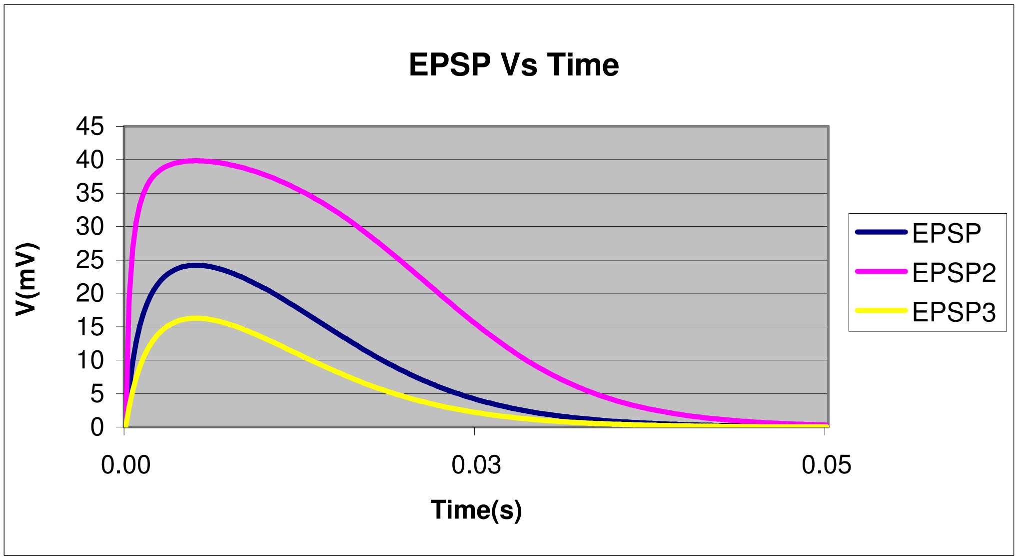


Figure 34. EPSPs with varying gmax.

4.3.2 ESPS with Varying Time Constant, τ

Figure 29 shows the changes in the curve of EPSP with varying time constant. The blue line shows the curve of EPSP when the time constant is set to 0.005. The pink line shows the curve of EPSP when the time constant is 0.01 and the yellow line shows the EPSP when the time constant is set to 0.001. This shows that the smaller the time constant the slower the rate at which the EPSP will decay. And the smaller the time constant, the slower the rate in which the EPSP will rise to the peak amplitude. The larger the value of the time constant, the faster the rate at which the EPSP will rise to the peak value and the faster it will decay exponentially. With the other parameters remaining constant, varying the time constant will not change the peak amplitude of EPSP. Thus for the summation of

EPSP to reach the threshold value faster, EPSP with large time constant will reach the threshold value faster than EPSP with small time constant at same frequency rate of firing the EPSP.

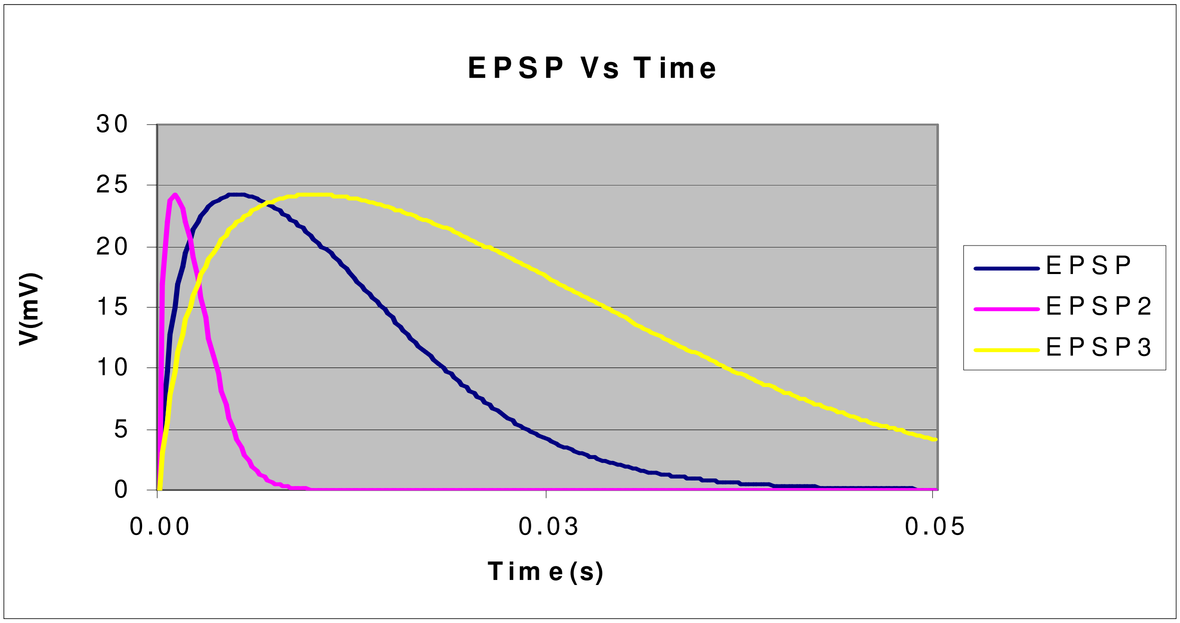


Figure 35. EPSPs with varying time constant.

4.3.3 Comparison of EPSP with Varying Frequency

The comparison of summation of EPSP with varying frequency is shown in figure 30 and 31. In figure 30, four excitatory synaptic inputs are being fired simultaneously at 2msec interval (500 Hz) while figure 31, four excitatory synaptic inputs are being fired simultaneously at 10msec interval (100 Hz). For the excitation at 500 Hz, 80mv is reached before the 20msec whereas for the excitation at 100 Hz, post-synaptic potential is only at 45 mV after 25msec. This shows that the higher the frequency of EPSP fired, the faster the postsynaptic potential reach the threshold value and an action potential will be triggered. The peak of the potential is also higher at higher frequency (80mV at 500 Hz and 45mV at 100 Hz). Thus excitatory synaptic inputs at higher frequency will make sure the neuron reaches threshold potential faster and a higher peak voltage.

Frequency = 500 Hz

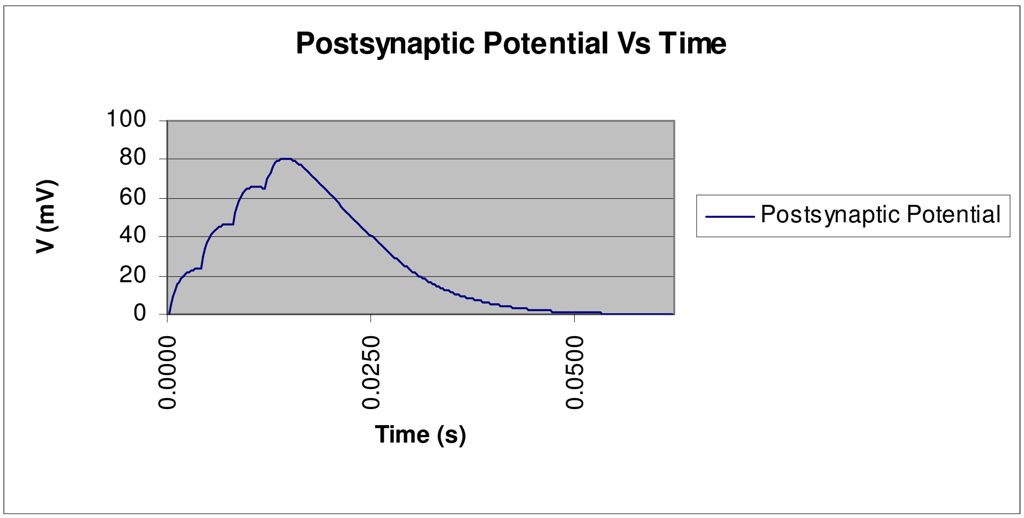


Figure 36. Four excitatory inputs at 2 msec interval.

Frequency = 100 Hz

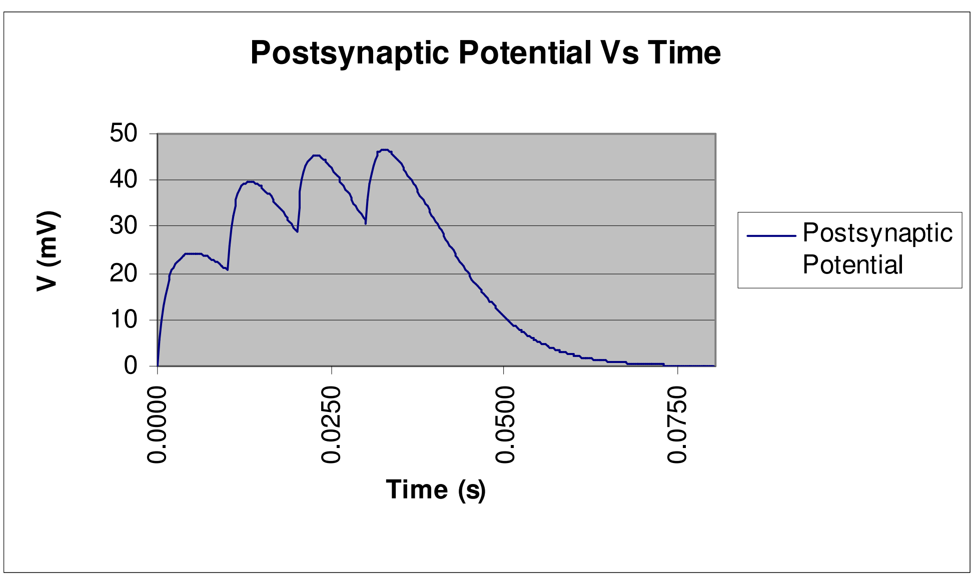


Figure 37. Four excitatory inputs at 10 msec interval.

4.3.4 Summation of Inhibitory Postsynaptic Potential

Figure 32 shows the summation of four inhibitory inputs at an interval of 2msec. The summation of IPSPs inhibits the postsynaptic potential to reach the threshold value and initiation of an action potential. From the graph we can see that the inhibitory inputs do not allow the potential inside the cell to increase thus no chance of firing an action potential.

In the synapse, and especially in poly-synaptic circuit, more than one neuron will be connected to the next one. Often, these connecting neurons come in an array of inhibitory and excitatory properties. Thus the outcome of the post-synaptic potential of the neuron will have to depend on the summation of IPSPs and EPSPs synapses existing along the dendrites.

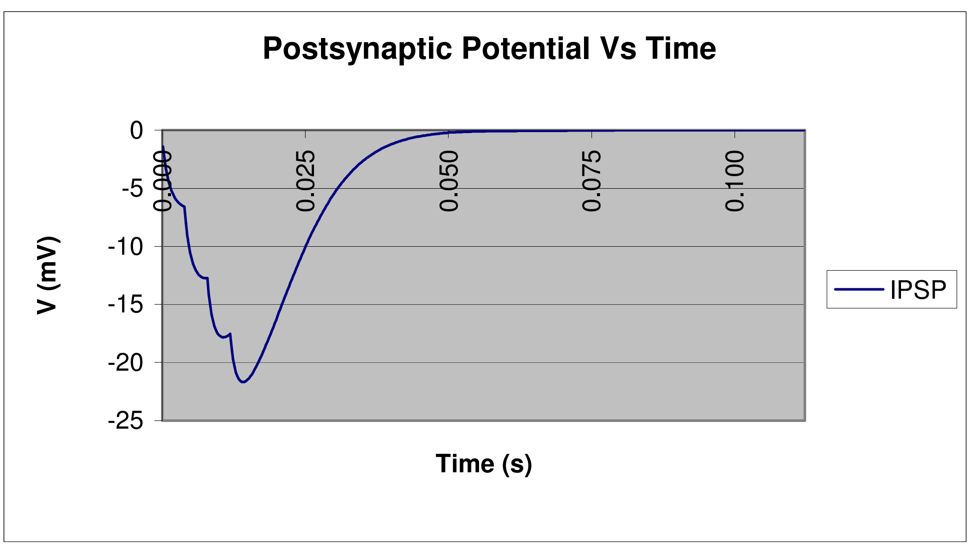


Figure 38. Summation of four inhibitory inputs.

4.4 Effects of Drug Transmission

The graph below shows the effect of drug transmission with the dose response curve. The vertical axis indicates the percentage change of the postsynaptic potential changes against the horizontal axis which is the arbitrary varying concentration of drug concentration. It shows the linear relationship of drug concentration and response for full agonist. We use a variable 'f' to represent linearity of the relationship. When 'f' is assumed to be 1, the response is linear which means that all receptors are occupied and bounded by the drugs. This will produce the maximum drug response. From the graph, we can deduce that the response to drug concentration increases exponentially until it reaches a plateau. This shows that any increase in drug concentration after the point where the response peak is useless and will not have any effect on physiological activities.

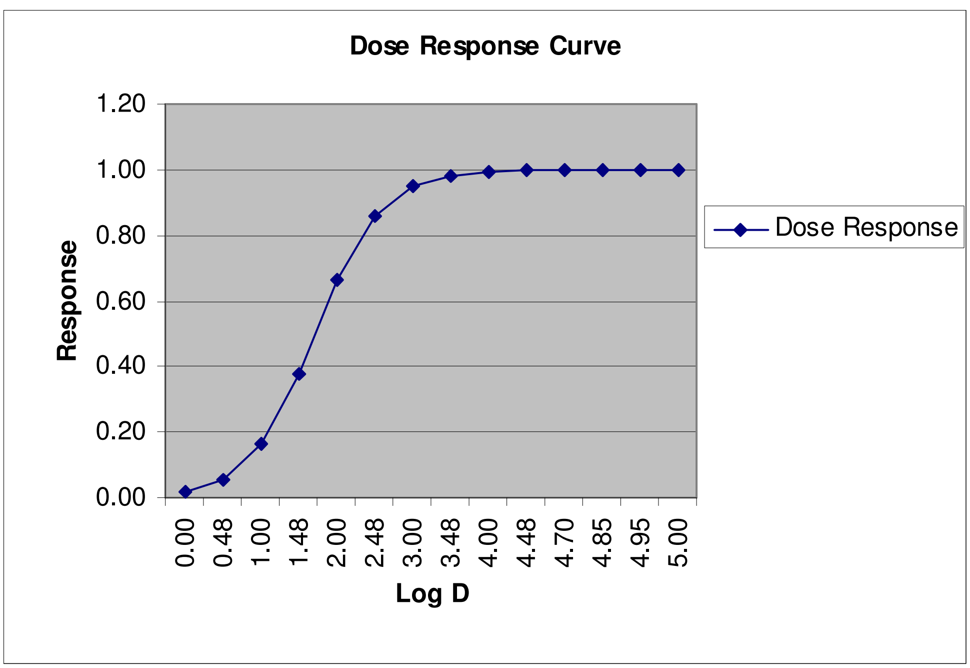


Figure 39. Dose-response curve

The following graph below shows the relationship of effect of drug transmission in a non-linear occupancy response system. This occurs when all the receptors are not occupied to produce the maximum drug response. From the graphs, using the same drug concentration, the higher the non-linearity, the greater the response will be.

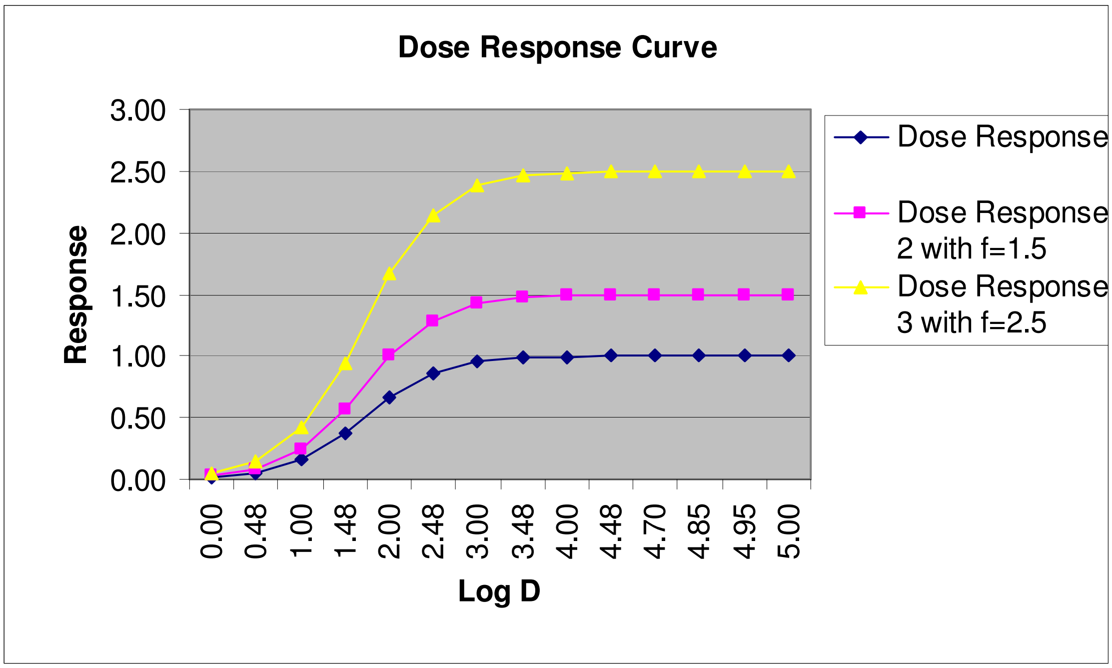


Figure 40. Dose-response with non linear occupancy.

The response changes to varying intrinsic activity graph below shows the comparison between the full agonist and partial agonist. Full agonist produce maximum response to drug concentration with intrinsic activity value of e =1. We will set e = 0.5 to simulate the effect of the partial agonist. From the graph, for the same concentration of drugs, the partial agonist has a lower response change.

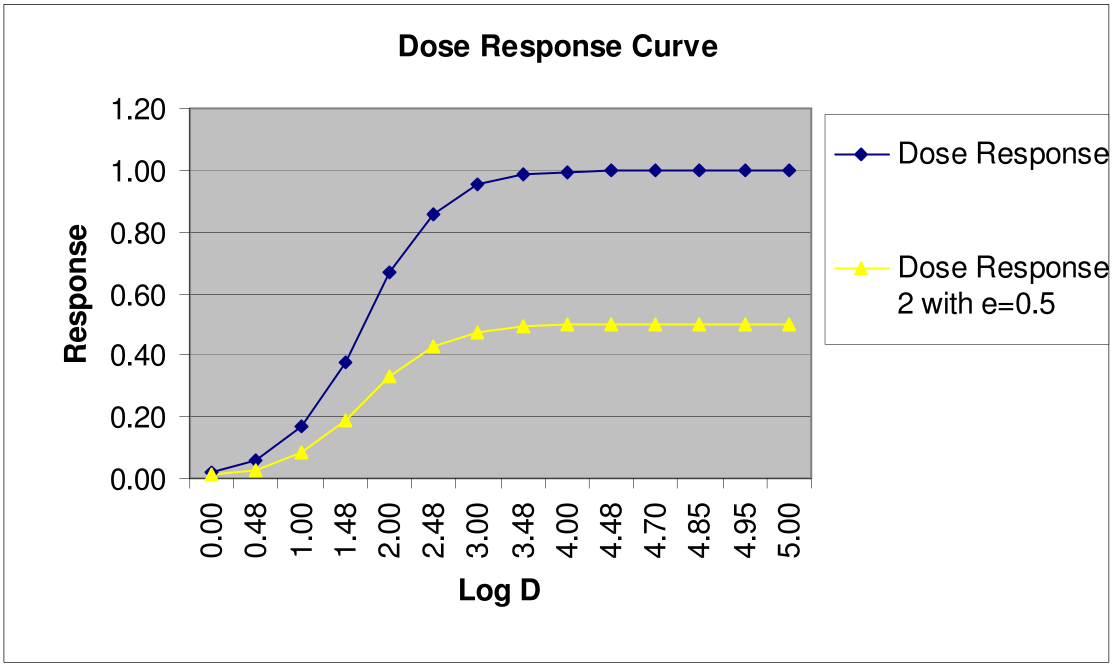


Figure 41. Response changes to varying intrinsic activity value.

The graph below shows the different relationship between the drug, agonist and antagonist with the response change. We can see that with addition of antagonist, the dose-response curve shifted right. This shows that the antagonist will block the binding between the receptor and agonist. Thus, a bigger concentration of agonist will be needed to overcome the action of the antagonist. Antagonist B which has 10 times more concentration of drugs compared to antagonist A shifted more to the right. This shows that higher amount of Antagonist will inhibit action of agonist further.

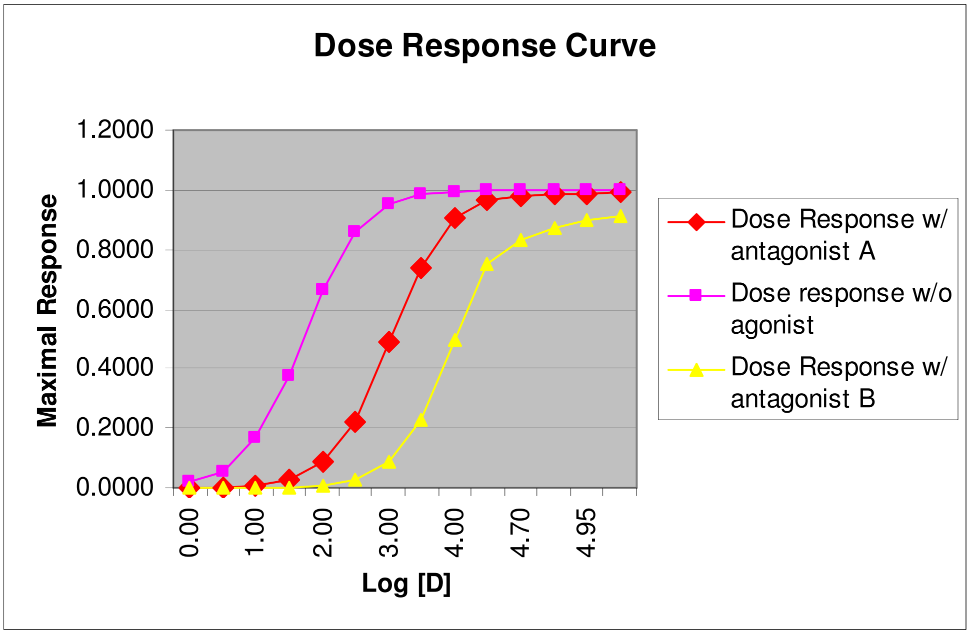


Figure 42. Dose response with interaction between agonist & antagonist.

4.5 Mechanical Parameters of Model

To solve the equations in chapter 3.2.2, we have to assume the dimensions of the limb segment and its muscle fibers with adequate proportionality of muscle to limb ratio.

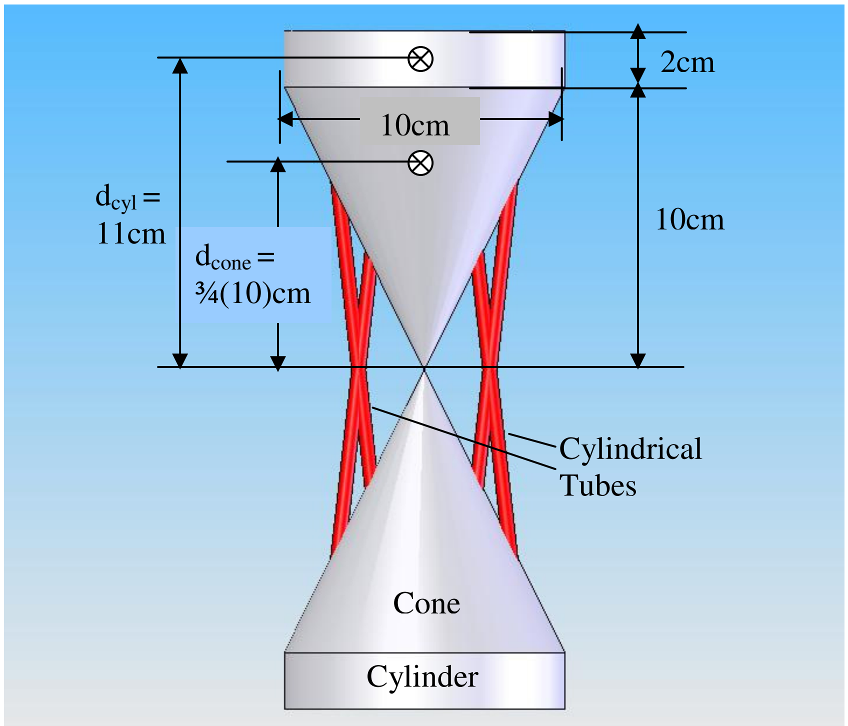


Figure 43. Limb Segment Dimensions.

a) Assume density of Limb Segment $\rho_{ls} \approx \rho_{bone} + \rho_{tissue}$

$\approx \rho_{bone} + \rho_{tissue}$

$\approx 1900\ kg/m^3 + 1000\ kg/m^3$

$\approx 1450\ kg/cm^3$

b) Total mass of limb segment = $m_{cyl} + m_{cone}$

= ρ (πr2hcyl) + ρ (1/3πr2hcone)

= 0.23kg + 1.14kg

= 1.37kg

c) I_{ls} (abt joint axis) = I_{cyl} (abt joint axis) + I_{cone} (abt joint axis)

I_{cyl} (abt joint axis) = $I_{cyl} + m_{cyl}d_{cyl}^2$

$= 1/4m_{cyl}r^2 + 1/12m_{cyl}h_{cyl}^2 + m_{cyl}d_{cyl}^2$

$= 1424gcm^2 + 76gcm^2 + 27563gcm^2$

$= 29063gcm^2$

$= 2.91kgm^2$

I_{cone} (abt joint axis) = $I_{cone} + m_{cone}d_{cone}^2$

$= 3/20m_{cone}r^2 + 3/5m_{cone}h_{cone}^2 + m_{cone}d_{cone}^2$

$= 4271gcm^2 + 68339gcm^2$

$= 72610gcm^2$

$= 7.26kgm^2$

Thus I_{ls} (abt joint axis) = $1.02x10^{-2}kgm^2$

d) Muscle cross sectional diameter = 0.5cm

= 0.0025m radius

Muscle $A_{cross\ sect} = 1.96x10^{-5}m^2$

e) σ_{max} = 0.3MPa---------------------------(Max physiological muscle stress of human)

F_{max}/Muscle $A_{cross\ sect}$ [31]

$F_{max} = A_{cross\ sect} \times \sigma_{max}$

$= 5.891N$

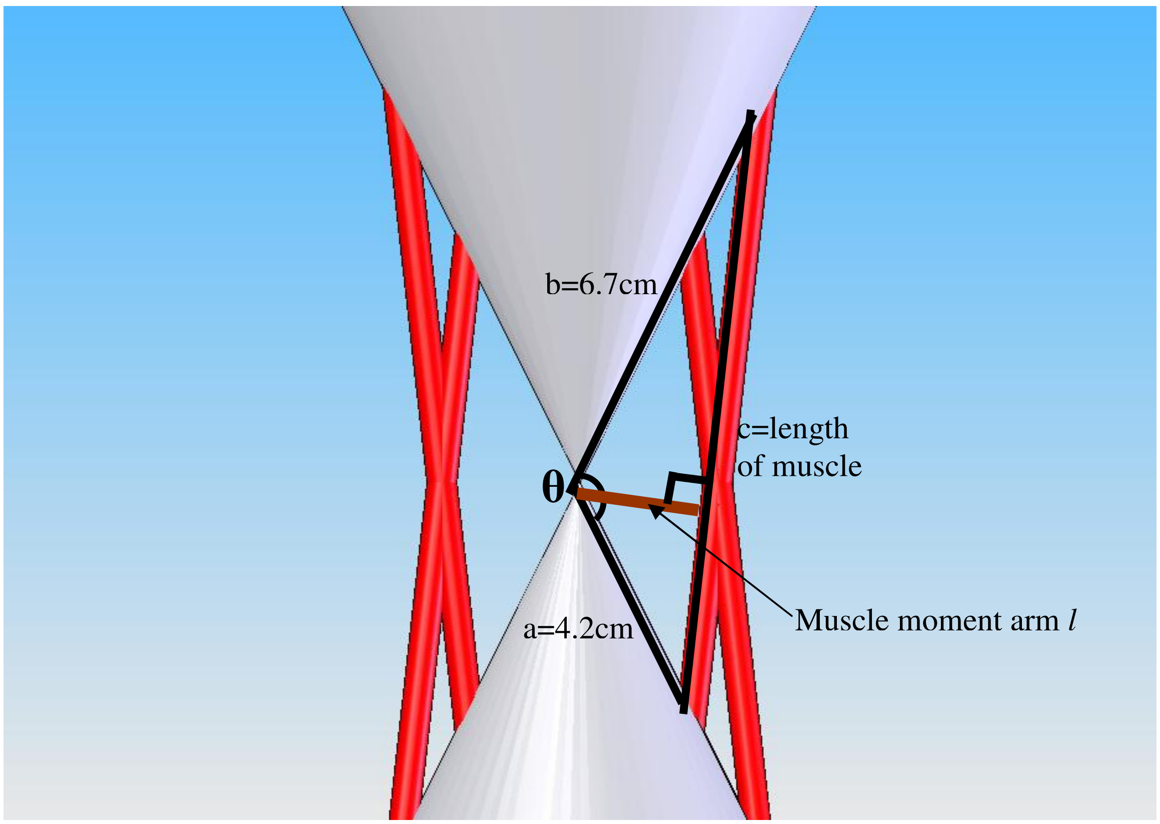


Figure 44. Muscle length and moment arm length.

f) Moment arm $l = dc/d\theta$

$c^2 = a^2 + b^2 - 2(a)(b)\cos\theta$

$= 0.006253 - 0.005628\cos\theta$

Thus $dc/d\theta = (0.002814\sin\theta)/(0.006253-0.005628\cos\theta)^{1/2}$ (9)

g) $v_0 = (16 + 6)/2$ x Muscle Fiber Length [32]

Since $v_0 = 6$ x Length of muscle fiber per second (slow twitch fiber)

and $v_0 = 16$ x Length of muscle fiber per second (fast twitch fiber) [33]

= (11)(0.098)

= 1.08m/s

h) $C_b/v_0 = 0.25$

$C_b = 0.27$

i) F_0 = (0.3MPa)(Cross-section Area)

$= 3000000 \times 1.96 \times 10^{-5}$

= 5.891N

j) $C_a/F_0 = 0.25$

Ca =1.47

4.6 Formulation of Table for Mechanical Parameters

After acquiring all the parameters we need, we will be able to formulate a table in excel spreadsheet to study the model. The mathematical model will be run for 2 instances. The first instance will be when the limb is in total upright position before a signal is passed to the muscle for it to exert maximum force tilting the limb to the right.
The second case will be when the limb is tilted 50° to the right and we assumed that at this angle, a signal will be passed to the opposing muscle on the left to pull the limb towards the opposite direction Instance 1.

Table 5. Mathematical Table for Model.

Time	Muscle Force 1	θ at instantaneous in degree	Muscle Moment Arm *l*	Muscle Acceleration	Muscle Velocity	Muscle Force 2	Muscle L	Power 1	Angular Velocity	Limb Moment	Power 2	θ Increment in radian	θ total Increment in radian	θ Increment in degree
0.0	0.0	127.0	0.02289	0.0	0.0	5.891	0.09818	0.0	0.0	0.13484	0.0	0.0	0.0	0.0

Time: In increment of 1msec

Muscle Force 1: Muscle force at (t). It will be used to calculate linear acceleration of muscle.

θ at instantaneous in degree: Angle between the two limb segment at point of time.

Muscle Moment Arm *l*: Moment arm of muscle at point of time using equation (31).

Muscle Acceleration: Linear acceleration of muscle using equation (30).

Muscle Velocity: Linear velocity of Muscle. Boundary condition of v = 0 when Force is at its maximum is applied here. Thus velocity is kept at 0 at 0sec while Maximum muscle force is used to start the model.

Muscle Force 2: Muscle force at $(t)_+$ using equation (24). Thus its value is Maximum muscle force at time 0msec where velocity is at 0.

Muscle L: Length of muscle during contraction.

Power 1: Power of muscle obtained from the product of muscle force and Muscle velocity.

Angular Velocity: Angular velocity of limb segment derived from vector division of linear velocity by muscle moment arm.

Limb Moment: Moment on limb segment derived from vector cross product of muscle force and muscle moment arm.

Power 2: Power of muscle obtained from the product of Limb moment and angular velocity.

θ Increment in radian: Increment of angle between limb segment in radian at every milliseconds.

θ total Increment in radian: Increment of angle between limb segment in radian from t=0 till t=t.

θ Increment in degree: Increment of angle between limb segment in degree at every milliseconds.

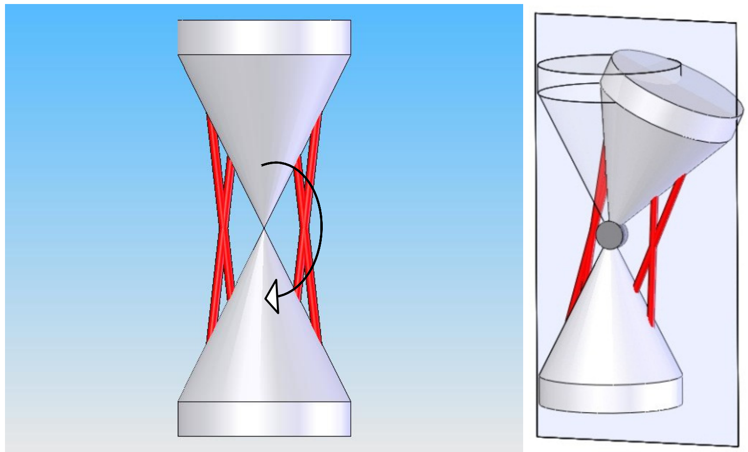


Figure 45. Instance 1 upper limb will move from upright position to the right.

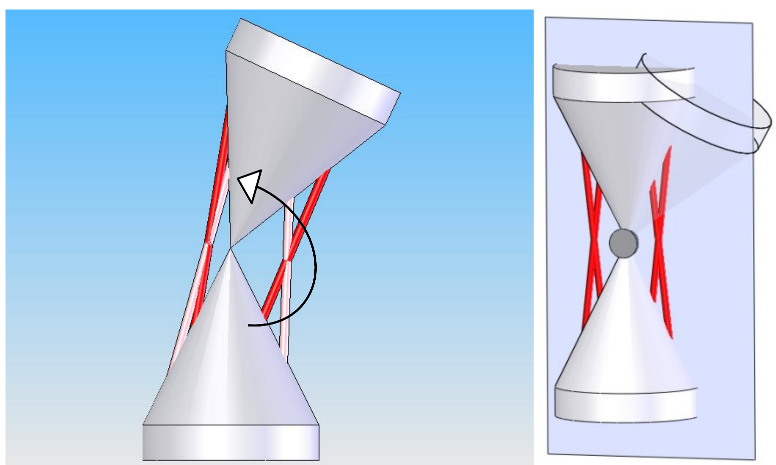


Figure 46. Instance 2 upper limb will move from tilted right back to upright position.

4.6.1 Muscle Velocity and Force Relationship

Figure 37 and 38 shows the results obtained from the spreadsheet we created from the equations and parameters obtained in the previous chapters. Both graphs have a gentle concave slope and we can see that the model complies with the Hill's equation which suggests that force increase with decreasing muscle velocity and vice versa. It is possible for us to measure the maximum force of the muscle at zero muscle velocity in reality. However it is not so when we come to the boundary condition of zero muscle force reach when velocity of muscle is at its maximum. In our model, although limb segment has already reached its minimum possible angle, zero force at maximum velocity is not reached.

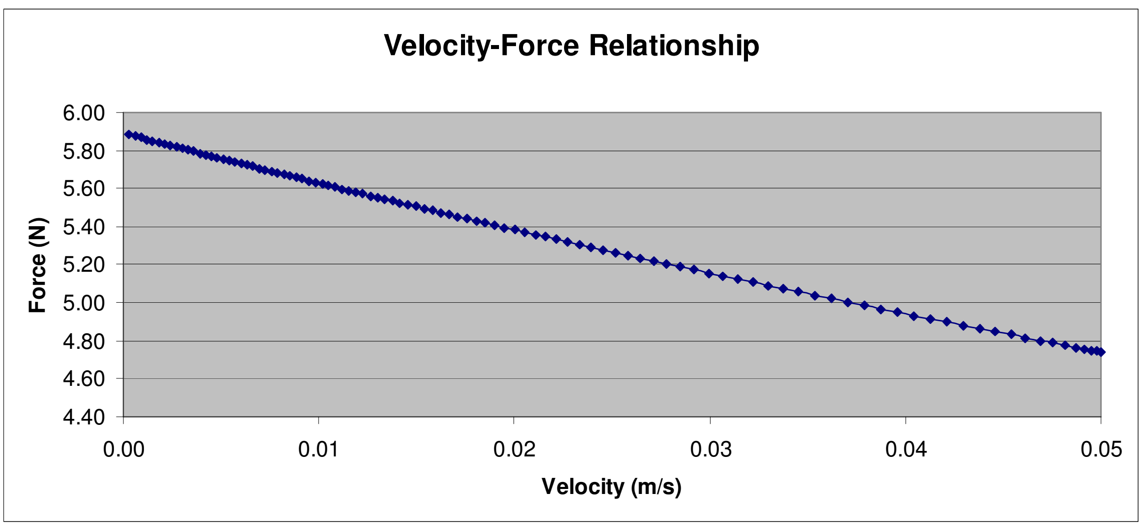


Figure 47. Muscle Velocity-Force Relationship, Instance 1.

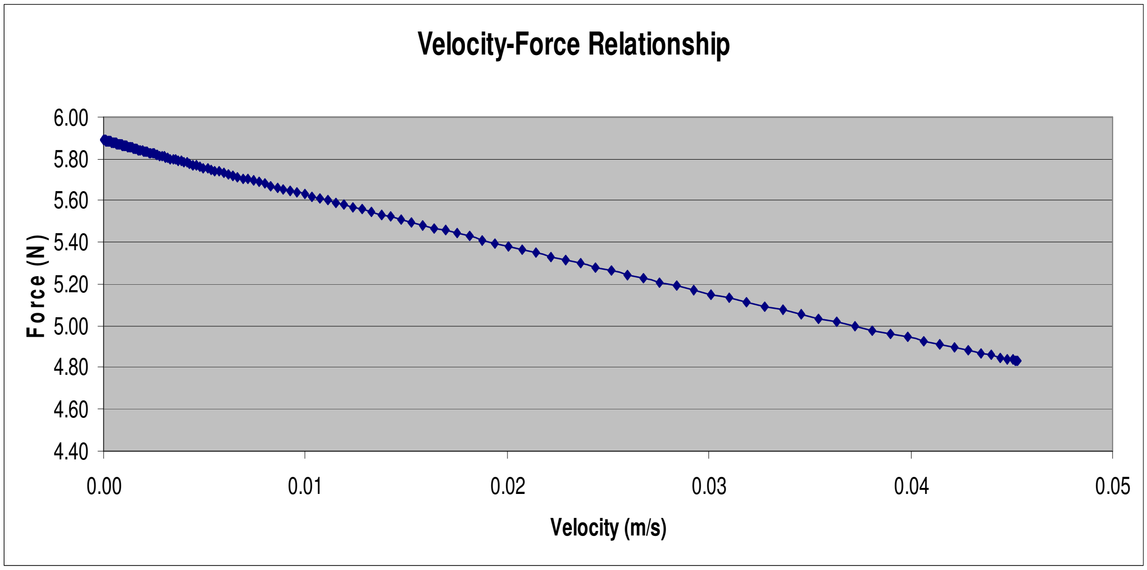


Figure 48. Muscle Velocity-Force Relationship, Instance 2.

4.6.2 Muscle Length and Time Relationship

From the graphs of muscle length against time of instance 1 below, we can see that the muscle length decrease slowly till it reaches the 0.04 sec where it starts to decrease exponentially. A point to note is that at about 0.09 sec, the muscle fiber is 60% [34] of its length at rest, thus under-stretching of muscle fibers occurs. This result is arguable as it is not common for muscle to be under-stretched for more than 60% its original length. For graphs of muscle length against time of instance 2, muscle length shortening is quite slow until when it reaches the upright position and tilting towards the left where the muscle length decrease exponentially. This takes place at around the time of 0.12sec where the limb segment is back to the full upright position.

In most cases, as the muscle on one side is contracting, opposing muscle will be extended. This extension will trigger the sensory neurons on the muscle spindle to send a signal to the CNS which in turn will activate the motor neurons to contract the initially extended muscle and inhibit the originally contracting muscle. Thus the muscle on the right would have stop contracting before under-stretching occurs. The limb segment as seen in the model will stop tilting to the right and rotate in the opposite direction towards the left till it reaches its equilibrium point again.

The downward slope at the end of the graphs suggest that the muscle may have been slow in contracting during the initial stage but as it pass the mark of 50% of its original length, shortening is rate is doubled.

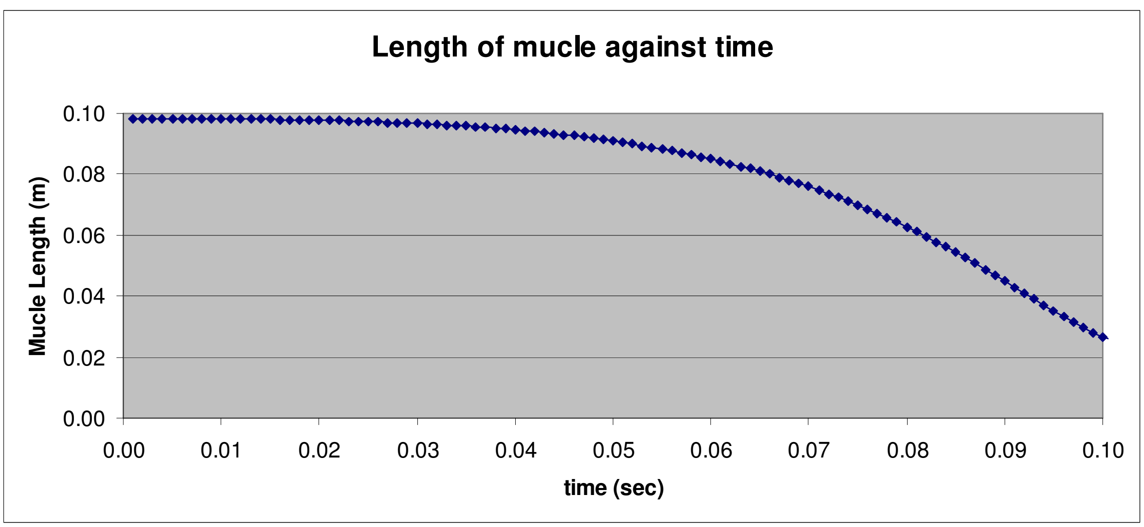


Figure 49. Muscle length against time, Instance 1.

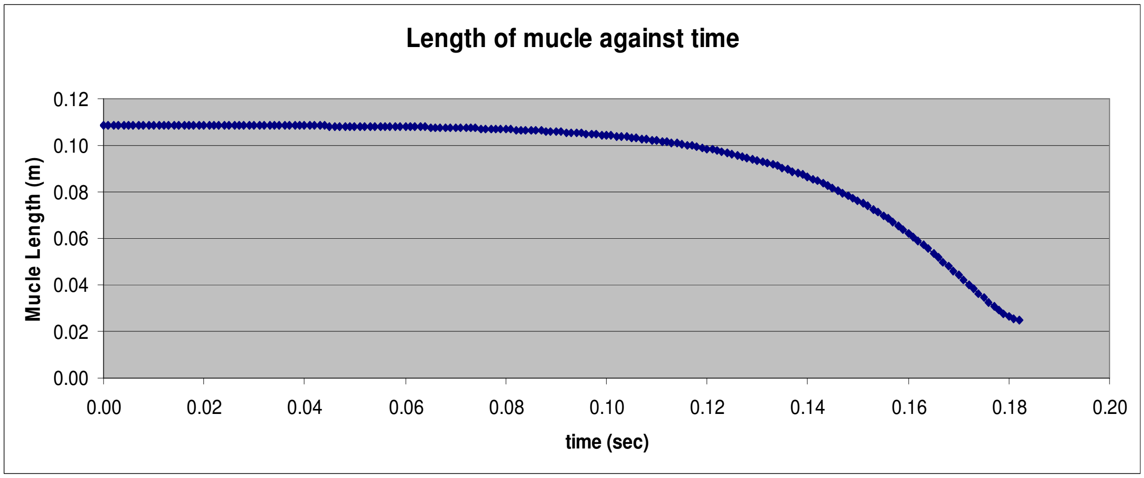


Figure 50. Muscle length against time, Instance 2.

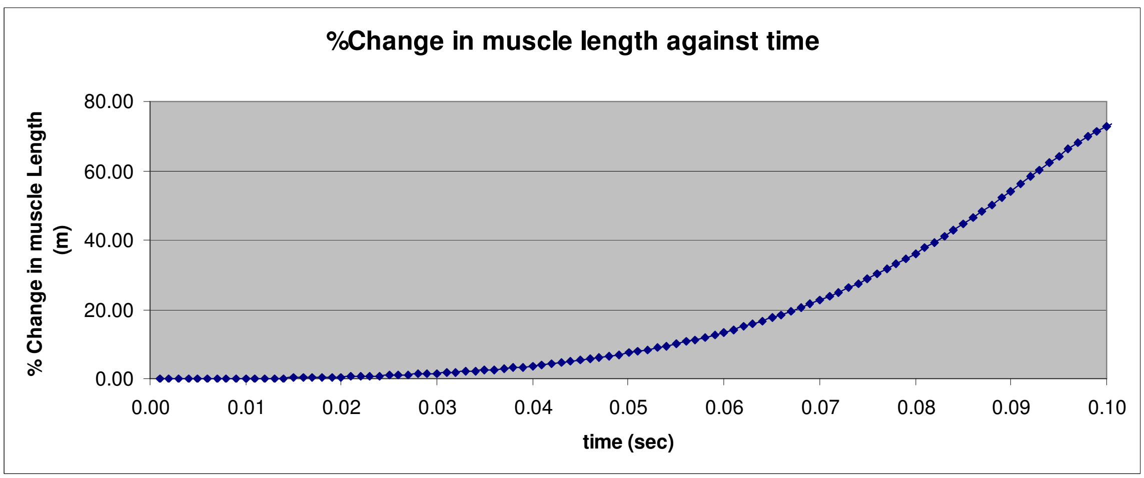


Figure 51. Percentage change in Muscle length against time, Instance 1.

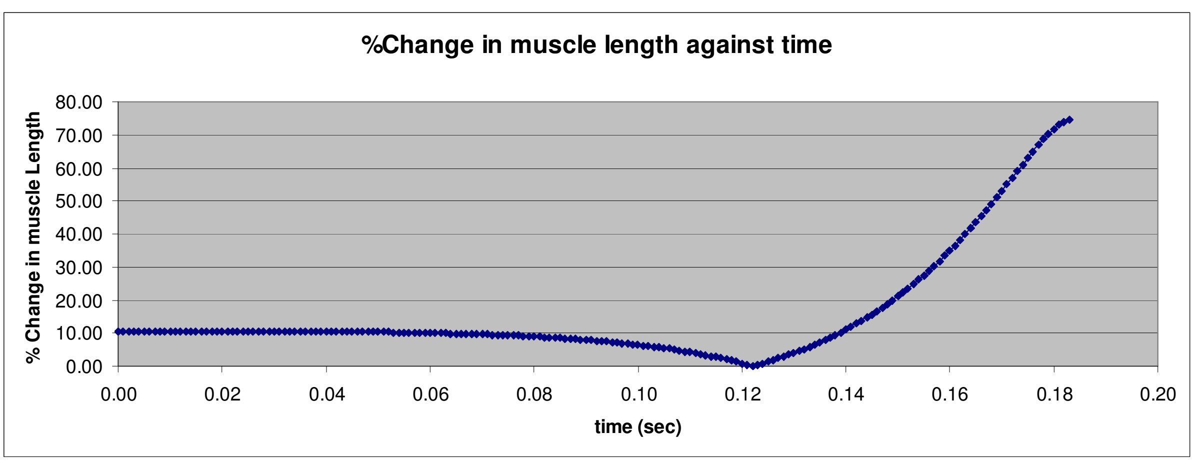


Figure 52. Percentage change in Muscle length against time, Instance 2.

4.6.3 Angular velocity of limb segment and Time Relationship

The angular velocity of the limb segment increase linearly until the point where the muscle is under stretched at around 0.09 sec for instance 1 and 017 sec for instant 2. Angular velocity exponentially increase after the point, showing the discontinuity in linear increment when the muscle reaches its under-stretched point for both instances.

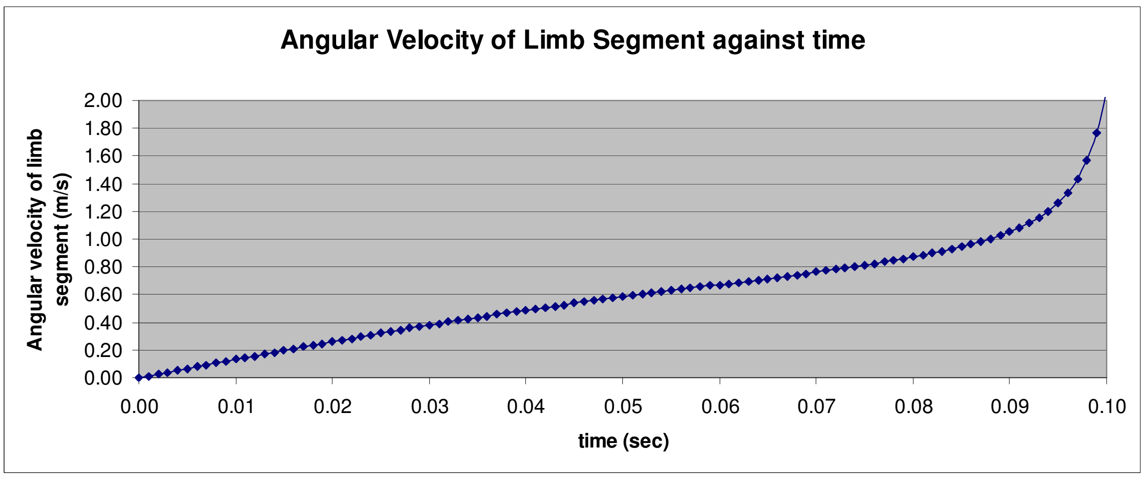


Figure 53. Angular velocity of limb segment against time, Instance 1.

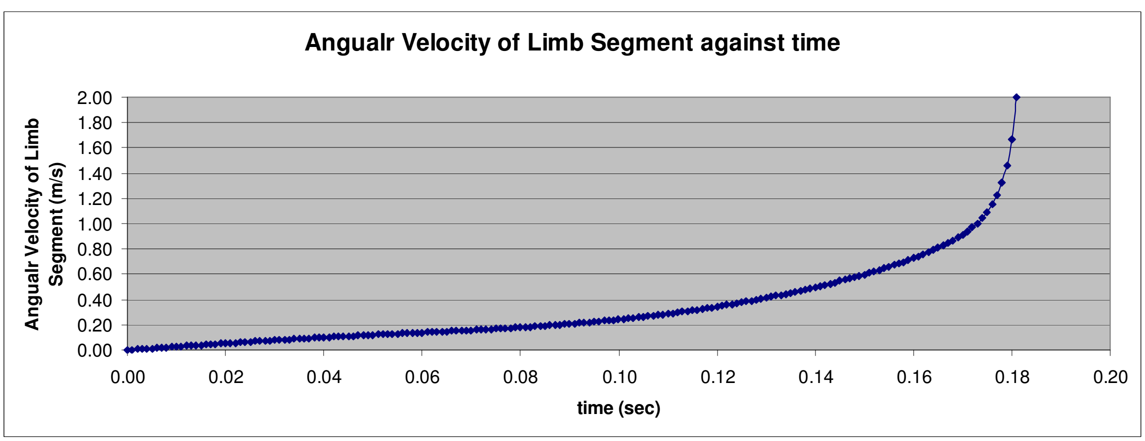


Figure 54. Angular velocity of limb segment against time, Instance 2.

4.6.4 Linear muscle fiber shortening velocity & acceleration

From the graphs below the linear acceleration of the muscle fibers dip exponentially after it reaches muscle under-stretched timing at 0.09 sec for instance 1 and 0.17 sec for instance 2. Muscle velocity increase linearly till about 0.05 sec and 0.10 sec before the slope of its curve increase due to the increase in acceleration. The slope of the muscle velocity-time graph for instance 1 becomes gentle again after 0.09 sec because of deceleration from the muscle as shown in figure 43 and for instance 2, slope became gentle at around 0.17 sec where deceleration starts as shown is figure 44.

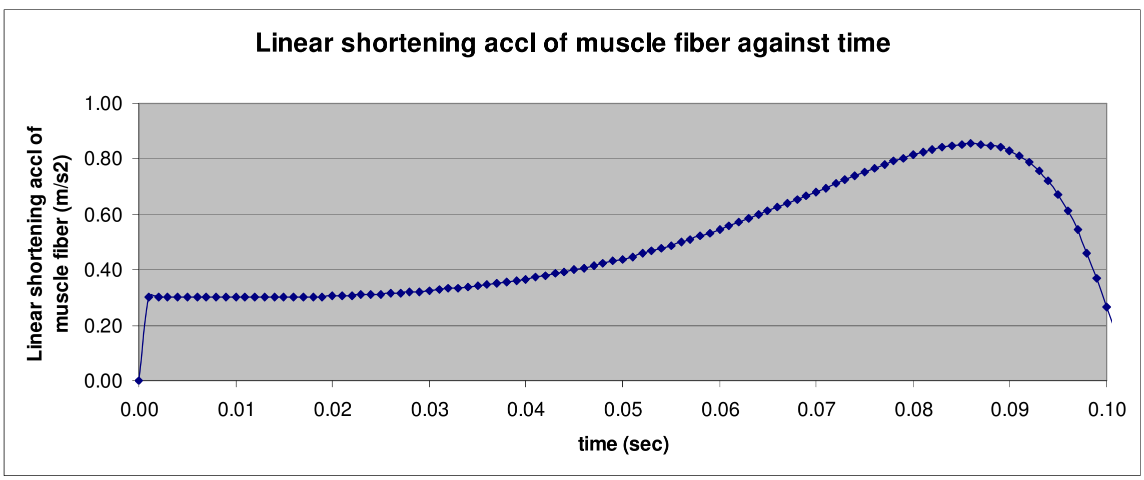


Figure 55. Acceleration of muscle fiber against time, Instance 1.

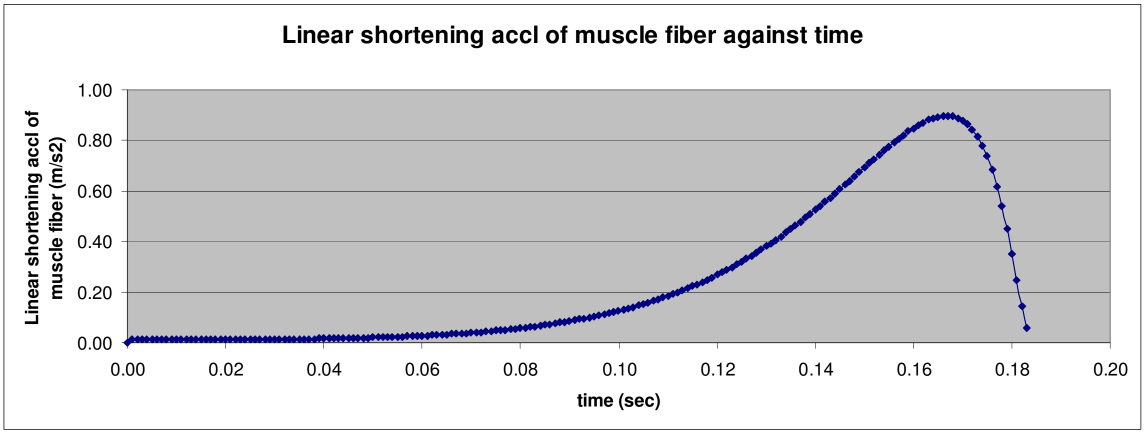


Figure 56. Acceleration of muscle fiber against time, Instance 2.

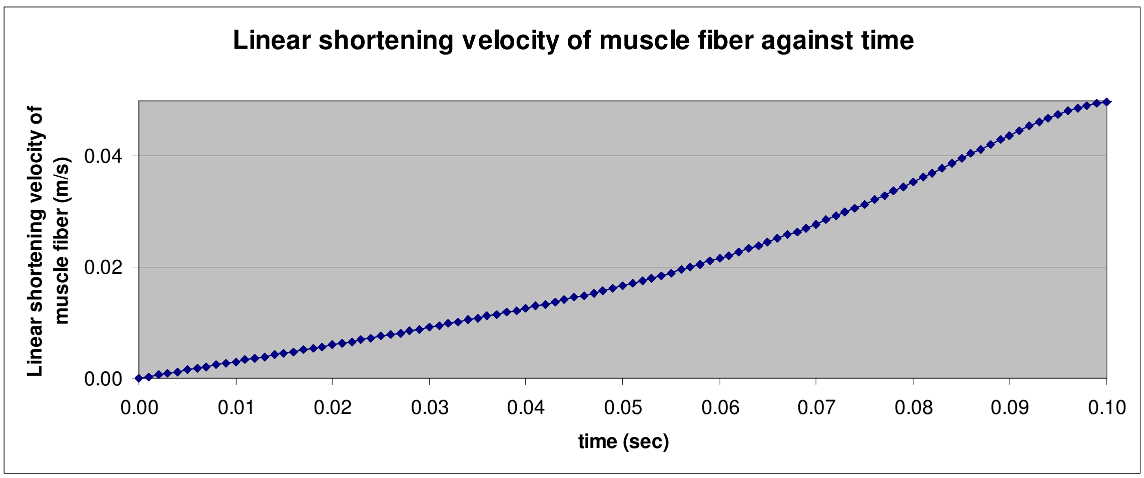


Figure 57. Velocity of muscle fiber against time, Instance 1.

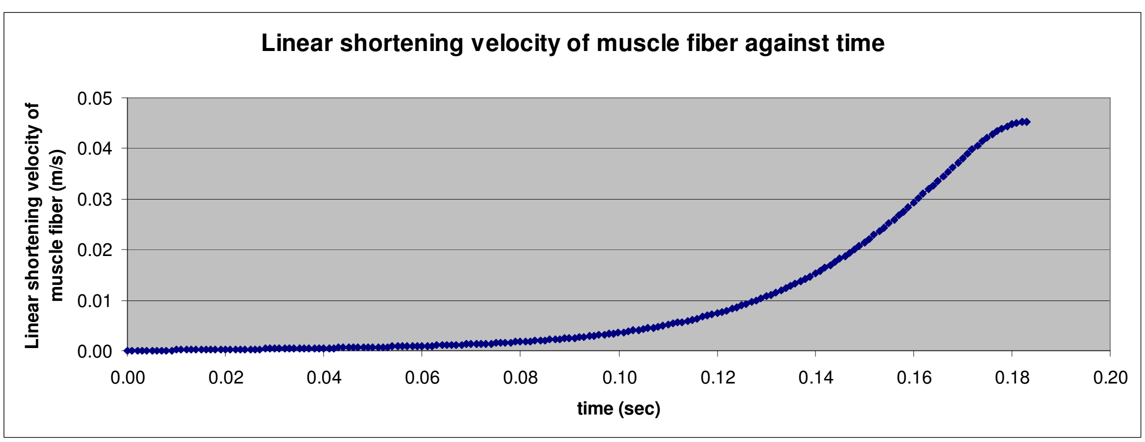


Figure 58. Velocity of muscle fiber against time, Instance 2.

4.6.5 Muscle Force and Length Relationship

Muscle Force-Length relationship of the model complies with the muscle tension-length graph (Huxley) in figure 14 where the slope is gentle and concaving outwards. In a skeletal muscle fiber, the amount of tension generated during a contraction depends on the number of pivoting cross-bridges in all the sarcomeres along all the myofibrils. The number of cross-bridges that can form depends on the degree of overlap between thick filaments and thin filaments. When the muscle fiber is stimulated to contract, only myosin heads in the zone of overlap can bind to active sites and produce tension. The tension produced by the entire muscle fiber can thus be related to the structure of an individual sarcomere. When the sarcomeres are as short as they can be, the thick filaments are jammed. Although cross-bridge binding can occur, the myosin heads cannot pivot, and no tension is produced. Within the optimal range of sarcomere lengths, the maximum number of cross-bridges can form and the tension produced is highest. Any further increase in sarcomere length reduces the tension produced by reducing the size of the zone of overlap and the number of potential cross-bridge interactions.

Both the graphs below exhibit the mechanical properties of muscle well. The muscle force is at its largest when the muscle length is at its original and subsequently, the tension the muscle can take reduces as its length is shortened. Soon the force in the muscle fiber will be less than 0 when it reaches its under-stretched length which occurs around 0.09 sec for instance 1 and 0.17 sec for instance 2 in our model.

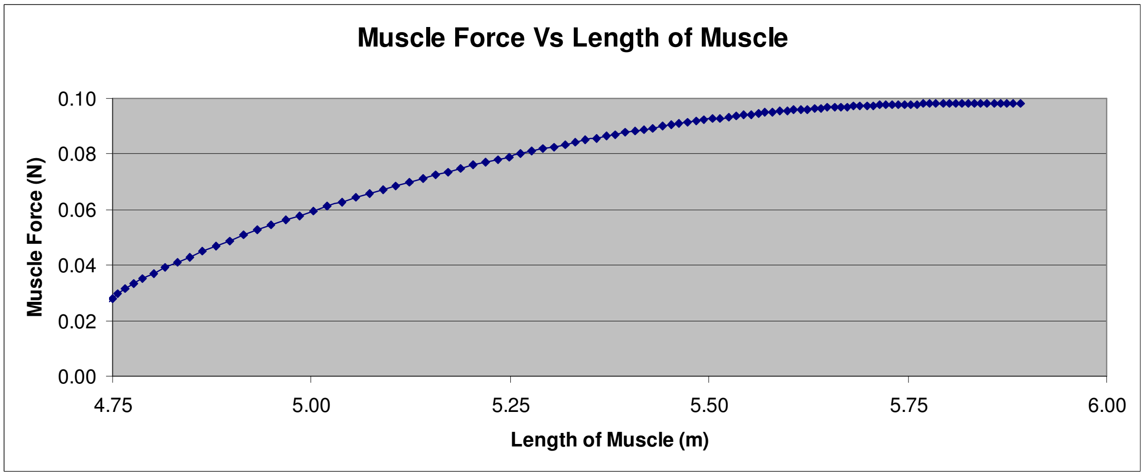


Figure 59. Muscle force against muscle Length, Instance 1.

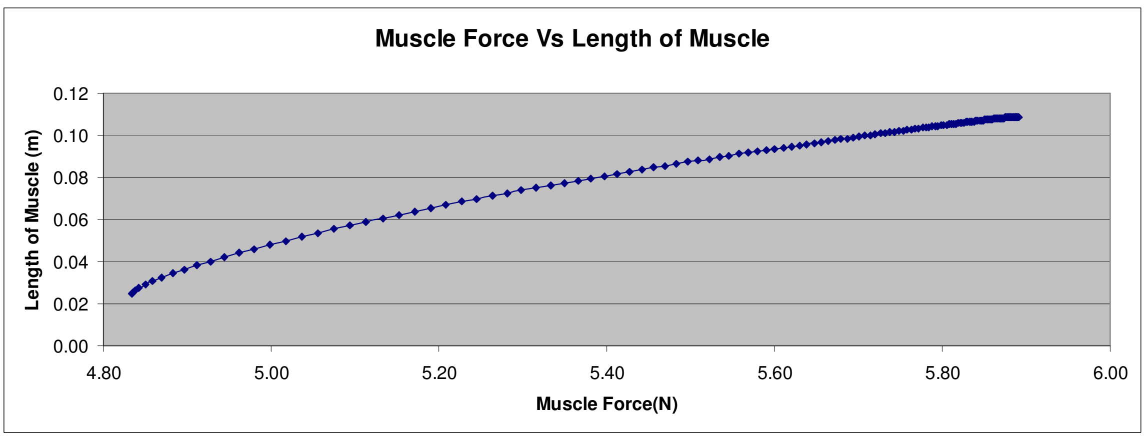


Figure 60. Muscle force against muscle Length, Instance 2.

From the results and graphs generated from the mechanical model, we can see that the model exhibits the properties of muscle very well. The model can certainly be used for simple modeling of muscle reflex circuit to provide a better understanding of neurological symptom analysis of muscle reflex. Similar mechanical model development on elbow flexion also using Hill equation had been carried out and validated with medically proven characteristics of muscle parameters. [35] Thus further prove that although the current model is a simplified model of a complex system, it is still able to provide accurate information for our studies.

4.7 Reflex Loop Quantitative Analysis

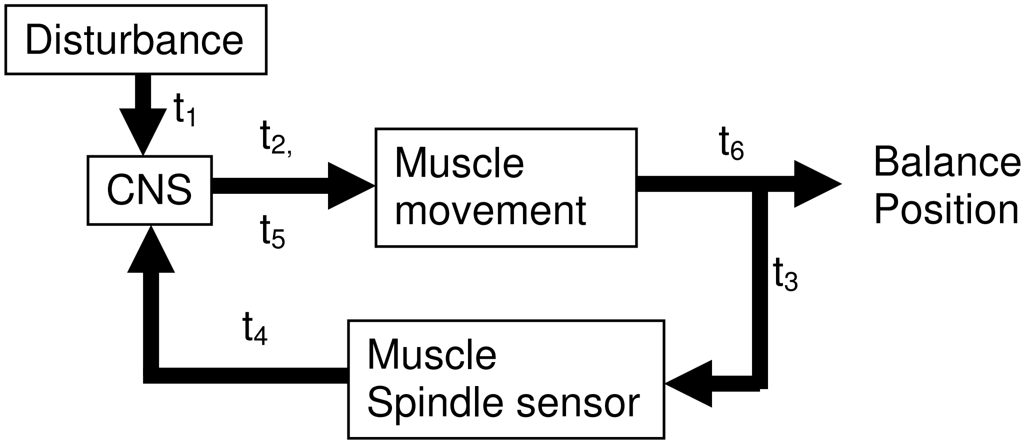


Figure 61. Reflex loop control system with feedback loop.

From our mechanical model, assuming that the muscle spindle will fire off a signal when the muscle on the left is over-stretched at and angle of 170°, t_3 = 0.07 sec. For the limb segment to move back to the upright position, time needed, t_6 = 0.122 sec. Time taken are based on estimated dimensions for the model. More precise dimensions and muscle length can be used, once the area of test is identified.

From literature, t_1 and t_4 which belong to the alpha neuron, they vary in diameter between 5-20 µm, conductance speed is between 12-130 m/s.

Axons of motor neurons that conduct impulses to skeletal muscles are also under the alpha type neuron. Thus t_2 and t_5 are between 5-20 µm in diameter with a conductance speed of 12-130m/s.

With this reflex loop circuit, known length of sensory and motor neurons and time taken by limb movement from the mechanical model, an estimated time of the whole reflex to balance motion can be derived. Here, we can also see that muscle length, velocity and neurons activation are all dependent determinants of muscle functioning. [36]

Results from drug transmission synaptic activity studies from section 4.4, allow us to understand how the type of drugs and its concentration will affect the synaptic response. The reflex loop control system can be used to monitor improvement of patients with motion disorder under the influence of drugs. Results and graphs from section 4.4 show how concentration of drugs affects the response of neuron. Benchmark response timing can be generated from the reflex control loop without any dosage of drugs initially and timing to complete the motion loop should be taken again now with known concentration of drugs that improves neural activities. A comparison of drug concentration and time taken to complete a motion loop will suggest if the drug is effective. From figure 38, we know that response to drugs will plateau as concentration of drug increases. Thus when there is no further improvement on recorded timing to finish the motion loop, with increased drug concentration, it means that response had plateau and no further increase of drug concentration should be introduced.

CHAPTER FIVE

Conclusion

It is important to understand synaptic activities as well as muscle mechanics when working with patients with infected nervous system or motion disorder. A more systematic way to quantify physical improvements of these patients is reached by achieving the objectives for this project. This project provides a better understanding of how the nervous system work as a whole with signal passed from neurons to CNS or effectors neuron moving the muscle and how to translate this into a physical model completed with a control system loop.

The concept reflex loop control system and mechanical model in this project is substantiated with data generated. Results from generated data show that the mechanical model complies with actual human muscle mechanics. With the objectives of this project achieved, the control system should act as a fast and simple tool to allow physiotherapist and doctors to monitor the improvement of their patients via time taken for them to complete a reflex loop motion. It should also aid them on deciding if certain drug is showing positive results on a patient. Results generated from the model may not be the exact timing but it will give a rough gauge of time taken to complete a certain reflex motion by a healthy subject.

There are some limitations to the present research which can be improved with some future studies and work. First and foremost, bone sections are usually joined together by tendon and although the proposed model proved to work well without consideration of tendon in joints, it will be good to include the elasticity of tendon to get a more accurate reading of time interval. [37]

The dimensions of the mechanical model in this project is estimated and assumed according to proper proportionality of muscle to limb ratio. To allow physiotherapist or doctors to be able to use this model and reflex control loop to monitor improvement of patient’s with Parkinson disease, we have to generate a database of variables which should include the true dimensions the of various bone segment and muscles, synaptic conductance speed which varies with position of neuron, age of subject and also the health condition of the subject. With all the information generated, a simple user interface software program can be constructed to allow user to choose the appropriate variables from a database and ultimately generate the correct timing of the limp reflex movement.

Clinical trials will be the final step needed before the system can be endorsed and implemented by practitioners. Having understood synaptic functions, its various activities and how drugs will affect signal processing, we had also theoretically proven the mechanical model of muscle limb segment and formulated the muscle reflex control loop. Before the model can be used by physiotherapist or practitioners, clinical studies and verifications had to be done to prove that the model and the reflex control loop is able to true.

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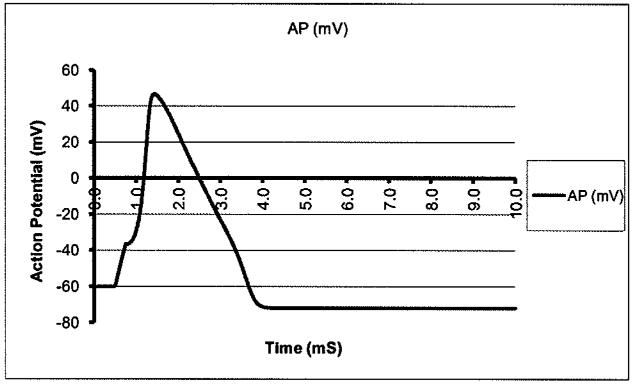
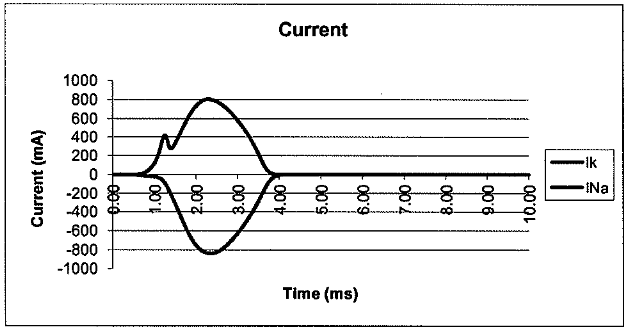
APPENDIX

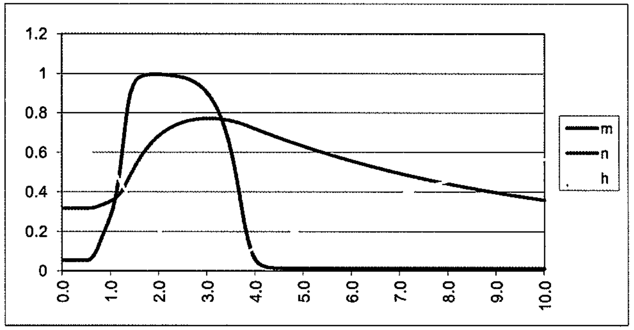
ACTION POTENTIAL

Constants	
Initial Vm	**-60**
Cm	**1**
Vna	**-115**
VK	**12**
VL	**-10.613**
gbarNa	**120**
gbarK	**36**
gbarL	**0.3**
delta t	**0.01**
Stim 0	**0**
Stim1	**100**

time	real mV	HH mV	I tot	Istim	IK	n	dn/dt	alpha n	beta n	Ina	m	dm/dt	alpha m	beta m	h	dh/dt	alpha h	beta h	I leak
0	-60	0	0.004224	0	-4.39973	0.317677	0	0.058198	0.125	1.220057	0.052932	0	0.223564	4	0.596121	0	0.07	0.047426	3.1839
0.01	-60	-4.2E-05	0.004195	0	-4.39975	0.317677	1.19E-07	0.058198	0.125	1.220057	0.052932	0	0.223564	3.999991	0.596121	-1.7E-07	0.07	0.047426	3.183887
0.02	-59.9999	-8.4E-05	0.004167	0	-4.39976	0.317677	2.36E-07	0.058198	0.125	1.220056	0.052932	1.11E-06	0.223565	3.999981	0.596121	-3.5E-07	0.07	0.047426	3.183875
0.03	-59.9999	-0.00013	0.004139	0	-4.39978	0.317677	3.53E-07	0.058198	0.125	1.220057	0.052932	2.22E-06	0.223566	3.999972	0.596121	-5.2E-07	0.07	0.047426	3.183862
0.04	-59.9998	-0.00017	0.004112	0	-4.3998	0.317677	4.68E-07	0.058198	0.125	1.220058	0.052933	3.27E-06	0.223566	3.999963	0.596121	-6.9E-07	0.069999	0.047427	3.18385
0.05	-59.9998	-0.00021	0.004086	0	-4.39981	0.317677	5.83E-07	0.058198	0.125	1.220059	0.052933	4.27E-06	0.223567	3.999954	0.596121	-8.5E-07	0.069999	0.047427	3.183837
0.06	-59.9998	-0.00025	0.004061	0	-4.39983	0.317677	6.96E-07	0.058199	0.125	1.220062	0.052933	5.21E-06	0.223568	3.999945	0.596121	-1E-06	0.069999	0.047427	3.183825
0.07	-59.9997	-0.00029	0.004037	0	-4.39984	0.317677	8.09E-07	0.058199	0.125	1.220065	0.052933	6.11E-06	0.223568	3.999936	0.596121	-1.2E-06	0.069999	0.047427	3.183813
0.08	-59.9997	-0.00033	0.004014	0	-4.39986	0.317677	9.21E-07	0.058199	0.124999	1.220069	0.052933	6.96E-06	0.223569	3.999927	0.596121	-1.4E-06	0.069999	0.047427	3.183801
0.09	-59.9996	-0.00037	0.003991	0	-4.39987	0.317677	1.03E-06	0.058199	0.124999	1.220073	0.052933	7.77E-06	0.223569	3.999918	0.596121	-1.5E-06	0.069999	0.047428	3.183789
0.1	-59.9996	-0.00041	0.003968	0	-4.39989	0.317677	1.14E-06	0.058199	0.124999	1.220078	0.052933	8.53E-06	0.22357	3.999909	0.596121	-1.7E-06	0.069999	0.047428	3.183777
0.11	-59.9996	-0.00045	0.003947	0	-4.3999	0.317677	1.25E-06	0.058199	0.124999	1.220084	0.052933	9.25E-06	0.223571	3.9999	0.596121	-1.8E-06	0.069998	0.047428	3.183765
0.12	-59.9995	-0.00049	0.003926	0	-4.39992	0.317677	1.36E-06	0.058199	0.124999	1.22009	0.052933	9.94E-06	0.223571	3.999891	0.596121	-2E-06	0.069998	0.047428	3.183753
0.13	-59.9995	-0.00053	0.003905	0	-4.39993	0.317677	1.47E-06	0.058199	0.124999	1.220096	0.052933	1.06E-05	0.223572	3.999883	0.596121	-2.2E-06	0.069998	0.047428	3.183741
0.14	-59.9994	-0.00057	0.003885	0	-4.39995	0.317677	1.57E-06	0.0582	0.124999	1.220103	0.052933	1.12E-05	0.223572	3.999874	0.596121	-2.3E-06	0.069998	0.047428	3.18373
0.15	-59.9994	-0.00061	0.003866	0	-4.39996	0.317677	1.68E-06	0.0582	0.124999	1.22011	0.052933	1.18E-05	0.223573	3.999865	0.596121	-2.5E-06	0.069998	0.047429	3.183718
0.16	-59.9994	-0.00065	0.003847	0	-4.39998	0.317677	1.79E-06	0.0582	0.124999	1.220118	0.052933	1.23E-05	0.223574	3.999857	0.596121	-2.6E-06	0.069998	0.047429	3.183706
0.17	-59.9993	-0.00068	0.003828	0	-4.39999	0.317677	1.89E-06	0.0582	0.124999	1.220126	0.052934	1.29E-05	0.223574	3.999848	0.596121	-2.8E-06	0.069998	0.047429	3.183695
0.18	-59.9993	-0.00072	0.00381	0	-4.40001	0.317677	2E-06	0.0582	0.124999	1.220134	0.052934	1.34E-05	0.223575	3.99984	0.59612	-2.9E-06	0.069997	0.047429	3.183683
0.19	-59.9992	-0.00076	0.003792	0	-4.40002	0.317677	2.1E-06	0.0582	0.124999	1.220143	0.052934	1.38E-05	0.223575	3.999831	0.59612	-3.1E-06	0.069997	0.047429	3.183672
0.2	-59.9992	-0.0008	0.003775	0	-4.40004	0.317677	2.2E-06	0.0582	0.124999	1.220152	0.052934	1.43E-05	0.223576	3.999823	0.59612	-3.2E-06	0.069997	0.047429	3.183661
0.21	-59.9992	-0.00084	0.003758	0	-4.40005	0.317677	2.3E-06	0.058201	0.124999	1.220162	0.052934	1.47E-05	0.223577	3.999814	0.59612	-3.4E-06	0.069997	0.04743	3.183649
0.22	-59.9991	-0.00087	0.003741	0	-4.40007	0.317677	2.4E-06	0.058201	0.124999	1.220171	0.052934	1.51E-05	0.223577	3.999806	0.59612	-3.5E-06	0.069997	0.04743	3.183638
0.23	-59.9991	-0.00091	0.003725	0	-4.40008	0.317677	2.5E-06	0.058201	0.124999	1.220181	0.052934	1.54E-05	0.223578	3.999798	0.59612	-3.7E-06	0.069997	0.04743	3.183627
0.24	-59.9991	-0.00095	0.003709	0	-4.4001	0.317677	2.6E-06	0.058201	0.124999	1.220191	0.052935	1.58E-05	0.223578	3.999789	0.59612	-3.8E-06	0.069997	0.04743	3.183616
0.25	-59.999	-0.00099	0.003693	0	-4.40011	0.317677	2.7E-06	0.058201	0.124998	1.220202	0.052935	1.61E-05	0.223579	3.999781	0.59612	-4E-06	0.069997	0.04743	3.183604
0.26	-59.999	-0.00102	0.003678	0	-4.40013	0.317677	2.8E-06	0.058201	0.124998	1.220213	0.052935	1.64E-05	0.223579	3.999773	0.59612	-4.1E-06	0.069996	0.04743	3.183593
0.27	-59.9989	-0.00106	0.003663	0	-4.40014	0.317677	2.9E-06	0.058201	0.124998	1.220223	0.052935	1.67E-05	0.22358	3.999765	0.59612	-4.3E-06	0.069996	0.047431	3.183582
0.28	-59.9989	-0.0011	0.003648	0	-4.40016	0.317677	3E-06	0.058201	0.124998	1.220235	0.052935	1.7E-05	0.223581	3.999757	0.59612	-4.4E-06	0.069996	0.047431	3.183571
0.29	-59.9989	-0.00113	0.003633	0	-4.40017	0.317677	3.1E-06	0.058202	0.124998	1.220246	0.052935	1.73E-05	0.223581	3.999748	0.59612	-4.6E-06	0.069996	0.047431	3.18356
0.3	-59.9988	-0.00117	0.003618	0	-4.40019	0.317677	3.19E-06	0.058202	0.124998	1.220257	0.052936	1.75E-05	0.223582	3.99974	0.59612	-4.7E-06	0.069996	0.047431	3.18355
0.31	-59.9988	-0.0012	0.003604	0	-4.4002	0.317677	3.29E-06	0.058202	0.124998	1.220269	0.052936	1.77E-05	0.223582	3.999732	0.59612	-4.9E-06	0.069996	0.047431	3.183539
0.32	-59.9988	-0.00124	0.00359	0	-4.40022	0.317677	3.38E-06	0.058202	0.124998	1.220281	0.052936	1.79E-05	0.223583	3.999724	0.59612	-5E-06	0.069996	0.047431	3.183528
0.33	-59.9987	-0.00128	0.003576	0	-4.40023	0.317677	3.48E-06	0.058202	0.124998	1.220293	0.052936	1.81E-05	0.223583	3.999716	0.59612	-5.1E-06	0.069996	0.047432	3.183517
0.34	-59.9987	-0.00131	0.003563	0	-4.40025	0.317678	3.57E-06	0.058202	0.124998	1.220305	0.052936	1.83E-05	0.223584	3.999708	0.59612	-5.3E-06	0.069995	0.047432	3.183506
0.35	-59.9987	-0.00135	0.003549	0	-4.40026	0.317678	3.66E-06	0.058202	0.124998	1.220317	0.052936	1.85E-05	0.223584	3.999701	0.59612	-5.4E-06	0.069995	0.047432	3.183496
0.36	-59.9986	-0.00138	0.003536	0	-4.40028	0.317678	3.76E-06	0.058202	0.124998	1.220329	0.052937	1.87E-05	0.223585	3.999693	0.59612	-5.6E-06	0.069995	0.047432	3.183485
0.37	-59.9986	-0.00142	0.003522	0	-4.40029	0.317678	3.85E-06	0.058202	0.124998	1.220342	0.052937	1.88E-05	0.223586	3.999685	0.59612	-5.7E-06	0.069995	0.047432	3.183474
0.38	-59.9985	-0.00145	0.003509	0	-4.40031	0.317678	3.94E-06	0.058203	0.124998	1.220354	0.052937	1.9E-05	0.223586	3.999677	0.59612	-5.8E-06	0.069995	0.047432	3.183464
0.39	-59.9985	-0.00149	0.003496	0	-4.40032	0.317678	4.03E-06	0.058203	0.124998	1.220367	0.052937	1.91E-05	0.223587	3.999669	0.59612	-6E-06	0.069995	0.047433	3.183453
0.4	-59.9985	-0.00152	0.003484	0	-4.40034	0.317678	4.12E-06	0.058203	0.124998	1.220379	0.052937	1.92E-05	0.223587	3.999661	0.59612	-6.1E-06	0.069995	0.047433	3.183443
0.41	-59.9984	-0.00156	0.003471	0	-4.40035	0.317678	4.21E-06	0.058203	0.124998	1.220392	0.052938	1.93E-05	0.223588	3.999654	0.596119	-6.2E-06	0.069995	0.047433	3.183432
0.42	-59.9984	-0.00159	0.003458	0	-4.40037	0.317678	4.3E-06	0.058203	0.124998	1.220405	0.052938	1.95E-05	0.223588	3.999646	0.596119	-6.4E-06	0.069994	0.047433	3.183422
0.43	-59.9984	-0.00163	0.003446	0	-4.40038	0.317678	4.39E-06	0.058203	0.124997	1.220418	0.052938	1.95E-05	0.223589	3.999638	0.596119	-6.5E-06	0.069994	0.047433	3.183412
0.44	-59.9983	-0.00166	0.003433	0	-4.4004	0.317678	4.48E-06	0.058203	0.124997	1.220431	0.052938	1.96E-05	0.223589	3.999631	0.596119	-6.7E-06	0.069994	0.047433	3.183401
0.45	-59.9983	-0.0017	0.003421	0	-4.40041	0.317678	4.57E-06	0.058203	0.124997	1.220444	0.052938	1.97E-05	0.22359	3.999623	0.596119	-6.8E-06	0.069994	0.047434	3.183391
0.46	-59.9983	-0.00173	0.003409	0	-4.40043	0.317678	4.66E-06	0.058204	0.124997	1.220457	0.052939	1.98E-05	0.22359	3.999615	0.596119	-6.9E-06	0.069994	0.047434	3.183381
0.47	-59.9982	-0.00177	0.003397	0	-4.40044	0.317678	4.74E-06	0.058204	0.124997	1.220471	0.052939	1.99E-05	0.223591	3.999608	0.596119	-7E-06	0.069994	0.047434	3.18337
0.48	-59.9982	-0.0018	0.003385	0	-4.40046	0.317678	4.83E-06	0.058204	0.124997	1.220484	0.052939	1.99E-05	0.223591	3.9996	0.596119	-7.2E-06	0.069994	0.047434	3.18336
0.49	-59.9982	-0.00183	0.003373	0	-4.40047	0.317678	4.92E-06	0.058204	0.124997	1.220497	0.052939	2E-05	0.223592	3.999593	0.596119	-7.3E-06	0.069994	0.047434	3.18335
0.5	-59.9981	-0.00187	100.0034	100	-4.40049	0.317678	5E-06	0.058204	0.124997	1.22051	0.052939	2E-05	0.223592	3.999585	0.596119	-7.4E-06	0.069993	0.047434	3.18334
0.51	-58.9981	-1.0019	99.32608	100	-4.76716	0.317678	0.002861	0.061667	0.123444	1.20991	0.05294	2.01E-05	0.239476	3.783438	0.596119	-0.00421	0.06658	0.052163	2.88333
0.52	-58.0048	-1.99516	98.65147	100	-5.13318	0.317707	0.005791	0.065259	0.121921	1.199297	0.05294	0.026505	0.256207	3.58032	0.596077	-0.00856	0.063354	0.057298	2.585352
0.53	-57.0183	-2.98168	97.99697	100	-5.49903	0.317765	0.008793	0.06898	0.120427	1.2066	0.053205	0.053102	0.273806	3.389376	0.595991	-0.0131	0.060305	0.062865	2.289397
0.54	-56.0384	-3.96165	97.36214	100	-5.86521	0.317853	0.011868	0.072828	0.118961	1.231944	0.053736	0.078907	0.292299	3.209782	0.59586	-0.01784	0.057421	0.068892	1.995406
0.55	-55.0647	-4.93527	96.74639	100	-6.23228	0.317971	0.015015	0.076805	0.117522	1.275348	0.054525	0.104112	0.311707	3.040776	0.595682	-0.0228	0.054693	0.075406	1.70332
0.56	-54.0973	-5.90273	96.14975	100	-6.60076	0.318122	0.018233	0.080909	0.116109	1.337431	0.055566	0.128913	0.332055	2.881655	0.595454	-0.028	0.05211	0.082434	1.413081


AP (mV)
Action Potential (mV)
60
40
20
0
-20
-40
-60
-80
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
AP (mV)
Time (mS)


Current
Current (mA)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Ik
INa
Time (ms)


1.2
1
0.8
0.6
0.4
0.2
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
m
n
h

EPSP

For dendrite or compartment of length l and diameter d

Parameter	*Value*	*Unit*
RM	5000	kohm/cm2
RA	25	kohm/cm
d	0.0002	cm
l	0.01	cm
Cm	0.000001	mF/cm2

Rm	7.96E+08 ohm	grest	1.26E-09	0.959
Cm	6.28E-09 F	Erest	-60	
tauM	5	E	47.5	

For inhibitory synapse

Esyn -75 mV

For excitatory synapse

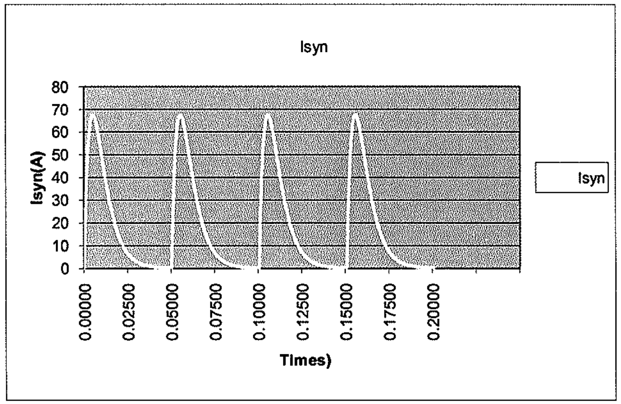
Esyn -12.5 mV

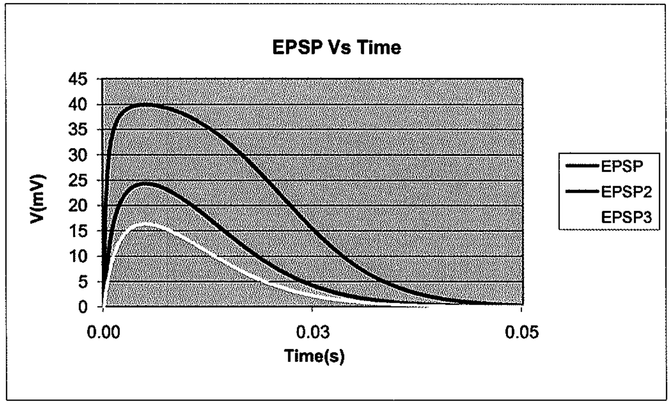
Isyn(t) = gsyn(t)(Vm-Esyn)

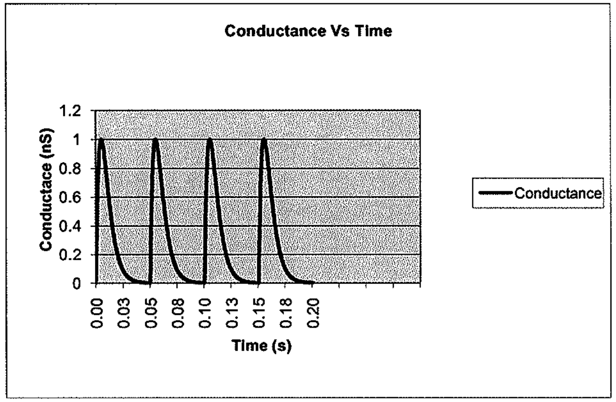
Rm = RM/πdl

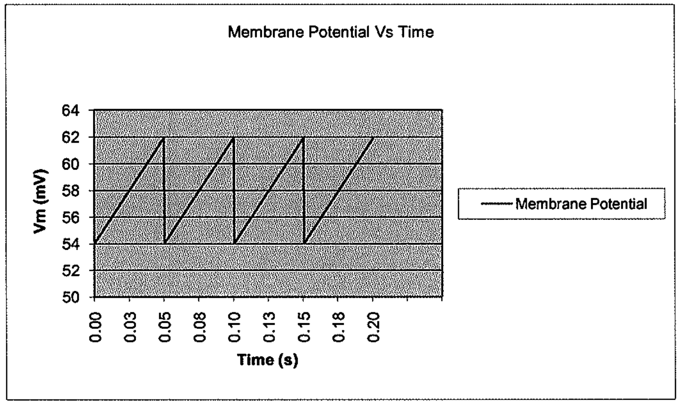
Cm = CMπdl

Ra =4RA/πd^2









A	1	tau	0.005	Iinject	0.000001
t(ms)	G(t)	T(graph)(s)	Vm	Isyn(t)	Vpsp
0.00000	0	0.00000	54	0	0
0.00025	0.129285	0.00025	54.03978	8.602628	5.64287637
0.00050	0.24596	0.00050	54.07956	16.37593	9.69585029
0.00075	0.350947	0.00075	54.11934	23.37986	12.7256931
0.00100	0.445108	0.00100	54.15912	29.67052	15.0576993
0.00125	0.52925	0.00125	54.19889	35.30039	16.8919033
0.00150	0.604126	0.00150	54.23867	40.31855	18.3580719
0.00175	0.670439	0.00175	54.27844	44.77089	19.5440643
0.00200	0.728848	0.00200	54.3182	48.70028	20.5114839
0.00225	0.779964	0.00225	54.35797	52.1468	21.3048035
0.00250	0.824361	0.00250	54.39774	55.14786	21.9569331
0.00275	0.862572	0.00275	54.4375	57.73839	22.4927494
0.00300	0.895095	0.00300	54.47726	59.951	22.9314075
0.00325	0.922394	0.00325	54.51702	61.81609	23.2878986
0.00350	0.944901	0.00350	54.55678	63.36203	23.5741257
0.00375	0.963019	0.00375	54.59653	64.61524	23.7996627
0.00400	0.977122	0.00400	54.63628	65.60035	23.9723013
0.00425	0.987559	0.00425	54.67603	66.3403	24.0984501
0.00450	0.994654	0.00450	54.71578	66.85643	24.1834332
0.00475	0.998708	0.00475	54.75553	67.1686	24.2317135
0.00500	1	0.00500	54.79527	67.29527	24.2470648
0.00525	0.998791	0.00525	54.83502	67.2536	24.2327041
0.00550	0.995321	0.00550	54.87476	67.05952	24.191395
0.00575	0.989814	0.00575	54.9145	66.72782	24.1255292
0.00600	0.982477	0.00600	54.95423	66.27223	24.0371919
0.00625	0.973501	0.00625	54.99397	65.70544	23.9282138
0.00650	0.963064	0.00650	55.0337	65.03926	23.800213
0.00675	0.951329	0.00675	55.07343	64.28456	23.65463
0.00700	0.938448	0.00700	55.11316	63.45144	23.4927553
0.00725	0.924561	0.00725	55.15289	62.54921	23.3157531
0.00750	0.909796	0.00750	55.19261	61.58647	23.1246801
0.00775	0.894272	0.00775	55.23234	60.57115	22.9205023
0.00800	0.878099	0.00800	55.27206	59.51055	22.7041074
0.00825	0.861376	0.00825	55.31178	58.4114	22.4763171
0.00850	0.844195	0.00850	55.35149	57.27989	22.237896
0.00875	0.826641	0.00875	55.39121	56.12169	21.9895597
0.00900	0.808792	0.00900	55.43092	54.94199	21.7319818
0.00925	0.790718	0.00925	55.47063	53.74558	21.4657992
0.00950	0.772482	0.00950	55.51034	52.53679	21.1916175
0.00975	0.754145	0.00975	55.55005	51.3196	20.9100148
0.01000	0.735759	0.01000	55.58975	50.09764	20.6215452
0.01025	0.717372	0.01025	55.62946	48.87419	20.3267416
0.01050	0.699029	0.01050	55.66916	47.65224	20.0261184
0.01075	0.680769	0.01075	55.70886	46.43448	19.7201734
0.01100	0.662627	0.01100	55.74855	45.22335	19.4093894
0.01125	0.644636	0.01125	55.78825	44.02105	19.0942359
0.01150	0.626823	0.01150	55.82794	42.82953	18.7751698
0.01175	0.609215	0.01175	55.86763	41.65056	18.4526364
0.01200	0.591833	0.01200	55.90732	40.48569	18.1270705
0.01225	0.574697	0.01225	55.94701	39.3363	17.7988961
0.01250	0.557825	0.01250	55.98669	38.20362	17.4685277

A	5	tau	0.005		
t(ms)	G(t)	T(graph)(s)	Vm	Isyn(t)	Vpsp
0	0	0	54	0	0
0.00025	0.646427	0.00025	54.03978	43.01314	19.12593613
0.0005	1.229802	0.0005	54.07956	81.87965	26.68838285
0.00075	1.754735	0.00075	54.11934	116.8993	30.71409509
0.001	2.225541	0.001	54.15912	148.3526	33.19574045
0.00125	2.64625	0.00125	54.19889	176.5019	34.86495396
0.0015	3.020629	0.0015	54.23867	201.5928	36.05358143
0.00175	3.352196	0.00175	54.27844	223.8544	36.93390761
0.002	3.644238	0.002	54.3182	243.5014	37.6042475
0.00225	3.899819	0.00225	54.35797	260.734	38.12477996
0.0025	4.121803	0.0025	54.39774	275.7393	38.53438995
0.00275	4.312859	0.00275	54.4375	288.692	38.85930907
0.003	4.475474	0.003	54.47726	299.755	39.11786417
0.00325	4.61197	0.00325	54.51702	309.0804	39.32323656
0.0035	4.724506	0.0035	54.55678	316.8101	39.48514062
0.00375	4.815095	0.00375	54.59653	323.0762	39.61088534
0.004	4.885611	0.004	54.63628	328.0018	39.70606816
0.00425	4.937796	0.00425	54.67603	331.7015	39.77504163
0.0045	4.973269	0.0045	54.71578	334.2822	39.8212351
0.00475	4.993538	0.00475	54.75553	335.843	39.84738153
0.005	5	0.005	54.79527	336.4764	39.85568048
0.00525	4.993954	0.00525	54.83502	336.268	39.8479173
0.0055	4.976606	0.0055	54.87476	335.2976	39.82555167
0.00575	4.949071	0.00575	54.9145	333.6391	39.78978442
0.006	4.912385	0.006	54.95423	331.3611	39.74160846
0.00625	4.867505	0.00625	54.99397	328.5272	39.68184815
0.0065	4.815318	0.0065	55.0337	325.1963	39.61119017
0.00675	4.756645	0.00675	55.07343	321.4228	39.53020776
0.007	4.69224	0.007	55.11316	317.2572	39.43938014
0.00725	4.622804	0.00725	55.15289	312.746	39.33910808
0.0075	4.54898	0.0075	55.19261	307.9323	39.22972661
0.00775	4.471361	0.00775	55.23234	302.8557	39.11151538
0.008	4.390493	0.008	55.27206	297.5527	38.9847072
0.00825	4.306878	0.00825	55.31178	292.057	38.84949519
0.0085	4.220975	0.0085	55.35149	286.3995	38.70603878
0.00875	4.133207	0.00875	55.39121	280.6084	38.55446872
0.009	4.043961	0.009	55.43092	274.71	38.39489146
0.00925	3.953588	0.00925	55.47063	268.7279	38.2273928
0.0095	3.862412	0.0095	55.51034	262.6839	38.05204115
0.00975	3.770725	0.00975	55.55005	256.598	37.86889033
0.01	3.678794	0.01	55.58975	250.4882	37.67798204
0.01025	3.586862	0.01025	55.62946	244.371	37.47934809
0.0105	3.495146	0.0105	55.66916	238.2612	37.27301235
0.01075	3.403845	0.01075	55.70886	232.1724	37.05899254
0.011	3.313136	0.011	55.74855	226.1168	36.83730189
0.01125	3.223179	0.01125	55.78825	220.1052	36.60795057
0.0115	3.134116	0.0115	55.82794	214.1477	36.37094716
0.01175	3.046073	0.01175	55.86763	208.2528	36.12629987
0.012	2.959164	0.012	55.90732	202.4285	35.87401777
0.01225	2.873486	0.01225	55.94701	196.6815	35.61411192
0.0125	2.789127	0.0125	55.98669	191.0181	35.34659645

A	0.5	tau	0.005		
t(ms)	G(t)	T(graph)(s)	Vm	Isyn(t)	Vpsp
0	0	0	54	0	0
0.00025	0.064643	0.00025	54.03978	4.301314	2.999611
0.0005	0.12298	0.0005	54.07956	8.187965	5.398951
0.00075	0.175474	0.00075	54.11934	11.68993	7.347013
0.001	0.222554	0.001	54.15912	14.83526	8.946962
0.00125	0.264625	0.00125	54.19889	17.65019	10.2725
0.0015	0.302063	0.0015	54.23867	20.15928	11.37769
0.00175	0.33522	0.00175	54.27844	22.38544	12.30312
0.002	0.364424	0.002	54.3182	24.35014	13.07981
0.00225	0.389982	0.00225	54.35797	26.0734	13.73194
0.0025	0.41218	0.0025	54.39774	27.57393	14.27862
0.00275	0.431286	0.00275	54.4375	28.8692	14.73516
0.003	0.447547	0.003	54.47726	29.9755	15.11396
0.00325	0.461197	0.00325	54.51702	30.90804	15.42522
0.0035	0.472451	0.0035	54.55678	31.68101	15.67739
0.00375	0.48151	0.00375	54.59653	32.30762	15.87751
0.004	0.488561	0.004	54.63628	32.80018	16.03155
0.00425	0.49378	0.00425	54.67603	33.17015	16.14459
0.0045	0.497327	0.0045	54.71578	33.42822	16.22097
0.00475	0.499354	0.00475	54.75553	33.5843	16.26444
0.005	0.5	0.005	54.79527	33.64764	16.27827
0.00525	0.499395	0.00525	54.83502	33.6268	16.26533
0.0055	0.497661	0.0055	54.87476	33.52976	16.22813
0.00575	0.494907	0.00575	54.9145	33.36391	16.16891
0.006	0.491238	0.006	54.95423	33.13611	16.08965
0.00625	0.48675	0.00625	54.99397	32.85272	15.99214
0.0065	0.481532	0.0065	55.0337	32.51963	15.878
0.00675	0.475664	0.00675	55.07343	32.14228	15.74867
0.007	0.469224	0.007	55.11316	31.72572	15.60549
0.00725	0.46228	0.00725	55.15289	31.2746	15.44967
0.0075	0.454898	0.0075	55.19261	30.79323	15.28233
0.00775	0.447136	0.00775	55.23234	30.28557	15.10449
0.008	0.439049	0.008	55.27206	29.75527	14.9171
0.00825	0.430688	0.00825	55.31178	29.2057	14.72105
0.0085	0.422098	0.0085	55.35149	28.63995	14.51717
0.00875	0.413321	0.00875	55.39121	28.06084	14.30623
0.009	0.404396	0.009	55.43092	27.471	14.08895
0.00925	0.395359	0.00925	55.47063	26.87279	13.866
0.0095	0.386241	0.0095	55.51034	26.26839	13.63804
0.00975	0.377072	0.00975	55.55005	25.6598	13.40567
0.01	0.367879	0.01	55.58975	25.04882	13.16945
0.01025	0.358686	0.01025	55.62946	24.4371	12.92993
0.0105	0.349515	0.0105	55.66916	23.82612	12.68763
0.01075	0.340385	0.01075	55.70886	23.21724	12.44302
0.011	0.331314	0.011	55.74855	22.61168	12.19657
0.01125	0.322318	0.01125	55.78825	22.01052	11.94871
0.0115	0.313412	0.0115	55.82794	21.41477	11.69987
0.01175	0.304607	0.01175	55.86763	20.82528	11.45043
0.012	0.295916	0.012	55.90732	20.24285	11.20077
0.01225	0.287349	0.01225	55.94701	19.66815	10.95124
0.0125	0.278913	0.0125	55.98669	19.10181	10.70217

0.01275	0.541232	0.01275	56.02638	37.08869	17.1363697
0.01300	0.524931	0.01300	56.06606	35.99245	16.8028169
0.01325	0.508932	0.01325	56.10574	34.91567	16.4682547
0.01350	0.493246	0.01350	56.14542	33.85904	16.1330586
0.01375	0.477878	0.01375	56.18509	32.82312	15.7975945
0.01400	0.462837	0.01400	56.22476	31.80836	15.4622182
0.01425	0.448126	0.01425	56.26444	30.81513	15.1272754
0.01450	0.433749	0.01450	56.3041	29.84371	14.7931015
0.01475	0.419709	0.01475	56.34377	28.89432	14.4600212
0.01500	0.406006	0.01500	56.38344	27.96708	14.1283481
0.01525	0.392641	0.01525	56.4231	27.06207	13.798385
0.01550	0.379615	0.01550	56.46276	26.17929	13.4704228
0.01575	0.366925	0.01575	56.50242	25.31872	13.1447411
0.01600	0.35457	0.01600	56.54208	24.48026	12.8216073
0.01625	0.342547	0.01625	56.58173	23.66377	12.5012768
0.01650	0.330854	0.01650	56.62139	22.8691	12.1839925
0.01675	0.319487	0.01675	56.66104	22.09603	11.8699851
0.01700	0.308441	0.01700	56.70069	21.34433	11.5594722
0.01725	0.297713	0.01725	56.74034	20.61374	11.252659
0.01750	0.287297	0.01750	56.77998	19.90397	10.949738
0.01775	0.27719	0.01775	56.81963	19.2147	10.6508885
0.01800	0.267385	0.01800	56.85927	18.54562	10.3562773
0.01825	0.257877	0.01825	56.89891	17.89638	10.0660583
0.01850	0.24866	0.01850	56.93855	17.26662	9.78037277
0.01875	0.239729	0.01875	56.97818	16.65597	9.4993495
0.01900	0.231078	0.01900	57.01781	16.06405	9.2231048
0.01925	0.222701	0.01925	57.05745	15.49049	8.95174282
0.01950	0.214591	0.01950	57.09708	14.93488	8.68535576
0.01975	0.206742	0.01975	57.1367	14.39682	8.42402409
0.02000	0.199148	0.02000	57.17633	13.87592	8.16781686
0.02025	0.191804	0.02025	57.21595	13.37177	7.916792
0.02050	0.184702	0.02050	57.25557	12.88398	7.67099667
0.02075	0.177836	0.02075	57.29519	12.41212	7.43046762
0.02100	0.171201	0.02100	57.33481	11.95581	7.19523151
0.02125	0.16479	0.02125	57.37443	11.51463	6.96530538
0.02150	0.158598	0.02150	57.41404	11.0882	6.74069702
0.02175	0.152617	0.02175	57.45365	10.67611	6.52140535
0.02200	0.146842	0.02200	57.49326	10.27798	6.30742093
0.02225	0.141268	0.02225	57.53287	9.893409	6.0987263
0.02250	0.135888	0.02250	57.57248	9.522025	5.89529648
0.02275	0.130697	0.02275	57.61208	9.163446	5.69709939
0.02300	0.125689	0.02300	57.65168	8.817304	5.50409627
0.02325	0.120859	0.02325	57.69128	8.483231	5.31624212
0.02350	0.116201	0.02350	57.73088	8.160869	5.13348618
0.02375	0.111709	0.02375	57.77048	7.849865	4.95577226
0.02400	0.10738	0.02400	57.81007	7.549875	4.78303925
0.02425	0.103207	0.02425	57.84966	7.260558	4.61522148
0.02450	0.099185	0.02450	57.88925	6.981584	4.45224914
0.02475	0.095311	0.02475	57.92884	6.712627	4.29404865
0.02500	0.091578	0.02500	57.96843	6.453371	4.14054304
0.02525	0.087983	0.02525	58.00801	6.203506	3.99165235
0.02550	0.084521	0.02550	58.04759	5.962728	3.84729391
0.02575	0.081187	0.02575	58.08717	5.730743	3.70738274

0.01275	2.706162	0.01275	56.02638	185.4435	35.07148957
0.013	2.624655	0.013	56.06606	179.9622	34.78881453
0.01325	2.544661	0.01325	56.10574	174.5784	34.49860054
0.0135	2.466228	0.0135	56.14542	169.2952	34.20088366
0.01375	2.389392	0.01375	56.18509	164.1156	33.89570762
0.014	2.314184	0.014	56.22476	159.0418	33.58312458
0.01425	2.24063	0.01425	56.26444	154.0756	33.26319593
0.0145	2.168745	0.0145	56.3041	149.2186	32.93599292
0.01475	2.098543	0.01475	56.34377	144.4716	32.60159739
0.015	2.030029	0.015	56.38344	139.8354	32.26010229
0.01525	1.963207	0.01525	56.4231	135.3103	31.91161231
0.0155	1.898075	0.0155	56.46276	130.8965	31.55624432
0.01575	1.834625	0.01575	56.50242	126.5936	31.19412785
0.016	1.772851	0.016	56.54208	122.4013	30.82540546
0.01625	1.712737	0.01625	56.58173	118.3189	30.45023305
0.0165	1.654271	0.0165	56.62139	114.3455	30.06878013
0.01675	1.597433	0.01675	56.66104	110.4802	29.68122999
0.017	1.542205	0.017	56.70069	106.7217	29.28777979
0.01725	1.488564	0.01725	56.74034	103.0687	28.88864064
0.0175	1.436487	0.0175	56.77998	99.51983	28.4840375
0.01775	1.38595	0.01775	56.81963	96.07351	28.07420912
0.018	1.336924	0.018	56.85927	92.7281	27.65940776
0.01825	1.289385	0.01825	56.89891	89.48189	27.23989894
0.0185	1.243302	0.0185	56.93855	86.33308	26.81596107
0.01875	1.198647	0.01875	56.97818	83.27984	26.38788499
0.019	1.155391	0.019	57.01781	80.32027	25.95597342
0.01925	1.113503	0.01925	57.05745	77.45244	25.52054033
0.0195	1.072953	0.0195	57.09708	74.67438	25.08191027
0.01975	1.033709	0.01975	57.1367	71.9841	24.64041759
0.02	0.995741	0.02	57.17633	69.3796	24.19640559
0.02025	0.959018	0.02025	57.21595	66.85887	23.7502256
0.0205	0.923509	0.0205	57.25557	64.41988	23.30223601
0.02075	0.889182	0.02075	57.29519	62.06061	22.85280126
0.021	0.856006	0.021	57.33481	59.77904	22.40229075
0.02125	0.823952	0.02125	57.37443	57.57317	21.95107769
0.0215	0.792988	0.0215	57.41404	55.441	21.499538
0.02175	0.763085	0.02175	57.45365	53.38056	21.04804909
0.022	0.734212	0.022	57.49326	51.38989	20.59698866
0.02225	0.70634	0.02225	57.53287	49.46705	20.14673352
0.0225	0.679441	0.0225	57.57248	47.61012	19.69765834
0.02275	0.653486	0.02275	57.61208	45.81723	19.25013448
0.023	0.628446	0.023	57.65168	44.08652	18.80452878
0.02325	0.604294	0.02325	57.69128	42.41615	18.3612024
0.0235	0.581003	0.0235	57.73088	40.80434	17.92050971
0.02375	0.558546	0.02375	57.77048	39.24933	17.48279718
0.024	0.536899	0.024	57.81007	37.74937	17.04840235
0.02425	0.516034	0.02425	57.84966	36.30279	16.61765282
0.0245	0.495927	0.0245	57.88925	34.90792	16.19086538
0.02475	0.476554	0.02475	57.92884	33.56314	15.76834507
0.025	0.457891	0.025	57.96843	32.26686	15.35038447
0.02525	0.439915	0.02525	58.00801	31.01753	14.93726294
0.0255	0.422603	0.0255	58.04759	29.81364	14.52924599
0.02575	0.405934	0.02575	58.08717	28.65371	14.12658473

0.01275	0.270616	0.01275	56.02638	18.54435	10.45389
0.013	0.262465	0.013	56.06606	17.99622	10.20668
0.01325	0.254466	0.01325	56.10574	17.45784	9.960839
0.0135	0.246623	0.0135	56.14542	16.92952	9.716622
0.01375	0.238939	0.01375	56.18509	16.41156	9.47428
0.014	0.231418	0.014	56.22476	15.90418	9.234044
0.01425	0.224063	0.01425	56.26444	15.40756	8.996132
0.0145	0.216874	0.0145	56.3041	14.92186	8.760747
0.01475	0.209854	0.01475	56.34377	14.44716	8.528075
0.015	0.203003	0.015	56.38344	13.98354	8.298291
0.01525	0.196321	0.01525	56.4231	13.53103	8.071555
0.0155	0.189807	0.0155	56.46276	13.08965	7.848012
0.01575	0.183463	0.01575	56.50242	12.65936	7.627796
0.016	0.177285	0.016	56.54208	12.24013	7.411028
0.01625	0.171274	0.01625	56.58173	11.83189	7.197816
0.0165	0.165427	0.0165	56.62139	11.43455	6.988258
0.01675	0.159743	0.01675	56.66104	11.04802	6.782439
0.017	0.154221	0.017	56.70069	10.67217	6.580435
0.01725	0.148856	0.01725	56.74034	10.30687	6.382308
0.0175	0.143649	0.0175	56.77998	9.951983	6.188113
0.01775	0.138595	0.01775	56.81963	9.607351	5.997896
0.018	0.133692	0.018	56.85927	9.27281	5.811691
0.01825	0.128938	0.01825	56.89891	8.948189	5.629525
0.0185	0.12433	0.0185	56.93855	8.633308	5.451417
0.01875	0.119865	0.01875	56.97818	8.327984	5.277376
0.019	0.115539	0.019	57.01781	8.032027	5.107407
0.01925	0.11135	0.01925	57.05745	7.745244	4.941504
0.0195	0.107295	0.0195	57.09708	7.467438	4.779657
0.01975	0.103371	0.01975	57.1367	7.19841	4.62185
0.02	0.099574	0.02	57.17633	6.93796	4.468059
0.02025	0.095902	0.02025	57.21595	6.685887	4.318256
0.0205	0.092351	0.0205	57.25557	6.441988	4.172409
0.02075	0.088918	0.02075	57.29519	6.206061	4.03048
0.021	0.085601	0.021	57.33481	5.977904	3.892425
0.02125	0.082395	0.02125	57.37443	5.757317	3.7582
0.0215	0.079299	0.0215	57.41404	5.5441	3.627755
0.02175	0.076308	0.02175	57.45365	5.338056	3.501036
0.022	0.073421	0.022	57.49326	5.138989	3.377988
0.02225	0.070634	0.02225	57.53287	4.946705	3.258553
0.0225	0.067944	0.0225	57.57248	4.761012	3.142669
0.02275	0.065349	0.02275	57.61208	4.581723	3.030274
0.023	0.062845	0.023	57.65168	4.408652	2.921302
0.02325	0.060429	0.02325	57.69128	4.241615	2.815688
0.0235	0.0581	0.0235	57.73088	4.080434	2.713364
0.02375	0.055855	0.02375	57.77048	3.924933	2.614262
0.024	0.05369	0.024	57.81007	3.774937	2.518311
0.02425	0.051603	0.02425	57.84966	3.630279	2.425442
0.0245	0.049593	0.0245	57.88925	3.490792	2.335584
0.02475	0.047655	0.02475	57.92884	3.356314	2.248665
0.025	0.045789	0.025	57.96843	3.226686	2.164616
0.02525	0.043991	0.02525	58.00801	3.101753	2.083364
0.0255	0.04226	0.0255	58.04759	2.981364	2.004839
0.02575	0.040593	0.02575	58.08717	2.865371	1.92897

0.02650	0.071913	0.02650	58.2059	5.084699	3.3134547
0.02675	0.069051	0.02675	58.24548	4.885078	3.19044709
0.02700	0.066298	0.02700	58.28505	4.692881	3.07143758
0.02725	0.063648	0.02725	58.32461	4.507859	2.95633342
0.02750	0.061099	0.02750	58.36418	4.329765	2.84504149
0.02775	0.058648	0.02775	58.40375	4.158362	2.73746846
0.02800	0.05629	0.02800	58.44331	3.993419	2.63352103
0.02825	0.054023	0.02825	58.48287	3.834711	2.53310615
0.02850	0.051843	0.02850	58.52243	3.682021	2.43613111
0.02875	0.049747	0.02875	58.56198	3.535138	2.34250379
0.02900	0.047733	0.02900	58.60154	3.393856	2.25213275
0.02925	0.045796	0.02925	58.64109	3.257978	2.1649274
0.02950	0.043935	0.02950	58.68064	3.12731	2.0807981
0.02975	0.042146	0.02975	58.72019	3.001666	1.99965628
0.03000	0.040428	0.03000	58.75974	2.880866	1.92141455
0.03025	0.038776	0.03025	58.79928	2.764734	1.84598681
0.03050	0.03719	0.03050	58.83882	2.653102	1.77328827
0.03075	0.035666	0.03075	58.87836	2.545805	1.70323559
0.03100	0.034203	0.03100	58.9179	2.442685	1.63574689
0.03125	0.032797	0.03125	58.95744	2.343589	1.57074184
0.03150	0.031447	0.03150	58.99697	2.248368	1.50814169
0.03175	0.030151	0.03175	59.03651	2.15688	1.44786933
0.03200	0.028906	0.03200	59.07604	2.068985	1.38984928
0.03225	0.027711	0.03225	59.11557	1.984551	1.33400776
0.03250	0.026564	0.03250	59.15509	1.903447	1.28027268
0.03275	0.025463	0.03275	59.19462	1.825549	1.22857367
0.03300	0.024406	0.03300	59.23414	1.750736	1.1788421
0.03325	0.023391	0.03325	59.27366	1.678893	1.13101103
0.03350	0.022418	0.03350	59.31318	1.609906	1.0850153
0.03375	0.021484	0.03375	59.3527	1.543667	1.04079142
0.03400	0.020587	0.03400	59.39221	1.480072	0.99827765
0.03425	0.019727	0.03425	59.43173	1.419019	0.95741396
0.03450	0.018902	0.03450	59.47124	1.360412	0.91814199
0.03475	0.018111	0.03475	59.51075	1.304157	0.88040505
0.03500	0.017351	0.03500	59.55025	1.250163	0.84414813
0.03525	0.016623	0.03525	59.58976	1.198343	0.80931784
0.03550	0.015924	0.03550	59.62926	1.148612	0.77586238
0.03575	0.015254	0.03575	59.66876	1.100891	0.74373157
0.03600	0.014612	0.03600	59.70826	1.0551	0.71287674
0.03625	0.013996	0.03625	59.74776	1.011165	0.68325079
0.03650	0.013405	0.03650	59.78725	0.969012	0.65480809
0.03675	0.012839	0.03675	59.82675	0.928574	0.6275045
0.03700	0.012296	0.03700	59.86624	0.889781	0.60129731
0.03725	0.011775	0.03725	59.90573	0.852569	0.57614519
0.03750	0.011276	0.03750	59.94521	0.816877	0.55200822
0.03775	0.010797	0.03775	59.9847	0.782644	0.5288478
0.03800	0.010339	0.03800	60.02418	0.749813	0.50662664
0.03825	0.009899	0.03825	60.06366	0.718327	0.48530874
0.03850	0.009478	0.03850	60.10314	0.688134	0.46485931
0.03875	0.009074	0.03875	60.14262	0.659182	0.4452448
0.03900	0.008687	0.03900	60.1821	0.631422	0.42643283
0.03925	0.008317	0.03925	60.22157	0.604805	0.40839213
0.03950	0.007962	0.03950	60.26104	0.579287	0.39109259
0.03975	0.007621	0.03975	60.30051	0.554824	0.37450515

0.0265	0.359567	0.0265	58.2059	25.4235	12.95302102
0.02675	0.345257	0.02675	58.24548	24.42539	12.57399099
0.027	0.331488	0.027	58.28505	23.46441	12.20134264
0.02725	0.318241	0.02725	58.32461	22.53929	11.83523369
0.0275	0.305497	0.0275	58.36418	21.64882	11.47580586
0.02775	0.29324	0.02775	58.40375	20.79181	11.12318497
0.028	0.281451	0.028	58.44331	19.96709	10.77748111
0.02825	0.270115	0.02825	58.48287	19.17356	10.43878883
0.0285	0.259215	0.0285	58.52243	18.41011	10.10718745
0.02875	0.248736	0.02875	58.56198	17.67569	9.782741379
0.029	0.238663	0.029	58.60154	16.96928	9.465500509
0.02925	0.22898	0.02925	58.64109	16.28989	9.155500649
0.0295	0.219674	0.0295	58.68064	15.63655	8.852763998
0.02975	0.210731	0.02975	58.72019	15.00833	8.557299658
0.03	0.202138	0.03	58.75974	14.40433	8.269104175
0.03025	0.193882	0.03025	58.79928	13.82367	7.988162106
0.0305	0.185951	0.0305	58.83882	13.26551	7.714446609
0.03075	0.178332	0.03075	58.87836	12.72902	7.447920043
0.031	0.171013	0.031	58.9179	12.21343	7.188534589
0.03125	0.163985	0.03125	58.95744	11.71794	6.936232871
0.0315	0.157235	0.0315	58.99697	11.24184	6.690948583
0.03175	0.150754	0.03175	59.03651	10.7844	6.452607113
0.032	0.144531	0.032	59.07604	10.34493	6.221126169
0.03225	0.138556	0.03225	59.11557	9.922754	5.996416392
0.0325	0.13282	0.0325	59.15509	9.517235	5.778381962
0.03275	0.127314	0.03275	59.19462	9.127745	5.566921188
0.033	0.12203	0.033	59.23414	8.753681	5.36192709
0.03325	0.116957	0.03325	59.27366	8.394463	5.163287958
0.0335	0.11209	0.0335	59.31318	8.049528	4.970887895
0.03375	0.107419	0.03375	59.3527	7.718334	4.784607338
0.034	0.102937	0.034	59.39221	7.400359	4.604323564
0.03425	0.098637	0.03425	59.43173	7.095097	4.429911164
0.0345	0.094511	0.0345	59.47124	6.802062	4.261242504
0.03475	0.090553	0.03475	59.51075	6.520786	4.09818816
0.035	0.086756	0.035	59.55025	6.250815	3.940617322
0.03525	0.083115	0.03525	59.58976	5.991714	3.788398187
0.0355	0.079622	0.0355	59.62926	5.743062	3.64139832
0.03575	0.076272	0.03575	59.66876	5.504454	3.49948499
0.036	0.07306	0.036	59.70826	5.2755	3.362525492
0.03625	0.069979	0.03625	59.74776	5.055823	3.23038744
0.0365	0.067025	0.0365	59.78725	4.845062	3.102939033
0.03675	0.064193	0.03675	59.82675	4.642868	2.980049313
0.037	0.061478	0.037	59.86624	4.448904	2.861588391
0.03725	0.058874	0.03725	59.90573	4.262847	2.747427652
0.0375	0.056379	0.0375	59.94521	4.084387	2.637439953
0.03775	0.053987	0.03775	59.9847	3.913222	2.531499789
0.038	0.051694	0.038	60.02418	3.749064	2.429483447
0.03825	0.049496	0.03825	60.06366	3.591636	2.331269145
0.0385	0.04739	0.0385	60.10314	3.440671	2.236737149
0.03875	0.045372	0.03875	60.14262	3.295911	2.145769886
0.039	0.043437	0.039	60.1821	3.157109	2.058252026
0.03925	0.041584	0.03925	60.22157	3.024027	1.974070569
0.0395	0.039808	0.0395	60.26104	2.896437	1.893114904
0.03975	0.038106	0.03975	60.30051	2.774118	1.815276869

0.0265	0.035957	0.0265	58.2059	2.54235	1.7166
0.02675	0.034526	0.02675	58.24548	2.442539	1.650659
0.027	0.033149	0.027	58.28505	2.346441	1.587029
0.02725	0.031824	0.02725	58.32461	2.253929	1.525644
0.0275	0.03055	0.0275	58.36418	2.164882	1.466437
0.02775	0.029324	0.02775	58.40375	2.079181	1.409345
0.028	0.028145	0.028	58.44331	1.996709	1.354304
0.02825	0.027012	0.02825	58.48287	1.917356	1.30125
0.0285	0.025922	0.0285	58.52243	1.841011	1.250123
0.02875	0.024874	0.02875	58.56198	1.767569	1.200863
0.029	0.023866	0.029	58.60154	1.696928	1.15341
0.02925	0.022898	0.02925	58.64109	1.628989	1.107707
0.0295	0.021967	0.0295	58.68064	1.563655	1.063697
0.02975	0.021073	0.02975	58.72019	1.500833	1.021326
0.03	0.020214	0.03	58.75974	1.440433	0.980539
0.03025	0.019388	0.03025	58.79928	1.382367	0.941284
0.0305	0.018595	0.0305	58.83882	1.326551	0.903509
0.03075	0.017833	0.03075	58.87836	1.272902	0.867165
0.031	0.017101	0.031	58.9179	1.221343	0.832203
0.03125	0.016398	0.03125	58.95744	1.171794	0.798575
0.0315	0.015724	0.0315	58.99697	1.124184	0.766235
0.03175	0.015075	0.03175	59.03651	1.07844	0.735139
0.032	0.014453	0.032	59.07604	1.034493	0.705242
0.03225	0.013856	0.03225	59.11557	0.992275	0.676503
0.0325	0.013282	0.0325	59.15509	0.951723	0.648881
0.03275	0.012731	0.03275	59.19462	0.912774	0.622335
0.033	0.012203	0.033	59.23414	0.875368	0.596827
0.03325	0.011696	0.03325	59.27366	0.839446	0.572319
0.0335	0.011209	0.0335	59.31318	0.804953	0.548775
0.03375	0.010742	0.03375	59.3527	0.771833	0.52616
0.034	0.010294	0.034	59.39221	0.740036	0.50444
0.03425	0.009864	0.03425	59.43173	0.70951	0.483581
0.0345	0.009451	0.0345	59.47124	0.680206	0.463551
0.03475	0.009055	0.03475	59.51075	0.652079	0.44432
0.035	0.008676	0.035	59.55025	0.625082	0.425858
0.03525	0.008311	0.03525	59.58976	0.599171	0.408136
0.0355	0.007962	0.0355	59.62926	0.574306	0.391126
0.03575	0.007627	0.03575	59.66876	0.550445	0.3748
0.036	0.007306	0.036	59.70826	0.52755	0.359133
0.03625	0.006998	0.03625	59.74776	0.505582	0.3441
0.0365	0.006703	0.0365	59.78725	0.484506	0.329676
0.03675	0.006419	0.03675	59.82675	0.464287	0.315838
0.037	0.006148	0.037	59.86624	0.44489	0.302564
0.03725	0.005887	0.03725	59.90573	0.426285	0.28983
0.0375	0.005638	0.0375	59.94521	0.408439	0.277617
0.03775	0.005399	0.03775	59.9847	0.391322	0.265904
0.038	0.005169	0.038	60.02418	0.374906	0.254671
0.03825	0.00495	0.03825	60.06366	0.359164	0.2439
0.0385	0.004739	0.0385	60.10314	0.344067	0.233573
0.03875	0.004537	0.03875	60.14262	0.329591	0.223671
0.039	0.004344	0.039	60.1821	0.315711	0.214178
0.03925	0.004158	0.03925	60.22157	0.302403	0.205078
0.0395	0.003981	0.0395	60.26104	0.289644	0.196355
0.03975	0.003811	0.03975	60.30051	0.277412	0.187994

EPSP

0.04000	0.007295	0.04000	60.33998	0.531372	0.3586018		0.04	0.036475	0.04	60.33998	2.656859	1.740450789		0.04	0.003648	0.04	60.33998	0.265686	0.17998
0.04025	0.006983	0.04025	60.37944	0.508891	0.34335555		0.04025	0.034913	0.04025	60.37944	2.544455	1.668533512		0.04025	0.003491	0.04025	60.37944	0.254446	0.172301
0.04050	0.006683	0.04050	60.41891	0.487343	0.32874039		0.0405	0.033417	0.0405	60.41891	2.436713	1.599424432		0.0405	0.003342	0.0405	60.41891	0.243671	0.164941
0.04075	0.006397	0.04075	60.45837	0.466689	0.31473127		0.04075	0.031983	0.04075	60.45837	2.333443	1.533025504		0.04075	0.003198	0.04075	60.45837	0.233344	0.157889
0.04100	0.006122	0.04100	60.49783	0.446893	0.30130405		0.041	0.03061	0.041	60.49783	2.234465	1.469241252		0.041	0.003061	0.041	60.49783	0.223446	0.151131
0.04125	0.005859	0.04125	60.53729	0.427921	0.28843552		0.04125	0.029295	0.04125	60.53729	2.139605	1.407978766		0.04125	0.002929	0.04125	60.53729	0.21396	0.144657
0.04150	0.005607	0.04150	60.57674	0.409739	0.27610329		0.0415	0.028035	0.0415	60.57674	2.048696	1.349147701		0.0415	0.002803	0.0415	60.57674	0.20487	0.138454
0.04175	0.005366	0.04175	60.6162	0.392316	0.26428585		0.04175	0.026828	0.04175	60.6162	1.961578	1.292660257		0.04175	0.002683	0.04175	60.6162	0.196158	0.132512
0.04200	0.005135	0.04200	60.65565	0.375619	0.25296247		0.042	0.025673	0.042	60.65565	1.878097	1.238431169		0.042	0.002567	0.042	60.65565	0.18781	0.126819
0.04225	0.004913	0.04225	60.6951	0.359621	0.24211322		0.04225	0.024566	0.04225	60.6951	1.798104	1.186377675		0.04225	0.002457	0.04225	60.6951	0.17981	0.121366
0.04250	0.004701	0.04250	60.73455	0.344292	0.23171893		0.0425	0.023506	0.0425	60.73455	1.721458	1.136419497		0.0425	0.002351	0.0425	60.73455	0.172146	0.116143
0.04275	0.004498	0.04275	60.77399	0.329604	0.22176115		0.04275	0.022491	0.04275	60.77399	1.648021	1.088478805		0.04275	0.002249	0.04275	60.77399	0.164802	0.11114
0.04300	0.004304	0.04300	60.81344	0.315532	0.21222214		0.043	0.021519	0.043	60.81344	1.577662	1.04248018		0.043	0.002152	0.043	60.81344	0.157766	0.106349
0.04325	0.004118	0.04325	60.85288	0.302051	0.20308485		0.04325	0.020589	0.04325	60.85288	1.510256	0.998350583		0.04325	0.002059	0.04325	60.85288	0.151026	0.10176
0.04350	0.00394	0.04350	60.89232	0.289136	0.19433289		0.0435	0.019698	0.0435	60.89232	1.445681	0.956019307		0.0435	0.00197	0.0435	60.89232	0.144568	0.097366
0.04375	0.003769	0.04375	60.93176	0.276764	0.18595049		0.04375	0.018845	0.04375	60.93176	1.38382	0.915417939		0.04375	0.001884	0.04375	60.93176	0.138382	0.093158
0.04400	0.003606	0.04400	60.97119	0.264913	0.17792251		0.044	0.018028	0.044	60.97119	1.324564	0.876480315		0.044	0.001803	0.044	60.97119	0.132456	0.089128
0.04425	0.003449	0.04425	61.01063	0.253561	0.1702344		0.04425	0.017247	0.04425	61.01063	1.267803	0.839142468		0.04425	0.001725	0.04425	61.01063	0.12678	0.08527
0.04450	0.0033	0.04450	61.05006	0.242687	0.16287218		0.0445	0.016498	0.0445	61.05006	1.213435	0.803342588		0.0445	0.00165	0.0445	61.05006	0.121344	0.081576
0.04475	0.003156	0.04475	61.08949	0.232272	0.15582239		0.04475	0.015782	0.04475	61.08949	1.161362	0.769020968		0.04475	0.001578	0.04475	61.08949	0.116136	0.078039
0.04500	0.003019	0.04500	61.12892	0.222298	0.14907216		0.045	0.015096	0.045	61.12892	1.111489	0.736119952		0.045	0.00151	0.045	61.12892	0.111149	0.074653
0.04525	0.002888	0.04525	61.16834	0.212745	0.14260907		0.04525	0.014439	0.04525	61.16834	1.063724	0.704583892		0.04525	0.001444	0.04525	61.16834	0.106372	0.071412
0.04550	0.002762	0.04550	61.20777	0.203596	0.13642124		0.0455	0.013811	0.0455	61.20777	1.01798	0.674359091		0.0455	0.001381	0.0455	61.20777	0.101798	0.068309
0.04575	0.002642	0.04575	61.24719	0.194835	0.13049723		0.04575	0.01321	0.04575	61.24719	0.974174	0.645393751		0.04575	0.001321	0.04575	61.24719	0.097417	0.065338
0.04600	0.002527	0.04600	61.28661	0.186445	0.12482607		0.046	0.012634	0.046	61.28661	0.932225	0.617637928		0.046	0.001263	0.046	61.28661	0.093222	0.062495
0.04625	0.002417	0.04625	61.32603	0.178411	0.11939722		0.04625	0.012083	0.04625	61.32603	0.892055	0.591043474		0.04625	0.001208	0.04625	61.32603	0.089206	0.059774
0.04650	0.002311	0.04650	61.36544	0.170718	0.11420059		0.0465	0.011556	0.0465	61.36544	0.853591	0.56556399		0.0465	0.001156	0.0465	61.36544	0.085359	0.057169
0.04675	0.00221	0.04675	61.40486	0.163352	0.10922646		0.04675	0.011052	0.04675	61.40486	0.816762	0.541154772		0.04675	0.001105	0.04675	61.40486	0.081676	0.054676
0.04700	0.002114	0.04700	61.44427	0.1563	0.10446553		0.047	0.010569	0.047	61.44427	0.7815	0.517772766		0.047	0.001057	0.047	61.44427	0.07815	0.05229
0.04725	0.002021	0.04725	61.48368	0.149548	0.09990886		0.04725	0.010107	0.04725	61.48368	0.747738	0.495376513		0.04725	0.001011	0.04725	61.48368	0.074774	0.050007
0.04750	0.001933	0.04750	61.52309	0.143083	0.09554788		0.0475	0.009665	0.0475	61.52309	0.715414	0.473926102		0.0475	0.000966	0.0475	61.52309	0.071541	0.047822
0.04775	0.001848	0.04775	61.56249	0.136894	0.09137435		0.04775	0.009242	0.04775	61.56249	0.684469	0.45338312		0.04775	0.000924	0.04775	61.56249	0.068447	0.045731
0.04800	0.001767	0.04800	61.6019	0.130969	0.0873804		0.048	0.008837	0.048	61.6019	0.654844	0.43371061		0.048	0.000884	0.048	61.6019	0.065484	0.04373
0.04825	0.00169	0.04825	61.6413	0.125297	0.08355845		0.04825	0.00845	0.04825	61.6413	0.626484	0.414873016		0.04825	0.000845	0.04825	61.6413	0.062648	0.041816
0.04850	0.001616	0.04850	61.6807	0.119867	0.07990125		0.0485	0.008079	0.0485	61.6807	0.599336	0.396836141		0.0485	0.000808	0.0485	61.6807	0.059934	0.039984
0.04875	0.001545	0.04875	61.7201	0.11467	0.07640184		0.04875	0.007725	0.04875	61.7201	0.57335	0.379567105		0.04875	0.000772	0.04875	61.7201	0.057335	0.038232
0.04900	0.001477	0.04900	61.7595	0.109695	0.07305353		0.049	0.007386	0.049	61.7595	0.548475	0.363034296		0.049	0.000739	0.049	61.7595	0.054847	0.036555
0.04925	0.001412	0.04925	61.79889	0.104933	0.06984993		0.04925	0.007062	0.04925	61.79889	0.524665	0.347207328		0.04925	0.000706	0.04925	61.79889	0.052467	0.034951
0.04950	0.00135	0.04950	61.83828	0.100375	0.0667849		0.0495	0.006751	0.0495	61.83828	0.501876	0.332057		0.0495	0.000675	0.0495	61.83828	0.050188	0.033416
0.04975	0.001291	0.04975	61.87768	0.096013	0.06385255		0.04975	0.006454	0.04975	61.87768	0.480065	0.317555256		0.04975	0.000645	0.04975	61.87768	0.048007	0.031948
0.05000	0.001234	0.05000	61.91706	0.091838	0.06104726		0.05	0.00617	0.05	61.91706	0.45919	0.303675141		0.05	0.000617	0.05	61.91706	0.045919	0.030543

For dendrite or compartment of length l and diameter d

Parameter	***Value***	***Unit***
RM	5000	ohm/cm2
RA	25	ohm/cm
d	0.0002	cm
l	0.01	cm
Cm	1	mF/cm2

$Rm = RM/\pi dl$

$Cm = CM\pi dl$

Rm	7.96E+08	ohm	grest	1.26E-09	1.2568
Cm	6.28E-09	F	Erest	-60	
tauM	5		E	-15	

For inhibitory synapse

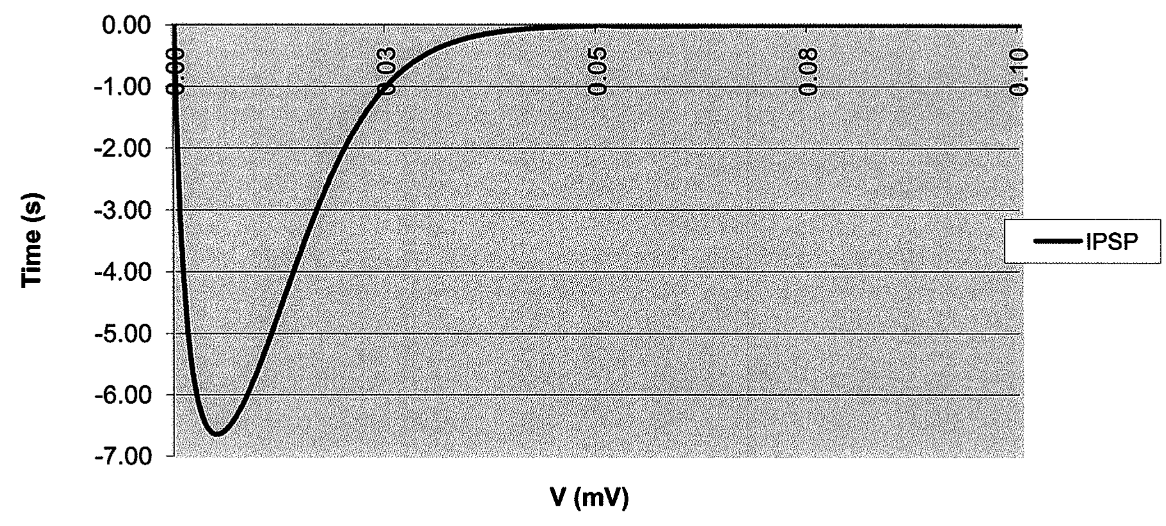
Esyn -75 mV

For excitatory synapse

Esyn -12.5 mV

Isyn(t) = gsyn(t)(Vm-Esyn)

IPSP Vs TIME

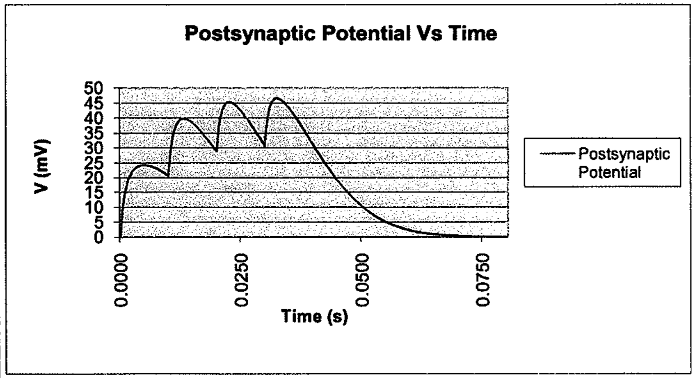


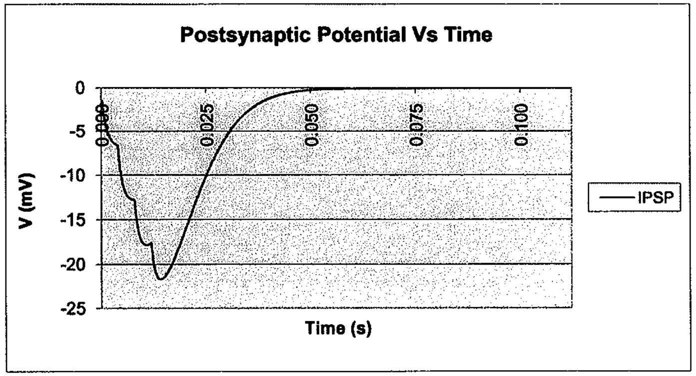
t(s)	G(t)	T(graph)(s)	Vm	Isyn(t)	Vpsp
0.00000	0	0.00000	54	0	0
0.00025	0.129285	0.00025	54.39783	16.72926	-1.399107
0.00050	0.24596	0.00050	54.79563	31.92457	-2.455085
0.00075	0.350947	0.00075	55.19342	45.69099	-3.274275
0.00100	0.445108	0.00100	55.59118	58.1272	-3.923022
0.00125	0.52925	0.00125	55.98893	69.32589	-4.444864
0.00150	0.604126	0.00150	56.38666	79.37407	-4.869559
0.00175	0.670439	0.00175	56.78436	88.35341	-5.218132
0.00200	0.728848	0.00200	57.18205	96.34056	-5.505868
0.00225	0.779964	0.00225	57.57972	103.4074	-5.744141
0.00250	0.824361	0.00250	57.97736	109.6213	-5.941593
0.00275	0.862572	0.00275	58.37499	115.0455	-6.104911
0.00300	0.895095	0.00300	58.7726	119.7392	-6.239349
0.00325	0.922394	0.00325	59.17018	123.7578	-6.349095
0.00350	0.944901	0.00350	59.56775	127.1532	-6.43753
0.00375	0.963019	0.00375	59.9653	129.9742	-6.507416
0.00400	0.977122	0.00400	60.36283	132.266	-6.561031
0.00425	0.987559	0.00425	60.76033	134.0714	-6.600275
0.00450	0.994654	0.00450	61.15782	135.4299	-6.626744
0.00475	0.998708	0.00475	61.55529	136.3788	-6.641793
0.00500	1	0.00500	61.95274	136.9527	-6.646579
0.00525	0.998791	0.00525	62.35017	137.1841	-6.642101
0.00550	0.995321	0.00550	62.74757	137.1031	-6.629225
0.00575	0.989814	0.00575	63.14496	136.7378	-6.608706
0.00600	0.982477	0.00600	63.54233	136.1146	-6.581211
0.00625	0.973501	0.00625	63.93968	135.2579	-6.547329
0.00650	0.963064	0.00650	64.33701	134.1904	-6.507587
0.00675	0.951329	0.00675	64.73432	132.9333	-6.462455
0.00700	0.938448	0.00700	65.13161	131.5062	-6.41236
0.00725	0.924561	0.00725	65.52888	129.9275	-6.357688
0.00750	0.909796	0.00750	65.92613	128.214	-6.298793
0.00775	0.894272	0.00775	66.32336	126.3815	-6.235999
0.00800	0.878099	0.00800	66.72057	124.4446	-6.169604
0.00825	0.861376	0.00825	67.11776	122.4168	-6.099888
0.00850	0.844195	0.00850	67.51493	120.3104	-6.027109
0.00875	0.826641	0.00875	67.91208	118.137	-5.95151
0.00900	0.808792	0.00900	68.30921	115.9074	-5.873319
0.00925	0.790718	0.00925	68.70632	113.6311	-5.792753
0.00950	0.772482	0.00950	69.10341	111.3173	-5.710016
0.00975	0.754145	0.00975	69.50048	108.9743	-5.625303
0.01000	0.735759	0.01000	69.89753	106.6096	-5.538799
0.01025	0.717372	0.01025	70.29456	104.2303	-5.450682
0.01050	0.699029	0.01050	70.69157	101.8427	-5.361122
0.01075	0.680769	0.01075	71.08856	99.45257	-5.270282
0.01100	0.662627	0.01100	71.48553	97.06531	-5.17832
0.01125	0.644636	0.01125	71.88248	94.68571	-5.085387
0.01150	0.626823	0.01150	72.27942	92.31814	-4.991628
0.01175	0.609215	0.01175	72.67633	89.96658	-4.897185
0.01200	0.591833	0.01200	73.07322	87.63458	-4.802193
0.01225	0.574697	0.01225	73.47009	85.32535	-4.706782
0.01250	0.557825	0.01250	73.86694	83.04176	-4.611079
0.01275	0.541232	0.01275	74.26378	80.78638	-4.515205
0.01300	0.524931	0.01300	74.66059	78.56148	-4.419278
0.01325	0.508932	0.01325	75.05738	76.36904	-4.32341

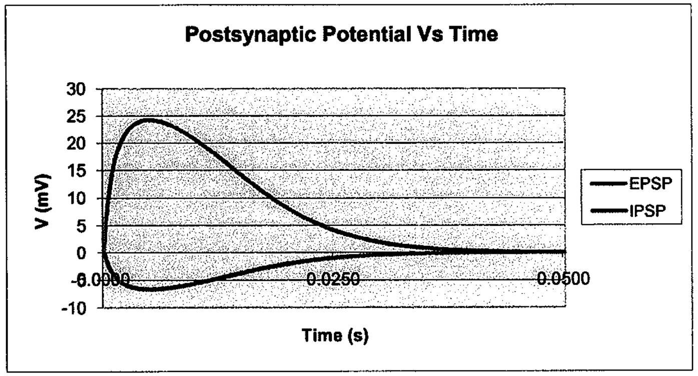
0.01350	0.493246	0.01350	75.45416	74.21084	-4.227709
0.01375	0.477878	0.01375	75.85091	72.08838	-4.132279
0.01400	0.462837	0.01400	76.24764	70.00299	-4.037221
0.01425	0.448126	0.01425	76.64436	67.95577	-3.942628
0.01450	0.433749	0.01450	77.04105	65.94765	-3.848593
0.01475	0.419709	0.01475	77.43772	63.97941	-3.755202
0.01500	0.406006	0.01500	77.83438	62.05165	-3.662537
0.01525	0.392641	0.01525	78.23101	60.16485	-3.570676
0.01550	0.379615	0.01550	78.62763	58.31934	-3.479694
0.01575	0.366925	0.01575	79.02422	56.51535	-3.38966
0.01600	0.35457	0.01600	79.42079	54.753	-3.300639
0.01625	0.342547	0.01625	79.81735	53.03229	-3.212693
0.01650	0.330854	0.01650	80.21388	51.35316	-3.125878
0.01675	0.319487	0.01675	80.6104	49.71545	-3.040247
0.01700	0.308441	0.01700	81.00689	48.11893	-2.955849
0.01725	0.297713	0.01725	81.40337	46.5633	-2.872728
0.01750	0.287297	0.01750	81.79983	45.0482	-2.790926
0.01775	0.27719	0.01775	82.19626	43.57322	-2.71048
0.01800	0.267385	0.01800	82.59268	42.1379	-2.631422
0.01825	0.257877	0.01825	82.98907	40.74174	-2.553781
0.01850	0.24866	0.01850	83.38545	39.38419	-2.477585
0.01875	0.239729	0.01875	83.78181	38.06468	-2.402854
0.01900	0.231078	0.01900	84.17814	36.78261	-2.329608
0.01925	0.222701	0.01925	84.57446	35.53733	-2.257863
0.01950	0.214591	0.01950	84.97076	34.32821	-2.18763
0.01975	0.206742	0.01975	85.36704	33.15458	-2.11892
0.02000	0.199148	0.02000	85.76329	32.01573	-2.051738
0.02025	0.191804	0.02025	86.15953	30.91099	-1.986088
0.02050	0.184702	0.02050	86.55575	29.83963	-1.921972
0.02075	0.177836	0.02075	86.95195	28.80094	-1.859388
0.02100	0.171201	0.02100	87.34812	27.7942	-1.798331
0.02125	0.16479	0.02125	87.74428	26.81869	-1.738796
0.02150	0.158598	0.02150	88.14042	25.87368	-1.680775
0.02175	0.152617	0.02175	88.53654	24.95845	-1.624256
0.02200	0.146842	0.02200	88.93264	24.07226	-1.569229
0.02225	0.141268	0.02225	89.32872	23.2144	-1.515678
0.02250	0.135888	0.02250	89.72478	22.38416	-1.463589
0.02275	0.130697	0.02275	90.12082	21.58081	-1.412945
0.02300	0.125689	0.02300	90.51684	20.80367	-1.363726
0.02325	0.120859	0.02325	90.91284	20.05202	-1.315915
0.02350	0.116201	0.02350	91.30882	19.32518	-1.269489
0.02375	0.111709	0.02375	91.70478	18.62247	-1.224427
0.02400	0.10738	0.02400	92.10072	17.94323	-1.180706
0.02425	0.103207	0.02425	92.49664	17.28678	-1.138304
0.02450	0.099185	0.02450	92.89254	16.65248	-1.097195
0.02475	0.095311	0.02475	93.28842	16.0397	-1.057355
0.02500	0.091578	0.02500	93.68428	15.4478	-1.018759
0.02525	0.087983	0.02525	94.08013	14.87618	-0.981381
0.02550	0.084521	0.02550	94.47595	14.32422	-0.945195
0.02575	0.081187	0.02575	94.87175	13.79133	-0.910174
0.02600	0.077977	0.02600	95.26753	13.27695	-0.876292
0.02625	0.074887	0.02625	95.66329	12.7805	-0.843523
0.02650	0.071913	0.02650	96.05904	12.30143	-0.811838
0.02675	0.069051	0.02675	96.45476	11.8392	-0.781212
0.02700	0.066298	0.02700	96.85046	11.39328	-0.751618

Summation Postsynaptic Potential

Summation of 4 EPSP (Frequency = 100 Hz)						*Summation of 4 IPSP*				
T(graph)(s)	V(mV)	V(mV)	V(mV)	V(mV)	Summation	V(mV)	V(mV)	V(mV)	V(mV)	Summation
0.00000	0				0	0				0
0.00025	5.642876				5.642876375	-1.39911				-1.399107247
0.00050	9.69585				9.695850287	-2.45509				-2.455085245
0.00075	12.72569				12.72569307	-3.27427				-3.2742747
0.00100	15.0577				15.05769928	-3.92302				-3.923021724
0.00125	16.8919				16.89190333	-4.44486				-4.44486439
0.00150	18.35807				18.35807192	-4.86956				-4.869558541
0.00175	19.54406				19.54406431	-5.21813				-5.218132177
0.00200	20.51148				20.51148388	-5.50587				-5.50586783
0.00225	21.3048				21.30480348	-5.74414				-5.744140551
0.00250	21.95693				21.95693311	-5.94159				-5.941593032
0.00275	22.49275				22.49274942	-6.10491				-6.104910959
0.00300	22.93141				22.93140753	-6.23935				-6.239348765
0.00325	23.2879				23.28789862	-6.34909				-6.349094753
0.00350	23.57413				23.57412568	-6.43753				-6.43753008
0.00375	23.79966				23.79966274	-6.50742				-6.507415934
0.00400	23.9723				23.97230126	-6.56103	0			-6.561031112
0.00425	24.09845				24.09845013	-6.60027	-1.39911			-7.999381933
0.00450	24.18343				24.18343317	-6.62674	-2.45509			-9.081828916
0.00475	24.23171				24.23171348	-6.64179	-3.27427			-9.916067222
0.00500	24.24706				24.24706483	-6.64658	-3.92302			-10.56960095
0.00525	24.2327				24.23270414	-6.6421	-4.44486			-11.08696579
0.00550	24.19139				24.19139498	-6.62922	-4.86956			-11.49878332
0.00575	24.12553				24.12552919	-6.60871	-5.21813			-11.82683819
0.00600	24.03719				24.03719191	-6.58121	-5.50587			-12.08707872
0.00625	23.92821				23.92821375	-6.54733	-5.74414			-12.29146973
0.00650	23.80021				23.80021299	-6.50759	-5.94159			-12.44917969
0.00675	23.65463				23.65462997	-6.46246	-6.10491			-12.56736597
0.00700	23.49276				23.49275529	-6.41236	-6.23935			-12.65170881
0.00725	23.31575				23.31575306	-6.35769	-6.34909			-12.70678312
0.00750	23.12468				23.12468014	-6.29879	-6.43753			-12.73632317
0.00775	22.9205				22.92050226	-6.236	-6.50742			-12.74341445
0.00800	22.70411				22.70410741	-6.1696	-6.56103	0		-12.73063521
0.00825	22.47632				22.47631713	-6.09989	-6.60027	-1.39911		-14.09926968
0.00850	22.2379				22.23789602	-6.02711	-6.62674	-2.45509		-15.10893757
0.00875	21.98956				21.98955973	-5.95151	-6.64179	-3.27427		-15.86757688
0.00900	21.73198				21.73198175	-5.87332	-6.64658	-3.92302		-16.44292019
0.00925	21.4658				21.46579918	-5.79275	-6.6421	-4.44486		-16.87971903
0.00950	21.19162				21.19161753	-5.71002	-6.62922	-4.86956		-17.20879961
0.00975	20.91001				20.91001485	-5.6253	-6.60871	-5.21813		-17.4521412
0.01000	20.62155	0			20.62154521	-5.5388	-6.58121	-5.50587		-17.62587777
0.01025	20.32674	5.642876			25.96961798	-5.45068	-6.54733	-5.74414		-17.74215168
0.01050	20.02612	9.69585			29.72196869	-5.36112	-6.50759	-5.94159		-17.81030157
0.01075	19.72017	12.72569			32.44586647	-5.27028	-6.46246	-6.10491		-17.83764823
0.01100	19.40939	15.0577			34.46708873	-5.17832	-6.41236	-6.23935		-17.83002901
0.01125	19.09424	16.8919			35.98613925	-5.08539	-6.35769	-6.34909		-17.79217013
0.01150	18.77517	18.35807			37.1332417	-4.99163	-6.29879	-6.43753		-17.72795166
0.01175	18.45264	19.54406			37.99670075	-4.89719	-6.236	-6.50742		-17.64059968
0.01200	18.12707	20.51148			38.63855436	-4.80219	-6.1696	-6.56103	0	-17.53282801
0.01225	17.7989	21.3048			39.10369962	-4.70678	-6.09989	-6.60027	-1.39911	-18.80605168







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0.01275	17.13637	22.49275			39.62911908	-4.51521	-5.95151	-6.64179	-3.27427	-20.38278211
0.01300	16.80282	22.93141			39.73422442	-4.41928	-5.87332	-6.64658	-3.92302	-20.86219809
0.01325	16.46825	23.2879			39.75615328	-4.32341	-5.79275	-6.6421	-4.44486	-21.20312867
0.01350	16.13306	23.57413			39.70718426	-4.22771	-5.71002	-6.62922	-4.86956	-21.43650836
0.01375	15.79759	23.79966			39.59725719	-4.13228	-5.6253	-6.60871	-5.21813	-21.58442036
0.01400	15.46222	23.9723			39.43451942	-4.03722	-5.5388	-6.58121	-5.50587	-21.66309828
0.01425	15.12728	24.09845			39.22572554	-3.94263	-5.45068	-6.54733	-5.74414	-21.68477978
0.01450	14.7931	24.18343			38.9765347	-3.84859	-5.36112	-6.50759	-5.94159	-21.65889452
0.01475	14.46002	24.23171			38.69173467	-3.7552	-5.27028	-6.46246	-6.10491	-21.59284997
0.01500	14.12835	24.24706			38.37541297	-3.66254	-5.17832	-6.41236	-6.23935	-21.49256589
0.01525	13.79838	24.2327			38.03108912	-3.57068	-5.08539	-6.35769	-6.34909	-21.36284663
0.01550	13.47042	24.19139			37.66181779	-3.47969	-4.99163	-6.29879	-6.43753	-21.2076461
0.01575	13.14474	24.12553			37.27027028	-3.38966	-4.89719	-6.236	-6.50742	-21.03025995
0.01600	12.82161	24.03719			36.85879921	-3.30064	-4.80219	-6.1696	-6.56103	-20.83346737
0.01625	12.50128	23.92821			36.42949053	-3.21269	-4.70678	-6.09989	-6.60027	-20.61963728
0.01650	12.18399	23.80021			35.98420553	-3.12588	-4.61108	-6.02711	-6.62674	-20.39080896
0.01675	11.86999	23.65463			35.52461502	-3.04025	-4.51521	-5.95151	-6.64179	-20.1487541
0.01700	11.55947	23.49276			35.05222747	-2.95585	-4.41928	-5.87332	-6.64658	-19.89502502
0.01725	11.25266	23.31575			34.56841211	-2.87273	-4.32341	-5.79275	-6.6421	-19.63099257
0.01750	10.94974	23.12468			34.07441812	-2.79093	-4.22771	-5.71002	-6.62922	-19.35787619
0.01775	10.65089	22.9205			33.57139075	-2.71048	-4.13228	-5.6253	-6.60871	-19.076768
0.01800	10.35628	22.70411			33.06038468	-2.63142	-4.03722	-5.5388	-6.58121	-18.78865218
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0.01950	8.685356	21.19162			29.87697329	-2.18763	-3.47969	-4.99163	-6.29879	-16.95774618
0.01975	8.424024	20.91001			29.33403894	-2.11892	-3.38966	-4.89719	-6.236	-16.64176368
0.02000	8.167817	20.62155	0		28.78936207	-2.05174	-3.30064	-4.80219	-6.1696	-16.32417406
0.02025	7.916792	20.32674	5.642876		33.88640998	-1.98609	-3.21269	-4.70678	-6.09989	-16.00545083
0.02050	7.670997	20.02612	9.69585		37.39296537	-1.92197	-3.12588	-4.61108	-6.02711	-15.68603728
0.02075	7.430468	19.72017	12.72569		39.87633408	-1.85939	-3.04025	-4.51521	-5.95151	-15.36634911
0.02100	7.195232	19.40939	15.0577		41.66232024	-1.79833	-2.95585	-4.41928	-5.87332	-15.04677674
0.02125	6.965305	19.09424	16.8919		42.95144463	-1.7388	-2.87273	-4.32341	-5.79275	-14.72768723
0.02150	6.740697	18.77517	18.35807		43.87393871	-1.68077	-2.79093	-4.22771	-5.71002	-14.40942596
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0.02275	5.697099	17.13637	22.49275		45.32621847	-1.41294	-2.40285	-3.7552	-5.27028	-12.8412829
0.02300	5.504096	16.80282	22.93141		45.23832068	-1.36373	-2.32961	-3.66254	-5.17832	-12.53419179
0.02325	5.316242	16.46825	23.2879		45.07239541	-1.31591	-2.25786	-3.57068	-5.08539	-12.22984095
0.02350	5.133486	16.13306	23.57413		44.84067043	-1.26949	-2.18763	-3.47969	-4.99163	-11.92844172
0.02375	4.955772	15.79759	23.79966		44.55302945	-1.22443	-2.11892	-3.38966	-4.89719	-11.63019191
0.02400	4.783039	15.46222	23.9723		44.21755867	-1.18071	-2.05174	-3.30064	-4.80219	-11.33527626
0.02425	4.615221	15.12728	24.09845		43.84094702	-1.1383	-1.98609	-3.21269	-4.70678	-11.04386689
0.02450	4.452249	14.7931	24.18343		43.42878384	-1.0972	-1.92197	-3.12588	-4.61108	-10.75612372
0.02475	4.294049	14.46002	24.23171		42.98578332	-1.05736	-1.85939	-3.04025	-4.51521	-10.47219484
0.02500	4.140543	14.12835	24.24706		42.51595602	-1.01876	-1.79833	-2.95585	-4.41928	-10.19221687

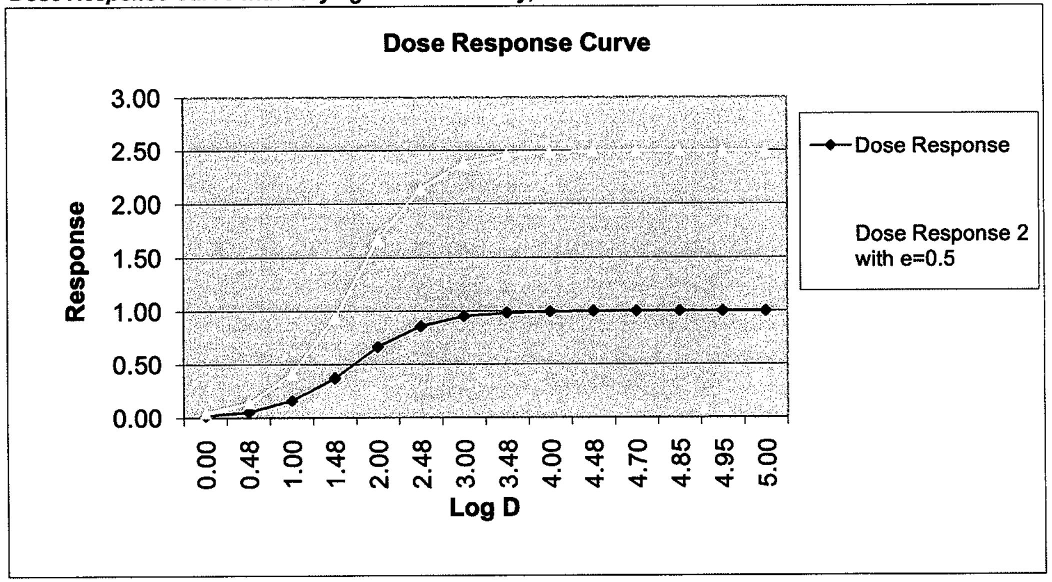
Response = E/Emax

f	1
e	1
Kd	50

Drug Conc (nM)	Log D	Response
1	0	0.019608
3	0.4771213	0.056604
10	1	0.17
30	1.4771213	0.38
100	2	0.67
300	2.4771213	0.86
1000	3	0.95
3000	3.4771213	0.98
10000	4	1.00
30000	4.4771213	1.00
50000	4.69897	1.00
70000	4.845098	1.00
90000	4.9542425	1.00
100000	5	1.00

Dose Response

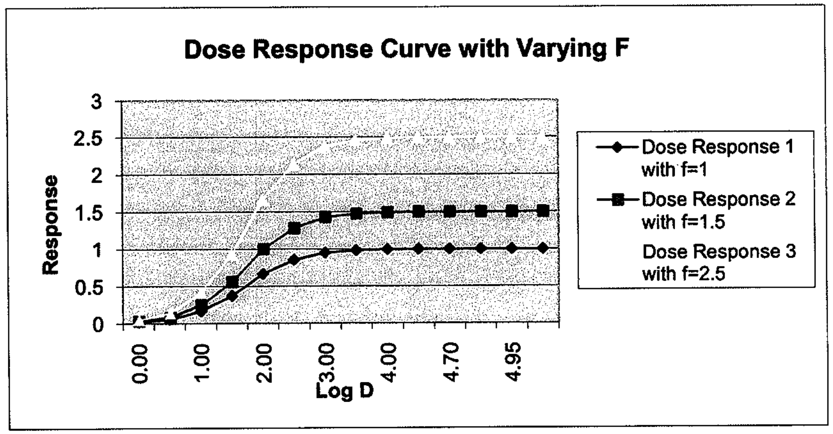
Dose Response Curve with varying intrinsic activity, e



f	1
e	0.5
Kd	50

Drug Conc (nM)	Log D	Response
1	0	0.01
3	0.4771213	0.03
10	1	0.08
30	1.4771213	0.19
100	2	0.33
300	2.4771213	0.43
1000	3	0.48
3000	3.4771213	0.49
10000	4	0.50
30000	4.4771213	0.50
50000	4.69897	0.50
70000	4.845098	0.50
90000	4.9542425	0.50
100000	5	0.50

Dose Response Curve with varying f



Dose Response

f	2.5
e	1
Kd	50

Drug Conc (nM)	Log D	Response
1	0	0.05
3	0.4771213	0.14
10	1	0.42
30	1.4771213	0.94
100	2	1.67
300	2.4771213	2.14
1000	3	2.38
3000	3.4771213	2.46
10000	4	2.49
30000	4.4771213	2.50
50000	4.69897	2.50
70000	4.845098	2.50
90000	4.9542425	2.50
100000	5	2.50

f	1.5
e	1
Kd	50

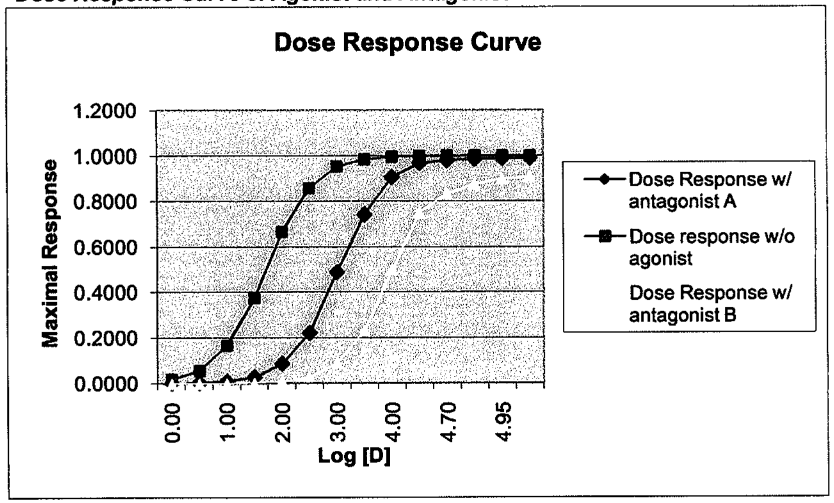
Drug Conc (nM)	Log D	Response
1	0	0.03
3	0.477121	0.08
10	1	0.25
30	1.477121	0.56
100	2	1.00
300	2.477121	1.29
1000	3	1.43
3000	3.477121	1.48
10000	4	1.49
30000	4.477121	1.50
50000	4.69897	1.50
70000	4.845098	1.50
90000	4.954243	1.50
100000	5	1.50

e	1
Kb	50
Kd	50

Agonist Conc (nM)	Antagonist Conc (nM)	Log D	Response
1	1000	0	0.0010
3	1000	0.477121	0.0028
10	1000	1	0.0094
30	1000	1.477121	0.0278
100	1000	2	0.0870
300	1000	2.477121	0.2222
1000	1000	3	0.4878
3000	1000	3.477121	0.7407
10000	1000	4	0.9050
30000	1000	4.477121	0.9662
50000	1000	4.69897	0.9794
70000	1000	4.845098	0.9852
90000	1000	4.954243	0.9885
100000	1000	5	0.9896

e	1
Kb	50
Kd	50

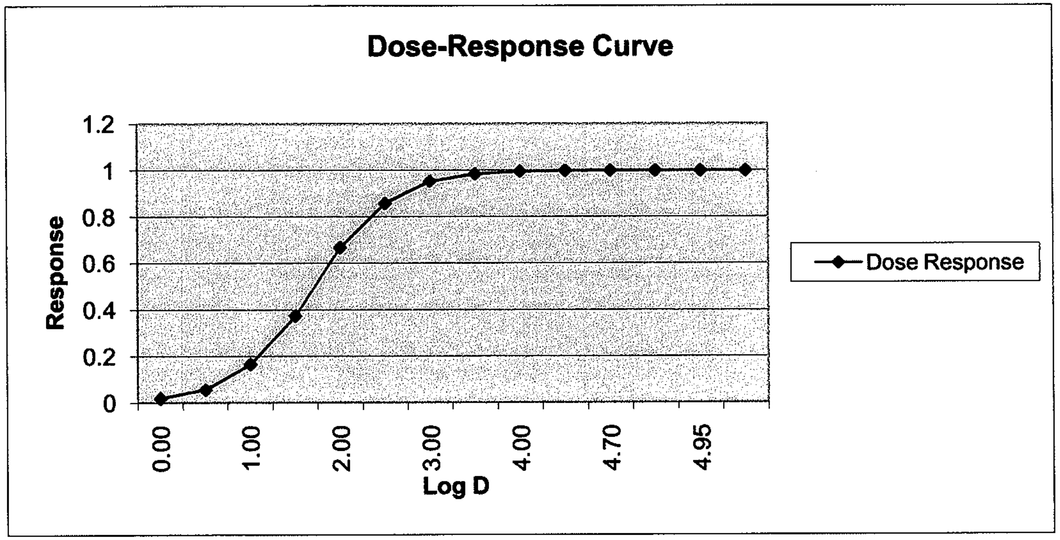
Dose Response Curve of Agonist and Antagonist



Agonist Conc (nM)	Antagonist Conc (nM)	Log D	Response
1	10000	0	0.0001
3	10000	0.477121	0.0003
10	10000	1	0.0010
30	10000	1.477121	0.0030
100	10000	2	0.0099
300	10000	2.477121	0.0290
1000	10000	3	0.0905
3000	10000	3.477121	0.2299
10000	10000	4	0.4988
30000	10000	4.477121	0.7491
50000	10000	4.69897	0.8326
70000	10000	4.845098	0.8745
90000	10000	4.954243	0.8996
100000	10000	5	0.9087

f	1
e	1
Kd	50

Drug Conc (nM)	Log D	Response
1	0	0.019608
3	0.4771213	0.056604
10	1	0.166667
30	1.4771213	0.375
100	2	0.666667
300	2.4771213	0.857143
1000	3	0.952381
3000	3.4771213	0.983607
10000	4	0.995025
30000	4.4771213	0.998336
50000	4.69897	0.999001
70000	4.845098	0.999286
90000	4.9542425	0.999445
100000	5	0.9995

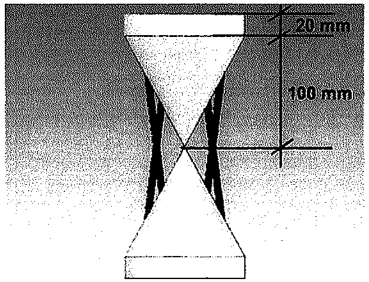


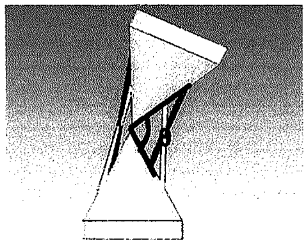
Mono-Synaptic Test Instance 1

time	force	theta-deg	Mnt Arm	accel	veloc	force2	Muscle L	%Δ muscle L
0	0.00000	127.00000	0.02289	0.00000	0.00000	5.89100	0.09818	-0.00364
0.001	5.89100	126.99924	0.02289	0.30259	0.00030	5.88276	0.09818	-0.00334
0.002	5.88276	126.99697	0.02289	0.30218	0.00060	5.87454	0.09818	-0.00241
0.003	5.87454	126.99243	0.02289	0.30178	0.00091	5.86636	0.09818	-0.00056
0.004	5.86636	126.98487	0.02290	0.30140	0.00121	5.85820	0.09818	0.00251
0.005	5.85820	126.97353	0.02290	0.30106	0.00151	5.85007	0.09817	0.00713
0.006	5.85007	126.95766	0.02291	0.30076	0.00181	5.84197	0.09817	0.01359
0.007	5.84197	126.93651	0.02291	0.30051	0.00211	5.83389	0.09816	0.02220
0.008	5.83389	126.90934	0.02293	0.30031	0.00241	5.82583	0.09815	0.03327
0.009	5.82583	126.87539	0.02294	0.30018	0.00271	5.81780	0.09813	0.04711
0.01	5.81780	126.83392	0.02295	0.30011	0.00301	5.80979	0.09812	0.06403
0.011	5.80979	126.78419	0.02297	0.30013	0.00331	5.80179	0.09810	0.08433
0.012	5.80179	126.72545	0.02300	0.30023	0.00361	5.79381	0.09807	0.10834
0.013	5.79381	126.65696	0.02302	0.30042	0.00391	5.78584	0.09805	0.13635
0.014	5.78584	126.57799	0.02306	0.30071	0.00421	5.77788	0.09801	0.16869
0.015	5.77788	126.48781	0.02309	0.30111	0.00451	5.76992	0.09798	0.20569
0.016	5.76992	126.38567	0.02313	0.30162	0.00482	5.76197	0.09794	0.24765
0.017	5.76197	126.27087	0.02318	0.30225	0.00512	5.75403	0.09789	0.29490
0.018	5.75403	126.14266	0.02323	0.30301	0.00542	5.74607	0.09784	0.34778
0.019	5.74607	126.00033	0.02328	0.30391	0.00572	5.73812	0.09778	0.40662
0.02	5.73812	125.84316	0.02334	0.30495	0.00603	5.73015	0.09772	0.47175
0.021	5.73015	125.67045	0.02341	0.30614	0.00634	5.72217	0.09765	0.54353
0.022	5.72217	125.48148	0.02349	0.30748	0.00664	5.71417	0.09757	0.62230
0.023	5.71417	125.27554	0.02357	0.30899	0.00695	5.70615	0.09748	0.70842
0.024	5.70615	125.05195	0.02365	0.31068	0.00726	5.69811	0.09739	0.80227
0.025	5.69811	124.81001	0.02375	0.31254	0.00758	5.69004	0.09729	0.90420
0.026	5.69004	124.54904	0.02385	0.31459	0.00789	5.68193	0.09718	1.01460
0.027	5.68193	124.26835	0.02396	0.31683	0.00821	5.67378	0.09707	1.13388
0.028	5.67378	123.96727	0.02407	0.31928	0.00853	5.66559	0.09694	1.26242
0.029	5.66559	123.64513	0.02420	0.32193	0.00885	5.65734	0.09680	1.40064
0.03	5.65734	123.30128	0.02433	0.32480	0.00917	5.64905	0.09666	1.54897
0.031	5.64905	122.93505	0.02447	0.32790	0.00950	5.64069	0.09650	1.70784
0.032	5.64069	122.54581	0.02462	0.33122	0.00983	5.63227	0.09634	1.87770
0.033	5.63227	122.13291	0.02478	0.33478	0.01017	5.62378	0.09616	2.05902
0.034	5.62378	121.69572	0.02495	0.33859	0.01050	5.61522	0.09597	2.25226
0.035	5.61522	121.23363	0.02512	0.34266	0.01085	5.60657	0.09577	2.45793
0.036	5.60657	120.74600	0.02531	0.34698	0.01119	5.59783	0.09555	2.67653
0.037	5.59783	120.23223	0.02551	0.35158	0.01155	5.58900	0.09532	2.90858
0.038	5.58900	119.69173	0.02571	0.35645	0.01190	5.58007	0.09508	3.15463
0.039	5.58007	119.12390	0.02592	0.36160	0.01226	5.57104	0.09483	3.41523
0.04	5.57104	118.52814	0.02615	0.36704	0.01263	5.56189	0.09456	3.69096
0.041	5.56189	117.90390	0.02638	0.37278	0.01300	5.55262	0.09427	3.98240
0.042	5.55262	117.25058	0.02662	0.37883	0.01338	5.54323	0.09397	4.29019
0.043	5.54323	116.56763	0.02688	0.38518	0.01377	5.53371	0.09365	4.61494
0.044	5.53371	115.85450	0.02714	0.39186	0.01416	5.52405	0.09331	4.95731
0.045	5.52405	115.11063	0.02741	0.39885	0.01456	5.51424	0.09296	5.31798

Accel a	=	$FL^2/m(r^2 + k^2)$
	=	$FL^2/m(r^2 + k^2)$
	=	$FL^2/(I + mr^2)$
L	=	$(2814\sin\theta)/(6253-5628\cos\theta)^{1/2}$
I	=	1.02×10^{-2} kgm²
F	=	$(F_0C_b - C_aV)/(C_b + V)$
F_0	=	(0.3MPa)(Cross-section Area)
	=	$3000000 \times 1.96\times10^{-5}$
	=	5.891
V_0	=	(16 + 6)/2 x Fibre Length
	=	(11)(0.098)
	=	1.08m/s
C_b/V_0	=	0.25
C_b	=	0.27
C_a/F_0	=	0.25
Ca	=	1.47275

Diameter of muscle is 0.5cm





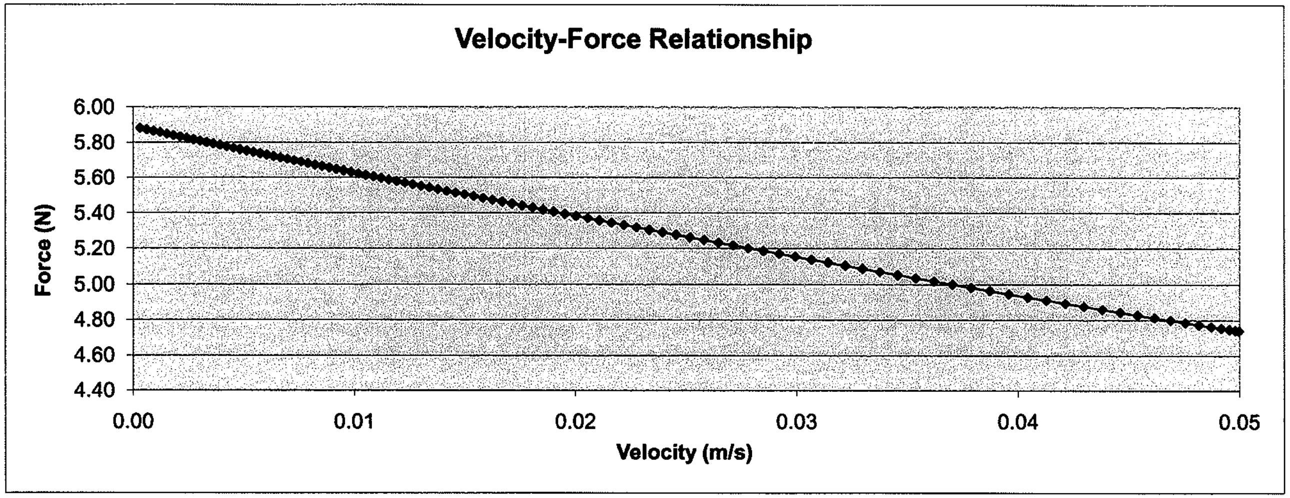
power	omega	moment	power2	theta-step	theta-integr	theta-deg
0.00000	0.00000	0.13484	0.00000	0.00000	0.00000	0.00000
0.00178	0.01322	0.13465	0.00178	0.00001	0.00001	0.00076
0.00355	0.02642	0.13447	0.00355	0.00003	0.00004	0.00227
0.00532	0.03960	0.13428	0.00532	0.00004	0.00008	0.00454
0.00708	0.05277	0.13411	0.00708	0.00005	0.00013	0.00756
0.00883	0.06591	0.13394	0.00883	0.00007	0.00020	0.01134
0.01057	0.07903	0.13378	0.01057	0.00008	0.00028	0.01587
0.01231	0.09213	0.13363	0.01231	0.00009	0.00037	0.02115
0.01404	0.10520	0.13350	0.01404	0.00011	0.00047	0.02717
0.01577	0.11825	0.13337	0.01577	0.00012	0.00059	0.03395
0.01749	0.13126	0.13327	0.01749	0.00013	0.00072	0.04147
0.01921	0.14424	0.13318	0.01921	0.00014	0.00087	0.04973
0.02092	0.15719	0.13311	0.02092	0.00016	0.00103	0.05874
0.02263	0.17009	0.13306	0.02263	0.00017	0.00120	0.06849
0.02434	0.18295	0.13303	0.02434	0.00018	0.00138	0.07897
0.02604	0.19577	0.13303	0.02604	0.00020	0.00157	0.09018
0.02774	0.20853	0.13305	0.02774	0.00021	0.00178	0.10213
0.02945	0.22123	0.13310	0.02945	0.00022	0.00200	0.11481
0.03115	0.23388	0.13317	0.03115	0.00023	0.00224	0.12821
0.03285	0.24645	0.13328	0.03285	0.00025	0.00248	0.14233
0.03455	0.25896	0.13341	0.03455	0.00026	0.00274	0.15717
0.03625	0.27139	0.13358	0.03625	0.00027	0.00301	0.17272
0.03796	0.28374	0.13378	0.03796	0.00028	0.00330	0.18897
0.03967	0.29601	0.13401	0.03967	0.00030	0.00359	0.20593
0.04138	0.30818	0.13428	0.04138	0.00031	0.00390	0.22359
0.04310	0.32026	0.13459	0.04310	0.00032	0.00422	0.24194
0.04483	0.33223	0.13493	0.04483	0.00033	0.00455	0.26097
0.04656	0.34410	0.13531	0.04656	0.00034	0.00490	0.28069
0.04830	0.35586	0.13574	0.04830	0.00036	0.00525	0.30108
0.05005	0.36751	0.13620	0.05005	0.00037	0.00562	0.32214
0.05182	0.37904	0.13670	0.05182	0.00038	0.00600	0.34385
0.05359	0.39044	0.13725	0.05359	0.00039	0.00639	0.36622
0.05537	0.40173	0.13784	0.05537	0.00040	0.00679	0.38924
0.05717	0.41288	0.13847	0.05717	0.00041	0.00721	0.41290
0.05899	0.42391	0.13915	0.05899	0.00042	0.00763	0.43719
0.06082	0.43480	0.13988	0.06082	0.00043	0.00807	0.46210
0.06267	0.44556	0.14065	0.06267	0.00045	0.00851	0.48763
0.06453	0.45618	0.14146	0.06453	0.00046	0.00897	0.51376
0.06642	0.46667	0.14232	0.06642	0.00047	0.00943	0.54050
0.06832	0.47703	0.14323	0.06832	0.00048	0.00991	0.56783
0.07025	0.48726	0.14418	0.07025	0.00049	0.01040	0.59575
0.07221	0.49735	0.14518	0.07221	0.00050	0.01090	0.62425
0.07418	0.50732	0.14623	0.07418	0.00051	0.01140	0.65332
0.07619	0.51715	0.14732	0.07619	0.00052	0.01192	0.68295
0.07822	0.52687	0.14846	0.07822	0.00053	0.01245	0.71313
0.08028	0.53647	0.14965	0.08028	0.00054	0.01298	0.74387

Mono-Synaptic Test Instance 1

0.046	5.51424	114.33548	0.02769	0.40618	0.01496	5.50428	0.09259	5.69764	0.08237	0.54596	0.15088	0.08237	0.00055	0.01353	0.77515
0.047	5.50428	113.52850	0.02799	0.41384	0.01538	5.49416	0.09219	6.09700	0.08449	0.55533	0.15215	0.08449	0.00056	0.01408	0.80697
0.048	5.49416	112.68918	0.02829	0.42184	0.01580	5.48388	0.09178	6.51680	0.08665	0.56461	0.15347	0.08665	0.00056	0.01465	0.83932
0.049	5.48388	111.81699	0.02860	0.43019	0.01623	5.47342	0.09135	6.95781	0.08884	0.57379	0.15483	0.08884	0.00057	0.01522	0.87220
0.05	5.47342	110.91139	0.02892	0.43888	0.01667	5.46279	0.09089	7.42080	0.09106	0.58289	0.15623	0.09106	0.00058	0.01581	0.90559
0.051	5.46279	109.97189	0.02925	0.44793	0.01712	5.45197	0.09042	7.90657	0.09332	0.59190	0.15767	0.09332	0.00059	0.01640	0.93951
0.052	5.45197	108.99796	0.02959	0.45732	0.01757	5.44095	0.08992	8.41594	0.09562	0.60084	0.15915	0.09562	0.00060	0.01700	0.97393
0.053	5.44095	107.98909	0.02994	0.46708	0.01804	5.42974	0.08939	8.94977	0.09796	0.60972	0.16067	0.09796	0.00061	0.01761	1.00887
0.054	5.42974	106.94478	0.03030	0.47718	0.01852	5.41833	0.08884	9.50893	0.10034	0.61854	0.16223	0.10034	0.00062	0.01823	1.04431
0.055	5.41833	105.86453	0.03067	0.48764	0.01901	5.40670	0.08827	10.09429	0.10276	0.62732	0.16381	0.10276	0.00063	0.01885	1.08025
0.056	5.40670	104.74784	0.03104	0.49846	0.01951	5.39485	0.08767	10.70677	0.10523	0.63607	0.16544	0.10523	0.00064	0.01949	1.11669
0.057	5.39485	103.59420	0.03142	0.50962	0.02001	5.38278	0.08704	11.34730	0.10774	0.64479	0.16709	0.10774	0.00064	0.02013	1.15364
0.058	5.38278	102.40312	0.03182	0.52113	0.02054	5.37049	0.08638	12.01682	0.11029	0.65351	0.16876	0.11029	0.00065	0.02079	1.19108
0.059	5.37049	101.17410	0.03221	0.53297	0.02107	5.35796	0.08570	12.71631	0.11289	0.66222	0.17047	0.11289	0.00066	0.02145	1.22902
0.06	5.35796	99.90663	0.03262	0.54514	0.02161	5.34519	0.08498	13.44674	0.11553	0.67094	0.17219	0.11553	0.00067	0.02212	1.26746
0.061	5.34519	98.60023	0.03303	0.55763	0.02217	5.33217	0.08423	14.20912	0.11822	0.67969	0.17394	0.11822	0.00068	0.02280	1.30641
0.062	5.33217	97.25437	0.03345	0.57043	0.02274	5.31891	0.08345	15.00445	0.12096	0.68847	0.17570	0.12096	0.00069	0.02349	1.34585
0.063	5.31891	95.86856	0.03388	0.58351	0.02333	5.30540	0.08263	15.83377	0.12375	0.69730	0.17747	0.12375	0.00070	0.02419	1.38581
0.064	5.30540	94.44230	0.03430	0.59687	0.02392	5.29164	0.08179	16.69811	0.12659	0.70620	0.17925	0.12659	0.00071	0.02489	1.42627
0.065	5.29164	92.97505	0.03474	0.61048	0.02453	5.27762	0.08090	17.59850	0.12948	0.71518	0.18104	0.12948	0.00072	0.02561	1.46725
0.066	5.27762	91.46631	0.03517	0.62431	0.02516	5.26334	0.07998	18.53601	0.13241	0.72425	0.18283	0.13241	0.00072	0.02633	1.50874
0.067	5.26334	89.91554	0.03561	0.63833	0.02580	5.24880	0.07902	19.51167	0.13540	0.73342	0.18461	0.13540	0.00073	0.02707	1.55076
0.068	5.24880	88.32222	0.03605	0.65252	0.02645	5.23400	0.07803	20.52653	0.13843	0.74273	0.18638	0.13843	0.00074	0.02781	1.59332
0.069	5.23400	86.68581	0.03649	0.66684	0.02712	5.21895	0.07699	21.58163	0.14151	0.75217	0.18814	0.14151	0.00075	0.02856	1.63642
0.07	5.21895	85.00575	0.03693	0.68123	0.02780	5.20364	0.07591	22.67799	0.14464	0.76178	0.18987	0.14464	0.00076	0.02932	1.68006
0.071	5.20364	83.28148	0.03736	0.69566	0.02849	5.18808	0.07480	23.81660	0.14782	0.77157	0.19158	0.14782	0.00077	0.03009	1.72427
0.072	5.18808	81.51242	0.03780	0.71007	0.02920	5.17227	0.07364	24.99846	0.15104	0.78157	0.19325	0.15104	0.00078	0.03088	1.76905
0.073	5.17227	79.69801	0.03822	0.72440	0.02993	5.15622	0.07243	26.22450	0.15431	0.79179	0.19489	0.15431	0.00079	0.03167	1.81442
0.074	5.15622	77.83762	0.03864	0.73857	0.03067	5.13994	0.07118	27.49561	0.15762	0.80226	0.19647	0.15762	0.00080	0.03247	1.86038
0.075	5.13994	75.93066	0.03905	0.75251	0.03142	5.12343	0.06989	28.81265	0.16097	0.81301	0.19799	0.16097	0.00081	0.03328	1.90696
0.076	5.12343	73.97648	0.03945	0.76613	0.03218	5.10671	0.06855	30.17637	0.16435	0.82407	0.19944	0.16435	0.00082	0.03411	1.95418
0.077	5.10671	71.97443	0.03984	0.77933	0.03296	5.08978	0.06717	31.58746	0.16777	0.83548	0.20081	0.16777	0.00084	0.03494	2.00205
0.078	5.08978	69.92383	0.04021	0.79198	0.03376	5.07267	0.06573	33.04651	0.17123	0.84729	0.20209	0.17123	0.00085	0.03579	2.05060
0.079	5.07267	67.82399	0.04055	0.80398	0.03456	5.05539	0.06425	34.55397	0.17471	0.85952	0.20326	0.17471	0.00086	0.03665	2.09984
0.08	5.05539	65.67417	0.04088	0.81515	0.03537	5.03796	0.06273	36.11014	0.17821	0.87226	0.20431	0.17821	0.00087	0.03752	2.14982
0.081	5.03796	63.47361	0.04117	0.82535	0.03620	5.02041	0.06115	37.71513	0.18174	0.88555	0.20523	0.18174	0.00089	0.03841	2.20056
0.082	5.02041	61.22152	0.04143	0.83437	0.03703	5.00277	0.05953	39.36885	0.18527	0.89947	0.20598	0.18527	0.00090	0.03931	2.25209
0.083	5.00277	58.91705	0.04165	0.84200	0.03788	4.98506	0.05786	41.07091	0.18881	0.91414	0.20655	0.18881	0.00091	0.04022	2.30447
0.084	4.98506	56.55931	0.04183	0.84798	0.03872	4.96732	0.05614	42.82059	0.19235	0.92965	0.20691	0.19235	0.00093	0.04115	2.35774
0.085	4.96732	54.14737	0.04195	0.85202	0.03958	4.94959	0.05438	44.61679	0.19588	0.94616	0.20703	0.19588	0.00095	0.04210	2.41195
0.086	4.94959	51.68019	0.04200	0.85379	0.04043	4.93193	0.05257	46.45789	0.19940	0.96385	0.20687	0.19940	0.00096	0.04306	2.46717
0.087	4.93193	49.15670	0.04197	0.85287	0.04128	4.91438	0.05072	48.34167	0.20288	0.98295	0.20640	0.20288	0.00098	0.04404	2.52349
0.088	4.91438	46.57570	0.04185	0.84881	0.04213	4.89701	0.04883	50.26515	0.20632	1.00377	0.20554	0.20632	0.00100	0.04505	2.58100
0.089	4.89701	43.93587	0.04163	0.84105	0.04297	4.87989	0.04691	52.22438	0.20970	1.02670	0.20425	0.20970	0.00103	0.04607	2.63983
0.09	4.87989	41.23576	0.04126	0.82896	0.04380	4.86311	0.04495	54.21424	0.21301	1.05227	0.20243	0.21301	0.00105	0.04713	2.70012
0.091	4.86311	38.47369	0.04074	0.81177	0.04461	4.84676	0.04298	56.22809	0.21623	1.08119	0.19999	0.21623	0.00108	0.04821	2.76207
0.092	4.84676	35.64777	0.04002	0.78861	0.04540	4.83096	0.04098	58.25734	0.21933	1.11447	0.19681	0.21933	0.00111	0.04932	2.82592
0.093	4.83096	32.75576	0.03905	0.75843	0.04616	4.81584	0.03899	60.29091	0.22230	1.15352	0.19271	0.22230	0.00115	0.05048	2.89201
0.094	4.81584	29.79497	0.03779	0.72008	0.04688	4.80155	0.03700	62.31452	0.22510	1.20042	0.18752	0.22510	0.00120	0.05168	2.96079
0.095	4.80155	26.76208	0.03616	0.67231	0.04755	4.78826	0.03504	64.30976	0.22769	1.25829	0.18096	0.22769	0.00126	0.05293	3.03289

Mono-Synaptic Test Instance 1

0.096	4.78826	23.65288	0.03407	0.61385	0.04817	4.77618	0.03313	66.25285	0.23005	1.33200	0.17271	0.23005	0.00133	0.05427	3.10920
0.097	4.77618	20.46177	0.03142	0.54365	0.04871	4.76552	0.03131	68.11319	0.23213	1.42955	0.16238	0.23213	0.00143	0.05570	3.19111
0.098	4.76552	17.18100	0.02808	0.46131	0.04917	4.75651	0.02960	69.85161	0.23388	1.56485	0.14946	0.23388	0.00156	0.05726	3.28077
0.099	4.75651	13.79916	0.02392	0.36775	0.04954	4.74934	0.02806	71.41852	0.23528	1.76406	0.13337	0.23528	0.00176	0.05902	3.38184
0.1	4.74934	10.29801	0.01880	0.26639	0.04981	4.74415	0.02675	72.75227	0.23628	2.08227	0.11347	0.23628	0.00208	0.06111	3.50115
0.101	4.74415	6.64460	0.01265	0.16447	0.04997	4.74096	0.02574	73.77779	0.23691	2.65735	0.08915	0.23691	0.00266	0.06376	3.65340
[redacted]															
0.103	4.73951	-1.64670	-0.00323	0.01355	0.05006	4.73925	0.02505	74.48926	0.23724	9.26890	0.02559	0.23724	0.00927	0.07699	4.41118

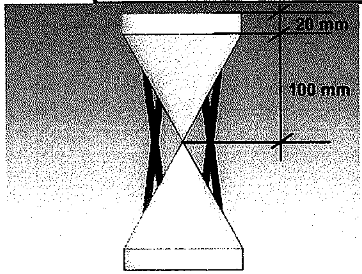


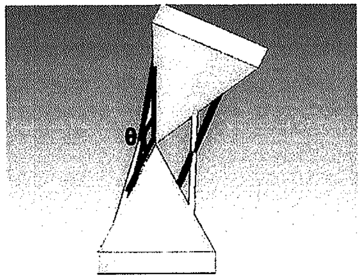
Mono-Synaptic Test Instance 2

time	force	theta-deg	Mnt Arm	accel	veloc	force2	Muscle L	%Δ muscle L
0	0.00000	170.00000	0.00450	0.00000	0.00000	5.89100	0.10861	10.62037
0.001	5.89100	169.99985	0.00450	0.01202	0.00001	5.89067	0.10861	10.62036
0.002	5.89067	169.99939	0.00450	0.01202	0.00002	5.89034	0.10861	10.62032
0.003	5.89034	169.99847	0.00450	0.01202	0.00004	5.89002	0.10861	10.62025
0.004	5.89002	169.99694	0.00450	0.01202	0.00005	5.88969	0.10861	10.62013
0.005	5.88969	169.99464	0.00450	0.01202	0.00006	5.88936	0.10861	10.61994
0.006	5.88936	169.99143	0.00450	0.01203	0.00007	5.88903	0.10861	10.61969
0.007	5.88903	169.98715	0.00450	0.01204	0.00008	5.88871	0.10861	10.61934
0.008	5.88871	169.98164	0.00451	0.01204	0.00010	5.88838	0.10861	10.61890
0.009	5.88838	169.97475	0.00451	0.01206	0.00011	5.88805	0.10861	10.61835
0.01	5.88805	169.96634	0.00451	0.01207	0.00012	5.88772	0.10860	10.61768
0.011	5.88772	169.95625	0.00452	0.01209	0.00013	5.88739	0.10860	10.61686
0.012	5.88739	169.94432	0.00452	0.01212	0.00014	5.88706	0.10860	10.61591
0.013	5.88706	169.93041	0.00453	0.01214	0.00016	5.88673	0.10860	10.61479
0.014	5.88673	169.91436	0.00454	0.01218	0.00017	5.88640	0.10860	10.61349
0.015	5.88640	169.89603	0.00455	0.01222	0.00018	5.88606	0.10860	10.61201
0.016	5.88606	169.87526	0.00456	0.01226	0.00019	5.88573	0.10860	10.61033
0.017	5.88573	169.85190	0.00457	0.01231	0.00021	5.88540	0.10860	10.60844
0.018	5.88540	169.82581	0.00458	0.01236	0.00022	5.88506	0.10859	10.60632
0.019	5.88506	169.79683	0.00459	0.01243	0.00023	5.88472	0.10859	10.60396
0.02	5.88472	169.76482	0.00460	0.01250	0.00024	5.88438	0.10859	10.60134
0.021	5.88438	169.72963	0.00462	0.01257	0.00026	5.88404	0.10859	10.59846
0.022	5.88404	169.69112	0.00464	0.01266	0.00027	5.88369	0.10858	10.59529
0.023	5.88369	169.64913	0.00466	0.01275	0.00028	5.88335	0.10858	10.59182
0.024	5.88335	169.60353	0.00468	0.01286	0.00029	5.88300	0.10858	10.58803
0.025	5.88300	169.55417	0.00470	0.01297	0.00031	5.88264	0.10857	10.58392
0.026	5.88264	169.50092	0.00472	0.01309	0.00032	5.88229	0.10857	10.57946
0.027	5.88229	169.44362	0.00475	0.01322	0.00033	5.88193	0.10856	10.57464
0.028	5.88193	169.38214	0.00478	0.01337	0.00035	5.88156	0.10856	10.56943
0.029	5.88156	169.31634	0.00481	0.01352	0.00036	5.88120	0.10855	10.56383
0.03	5.88120	169.24609	0.00484	0.01369	0.00037	5.88082	0.10855	10.55781
0.031	5.88082	169.17125	0.00487	0.01387	0.00039	5.88045	0.10854	10.55135
0.032	5.88045	169.09168	0.00491	0.01406	0.00040	5.88006	0.10853	10.54443
0.033	5.88006	169.00726	0.00494	0.01427	0.00042	5.87968	0.10853	10.53704
0.034	5.87968	168.91785	0.00498	0.01449	0.00043	5.87928	0.10852	10.52915
0.035	5.87928	168.82333	0.00503	0.01472	0.00045	5.87888	0.10851	10.52074
0.036	5.87888	168.72356	0.00507	0.01497	0.00046	5.87847	0.10850	10.51179
0.037	5.87847	168.61842	0.00512	0.01524	0.00048	5.87806	0.10849	10.50226
0.038	5.87806	168.50779	0.00517	0.01552	0.00049	5.87764	0.10848	10.49215
0.039	5.87764	168.39154	0.00522	0.01582	0.00051	5.87721	0.10847	10.48141
0.04	5.87721	168.26955	0.00527	0.01614	0.00052	5.87677	0.10846	10.47003
0.041	5.87677	168.14171	0.00533	0.01648	0.00054	5.87632	0.10845	10.45798
0.042	5.87632	168.00789	0.00539	0.01684	0.00056	5.87586	0.10844	10.44523
0.043	5.87586	167.86798	0.00545	0.01722	0.00057	5.87540	0.10842	10.43174
0.044	5.87540	167.72186	0.00552	0.01762	0.00059	5.87492	0.10841	10.41748
0.045	5.87492	167.56943	0.00559	0.01804	0.00061	5.87443	0.10839	10.40243
0.046	5.87443	167.41055	0.00566	0.01849	0.00063	5.87393	0.10838	10.38655
0.047	5.87393	167.24514	0.00573	0.01896	0.00065	5.87341	0.10836	10.36980

Accel a	=	$FL^2/m(r^2 + k^2)$
	=	$FL^2/m(r^2 + k^2)$
	=	$FL^2/(I + mr^2)$
L	=	$(2814\sin\theta)/(6253-5628\cos\theta)^{1/2}$
I	=	0.982×10^{-2} kgm^2
mr^2	=	$(1.32) \times (0.0088)^2$
	=	1.02×10^{-4} kgm^2
F	=	$(F_0C_b - C_aV)/(C_b + V)$
F_0	=	(0.3MPa)(Cross-section Area)
	=	$3000000 \times 1.96\times10^{-5}$
	=	5.891
V_0	=	(16 + 6)/2 x Fibre Length
	=	(11)(0.098)
	=	1.08m/s
C_b/V_0	=	0.25
C_b	=	0.27
Ca/F_0	=	0.25
Ca	=	1.47275

Diameter of muscle is 0.5cm





power	omega	moment	power2	theta-step	theta-integr	theta-deg
0.00000	0.00000	0.02650	0.00000	0.00000	0.00000	0.00000
0.00007	0.00267	0.02650	0.00007	0.00000	0.00000	0.00015
0.00014	0.00534	0.02650	0.00014	0.00001	0.00001	0.00046
0.00021	0.00801	0.02650	0.00021	0.00001	0.00002	0.00092
0.00028	0.01068	0.02650	0.00028	0.00001	0.00003	0.00153
0.00035	0.01335	0.02651	0.00035	0.00001	0.00004	0.00230
0.00042	0.01602	0.02651	0.00042	0.00002	0.00006	0.00321
0.00050	0.01869	0.02652	0.00050	0.00002	0.00007	0.00428
0.00057	0.02136	0.02653	0.00057	0.00002	0.00010	0.00551
0.00064	0.02402	0.02654	0.00064	0.00002	0.00012	0.00688
0.00071	0.02668	0.02656	0.00071	0.00003	0.00015	0.00841
0.00078	0.02934	0.02658	0.00078	0.00003	0.00018	0.01009
0.00085	0.03199	0.02660	0.00085	0.00003	0.00021	0.01193
0.00092	0.03463	0.02663	0.00092	0.00003	0.00024	0.01391
0.00099	0.03727	0.02667	0.00099	0.00004	0.00028	0.01605
0.00107	0.03991	0.02671	0.00107	0.00004	0.00032	0.01833
0.00114	0.04253	0.02676	0.00114	0.00004	0.00036	0.02077
0.00121	0.04515	0.02681	0.00121	0.00005	0.00041	0.02336
0.00128	0.04775	0.02687	0.00128	0.00005	0.00046	0.02609
0.00136	0.05034	0.02694	0.00136	0.00005	0.00051	0.02898
0.00143	0.05292	0.02701	0.00143	0.00005	0.00056	0.03201
0.00150	0.05549	0.02709	0.00150	0.00006	0.00061	0.03519
0.00158	0.05804	0.02719	0.00158	0.00006	0.00067	0.03851
0.00165	0.06058	0.02729	0.00165	0.00006	0.00073	0.04199
0.00173	0.06309	0.02739	0.00173	0.00006	0.00080	0.04560
0.00180	0.06559	0.02751	0.00180	0.00007	0.00086	0.04936
0.00188	0.06807	0.02764	0.00188	0.00007	0.00093	0.05326
0.00196	0.07052	0.02778	0.00196	0.00007	0.00100	0.05730
0.00204	0.07296	0.02793	0.00204	0.00007	0.00107	0.06148
0.00212	0.07537	0.02809	0.00212	0.00008	0.00115	0.06580
0.00220	0.07775	0.02826	0.00220	0.00008	0.00123	0.07025
0.00228	0.08011	0.02845	0.00228	0.00008	0.00131	0.07484
0.00236	0.08245	0.02864	0.00236	0.00008	0.00139	0.07957
0.00245	0.08476	0.02885	0.00245	0.00008	0.00147	0.08442
0.00253	0.08704	0.02907	0.00253	0.00009	0.00156	0.08941
0.00262	0.08929	0.02930	0.00262	0.00009	0.00165	0.09452
0.00270	0.09152	0.02955	0.00270	0.00009	0.00174	0.09977
0.00279	0.09372	0.02981	0.00279	0.00009	0.00184	0.10514
0.00288	0.09589	0.03009	0.00288	0.00010	0.00193	0.11063
0.00298	0.09803	0.03037	0.00298	0.00010	0.00203	0.11625
0.00307	0.10014	0.03068	0.00307	0.00010	0.00213	0.12199
0.00317	0.10223	0.03100	0.00317	0.00010	0.00223	0.12784
0.00327	0.10429	0.03133	0.00327	0.00010	0.00234	0.13382
0.00337	0.10632	0.03168	0.00337	0.00011	0.00244	0.13991
0.00347	0.10833	0.03205	0.00347	0.00011	0.00255	0.14612
0.00358	0.11032	0.03243	0.00358	0.00011	0.00266	0.15244
0.00369	0.11228	0.03283	0.00369	0.00011	0.00277	0.15887
0.00380	0.11422	0.03324	0.00380	0.00011	0.00289	0.16542

Mono-Synaptic Test Instance 2

0.048	5.87341	167.07307	0.00581	0.01946	0.00067	5.87288	0.10834	10.35214
0.049	5.87288	166.89424	0.00589	0.01998	0.00069	5.87234	0.10833	10.33354
0.05	5.87234	166.70853	0.00597	0.02053	0.00071	5.87178	0.10831	10.31396
0.051	5.87178	166.51585	0.00606	0.02112	0.00073	5.87121	0.10829	10.29335
0.052	5.87121	166.31608	0.00615	0.02173	0.00075	5.87062	0.10826	10.27168
0.053	5.87062	166.10913	0.00624	0.02237	0.00077	5.87002	0.10824	10.24889
0.054	5.87002	165.89488	0.00634	0.02305	0.00079	5.86939	0.10822	10.22493
0.055	5.86939	165.67323	0.00644	0.02375	0.00082	5.86875	0.10819	10.19977
0.056	5.86875	165.44407	0.00654	0.02450	0.00084	5.86808	0.10817	10.17334
0.057	5.86808	165.20731	0.00664	0.02528	0.00087	5.86740	0.10814	10.14560
0.058	5.86740	164.96283	0.00675	0.02610	0.00089	5.86669	0.10811	10.11649
0.059	5.86669	164.71054	0.00687	0.02696	0.00092	5.86596	0.10808	10.08595
0.06	5.86596	164.45033	0.00698	0.02787	0.00095	5.86520	0.10805	10.05392
0.061	5.86520	164.18209	0.00710	0.02881	0.00098	5.86442	0.10802	10.02035
0.062	5.86442	163.90572	0.00722	0.02980	0.00101	5.86362	0.10798	9.98516
0.063	5.86362	163.62112	0.00735	0.03084	0.00104	5.86278	0.10795	9.94829
0.064	5.86278	163.32817	0.00748	0.03193	0.00107	5.86192	0.10791	9.90967
0.065	5.86192	163.02677	0.00762	0.03307	0.00110	5.86102	0.10787	9.86922
0.066	5.86102	162.71681	0.00775	0.03426	0.00114	5.86010	0.10783	9.82688
0.067	5.86010	162.39817	0.00789	0.03550	0.00117	5.85914	0.10778	9.78256
0.068	5.85914	162.07076	0.00804	0.03681	0.00121	5.85814	0.10774	9.73619
0.069	5.85814	161.73445	0.00819	0.03817	0.00125	5.85711	0.10769	9.68767
0.07	5.85711	161.38913	0.00834	0.03959	0.00129	5.85604	0.10764	9.63693
0.071	5.85604	161.03468	0.00850	0.04108	0.00133	5.85493	0.10759	9.58386
0.072	5.85493	160.67099	0.00866	0.04264	0.00137	5.85378	0.10753	9.52838
0.073	5.85378	160.29793	0.00883	0.04426	0.00142	5.85258	0.10748	9.47039
0.074	5.85258	159.91538	0.00900	0.04596	0.00146	5.85134	0.10742	9.40979
0.075	5.85134	159.52322	0.00917	0.04773	0.00151	5.85006	0.10736	9.34647
0.076	5.85006	159.12132	0.00935	0.04957	0.00156	5.84872	0.10729	9.28032
0.077	5.84872	158.70954	0.00953	0.05150	0.00161	5.84733	0.10722	9.21124
0.078	5.84733	158.28776	0.00972	0.05351	0.00166	5.84589	0.10715	9.13909
0.079	5.84589	157.85583	0.00991	0.05561	0.00172	5.84439	0.10708	9.06376
0.08	5.84439	157.41362	0.01010	0.05780	0.00178	5.84284	0.10700	8.98512
0.081	5.84284	156.96099	0.01030	0.06008	0.00184	5.84122	0.10692	8.90305
0.082	5.84122	156.49779	0.01050	0.06246	0.00190	5.83954	0.10684	8.81740
0.083	5.83954	156.02387	0.01071	0.06493	0.00197	5.83779	0.10675	8.72803
0.084	5.83779	155.53908	0.01092	0.06751	0.00203	5.83598	0.10666	8.63480
0.085	5.83598	155.04326	0.01114	0.07020	0.00210	5.83409	0.10656	8.53755
0.086	5.83409	154.53625	0.01136	0.07300	0.00218	5.83213	0.10646	8.43612
0.087	5.83213	154.01789	0.01159	0.07591	0.00225	5.83010	0.10636	8.33036
0.088	5.83010	153.48801	0.01182	0.07894	0.00233	5.82798	0.10625	8.22009
0.089	5.82798	152.94644	0.01206	0.08210	0.00241	5.82578	0.10614	8.10513
0.09	5.82578	152.39300	0.01230	0.08538	0.00250	5.82349	0.10602	7.98531
0.091	5.82349	151.82750	0.01255	0.08879	0.00259	5.82112	0.10590	7.86042
0.092	5.82112	151.24977	0.01280	0.09234	0.00268	5.81865	0.10577	7.73029
0.093	5.81865	150.65962	0.01305	0.09603	0.00278	5.81608	0.10564	7.59469
0.094	5.81608	150.05684	0.01331	0.09987	0.00288	5.81341	0.10550	7.45343
0.095	5.81341	149.44125	0.01358	0.10386	0.00298	5.81064	0.10535	7.30627
0.096	5.81064	148.81263	0.01385	0.10800	0.00309	5.80776	0.10520	7.15300
0.097	5.80776	148.17078	0.01413	0.11230	0.00320	5.80476	0.10505	6.99338
0.098	5.80476	147.51547	0.01441	0.11677	0.00332	5.80166	0.10488	6.82716
0.099	5.80166	146.84650	0.01470	0.12141	0.00344	5.79843	0.10471	6.65409

0.00391	0.11614	0.03367	0.00391	0.00012	0.00300	0.17207
0.00403	0.11804	0.03412	0.00403	0.00012	0.00312	0.17883
0.00415	0.11992	0.03459	0.00415	0.00012	0.00324	0.18570
0.00427	0.12179	0.03507	0.00427	0.00012	0.00336	0.19268
0.00440	0.12365	0.03557	0.00440	0.00012	0.00349	0.19977
0.00453	0.12549	0.03609	0.00453	0.00013	0.00361	0.20696
0.00466	0.12732	0.03663	0.00466	0.00013	0.00374	0.21425
0.00480	0.12915	0.03719	0.00480	0.00013	0.00387	0.22165
0.00495	0.13097	0.03777	0.00495	0.00013	0.00400	0.22915
0.00509	0.13279	0.03836	0.00509	0.00013	0.00413	0.23676
0.00525	0.13460	0.03898	0.00525	0.00013	0.00427	0.24447
0.00540	0.13642	0.03961	0.00540	0.00014	0.00440	0.25229
0.00557	0.13824	0.04027	0.00557	0.00014	0.00454	0.26021
0.00573	0.14007	0.04094	0.00573	0.00014	0.00468	0.26824
0.00591	0.14191	0.04164	0.00591	0.00014	0.00482	0.27637
0.00609	0.14376	0.04235	0.00609	0.00014	0.00497	0.28461
0.00628	0.14563	0.04309	0.00628	0.00015	0.00511	0.29295
0.00647	0.14751	0.04385	0.00647	0.00015	0.00526	0.30140
0.00667	0.14941	0.04463	0.00667	0.00015	0.00541	0.30996
0.00687	0.15133	0.04543	0.00687	0.00015	0.00556	0.31863
0.00709	0.15328	0.04625	0.00709	0.00015	0.00571	0.32741
0.00731	0.15525	0.04709	0.00731	0.00016	0.00587	0.33631
0.00754	0.15726	0.04796	0.00754	0.00016	0.00603	0.34532
0.00778	0.15929	0.04885	0.00778	0.00016	0.00619	0.35445
0.00803	0.16136	0.04976	0.00803	0.00016	0.00635	0.36369
0.00829	0.16347	0.05069	0.00829	0.00016	0.00651	0.37306
0.00855	0.16561	0.05165	0.00855	0.00017	0.00668	0.38255
0.00883	0.16780	0.05263	0.00883	0.00017	0.00684	0.39216
0.00912	0.17003	0.05363	0.00912	0.00017	0.00701	0.40190
0.00942	0.17231	0.05466	0.00942	0.00017	0.00719	0.41178
0.00973	0.17464	0.05571	0.00973	0.00017	0.00736	0.42178
0.01005	0.17702	0.05678	0.01005	0.00018	0.00754	0.43193
0.01039	0.17945	0.05788	0.01039	0.00018	0.00772	0.44221
0.01073	0.18193	0.05900	0.01073	0.00018	0.00790	0.45263
0.01110	0.18448	0.06015	0.01110	0.00018	0.00808	0.46320
0.01147	0.18708	0.06132	0.01147	0.00019	0.00827	0.47392
0.01186	0.18975	0.06251	0.01186	0.00019	0.00846	0.48479
0.01227	0.19248	0.06374	0.01227	0.00019	0.00865	0.49582
0.01269	0.19527	0.06498	0.01269	0.00020	0.00885	0.50701
0.01313	0.19814	0.06625	0.01313	0.00020	0.00905	0.51836
0.01358	0.20107	0.06755	0.01358	0.00020	0.00925	0.52988
0.01406	0.20408	0.06887	0.01406	0.00020	0.00945	0.54157
0.01455	0.20716	0.07022	0.01455	0.00021	0.00966	0.55344
0.01506	0.21032	0.07160	0.01506	0.00021	0.00987	0.56549
0.01559	0.21355	0.07300	0.01559	0.00021	0.01008	0.57773
0.01614	0.21687	0.07443	0.01614	0.00022	0.01030	0.59015
0.01671	0.22027	0.07588	0.01671	0.00022	0.01052	0.60278
0.01731	0.22375	0.07736	0.01731	0.00022	0.01074	0.61560
0.01793	0.22732	0.07887	0.01793	0.00023	0.01097	0.62862
0.01857	0.23097	0.08040	0.01857	0.00023	0.01120	0.64185
0.01924	0.23472	0.08196	0.01924	0.00023	0.01144	0.65530
0.01993	0.23855	0.08355	0.01993	0.00024	0.01168	0.66897

Mono-Synaptic Test Instance 2

0.1	5.79843	146.16364	0.01499	0.12623	0.00356	5.79507	0.10454	6.47391
0.101	5.79507	145.46665	0.01529	0.13122	0.00369	5.79159	0.10435	6.28635
0.102	5.79159	144.75531	0.01559	0.13641	0.00383	5.78797	0.10416	6.09112
0.103	5.78797	144.02936	0.01590	0.14178	0.00397	5.78421	0.10396	5.88793
0.104	5.78421	143.28856	0.01621	0.14736	0.00412	5.78031	0.10375	5.67649
0.105	5.78031	142.53266	0.01653	0.15314	0.00427	5.77626	0.10354	5.45647
0.106	5.77626	141.76140	0.01686	0.15913	0.00443	5.77205	0.10331	5.22757
0.107	5.77205	140.97451	0.01719	0.16534	0.00460	5.76769	0.10308	4.98943
0.108	5.76769	140.17172	0.01753	0.17176	0.00477	5.76317	0.10284	4.74171
0.109	5.76317	139.35276	0.01787	0.17842	0.00495	5.75847	0.10258	4.48405
0.11	5.75847	138.51734	0.01822	0.18531	0.00513	5.75360	0.10232	4.21609
0.111	5.75360	137.66516	0.01857	0.19244	0.00533	5.74855	0.10205	3.93743
0.112	5.74855	136.79594	0.01893	0.19982	0.00553	5.74331	0.10176	3.64769
0.113	5.74331	135.90936	0.01930	0.20745	0.00573	5.73788	0.10147	3.34644
0.114	5.73788	135.00512	0.01967	0.21534	0.00595	5.73225	0.10116	3.03326
0.115	5.73225	134.08291	0.02005	0.22349	0.00617	5.72642	0.10084	2.70772
0.116	5.72642	133.14238	0.02043	0.23192	0.00640	5.72038	0.10051	2.36936
0.117	5.72038	132.18323	0.02082	0.24062	0.00664	5.71413	0.10016	2.01771
0.118	5.71413	131.20509	0.02121	0.24960	0.00689	5.70765	0.09980	1.65228
0.119	5.70765	130.20764	0.02161	0.25886	0.00715	5.70094	0.09943	1.27258
0.12	5.70094	129.19052	0.02202	0.26842	0.00742	5.69400	0.09904	0.87809
0.121	5.69400	128.15336	0.02243	0.27828	0.00770	5.68682	0.09864	0.46828
0.122	5.68682	127.09580	0.02285	0.28844	0.00799	5.67939	0.09822	0.04259
0.123	5.67939	126.01746	0.02328	0.29891	0.00829	5.67171	0.09779	0.39953
0.124	5.67171	124.91795	0.02371	0.30968	0.00860	5.66376	0.09734	0.85867
0.125	5.66376	123.79690	0.02414	0.32077	0.00892	5.65556	0.09687	1.33543
0.126	5.65556	122.65389	0.02458	0.33218	0.00925	5.64708	0.09638	1.83043
0.127	5.64708	121.48851	0.02503	0.34391	0.00959	5.63832	0.09588	2.34431
0.128	5.63832	120.30037	0.02548	0.35596	0.00995	5.62928	0.09535	2.87771
0.129	5.62928	119.08901	0.02594	0.36833	0.01032	5.61994	0.09481	3.43131
0.13	5.61994	117.85403	0.02640	0.38102	0.01070	5.61032	0.09425	4.00580
0.131	5.61032	116.59497	0.02687	0.39404	0.01109	5.60039	0.09366	4.60188
0.132	5.60039	115.31138	0.02734	0.40738	0.01150	5.59015	0.09305	5.22029
0.133	5.59015	114.00280	0.02781	0.42105	0.01192	5.57960	0.09242	5.86177
0.134	5.57960	112.66877	0.02829	0.43503	0.01236	5.56874	0.09177	6.52707
0.135	5.56874	111.30881	0.02878	0.44932	0.01281	5.55755	0.09109	7.21698
0.136	5.55755	109.92243	0.02927	0.46392	0.01327	5.54603	0.09039	7.93229
0.137	5.54603	108.50913	0.02976	0.47882	0.01375	5.53419	0.08966	8.67382
0.138	5.53419	107.06841	0.03026	0.49401	0.01424	5.52201	0.08891	9.44238
0.139	5.52201	105.59976	0.03075	0.50948	0.01475	5.50950	0.08813	10.23883
0.14	5.50950	104.10265	0.03126	0.52522	0.01528	5.49664	0.08732	11.06403
0.141	5.49664	102.57654	0.03176	0.54121	0.01582	5.48344	0.08648	11.91883
0.142	5.48344	101.02089	0.03226	0.55744	0.01638	5.46990	0.08561	12.80412
0.143	5.46990	99.43514	0.03277	0.57388	0.01695	5.45602	0.08471	13.72079
0.144	5.45602	97.81871	0.03328	0.59052	0.01754	5.44179	0.08378	14.66973
0.145	5.44179	96.17105	0.03378	0.60733	0.01815	5.42721	0.08281	15.65186
0.146	5.42721	94.49154	0.03429	0.62428	0.01877	5.41230	0.08182	16.66808
0.147	5.41230	92.77960	0.03479	0.64134	0.01941	5.39704	0.08078	17.71929
0.148	5.39704	91.03460	0.03529	0.65848	0.02007	5.38144	0.07972	18.80640
0.149	5.38144	89.25593	0.03579	0.67564	0.02075	5.36551	0.07861	19.93030
0.15	5.36551	87.44293	0.03629	0.69279	0.02144	5.34926	0.07747	21.09188
0.151	5.34926	85.59496	0.03677	0.70988	0.02215	5.33268	0.07629	22.29200

0.02065	0.24248	0.08517	0.02065	0.00024	0.01192	0.68286
0.02140	0.24651	0.08681	0.02140	0.00025	0.01216	0.69699
0.02218	0.25063	0.08848	0.02218	0.00025	0.01242	0.71135
0.02298	0.25485	0.09018	0.02298	0.00025	0.01267	0.72595
0.02382	0.25917	0.09190	0.02382	0.00026	0.01293	0.74080
0.02469	0.26359	0.09365	0.02469	0.00026	0.01319	0.75590
0.02559	0.26811	0.09543	0.02559	0.00027	0.01346	0.77126
0.02652	0.27274	0.09723	0.02652	0.00027	0.01373	0.78689
0.02749	0.27748	0.09907	0.02749	0.00028	0.01401	0.80279
0.02849	0.28233	0.10093	0.02849	0.00028	0.01429	0.81896
0.02954	0.28729	0.10281	0.02954	0.00029	0.01458	0.83542
0.03062	0.29236	0.10472	0.03062	0.00029	0.01487	0.85218
0.03174	0.29755	0.10666	0.03174	0.00030	0.01517	0.86922
0.03290	0.30285	0.10862	0.03290	0.00030	0.01547	0.88658
0.03410	0.30827	0.11061	0.03410	0.00031	0.01578	0.90424
0.03534	0.31381	0.11263	0.03534	0.00031	0.01610	0.92222
0.03663	0.31947	0.11467	0.03663	0.00032	0.01642	0.94052
0.03797	0.32525	0.11673	0.03797	0.00033	0.01674	0.95916
0.03935	0.33116	0.11882	0.03935	0.00033	0.01707	0.97813
0.04078	0.33720	0.12094	0.04078	0.00034	0.01741	0.99745
0.04226	0.34337	0.12307	0.04226	0.00034	0.01775	1.01713
0.04379	0.34966	0.12523	0.04379	0.00035	0.01810	1.03716
0.04537	0.35609	0.12741	0.04537	0.00036	0.01846	1.05756
0.04700	0.36265	0.12961	0.04700	0.00036	0.01882	1.07834
0.04869	0.36935	0.13183	0.04869	0.00037	0.01919	1.09950
0.05043	0.37619	0.13407	0.05043	0.00038	0.01957	1.12106
0.05223	0.38316	0.13632	0.05223	0.00038	0.01995	1.14301
0.05409	0.39028	0.13860	0.05409	0.00039	0.02034	1.16537
0.05601	0.39754	0.14089	0.05601	0.00040	0.02074	1.18815
0.05799	0.40495	0.14319	0.05799	0.00040	0.02114	1.21135
0.06002	0.41251	0.14551	0.06002	0.00041	0.02155	1.23499
0.06213	0.42022	0.14784	0.06213	0.00042	0.02197	1.25906
0.06429	0.42808	0.15018	0.06429	0.00043	0.02240	1.28359
0.06652	0.43609	0.15253	0.06652	0.00044	0.02284	1.30858
0.06881	0.44426	0.15489	0.06881	0.00044	0.02328	1.33403
0.07117	0.45259	0.15725	0.07117	0.00045	0.02374	1.35996
0.07359	0.46109	0.15961	0.07359	0.00046	0.02420	1.38638
0.07609	0.46975	0.16197	0.07609	0.00047	0.02467	1.41330
0.07865	0.47857	0.16434	0.07865	0.00048	0.02515	1.44072
0.08128	0.48757	0.16670	0.08128	0.00049	0.02563	1.46865
0.08397	0.49674	0.16905	0.08397	0.00050	0.02613	1.49711
0.08674	0.50609	0.17139	0.08674	0.00051	0.02664	1.52611
0.08957	0.51563	0.17372	0.08957	0.00052	0.02715	1.55565
0.09248	0.52534	0.17603	0.09248	0.00053	0.02768	1.58575
0.09545	0.53525	0.17833	0.09545	0.00054	0.02821	1.61642
0.09849	0.54535	0.18060	0.09849	0.00055	0.02876	1.64767
0.10160	0.55566	0.18285	0.10160	0.00056	0.02931	1.67950
0.10477	0.56617	0.18506	0.10477	0.00057	0.02988	1.71194
0.10801	0.57689	0.18724	0.10801	0.00058	0.03046	1.74500
0.11132	0.58783	0.18937	0.11132	0.00059	0.03104	1.77868
0.11469	0.59901	0.19147	0.11469	0.00060	0.03164	1.81300
0.11812	0.61042	0.19351	0.11812	0.00061	0.03225	1.84797

Mono-Synaptic Test Instance 2

0.152	5.33268	83.71134	0.03726	0.72685	0.02288	5.31579	0.07508	23.53149
0.153	5.31579	81.79140	0.03773	0.74364	0.02362	5.29860	0.07382	24.81118
0.154	5.29860	79.83444	0.03819	0.76017	0.02438	5.28111	0.07252	26.13183
0.155	5.28111	77.83973	0.03864	0.77637	0.02516	5.26334	0.07119	27.49417
0.156	5.26334	75.80655	0.03908	0.79215	0.02595	5.24531	0.06981	28.89884
0.157	5.24531	73.73414	0.03950	0.80741	0.02676	5.22703	0.06839	30.34644
0.158	5.22703	71.62173	0.03990	0.82203	0.02758	5.20853	0.06692	31.83745
0.159	5.20853	69.46852	0.04029	0.83590	0.02841	5.18981	0.06542	33.37226
0.16	5.18981	67.27370	0.04064	0.84887	0.02926	5.17091	0.06386	34.95112
0.161	5.17091	65.03640	0.04097	0.86078	0.03012	5.15186	0.06227	36.57411
0.162	5.15186	62.75575	0.04126	0.87145	0.03100	5.13268	0.06063	38.24112
0.163	5.13268	60.43084	0.04151	0.88067	0.03188	5.11341	0.05896	39.95181
0.164	5.11341	58.06070	0.04172	0.88820	0.03276	5.09408	0.05723	41.70555
0.165	5.09408	55.64435	0.04188	0.89378	0.03366	5.07475	0.05547	43.50136
0.166	5.07475	53.18072	0.04198	0.89708	0.03456	5.05547	0.05367	45.33785
0.167	5.05547	50.66870	0.04200	0.89773	0.03545	5.03628	0.05183	47.21309
0.168	5.03628	48.10709	0.04194	0.89531	0.03635	5.01726	0.04995	49.12452
0.169	5.01726	45.49461	0.04178	0.88932	0.03724	4.99847	0.04804	51.06879
0.17	4.99847	42.82984	0.04149	0.87917	0.03812	4.98000	0.04610	53.04155
0.171	4.98000	40.11126	0.04107	0.86417	0.03898	4.96196	0.04414	55.03720
0.172	4.96196	37.33711	0.04047	0.84351	0.03982	4.94444	0.04217	57.04857
0.173	4.94444	34.50542	0.03967	0.81626	0.04064	4.92757	0.04019	59.06646
0.174	4.92757	31.61391	0.03860	0.78136	0.04142	4.91151	0.03821	61.07912
0.175	4.91151	28.65981	0.03722	0.73762	0.04216	4.89643	0.03626	63.07150
0.176	4.89643	25.63977	0.03546	0.68380	0.04284	4.88251	0.03434	65.02431
0.177	4.88251	22.54951	0.03322	0.61874	0.04346	4.86996	0.03248	66.91291
0.178	4.86996	19.38334	0.03040	0.54163	0.04400	4.85902	0.03072	68.70587
0.179	4.85902	16.13338	0.02687	0.45249	0.04446	4.84991	0.02910	70.36345
0.18	4.84991	12.78788	0.02253	0.35300	0.04481	4.84282	0.02765	71.83609
0.181	4.84282	9.32778	0.01725	0.24765	0.04506	4.83785	0.02645	73.06325
0.182	4.83785	5.71750	0.01097	0.14502	0.04520	4.83495	0.02555	73.97247
0.183	4.83495	1.87084	0.00367	0.05865	0.04526	4.83378	0.02506	74.47553
[redacted]								
0.185	4.83365	-6.74273	-0.01282	0.01340	0.04528	4.83338	0.02577	73.75557

0.12161	0.62208	0.19549	0.12161	0.00062	0.03288	1.88361
0.12516	0.63401	0.19740	0.12516	0.00063	0.03351	1.91994
0.12876	0.64621	0.19925	0.12876	0.00065	0.03416	1.95697
0.13241	0.65870	0.20102	0.13241	0.00066	0.03481	1.99471
0.13611	0.67151	0.20270	0.13611	0.00067	0.03549	2.03318
0.13986	0.68465	0.20428	0.13986	0.00068	0.03617	2.07241
0.14364	0.69816	0.20575	0.14364	0.00070	0.03687	2.11241
0.14747	0.71207	0.20710	0.14747	0.00071	0.03758	2.15321
0.15132	0.72641	0.20831	0.15132	0.00073	0.03831	2.19483
0.15520	0.74123	0.20938	0.15520	0.00074	0.03905	2.23730
0.15909	0.75659	0.21027	0.15909	0.00076	0.03980	2.28065
0.16300	0.77256	0.21098	0.16300	0.00077	0.04058	2.32491
0.16691	0.78923	0.21148	0.16691	0.00079	0.04137	2.37013
0.17081	0.80670	0.21174	0.17081	0.00081	0.04217	2.41635
0.17469	0.82511	0.21172	0.17469	0.00083	0.04300	2.46363
0.17855	0.84462	0.21140	0.17855	0.00084	0.04384	2.51202
0.18237	0.86547	0.21072	0.18237	0.00087	0.04471	2.56161
0.18613	0.88795	0.20962	0.18613	0.00089	0.04560	2.61248
0.18982	0.91243	0.20804	0.18982	0.00091	0.04651	2.66476
0.19342	0.93944	0.20589	0.19342	0.00094	0.04745	2.71859
0.19691	0.96969	0.20307	0.19691	0.00097	0.04842	2.77415
0.20026	1.00417	0.19943	0.20026	0.00100	0.04942	2.83168
0.20345	1.04430	0.19482	0.20345	0.00104	0.05047	2.89152
0.20643	1.09217	0.18901	0.20643	0.00109	0.05156	2.95409
0.20918	1.15096	0.18175	0.20918	0.00115	0.05271	3.02004
0.21166	1.22569	0.17269	0.21166	0.00123	0.05394	3.09027
0.21382	1.32466	0.16141	0.21382	0.00132	0.05526	3.16616
0.21561	1.46254	0.14742	0.21561	0.00146	0.05672	3.24996
0.21700	1.66743	0.13014	0.21700	0.00167	0.05839	3.34550
0.21798	2.00028	0.10897	0.21798	0.00200	0.06039	3.46011
0.21855	2.62101	0.08338	0.21855	0.00262	0.06301	3.61028
0.21878	4.12565	0.05303	0.21878	0.00413	0.06714	3.84666
[redacted]						
0.21886	-8.63518	-0.02535	0.21886	-0.00864	0.07085	4.05940