4 Muscular Work and Nervous Control of Movements

4.1 LEARNING GOALS

This chapter will provide an explanation of the functionality, relationship, and elements of the integrated roles of the muscular system and nervous system. The execution and control of movements as a function of these systems will also be provided to gain an in-depth understanding of these processes.

4.2 KEY TOPICS

- Muscular work
- Muscular contractile system
- Mechanism of contraction
- Method to stimulate and control the mechanism of contraction
- Energy to drive mechanism of contraction
- Innervation of the muscular system
- Reflexes
- Energy transformation process for muscle activity
- Types of muscular work
- Muscular fatigue
- Types of muscle contraction
- Measurement of muscular strength

4.3 INTRODUCTION AND BACKGROUND

The relationship between the musculoskeletal system and the nervous system is highly integrated in describing muscular work and movement. In light work or intense efforts, the communication and responses between the muscles and nerves enable the human system to perform tasks ranging from simple to extremely complex, requiring the coordinated action of both the nervous and muscle tissues. This was first shown by Galen Pergamum (129–199), a physician in ancient Greece, in experiments he conducted on animals. He demonstrated the importance of the central nervous system by cutting the spinal cord in varying positions, which resulted in the corresponding level of paralysis in the animal. Galen was also the first to identify muscles and show that muscles operate in combination as groups. This was further expanded on by von Haller (1708–1777), a Swiss physiologist who found that all nerves within the body eventually lead to the brain or spinal cord (Williams, 2009). This observation led him to conclude that the brain and spinal cord act as sensory perception and response action centers. He also demonstrated that muscles could be activated, that is, made to constrict at the introduction of a stimulus transmitted by a nerve. Later, in 1780, Luigi Galvani (1737–1798) noticed while dissecting the legs of a frog that electrical stimuli caused the legs to twitch. This finding showed that the electrical impulses are involved in nerve and muscle simulation. Based on these principles, Galvani created a crude battery that combined metals and natural juices from a frog, which led his colleague, Alessandro Volta, to design the first electric battery (which, incidentally, did not require frog juice) (Pancaldi, 2003).

Today's neuromuscular research includes the controversial use of stem cell transplantation from umbilical cord blood and bone marrow to treat paralyzing spinal cord injuries and degenerative diseases. The moral and ethical issues surrounding stem cell research are aimed mostly at the closely related issues of cloning, reproductive techniques, and—at its most extreme interpretation—eugenics, which many fear could lead to the Hitler-era race purification of apocalyptic proportions. For this reason, scientific discovery in American stem cell research is often delayed. While many opponents of stem cell research exist within the United States, countries without such sociopolitical challenges have been able to make several medical breakthroughs with the use of stem cells. This has led to greater collaboration among American and non-American stem cell research institutions (Magnus and Cho, 2005).

4.4 MUSCULAR WORK

Muscle contraction is a function of a sophisticated muscle contractile process. The ability to voluntarily exert muscular force produces strength, which in turn produces work. The contractile process, energy exchange, and other musculoskeletal system actions integrate to accomplish the goals of the muscular work.

4.4.1 Muscular Contractile System

The contractile properties of muscles allow the tissue to execute a variety of mechanical activities with the bones and joints. A very unique characteristic of a muscle is its ability to shorten or contract to about half its normal resting length. Each muscle fiber contains proteins, including actin, myosin, tropomyosin B, and troponin. However, the two proteins that play the most important role in muscular contraction are actin and myosin. There are three aspects to the muscular contractile system and these include the following (Figure 4.1):

- Mechanism of contraction (sliding filament model)
- Method to stimulate and control the mechanism of contraction
- Energy to drive the mechanism of contraction

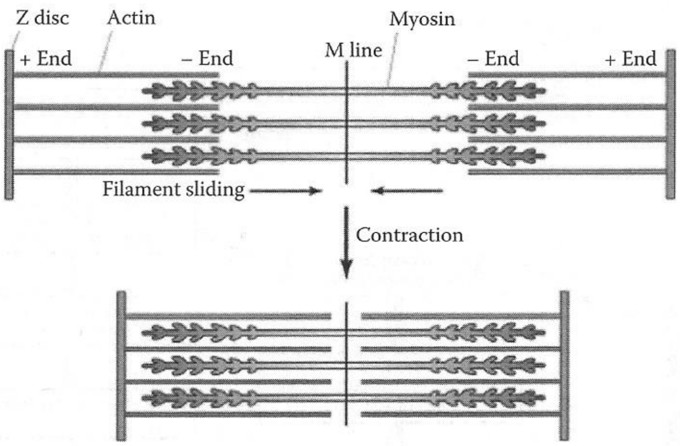

FIGURE 4.1 Sliding filament model.

4.4.1.1 Mechanism of Contraction (Sliding Filament Model)

For muscle fibers to shorten when they contract, they must generate a force that is greater than the opposing force that is acting to prevent movement of the muscle fiber insertion. The A bands within each muscle fiber are composed of thick filaments, while the I bands contain thin filaments. The movement of cross bridges that extend from the thick to the thin filaments produces the sliding of the filaments, resulting in muscle tension and shortening. The activity of the cross bridges is regulated by the availability of calcium, which is increased by electrical stimulation of the muscle fiber. Electrical stimulation produces contraction of the muscle through the binding of calcium to regulatory proteins within the thin filaments (Figure 4.2).

Before a muscular contraction takes place, the myosin and actin filaments are at an angle to each other. Each molecule of myosin in the thick filaments contains a globular subunit called the myosin head. The myosin heads have binding sites for the actin molecules in the thin filaments and adenosine triphosphate (ATP). The following steps describe the muscle contraction process:

- In order to initiate contraction, the myosin heads protrude from the thick filaments along its length and form a cross bridge with the actin.
- The myosin heads change configuration by rotating and pulling one filament against the next.
- The filaments "swivel" to a new angle, thus pulling the actin filaments past the thick or myosin filaments.
- The sarcomere shortens, which results in a muscular contraction.

As the muscle contracts, the Z lines come closer together, the width of the I bands and H zone decreases, and there is no change in the width of the A band. Conversely, when a muscle is stretched, the width of the I bands and H zone increases, but the width of the A band does not change (Huxley and Niedergerice, 1954).

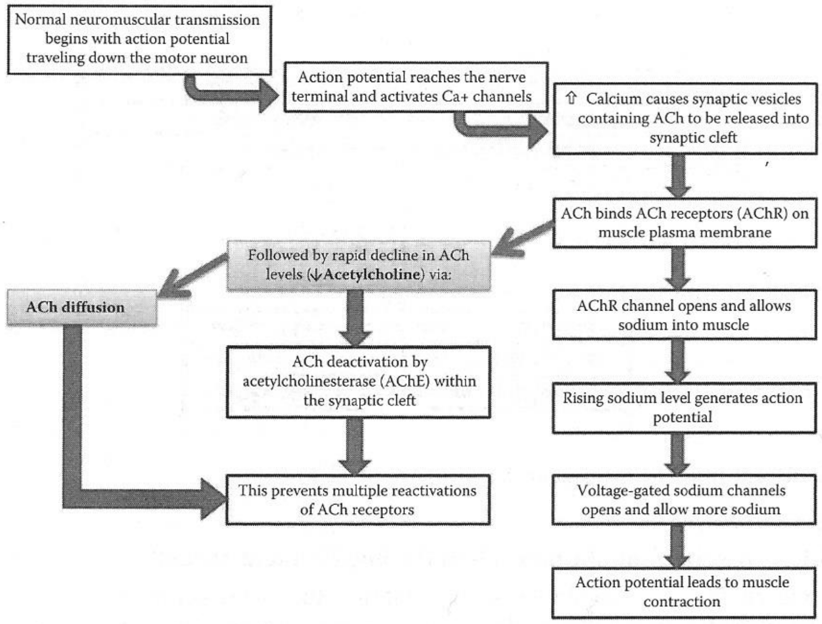

FIGURE 4.2 Model of muscle contraction.

4.4.1.2 Method to Stimulate and Control the Mechanism of Contraction

The number of actively contracting muscle fibers determines how much strength is developed during the period of contraction and regulates the speed of the muscular contraction or movement. A muscle produces its greatest active strength at the beginning of its contraction, when it is still near its relaxed length and as it shortens the ability to produce force declines. The number of nervous impulses determines the amount of muscle strength produced. During slow or maintained muscular contractions, muscle fibers are brought into active contraction in succession, allowing them to alternate. This gives the fibers some resting periods, which permits recuperation from fatigue.

A person's muscular strength depends on the cross section of his or her muscles. Each muscle fiber contracts with a specific force, thus men and women can become equally strong per cross section if both receive equal training. However, women, as a group, have narrower muscles and, therefore, on average are able to only about exert two-thirds the force of men.

4.4.1.3 Energy That Drives Contraction

Glucose and components of fat and protein are the indirect sources of energy required for the continuous replenishment of energy reserves in the form of ATP or other energy-rich phosphate compounds. Glucose is the main energy supply in intensive physical work, since it is immediately available and easily converted. Also, oxygen plays an important role in the production of energy in muscles.

As glucose passes out of the bloodstream and into the cells, it is converted into pyruvic acid. If oxygen is present, the pyruvic acid is broken down by oxidation, resulting in water and carbon dioxide. This process releases enough energy to restore large amounts of ATP. However, if there is a lack of oxygen, the breakdown of pyruvic acid will not take place. In this case, the pyruvic acid is converted into lactic acid, a form of metabolic waste product, which causes muscle fatigue. This process releases less energy for the restoration of energy-rich phosphate compounds and allows a higher muscular performance for a short time, under low oxygen conditions. An example would be when a person performs a heavy muscular task and becomes out of breath.

4.4.2 Innervation of the Muscular System

The contraction of skeletal muscle is controlled by the nervous system. As described in the previous section, the efferent and afferent nervous systems work in tandem to receive and send information between the peripheral nervous system and the central nervous system. The efferent (motor) nerves and the afferent (sensory) nerves support this communication process throughout the musculoskeletal system.

4.4.2.1 Efferent Nerves

Motor neurons leading to skeletal muscles have branching axons, each of which terminates in a neuromuscular junction with a single muscle fiber. Nerve impulses passing down a single motor neuron will trigger contraction in the muscle fibers, at which the branches of that neuron terminate. This group of muscle fibers, innervated by branches of the same efferent neuron axon, is called a motor unit. The motor unit is the functional unit of the muscle and varies in size based on the number of fibers innervated and the function of the muscle. A motor unit is small in muscles where precise control is important, such as in eye muscles. Motor units are larger in coarse acting muscles, such the biceps. The motor impulse leaps across from the nerve fiber to the muscle fiber at the motor end plates. The junction between the terminal of a motor neuron and a muscle fiber is called the neuromuscular junction. The motor end plates are the axonal effector endings, which initiate muscular contraction (Figure 4.3).

4.4.2.2 Sensory Nerves

Sensory nerves transmit impulses from the muscles into the central nervous system, either to the brain or to the spinal cord. Sensory impulses contain signals, which are utilized in the central nervous system to direct muscular work and to store as information. Muscle spindles, which run parallel to muscle fibers, are receptor organs that detect dynamic and static changes in muscle length and send sensory impulses to the spinal cord whenever a muscle changes in length. The Golgi tendon organ is another sensory receptor organ embedded in the tendons that. These organs monitor the tension that develops in a muscle and carry sensory impulses to the spinal cord whenever the tendon is under tension. When a sensory receptor is stimulated, the following process occurs:

- Sensory signals pass from the receptor along a sensory neuron to the spinal cord.

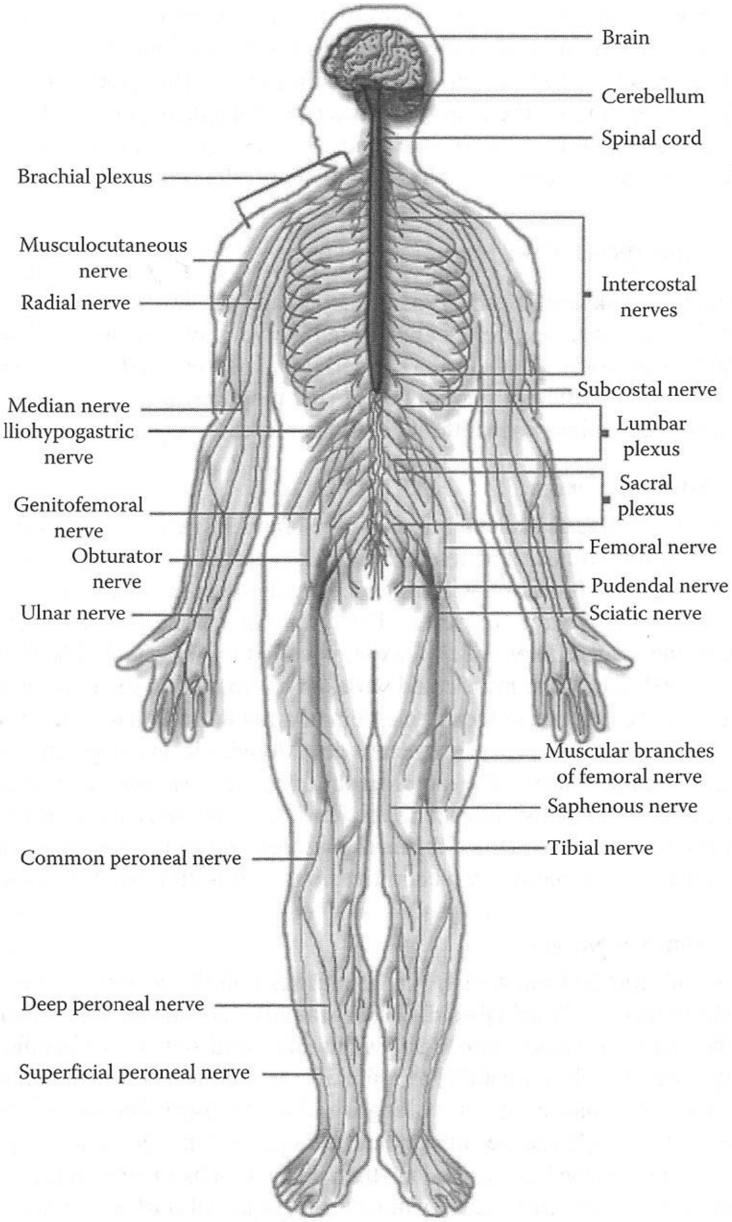

FIGURE 4.3 Efferent nerves.

- In the spinal cord, sensory impulses pass through the interneuron, which then makes contact with a motor neuron.
- Finally, the motor neuron carries efferent impulses to the muscle, which produces the response.

This pathway created from the afferent sensory nerves and efferent motor nerves in a muscle is called a reflex arc. The reflexes allow the muscle tension and muscle length to continually adapt and remain compatible; the muscle spindle and the Golgi tendon organ are the detectors in this regulatory system.

4.4.3 Reflexes

Reflexes play crucial roles in certain muscular movements and activities. Reflexes are not consciously directed and, therefore, may be considered automatic in a physiological sense. A reflex comprises three parts:

- An impulse, which travels along a sensory nerve, carrying the information to the spinal cord or to the brain
- Interneurons, which transmit the impulse across to a motor nerve
- A final impulse along the motor nerve, which activates the appropriate muscle fibers producing the resulting movement

An example of a reflex is the blinking of the eyelids, when an unexpected object moves close to either eye. It is the unexpected movement in the visual field that provides the initial stimulus. The sensory impulse then travels to a particular center in the brain, where it acts as the interneuron and transmits the message to a motor nerve, which operates the muscles of the eyelids and causes the blink. The transmission time for neurons in some cases is greater than the recorded time for actual reflexes. Thus, it is suggested that the actions associated with a reflex may, in fact, be processed in the spinal cord rather than traveling the full distance to and from the brain (Hockenbury and Hockenbury, 2008).

Reflex blinking can be thought of as an automatic protective mechanism, which protects the eyes against any imminent damage. The human body uses thousands of similar reflexes, not just for protection, but also as part of normal control functions. A more complex reflex is the antagonistic control of a muscular movement between two muscles. For example, when the lower arm is bent, the bending muscles contract by stimulating motor nerves. In order for this muscle contraction to proceed smoothly, the opposing muscles behind the arm must be simultaneously relaxed by exactly the right amount. This co-contraction is an automatic reflex, producing a movement that is executed in a well-controlled manner.

4.4.4 Energy Transformation Process for Muscle Activity

In order for a person to do work, he or she has to make use of muscles. Muscles work only when there is energy to permit muscular contraction to take place, and the contractile process requires considerable energy. This energy, in the form of high-energy phosphate compounds, such as creatine phosphate (CP) and ATP, is transformed from nutrients by oxidative and non-oxidative processes known as metabolism.

During muscular work, chemical energy is transformed into mechanical energy. During this transformation the mechanical energy acts on the protein molecules of the actin and myosin filaments. Energy-rich phosphate compounds, which change from a high-energy state to a low-energy state during the chemical reactions, are the immediate sources of energy for muscle contraction. Some of these sources of energy include acetylcholine (ACh), ATP, and adenosine diphosphate (ADP). However, ATP, which acts as a reservoir of readily available energy, is the primary source of energy in muscle contraction. The regeneration of high-energy phosphates in muscles takes place continuously so that the supply of energy available to the muscles is not diminished.

The ATP needed for muscle work can be produced from aerobic or anaerobic metabolism. The aerobic metabolism of nutrients occurs in the oxidation of glucose or glycogen molecules and fatty acids to create ATP; this process is referred to as aerobic glycolysis. This metabolic process requires a continuous supply of blood in order to receive the required oxygen and nutrients to drive the process. Likewise, the muscles can produce ATP, work, or energy without oxygen, although the level of work produced is substantially less than that produced under aerobic conditions. In anaerobic conditions, the most immediate source of energy is through the production of the ATP molecule by breaking high-energy phosphate bonds in the CP molecule. The CP molecule contributes a phosphate (P) to an ADP molecule to create an ATP molecule and the required energy.

4.4.5 Types of Muscular Work

Muscular work in occupational activities can be broadly categorized into groups: dynamic muscle work or static work. Dynamic muscular work involves coordinated groups of muscles working simultaneously to perform a movement in task execution. This type of work allows the flow of nutrients and oxygen to the muscles performing the task and allows longer duration in task performance, as compared to static muscular work. Most tasks involve some form of dynamic muscular work, even if it is only walking or occasional movement of the trunk or upper limbs. Static loads exist anytime a muscle has to perform a task without the benefit of the rhythmic movements that refresh the muscular system. This type of task activity is found in many occupations, but it is most frequently seen as a muscular activity isolated to a component of the body, such as the arms in holding a load during manual material handling. Additionally, static tasks are found in most material handling, environments, the electronics industry, and in repair and maintenance tasks (Figure 4.4).

Although dynamic work is preferable to static, even dynamic muscular contractions over extended periods of time can result in fatigue and a reduction in task performance. The amount of time an individual can sustain dynamic work is dependent upon the intensity of the work, the level of fitness of the individual, and environmental factors. A greater intensity of work can be sustained only over a short duration. Thus, if a very intense activity is required, this element of the task

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should be limited in duration, and a rest or refresh period should be designed into the process. Astrand and Rodhal (1970) found that for an individual to maintain an 8 h work shift, the task should not average more than 33% of the worker's maximum capacity for that task.

While dynamic work will lead to fatigue over an extended period of time, static work over a relatively short duration will also result in fatigue. In addition to the short-term strain that the body experiences from static loading, long-term injuries can result if static work is regularly performed. Injuries that can occur from extended or intense static work generally impact the soft tissues and spine. The conditions that can result include

- Arthritis due to mechanical stress
- Inflammation of the tendons and tendon sheaths
- Symptoms of arthrosis, a chronic degeneration of the joints
- Muscle spasms and soreness
- Intervertebral disc troubles

Static work increases the pressure inside the muscle, which together with the mechanical compression occludes blood circulation partially or totally and, as a result, muscles become fatigued more easily than in dynamic work. A muscle that is performing strong static effort is not receiving fresh blood, sugar, or oxygen and, therefore, must depend upon its reserves. A heavy static effort compresses blood vessels, caused by the internal pressure of the muscle tissue so that blood no longer flows through the muscle. Furthermore, waste products such as lactic acid are not removed during a strong static effort, and thus accumulate, producing pain, muscular fatigue, and latent muscle soreness.

As previously stated, there is a static component in most lifting, material handling, and physically intensive tasks. Making short, intermittent exertions and shifting the load between several muscle groups are strategies used to reduce rapid fatigue in statically loaded postures. Examples of task actions that involve static work include (Kroemer et al., 1994; Helander, 1995)

- Bending the back either forward or sideways
- Holding or carrying loads in the arms
- Manipulations that require the arms to be held out horizontally or at levels above the shoulders
- Resting the body weight on one leg while the other works a pedal
- Standing in one place for long periods of time
- Pushing and pulling heavy objects
- Tilting the head strongly forward or backward for extended periods
- Raising the arms above the shoulders for long periods of time
- Exertion of force to balance a load

In the initial stages of job design, it is important to find ways to reduce the static component of a task, as this can reduce the likelihood of premature muscle fatigue, and ensure that productivity is not negatively impacted.

Excessive efforts repeated over long periods of time, whether static or dynamic, can result in moderate to intense muscular aches and pains. These aches and pains may involve not only the muscles, but also the soft tissues, which can ultimately lead to cumulative injuries in the ligaments, joints, and tendons. These injuries are referred to as musculoskeletal disorders and are cumulative in development. They will be discussed in Chapter 7.

Symptoms of muscle overstress can be categorized into two groups:

- Reversible musculoskeletal problems
  - Pains of weariness, mostly localized to strained muscles and tendons
  - Short-lived
  - Pains disappear as soon as the load is relieved
- Persistent musculoskeletal problems
  - Localized to strained muscles and tendons
  - Affects the joints and adjacent soft tissues
  - Pains do not disappear when workload is relieved

Musculoskeletal pain and discomfort that is continually present over a number of years can lead to chronic inflammations of tendons and tendon sheaths, and deformation of joints. These types of conditions can lead to permanent disabilities and debilitating pain.

Epidemiological data indicates that maintaining static repetitive loads lead to a higher risk of the following:

- Inflammation of the tendons and possibly tendon sheaths (tendinitis or tenosynovitis)
- Inflammation of the attachment points of tendons
- Symptoms of arthrosis (chronic degeneration of the joints)

- Painful muscle spasms
- Sprains and strains
- Arthritis of the joints due to mechanical stress
- Intervertebral disc troubles

Although most of these conditions may be temporary, the continual exposure to risk factors can lead to permanent damage. The key is to recognize that occasional static muscular exertion in task performance is acceptable; however, the objective in task design should be to minimize the frequency and duration of these types of muscular contractions.

4.4.6 Types of Muscle Fibers in Muscular Contraction

Different muscles contain different types of muscle fibers. Some fibers contract rapidly, are glycolytic, and fatigue rapidly; these are known as fast twitch fibers. Other fibers are slowly contracting, oxidative, and slowly fatiguing and these are known as slow twitch fibers. Then there are fibers that are essentially a combination of these two types of fibers as they can contract rapidly and are both oxidative and glycolytic. Although a motor unit consists of only one kind of muscle fiber, most muscles are mixtures of fast and slow twitch fibers.

The slow twitch fibers are red in color due to an abundance of capillaries to provide oxygenated blood for the long-duration activities these muscles perform. Fast twitch muscle fibers have considerably fewer capillaries and thus tend to be white in color.

These two types of muscle fibers receive different types of innervation. Fibers in red muscles are innervated by motor neurons of small diameter, thus have a lower conduction velocity that discharge nearly continuously at low frequency. Fibers in white muscles receive innervation from larger motor neurons that have longer periods of silence between discharges, but discharge at high frequencies.

The properties of both slow and fast twitch muscle fibers are summarized in Table 4.1. The properties of slow muscle fibers make them most suited for extended periods of contraction where a minimum force is required, for example, in the maintenance of posture. Fast twitch muscle fibers are better suited to short periods of rapid contraction at higher forces, for example, in sprint running. Strength training leads to hypertrophy of mainly white muscles and while the number of fibers does not increase, the size of the fibers and the number of myofibrils do increase. This increases both the strength and velocity of contraction.

4.4.7 Muscular Fatigue

During prolonged, repetitive, or intense contraction, muscle fatigue can occur. Studies on athletes during prolonged submaximal exercise have shown that muscle fatigue increases in almost direct proportion to the rate of muscle glycogen depletion. This can happen in static or dynamic muscular movement; however, the onset of fatigue is much faster in static contractions. The rapid fatigue during static contraction is due to the lack of nutrients refreshing the muscles and an accumulation of waste byproducts, such as

TABLE 4.1
Properties of Fast and Slow Twitch Muscle Fibers

Property	Fast Twitch Muscle Fibers (Type II)	Slow twitch Muscle Fibers (Type I)
Example		Soleus (calf) muscle
Twitch contraction time	Fast	Slow
General color	White	Red
Capillary blood flow	Low	High
Myoglobin content	Low	High
Primary source of ATP	Glycolysis	Oxidative phosphorylation
Glycogen	High	Low
Tension/force produced	Larger	Smaller
Myosin-ATP activity	High	Low
Resistance to fatigue	Low	High
Nerve fiber size	Large	Small
Nerve fiber activity	Intermittent, high frequency	Continuous, low frequency
Oxidative capacity	Low	High

lactic acid. Also, during vigorous dynamic exercise, the circulatory system cannot supply oxygen to muscle fibers quickly enough. In the absence of oxygen, the muscle cells begin to produce lactic acid, which accumulates in the muscle. The lactic acid buildup lowers pH, and as a result, muscle fibers no longer respond to stimulation.

To reduce the likelihood and occurrence of muscular fatigue in occupations, the task should be designed such that submaximal strength requirements are expected, and dynamic muscular activities are the primary task activity. Additionally, work-rest cycles should be integrated into the process by adding breaks to the task, job sharing (two or more operators performing a task), or task variation (allow the operator to do multiple tasks during a complete cycle of task performance).

It is important to effectively address muscular fatigue and recognize the impact of fatigue on task performance, especially when it is premature or occurs frequently. Studies have shown that muscular fatigue can be an indicator of poor task design and lead to occupational injuries; thus, addressing this seemingly benign risk factor can be effective in promoting a more efficient and safe work environment.

4.4.8 Types of Muscle Contractions

The types of muscle contractions include five categories of contractile functionality. The types of muscle contractions include isometric, isoinertial, eccentric, isotonic, and isokinetic.

4.4.8.1 Isometric Contractions (Static Muscular Contraction)

An isometric contraction is one in which the muscle is activated, but instead of being allowed to lengthen or shorten, it is held at a constant length. An example of an isometric contraction would be carrying an object in front of the body. The weight of the object would be pulling downward, but the hands and arms would be opposing the motion with equal force going upward. Since the arms are neither raising nor lowering, the biceps will be performing an isometric contraction.

4.4.8.2 Isoinertial Contractions (Constant Load)

In isoinertial contractions a constant load is applied to the muscles. In this type of muscular contraction, the muscles are responding to a constant load where the measurement system considers acceleration and velocity.

4.4.8.3 Eccentric Contractions (Lengthening of the Muscle)

Eccentric contraction causes a muscle to lengthen under tension. Such contractions are used to resist external forces such as gravity. The quadriceps muscles, for instance, undergo eccentric contractions when a person walks down steps, runs downhill, or lowers a weight. Eccentric contractions also occur during the deceleration phases of running. The downward phase of a biceps curl, for example, requires eccentric action of the biceps muscle.

4.4.8.4 Isotonic Contractions (Concentric Shortening)

In isotonic contractions, the muscle contracts and shortens, giving movement. Isotonic contractions involve the muscle in a situation where an equal amount of tension is being developed in the muscle throughout the exercise. The muscle develops equal tension while the muscle length changes. Some examples are pull-ups, push-ups, and lifting weights.

4.4.8.5 Isokinetic Contractions (Constant Force)

In isokinetic contractions, the muscles exert a constant force. An isokinetic muscle contraction is one in which the muscle contracts and shortens at a constant rate of speed. This type of muscle contraction usually requires special, training equipment that increases the load as it senses that the muscle contraction is speeding up.

4.4.9 Measurement of Muscular Strength

The measurement of muscular strength is a reliable approach to assess human capability and limitations related to task performance, product design, or recreational activities. A number of factors should be considered when designing an approach to measure muscular strength, including the objective of strength testing (i.e., task evaluation, product design, or risk assessment), muscular requirements, costs, and types of task activities. In ergonomics, the most common strength-testing methodologies are three broad categories that include isometric, dynamic (isoinertial and isokinetic), and psychophysical testing (Gallagher et al., 1998; Kroemer, 2006b.)

4.4.9.1 Isometric Strength Testing

Isometric strength is defined as the capacity to produce force or torque with a voluntary muscular contraction while maintaining constant muscular length (Gallagher, 1998). Isometric strength-testing equipment has not been standardized, and a variety of products are available to assess static strength, given the muscles being evaluated. This is perhaps the most studied and measured strength-testing approach, as it is comparatively easy to conduct, measure, and understand. The ease of use and reduced likelihood for injury are advantages associated with isometric testing. However, a primary criticism of this method is that these static strength tests are not compatible with most task performance, given the dynamic nature of most jobs particularly those involving material handling. Nonetheless, this is a widely accepted approach for strength assessment in applied and research ergonomics, due to the historic success in applying results of static tests to task evaluation, injury prediction, and design.

4.4.9.2 Dynamic Strength Testing

Dynamic strength tests include any type of assessment that allows the movement of the muscle during the testing process. Isoinertial strength assessment is done when mass properties of an object remain constant during the dynamic muscular exertion, such as a task where a weight is lifted over a predetermined distance. Isokinetic strength testing maintains a constant load throughout a predetermined range of motion.

4.4.9.3 Psychophysical Testing

The psychophysical assessment for determining maximum dynamic lifting capacities has been used in physiological research for many years. The term "psychophysical" refers to a methodology in which subjects perform lifts to determine maximum, safe levels of exertion based on their personal perspective of acceptable risk. In practice, this method is dependent upon cooperation from the subject, expertise from the evaluator, and good judgment on the part of both the subject and evaluator to ensure the safety of the test and the accuracy of the physical performance data.

4.4.9.4 Procedure for Strength Testing

Regardless of whether or not the test is dynamic or static, the basic factors to consider when designing a process for strength testing are as follows (Gallagher et al., 1998):

- Equipment available to make the measurements
- Instructions to give to subjects being tested
- Duration of measurement period
- Duration of rest period
- Body posture (torso, arms, legs) during test
- Number of trials
- Physical condition of subject
- Type of postural control during test
- Environmental conditions during test
- Subject motivation

The initial protocol for isometric strength testing was developed by Caldwell et al. (1974) and adapted in succeeding years as research revealed needed adjustments to the approach. Although this test approach was designed for static testing, it can be adapted for dynamic testing as well. The procedure from the Caldwell protocol is described as follows (Plog and Quinlan, 2002) for the measurement of static strength:

- Determine type of static muscular exertion to be measured.
  - Ensure relevance of measured to intended research or application.
- Measure static strength as follows:
  - Assess static strength during a steady exertion for 4 s.
  - Disregard transient periods of 1 s before and 1 s after exertion.
  - The strength datum is the mean score recorded during the first 3 s of the steady exertion.
- Treat subjects as follows:
  - Inform subject about the purpose of the test, equipment, and procedures.
  - Provide detailed and factual instructions without emotion or coaching.
  - Instruct subject to "increase maximal exertion (without jerk) in one second and then maintain this effort during a four second period."
  - A different time and procedure may be utilized for special conditions, such as obtaining finger strength.
  - Provide feedback to subject during the test in a qualitative, noncomparative, positive manner. Do not give instantaneous feedback during the exertion period.
  - Avoid incentives that can affect subject's motivation such as rewards, goal setting, competition, spectators, fear, and environmental factors (i.e., noise, heat).
- Provide a minimal rest period of 2 min between related efforts and exertions, more if symptoms of fatigue are apparent.
- Describe the conditions that will exist during strength testing as follows:
  - Body parts and muscles primarily used.
  - Body posture and movement.
  - Body support or reaction force available.
  - Coupling of the subject to measuring device.
  - Strength measurement and recording device.
- Describe the following subjects:
  - Population and sample selection including sample size.
  - General health (survey or medical examination recommended).
  - Gender.
  - Relevant anthropometrics.
  - Training related to strength testing.
  - Occupation.
- Report results of experiment.

The analysis of data on strength testing should include calculation of summary statistics, distribution of data, and statistical analysis to evaluate relevant hypotheses that can be useful in assessing the compatibility of the strength values with the intended population. The data to be reported includes the following at a minimum:

- Measures of central tendency (mean, media, mode)
- Measures of variation (standard deviation, variance, and range)

- Identification of outliers
- Skewness of data
- Graphical representation of data (i.e., histogram)
- Percentiles

Upon completion of data collection and analysis, the results are then ready to be used for making inferences about the subject population.

4.5 SUMMARY

Muscles skeletal and nervous systems are the integrated systems that permit movement of the human body. They convert chemical energy, obtained from food and drinks, into mechanical energy, which creates force and allows movement of the body limbs and activities that result in task performance. Designing occupational environments, equipment, and processes to be compatible with the musculoskeletal system is a goal of ergonomics. Understanding muscle work and how stimuli are processed by the body is imperative for the ergonomist. How multiple bodily functions interact to allow task performance requires knowledge of not only the musculoskeletal system but the nervous system as well. The nervous system controls the musculoskeletal system via motor and sensory nerves, which, in turn, communicate with the central nervous system. Additionally, understanding the science behind the transformation of energy into muscle movement and also the factors contributing to fatigue will aid in efficient and safe task design.

Case Study

Ergonomic Analysis of a Telemarketing Operation
By Robert O. Andres, David D. Wood, and Nancy E. Laurie

Introduction

This report presents the results of our ergonomic analysis a telemarketing operation in the call center of a large mail order firm. Dr. Andres first observed the telemarketing floor during his visit on November 5, 1993. A subsequent site visit took place May 4, 1994; ergonomists Nancy Laurie, M.S. and David Wood, M.S.I.E. accompanied Dr. Andres and performed the analyses summarized in this report. It has been brought to our attention that since our last visit a possible change is being considered—the supervisors would be distributed about the floor so that the lead station and supervisors' offices would no longer be centralized. The implications of this change will be discussed in the Conclusions and Recommendations section.

Methods

The site visit on 5/4/94 yielded several types of data. Video records of task performance were acquired, both to document worker technique and worker interaction with their workstation as well as to provide examples that can be used during training (if training is pursued as an intervention). We measured the dimensions of the existing workstations across the entire floor area to determine what is available. We were also supplied with OSHA 200 logs so that we could understand the nature of the injuries and illnesses experienced by workers overall and in the telemarketing area.

Clerical worker exposure to ergonomic risk factors was estimated from both the on-site visit and a video tape analysis in our lab. Observational data and video data were summarized using ANSI's Z-365 checklist. The OSHA 200 Logs were reviewed; only ergonomic injuries were summarized (cumulative trauma disorders [CTDs]).

Results

There were three lost time ergonomic injuries in 1993 in the clerical operation. We estimated the severity rate using the following formulas (Bureau of Labor Statistics [BLS]):

$$\text{Total hours per year} = 415(\text{workers}) \times 30(\text{h/week}) \times 50(\text{weeks/year}) 622{,}500 \text{ h/year}$$

$$\text{Severity rate for lost days} = \text{number of lostdays/200,000 h/year} (57[\text{lost days}] \times 200{,}000)/622{,}500 = 18.31 \text{ lost days per 100 person years}$$

$$\text{Incidence rate for lost time injuries} = \text{number of lost time injuries/200,000 h/year } (3 \times 200{,}000) / 622{,}500 = 0.96 \text{ incidents per 100 person years}$$

There were nine other lifting injuries; each had no associated lost time. There were 268 lost days due to three slip/fall incidents. Seventeen other falls had no associated lost time. We gave a quick glance at the warehouse OSHA 200 Log ergonomic injuries. In absolute terms the number of lost days was some 10–12 times higher than those in telemarketing. However, without knowing the number of hours spent working last year in the warehouse, the incidence and severity rates could not be calculated.

After the site visit and viewing the video shot during our visit an ANSI Z-365 general ergonomic risk assessment checklist was filled out. Two aspects of the telemarketing operator's work (mechanical pressure at wrist and neck flexion) were above the trigger point (meaning that engineering or administrative controls should be implemented to reduce the physical stress on the workers). The workers rest their wrists on whatever surface is available as they type. This mechanical pressure is a risk factor for CTDs of the hand/wrist. The neck is also a potential site for CTDs. Workers must continuously look down at forms and papers on their desks and then look up at their computer monitor.

Table 4.2 contains a summary of the workstation heights. Only workstations with a computer and chair were included; the actual number of workstations used varies over time with the volume of sales.

TABLE 4.2
Workstation Height Summary

Workstation Height (in.)	Number
26.50	11
26.75	154
27.00	71
28.00	90
28.25	18
30.25	3
30.50	59
30.75	1
31.00	4
Total	411

Conclusions and Recommendations

The number of CTDs found on the OSHA 200 logs was small (3). Comparing the incidence and number of lost workdays with nationally published values for the finance, real estate, and insurance sectors (which are the most clerical of the classifications published by the Bureau of Labor Statistics in Accident Facts, 1993 Edition, referring to the 1991 statistics), the national average incidence of lost workday rate was 1.1 (versus 0.96 at here) while the average lost workdays were 24.1 (versus 18.3 at here). The clerical operation is better than the national average for the number of lost workday cases and for the number of lost workdays. That does not mean that improvements cannot be made.

Suggested improvements will be proposed on both a short term and a long term basis. The short term suggestions are generally administrative controls, whereas the long term suggestions involve engineering controls as well.

Short term improvements

Assign workers to proper work surfaces based on height:

We understand that you are considering dividing the floor into teams; this may make assignment more complicated but we will provide worker heights matched to work surface heights if you elect to pursue this approach.

Make sure that footrests are placed where needed:

We noticed that footrests were not present in all workstations, and we also noticed that they were pushed to the side and not used in several situations where the worker was too tall for their work surface.

Provide palm rests for the workers with wrist/hand complaints:

This may involve getting more palm rests because you do not want to take them away from people that already have them (we understand that this did happen at some locations on the floor as a result of the December 1, 1993 incident, and many workers expressed their dismay that they had been taken away).

We do not believe that all workers need these, but for those that experience some discomfort or have developed some early symptoms (see #6 below) they could be provided on a case by case basis.

Train the workers to properly adjust their chairs and to sit properly:
The chairs that the majority of workers sit in seem to be adequate ergonomically. However, a good chair set in the wrong position can still cause problems during prolonged sitting. Training should be provided on how to adjust the chairs, and why. For example, if discomfort develops in the low back, the seat back may be too high, or if the back of the legs get sore then the seat pan may be set too high. Proper sitting posture should also be taught.

Train the workers how to stretch properly, and provide them with stretch breaks:
We have worked with clients who have implemented stretch break programs ranging from voluntary when the worker feels the need to mandatory 5 min every hour. The stretches need to be appropriate and they need to be either led by properly trained leaders or the individual workers need to receive training. We have developed a stretch guide for workers that was designed to fulfill this need.

Implement a medical management program that would include training for the workers and supervisors so that they can recognize early symptoms of CTD problems, and make sure that management promotes a policy of early reporting so that CTDs are prevented:
This type of program would need to be corporate-wide to be effective. Our experience indicates that an effective medical management program can prevent minor aches and pains from becoming lost workday incidents. You can make all the biomechanical modifications possible and still have a large number of lost days if early reporting and aggressive pursuit of conservative treatment are not part of corporate policy.

Long term improvements

Provide better work surfaces with rounded front edges:
The sharp front edges on the existing stations can cause mechanical stress concentrations on the tendons of the forearms if workers rest their arms on them.

Investigate adjustable work surfaces:
These adjustable surfaces are rapidly coming down in price. In future facilities, it may be cost effective to buy a percentage of adjustable work surfaces to adapt to anthropometric extremes. This will become more cost effective if the company moves to more multiple shifts sharing the same stations.

Provide a small number of standing work stations:
These standing stations could be placed along a side wall, and as long as the workers can maintain their identity by logging on to one of these stations, they could be used for up to 20 min at a time on a voluntary basis for workers that tire from continuous sitting.

Provide monitor stands:
Although the monitor heights in the current workstations appear adequate, as workers are trained to better adjust their chair to their worksurface height

to promote the best body postures for keyboard work and writing, the need for adjustment of monitor height will increase. These devices will be needed most by the taller workers. These devices will also help if multiple shifts will be using the same workstation. However, the nature of the work performed should be taken into account—you do not want to raise all of the monitors if it will force people to look up and down more.

Before concluding this report, the lifting and slip and fall incidents need to be addressed. Even though lifting is not a primary component of the jobs performed by those answering the phones (and perhaps because it occurs so infrequently), there were nine incidents due to lifting in clerical employees. These employees need to be trained in proper lifting mechanics. The prevention of slips and falls for these workers is more a safety issue than an ergonomic issue, but slips and falls often lead to back injuries. Three lost day incidents were caused by falls experienced by clerical workers. Seventeen other falls or trips were experienced by office workers, but these did not lead to lost days. Although the injury log did not indicate where the falls took place, most of them may have taken place in another location besides the Telemarketing floor. Disparate surfaces (like tile and carpet or concrete and ice) can cause slips or trips when people move from one surface to the other. Obvious trip hazards in the telemarketing area should be removed if found.

The implementation of any of these short or long term interventions could best be handled by an active Ergonomics Committee as part of a structured Ergonomics Program. Such a program would include the training for the managers, supervisors, and employees that is referred to above, as well as generally raising the level of awareness of ergonomic issues across the entire telemarketing operation. With the approaching Ergonomics Standard being developed by OSHA, it would be better to start this process sooner instead of later.

In summary, even though the telemarketing operation currently has incidence and severity rates below the national average, several suggestions for improvements have been presented. Based on the OSHA logs we reviewed, however, it appears that the maximum opportunity for cost justifying ergonomic interventions is found in the Fulfillment Center distribution operation.

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EXERCISES

4.1 Define muscular work.

4.2 Explain how energy (work) can be exerted without actually performing work as defined by laws of physics.

4.3 Explain the muscle contraction process.

4.4 Explain the chemical processes that take place in aerobic an anaerobic contraction.

4.5 Define braches of the peripheral nervous system that innervate the muscles.

4.6 What is the difference in a reflex and a muscular movement such as kicking a ball?