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## Warming-up For Martial Arts Practice: Scientific Foundations

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# WARMING-UP FOR MARTIAL ARTS PRACTICE: SCIENTIFIC FOUNDATIONS

by Brett L. Netherton, M.S. and Larry Durstine, Ph.D.

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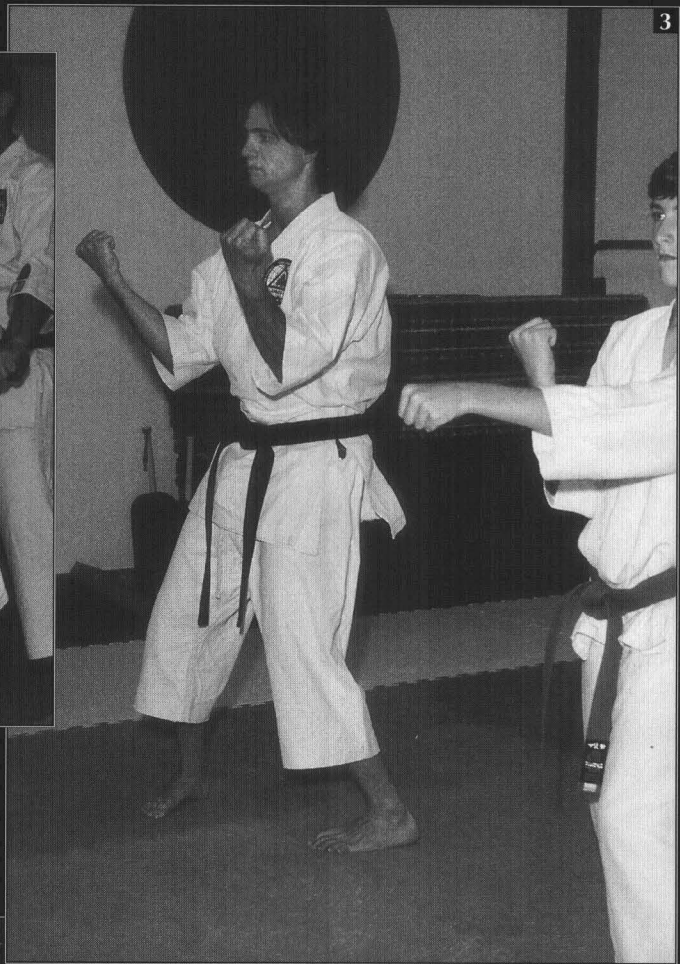
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*Illustrations by David C. Robinson.*



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# MARTIAL ARTS TRAINING: SCIENTIFIC FOUNDATIONS FOR WARM-UP EXERCISES

BRETT L. NETHERTON, M.S., AND J. LARRY DURSTINE, PH.D.



The origins and development of martial arts can be traced to diligent, patient individuals who used observation along with trial and error to understand how to make the human body execute movements at the highest and best level. The libraries of modern science were not available to these individuals. Yet, today, modern science, in many ways, validates the methods and techniques used in the martial arts. In other words, the fundamental techniques tend to represent, biomechanically speaking, the best way to accomplish the indicated task.

As martial arts practitioners today, we should recognize the diligence that the masters applied to understanding the complexities of the body. Our training can be enhanced if we apply this same diligence not only to studying our art as handed down to us but also to understanding what modern science tells us about our bodies. This article is directed toward the general martial arts population, the majority of whom perform warm-up routines prior to exercise. Many books and ideas are readily available regarding various methods used to warm-up, some well researched, some not. Presently, however, most available literature that explains the physiology of warm-up is limited to sports-medicine journals and other scientific publications.

This article addresses the current sports-medicine views of the physiology of warm-up. Primary sports-medicine research as well as published literature of the American College of Sports Medicine (ACSM) provides the scientific foundation for the information presented herein.

PAGE 86:  
INCLUDED AMONG  
TRAINING-SPECIFIC EXERCISES  
RECOMMENDED FOR WARM-UP  
ARE BLOCKING OR WALKING  
DRILLS (PHOTOS 1 AND 2),  
IN WHICH A PARTNER GENTLY  
APPLIES CONSTANT RESISTANCE  
TO A MOVEMENT WHILE THE  
MOVEMENT IS PERFORMED.  
TENSION/RELAXATION KATAS  
(PHOTO 3) OFFER EXCELLENT  
WARM-UP BENEFITS.  
ISOMETRIC AND SLOW,  
DELIBERATE CONCENTRIC  
AND ECCENTRIC CONTRAC-  
TIONS WARM MUSCLES, WHILE  
ONE MOVES THE MUSCULAR-  
SKELETAL SYSTEM GENTLY  
THROUGH THE NATURAL  
RANGE OF MOTION.

As the body makes a transition from a state of rest to light physical activity, a host of responses occur. Each response contributes to preparing the body for more vigorous activity. This review will examine changes in blood flow and body temperature and the impact of these changes on muscle tissue as an individual goes through the warm-up process.

## BLOOD FLOW REDISTRIBUTION

The cardiovascular system consists of the heart, the blood vessels, and the blood in the system. Blood serves to transport oxygen, carbon dioxide, nutrients, wastes, and hormones, and aids in the regulation of body temperature, pH, and the water content of all body cells. The blood vessels are a unique canal system that moves blood to the various parts of the body. The heart serves as the pump for this system. Several mechanisms exist that enable the cardiovascular system to shift or direct blood flow to tissue that is working and in need of more oxygen carried by the blood. After the onset of exercise, the following responses occur that shift blood flow toward the working muscle tissue and the skin and away from the abdominal internal organs: mainly the spleen, kidney, liver and digestive tract.

❖ Within the active muscle, metabolites (by-products of muscular work) are released and are detected by chemical sensors called “chemoreceptors,” triggering dilation of the arteries that feed blood to the working area. This process provides more blood locally to the working tissue.

❖ Local regulating chemicals are released within the exercising muscle causing further arterial dilation and further increases in blood to the working tissue.

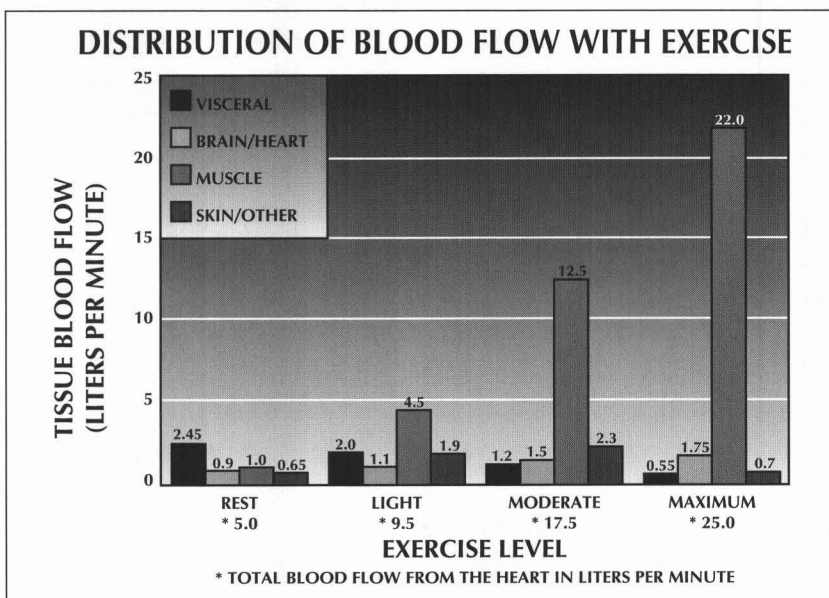
❖ The endocrine system releases hormones within the gut and non-exercising muscle that cause constriction of arteries, reducing the amount of blood to these areas.

❖ Blood pressure sensors called “baroreceptors” respond to changes in overall blood pressure in many ways, one of which is important for warm-up. When the pressure of the blood returning to the heart via the veins increases

with physical activity, baroreceptors in the right top chamber of the heart stimulate the cardiac regulatory center in the base of the brain, increasing heart rate and strength of heart contraction. This mechanism, called “the Bainbridge Reflex,” results in an increase in the amount of blood pumped by the heart each minute in order to meet the oxygen demands of physical activity.

Figure One, adapted from the resource manual of the ACSM, highlights the trend in blood flow redistribution from rest to light to moderate to maximal exercise. Two important trends are evident from this graph.

▼ FIGURE ONE.

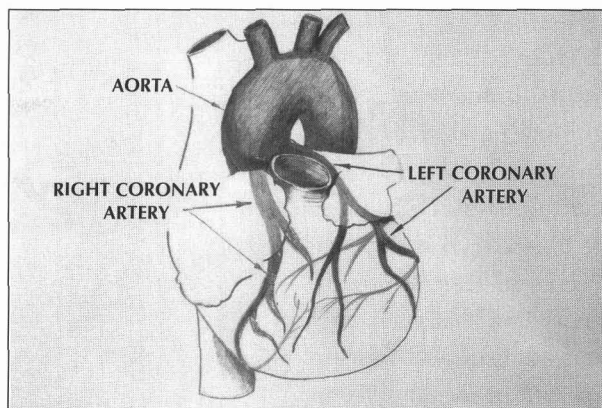




First, cardiac output (the amount of blood pumped by the heart each minute), increases in a nearly linear fashion with increasing exercise intensity. This increase in cardiac output is significant, and the heart can pump as much as five times more blood during maximal exercise than at rest. Second, with the onset of exercise and further increases in exercise intensity, the blood flow to the gut decreases and is redirected toward the active muscle tissue. Researchers have found blood flow to the active muscle tissue to increase by as much as twenty-five times above the resting level.

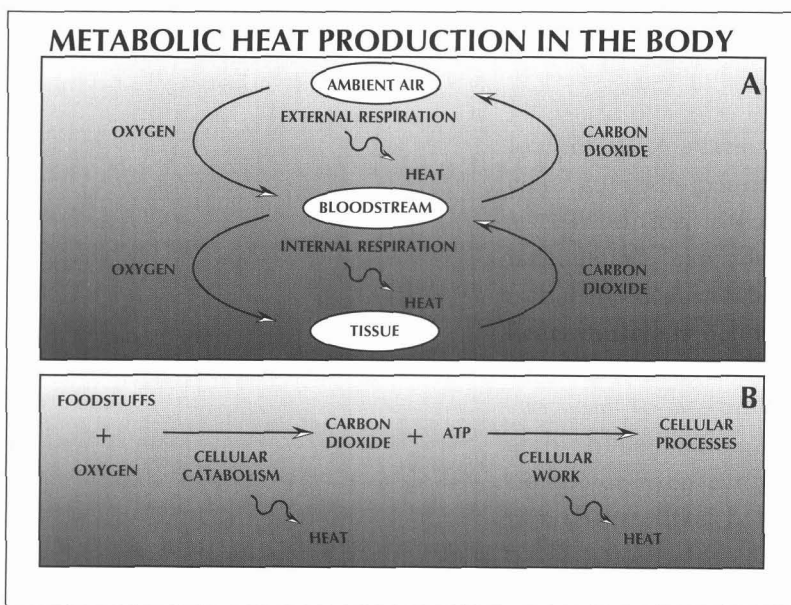
The use of a light-intensity warm-up regimen prior to moderate or heavy exercise allows the cardiovascular system to gradually redistribute the blood flow more gently than if moderate to heavy exercise were initiated from rest. Initiating heavy exercise from rest can have negative effects on the heart itself.

Illustration One highlights the arteries that provide blood to the muscle of the heart. When exercise is initiated, the oxygen consumption of the heart muscle increases because it also is working harder to pump more blood. Present research indicates that, during exercise, the amount of oxygen consumed by the heart can be as much as three to four times the amount consumed at rest. Safran and other researchers at Duke University note that without a low-intensity warm-up period of sufficient duration prior to vigorous exercise, a condition called “myocardial ischaemia” can develop. Myocardial ischaemia occurs when blood flow to the heart muscle is below the level needed to supply adequate amounts of oxygen. This can lead to angina (heart pain), heart arrhythmias (irregular heart contractions), or even acute myocardial infarction (heart attack).



▲ ILLUSTRATION ONE.

▼ FIGURE TWO.



## BODY TEMPERATURE SHIFTS

Metabolism refers to all of the chemical reactions of the body. The body constantly generates heat resulting from the chemical reactions that are constantly taking place. Figure Two is a brief graphic explanation of the body's metabolism and heat production. Block A highlights the processes involved in getting oxygen to the metabolically active tissue and removing the metabolic by-product carbon dioxide from the tissue. Block B highlights the metabolic activities that occur at the tissue level once oxygen is available to the tissue. A key result of both the transport and utilization of oxygen is the release of heat.

❖ **EXTERNAL RESPIRATION** is the exchange of oxygen and carbon dioxide between the respiratory membrane lining of the lungs and the pulmonary blood capillaries of the bloodstream.

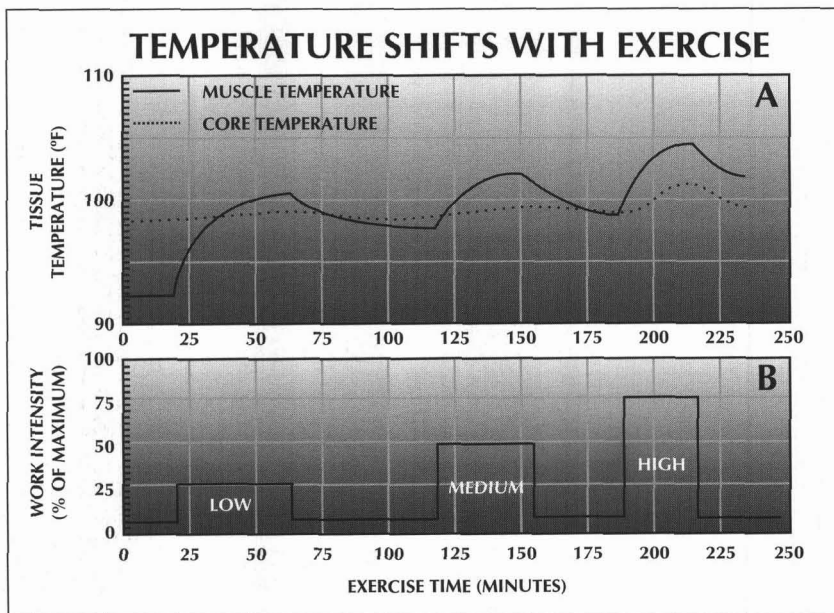
❖ **INTERNAL RESPIRATION** is the exchange of oxygen and carbon dioxide between the metabolically active tissue and the blood in the capillaries of the cardiovascular system.

❖ **CELLULAR CATABOLISM** is the breakdown of complex compounds from foodstuffs, usually involving oxygen, to form the basic source of immediate cellular energy. Usually the energy storage molecule is adenosine triphosphate (ATP). This step is equivalent to filling the gas tank of the cell in preparation for work.

❖ **CELLULAR WORK** is the breakdown of the immediate energy molecule (ATP), resulting in the release of energy for some cellular process. This step is equivalent to running the cellular motor. For a muscle cell, this would be the muscle contraction.

Notice that heat is released at each of these steps (as mentioned earlier, this description is only a brief overview of a very complex process). The point to remember is that heat is a normal by-product of both the process of breaking down food for energy and the process of using that energy for cellular work. Increases in metabolism with exercise will cause increases in heat production within the working tissue. Saltin and other researchers at Yale University have shown that muscle tissue temperature is primarily a function of the intensity of the work being performed. Figure Three summarizes the response of body temperatures to varying intensities of exercise as determined by the Yale studies.

▼ **FIGURE THREE.**



Each of the subjects in the Yale study rode a stationary bicycle at varying work rates. Part B of the graph indicates the changes in work rate experienced by the subjects. The intensity is shown as a percent of maximum functional capacity. This maximum functional capacity refers to an actual measurement called "the rate of maximal oxygen consumption," which is a rather complex measurement for the present discussion. Suffice it to say that one's maximum functional capacity would occur near the exercise work rate that could only be performed for several minutes before exhaustion would occur. The subjects in the Yale study worked at

three work rates: low or 25% of maximum, medium or 50% of maximum, and high or 75% of maximum work rate. Part A of the graph shows two temperatures, muscle temperature and core temperature. The muscle temperature was monitored in the quadriceps (thigh) and calf muscles while the subjects exercised. The core temperature shown in the graph is an average of rectal and esophageal measurements, both being good indicators of the body's core temperature. The exercise was performed at two different environmental temperatures (68°F and 86°F) with the average indicated here. Keep in mind that the

body's change in core temperature may be different, to some extent, for various exercises and environmental temperatures. This study illustrates several important points:

❖ The core temperature remains rather stable with increases in exercise intensity until high intensities are reached. The range of change is between 98°F and 102°F. This is because the thermoregulatory system of the body is very effective at transporting heat from the body's core to the skin via the blood. Muscle tissue, on the other hand, tends to have a more dramatic response.

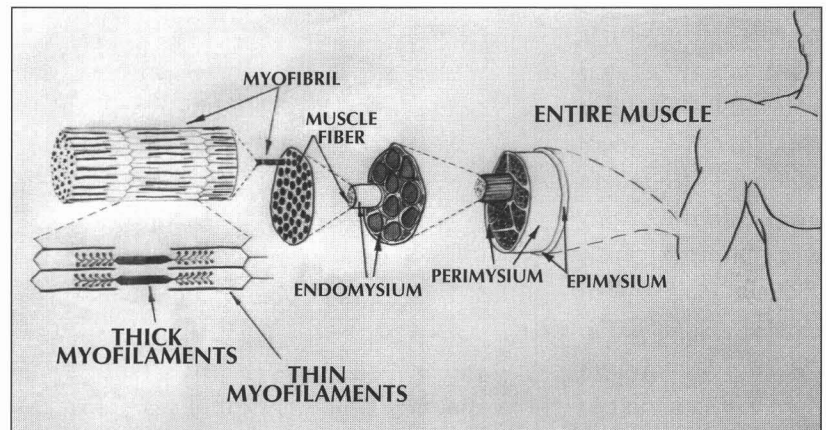
❖ Muscle tissue is able to track changes in exercise intensity both more quickly and with a greater range of response than the body's core. In this experiment, the muscle tissue temperature went from approximately 92°F to over 104°F. The muscle temperature varied almost twelve degrees while the body's core temperature varied only four degrees.

❖ For muscle, the most dramatic period of thermal adjustment is the first ten minutes of the exercise with the first five minutes having the highest rate of temperature increase.

❖ For muscle, when exercise intensities between 25 and 75 percent of maximum are considered, it appears that the muscle temperature increases at approximately the same rate for the first five to ten minutes regardless of the intensity of the exercise.

With these points in mind, we can draw some tentative conclusions about warm-up. First, muscle temperature is highly responsive to exercise, regardless of the intensity and shows significant increases in temperature within the first five to ten minutes of exercise. Second, to raise the temperature of the muscle (over 102°F) requires some time unless the exercise is very vigorous from the start. However, remember that high-intensity exercise without a low-intensity warm-up period can be very stressful on the cardiovascular system as well as the muscle tissue and tendons. Therefore, low-intensity exercise during the first ten minutes of activity is not only safer for the cardiovascular system, but also yields near optimal muscle-temperature increases as well. Since roughly half of all sports-related injuries involve muscle and muscle tendons, we need to take a closer look at muscle and its associated tissue.

▼ ILLUSTRATION TWO.



## MUSCLE TISSUE

Before the effects of warm-up on muscle tissue are discussed, it is important to briefly review the physiology of muscle tissue and the connective tissue associated with it. Illustration Two shows the muscle-tendon structure of a typical muscle, the bicep muscle. The muscle shown here, for the purpose of this discussion, is representative of the approximately 700 muscles that are attached to bones and move parts of the skeleton.



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The muscle-tendon structure is composed of muscle and an intricate network of connective tissue that serves to attach the muscle tissue to the bone. The entire muscle-tendon structure can be broken down into two networks: a parallel elastic component and a series elastic component. These two components, along with two very important characteristics of the muscle-tendon structure, viscoelasticity and reflex reaction, are briefly discussed next.

➤ PARALLEL ELASTIC COMPONENT

The parallel elastic component includes all of the connective tissue that surrounds or encompasses the muscle fibers and serves to hold the muscle in its particular shape. The muscle fibers are responsible for producing tension so that the entire muscle can shorten to move the skeleton, yet without the parallel connective fascia tissue the muscle would have no form when relaxed (like a soft rope, the muscle would have no shape).

The parallel elastic component includes three main layers of tissue. The *epimysium* is a connective tissue layer that encloses the entire muscle. The *perimysium* is a layer of fibrous connective tissue that encloses each muscle fiber bundle called "fascicles." The *endomysium* is a layer of fibrous connective tissue that encloses each individual muscle fiber.

➤ SERIES ELASTIC COMPONENT

The series elastic component consists of the portion of the muscle that can produce tension and the parts that transmit the force generated by the contraction to the skeleton. At the heart of the series elastic component is the muscle fiber. The muscle fiber is capable of producing tension by shortening itself through the interactions of thick and thin myofilaments. As shown in illustration two (p. 91), the thick myofilament has projections that tend to hinge or ratchet to pull against the thin myofilaments and shorten the muscle fiber. The muscle fiber is connected to the tendon by collagenous connective tissue, and the tendon is, in turn, connected to bone. The series elastic component then is made up of the muscle fibers, the tendon, and the connective tissue between the muscle fiber and the tendon.

➤ VISCOELASTICITY

Viscoelastic materials have both viscous and elastic properties. *Viscosity* is an internal friction characteristic of a fluid. Motor oil is an excellent example. When oil is cold, it flows slowly due to its high internal friction. When the oil is warmed, the internal friction is lowered, meaning lower viscosity, and the oil flows more rapidly. While muscle tissue is not liquid, a major component is water, and thus, muscle does show some fluid properties. Imagine the muscle-tendon structure in illustration two (p. 91) being stretched from both ends. The connective tissue layers would, to some extent, be forced to slide over each other with some amount of friction, giving the tissue some amount of viscosity. A material with elastic properties will stretch when pulled on and return to its original position when relaxed. A perfectly elastic material will stretch twice as far when the pulling tension is doubled. While muscle tissue is not perfectly elastic, the series elastic connective tissue layers, the muscle fibers, and the tendon, show some elastic properties over portions of the mus-

cle-tendon structure's range of motion. Due to viscoelasticity, the muscle-tendon structure shows the following properties:

**Stress relaxation** – If the muscle-tendon structure is stretched with a given tension and held, the amount of tension required to maintain the same length gradually decreases.

**Creep** – If the muscle-tendon structure is stretched with a given tension and the tension is held constant, the length of stretch gradually increases.

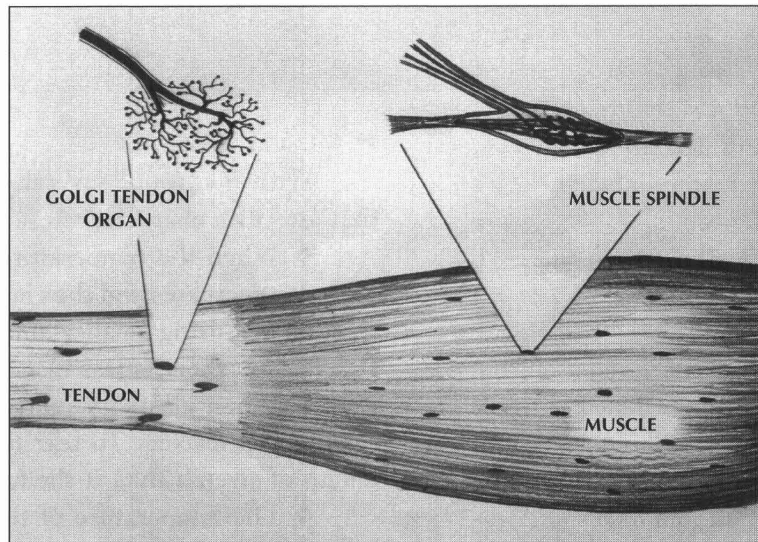
**Strain rate dependence** – If a muscle-tendon structure is stretched from rest to a given length at two different rates, a higher tension will be required to pull it at the faster rate than the slower rate. This is because the slower rate allows more time for relaxation to occur within the muscle-tendon structure while it is being stretched.

### ► REFLEX REACTION

Two reflex reactions that influence the movements of the muscle-tendon structure are the Golgi tendon organ reflex and the muscle spindle stretch reflex. Illustration Three shows both the Golgi tendon organ and the muscle spindle.

The Golgi tendon organ protects the muscle-tendon structure from excessive tension. Located within the tendon near the junction of the tendon and muscle, the tendon organ is the tool that the central nervous system uses to monitor tension in the muscle-tendon structure. When tension becomes excessive, the tendon organ inhibits the muscles that are producing tension on the tendon in order to decrease the tension on the muscle-tendon structure.

Multiple muscle spindles are distributed throughout the muscle tissue and send to the central nervous system information on the rate and amount of muscle stretch. When the muscle spindle senses excessive rate of stretch, it will, by a complex nerve reflex response, cause the muscle being stretched to contract as well as inhibit the body from further stretching this muscle. For example, when a front kick is performed, the quadricep muscles contract to extend the lower leg and foot, thus stretching the hamstring muscles on the back of the leg. When the rate of stretch reaches a dangerous level as detected by the muscle spindles in the hamstring muscles, the spindles activate the hamstring muscles to contract and inhibit the quadricep muscles, effectively slowing down the movement. Both the tendon organ reflex and the spindle stretch reflex are very rapid, with reflex inhibition and excitation occurring within 30-msec of the initial detection of excessive stretch or tension. Both reflexes are also involuntary, meaning that conscious thought is not required to perform them. However, by the use of conscious effort from higher centers of the central nervous system, it is possible to voluntarily override the tendon organ reflex and spindle stretch reflex. As an example, consider the sport of wrist wrestling. The muscles involved have the capability to break tendons or even bones if unchecked, but are controlled by protective mechanisms. Yet,



▲ ILLUSTRATION THREE.