## Human Movement Science

Movement represents the integrated functioning of three main systems within the human body: the nervous system, the skeletal system, and the muscular system. These collective components and structures represent the human movement system (HMS) (Figure 7-1). Although separate in structure and function, the HMS relies on a collaborative effort to form interdependent links that form a functional kinetic chain. For example, an individual’s arm, shoulder, and spine are interconnected segments that function together to perform movement.

If any part of the kinetic chain is injured or not functioning properly, the entire link is compromised, resulting in less than optimal performance. Body segments and their movements must be coordinated to allow for the efficient transfer of energy and power throughout the body when moving from one body segment to the next. This concept of how the functioning of one segment of the body can impact other areas is referred to as the regional interdependence model (Sueki et al., 2013). This chapter focuses on how the HMS works interdependently to learn and produce efficient human movement.

STRETCH YOUR KNOWLEDGE

Regional interdependence emphasizes the importance of integrated HMS functioning. For example, a client with normal functioning muscular and nervous systems should be able to complete a front shoulder raise through the shoulder joint’s full range of motion (ROM). However, if there was articular (joint) system stiffness, the movement may not be completed through the full ROM, despite a normally functioning muscular and nervous system. On the other hand, if the nervous system that supplies the message to the deltoid (shoulder muscle) was not working properly, a client would not be able to raise their arm despite having normal articular movement and an intact muscle.

### Biomechanics

Biomechanics is the study of mechanical laws or principles relating to movement. In other words, biomechanics uses scientific principles of physics to study how the body creates movement at the joints, especially in the context of exercise and sport. Kinesiology is another formal discipline that studies movement. While kinesiology is still concerned with the principles of biomechanics, it investigates movement further because it additionally relates to human anatomy and physiology.

The exploration of human movement science focuses on the various motions that the HMS produces and the forces that act on it (Hamill & Knutzen, 2003; Levangie et al., 2019). Fitness and sport training require a strong understanding of basic anatomical terminology, planes of motion, joint motions, muscle actions, force-couples, levers, forces, and the intramuscular relationship between force and velocity.

**Biomechanical terminology**

It is important for fitness professionals to understand the terminology used in the study of biomechanics and kinesiology. This prepares them with a better understanding of and ability to apply the scientific principles behind assessing clients’ movements and implementing exercise programs with clients.

It is important to keep in mind that biomechanical terms always refer to the body in the anatomic position (Figure 7-2). The anatomic position is when the body is in a standing posture, with the arms hanging down by the sides and palms facing forward. This position is important because it gives a universal point of reference from which all allied health professionals can accurately discuss human biomechanics.

**Anatomic locations**

Anatomic locations describe the relative positioning of segments of the body. Anatomical terms commonly used in the fitness industry include *medial, lateral, contralateral, ipsilateral, anterior, posterior, proximal, distal, inferior*, and *superior* (Figure 7-3; Table 7-1). These terms are used to describe where various bodily structures are located in more specific ways than common terms such as *above* and *below* or *front* and *rear*.

TABLE 7-1 Anatomic Location Definitions and Examples

| **Anatomic Location** | **Definition** | **Example** |
| --- | --- | --- |
| Medial | Relatively closer to the midline of the body | The adductors (inner thigh muscles) attach to the medial side of the femur (thigh bone). |
| Lateral | Relatively farther away from the midline or toward the outside of the body | The ears are positioned laterally on the head. |
| Contralateral | Positioned on the opposite side of the body | The right foot is contralateral to the left hand. |
| Ipsilateral | Positioned on the same side of the body | The right foot is ipsilateral to the right hand. |
| Anterior | Positioned on or toward the front of the body | The quadriceps are located on the anterior aspect of the thigh. |
| Posterior | Positioned on or toward the back of the body | The hamstring complex is located on the posterior aspect of the thigh. |
| Proximal | Positioned nearest to the centre of the body or other identified reference point | The wrist is more proximal to the elbow than the fingers. |
| Distal | Positioned farthest from the centre of the body or other identified reference point | The ankle is more distal to the hip than the knee. |
| Inferior | Positioned below an identified reference point | The soleus (calf muscle) is inferior to the hamstring complex. |
| Superior | Positioned above an identified reference point | The pelvis is superior to the tibia (shin bone). |

**Planes of motion, axes, and joint motions**

The universally accepted method of describing human movement is in reference to three dimensions and is based on a system of three imaginary planes: sagittal, frontal, and transverse (Figure 7-4). These planes are positioned at right angles, so they intersect in the centre. Although movements can be dominant in a single plane of motion, it is important to remember that typical daily movement rarely occurs strictly in one plane of motion. However, movements, joint motions, and many common exercises are classified as being predominantly in a specific plane of motion if they run along that plane (i.e., parallel to it). Movement patterns that take the body through motions in more than one plane are termed *multiplanar*.

Movement in each plane occurs on an axis running perpendicular to that plane, much like the axle that a car wheel revolves around. This is known as *joint motion*. Joint motions are termed for their action in each of the three planes of motion. A more specific term used to describe the movements we can observe or see is osteokinematic, whereas the movements taking place inside the joint itself that we cannot see are referred to as arthrokinematic movement (Levangie et al., 2019). Osteo- and arthrokinematic movements are both required for normal movement to occur.

**The sagittal plane**

The sagittal plane is an imaginary line that bisects the body into right and left sides. Sagittal plane joint motion occurs around a medial-lateral axis, as is seen when bending at the knees. Movements in the sagittal plane include flexion and extension (Figure 7-5). Flexion is a bending movement in which the relative angle between two adjacent segments decreases. Extension is a straightening movement in which the relative angle between two adjacent segments increases (Hamill & Knutzen, 2003; Levangie et al., 2019).

STRETCH YOUR KNOWLEDGE

Hyperextension is the extension of a joint beyond the normal limit or ROM and may result in injury. The term *hyperextension* is reserved for movements where normal extension values have been exceeded and should not be used to describe someone who has full available extension ROM.

HELPFUL HINT

To better understand the sagittal plane, imagine being stuck in a very narrow hallway with no room to move to the left or right or to rotate in any fashion. In addition, the walls are made completely of glass, which you don’t want to break. Based on this analogy, the only available movements in our narrow sagittal plane hallway are front-to-back and up-and-down movements.

Flexion and extension occur in many joints in the body, including the spine, shoulder, elbow, wrist, hip, knee, foot, and hand. At the ankle, flexion is referred to as dorsiflexion and extension is plantar flexion (Levangie et al., 2019). Examples of predominantly sagittal plane exercises include biceps curls, triceps pushdowns, squats, front lunges, calf raises, walking, running, vertical jump, climbing stairs, and shooting a basketball.

STRETCH YOUR KNOWLEDGE

Hip Flexion in the Sagittal Plane

Hip flexion occurs when an individual decreases the angle between the femur (thigh bone) and the pelvis or lumbar spine. This can occur when an individual elevates the knee toward the abdomen (femoral-on-pelvic hip flexion). During this motion, the pelvis and spine are fixed while the femur rotates. Another version of hip flexion can occur when an individual bends forward from the trunk (as if touching their toes). In this instance, the pelvis and lumbar spine rotate together over a fixed femur (pelvic-on-femoral rotation).

HELPFUL HINT

To best remember dorsiflexion, think about the dorsal fin of a dolphin on the top side of its body. In this context, *dorsal* represents the top side of the foot and the direction it moves when the ankle flexes.

To remember plantar flexion, think about planting a garden in the ground. In this context, *plantar* represents the bottom side of the foot and the direction it moves when the ankle extends.

**The frontal plane**

The frontal plane bisects the body to create front and back halves. Frontal plane joint motion occurs around an anterior-posterior axis, like is seen at the shoulder when doing jumping jacks. Movements in the frontal plane include abduction and adduction of the limbs (relative to the trunk), lateral flexion of the spine, and eversion and inversion at the foot and ankle complex (Figure 7-6) (Hamill & Knutzen, 2003; Levangie et al., 2019).

Abduction is a movement away from the midline of the body. Similar to extension, it is an increase in the angle between two adjoining segments, except in the frontal plane. Adduction is a movement of a segment toward the midline of the body. Like flexion, it is a decrease in the angle between two adjoining segments, except in the frontal plane (Hamill & Knutzen, 2003; Kendall et al., 2005; Levangie et al., 2019).

Lateral flexion is the bending of the spine from side to side in the frontal plane. Additionally, similar to flexion and extension, joint motion at the feet is termed a bit differently. Eversion and inversion follow the same principle as lateral flexion but relate specifically to the pendulum-like movement of the calcaneus (heel bone) and tarsals (ankle bones) in the frontal plane (Hamill & Knutzen, 2003; Kendall et al., 2005; Levangie et al., 2019). When a foot everts, the calcaneus swings laterally (away from the midline); when a foot inverts, the calcaneus swings medially (toward the midline). Examples of predominantly frontal plane exercises include jumping jacks, side lunges, lateral shoulder raises, and side shuffling.

HELPFUL HINT

To better understand the frontal plane, imagine walls in front of and behind you, with no room to move forward or backward or to rotate. Like last time, the walls are made completely of glass, which you do not want to break. As a result, movements in the frontal plane are primarily side-to-side motions.

**The transverse plane**

The transverse plane bisects the body to create upper and lower halves. Transverse plane motion occurs around a longitudinal or vertical axis. Movements in the transverse plane include internal rotation and external rotation for the limbs, right and left rotation for the head and trunk, horizontal abduction and horizontal adduction of the limbs, and radioulnar pronation and radioulnar supination forearm rotation (Figure 7-7) (Hamill & Knutzen, 2003; Levangie et al., 2019). Examples of predominantly transverse plane exercises include performing a cable trunk rotation, a dumbbell chest fly, and swinging a bat or golf club.

STRETCH YOUR KNOWLEDGE

The transverse plane involves rotational movement of the head, torso, arms, and legs. In addition, movement in the transverse plane involves horizontal abduction and adduction, which can occur at either the shoulders or hips. For example, a machine chest fly exercise involves horizontal abduction and adduction at the shoulder, whereas a hip abductor machine involves horizontal abduction and adduction at the hips.

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GETTING TECHNICAL

Just like with dorsiflexion, plantar flexion, eversion, and inversion in the sagittal and frontal planes, there is unique terminology for transverse plane movement of the feet. In this context, rotating the foot outward at the ankle (with no rotation of the leg as a whole) is called abduction (toes rotating laterally), while inward rotation of the foot at the ankle is called adduction (toes pointing medially) (Hamill & Knutzen, 2003; Levangie et al., 2019).

To move the body functionally, however, the foot and ankle complex rarely performs its single plane movements in isolation. Instead, the ankle moves through its own version of pronation and supination, which is different from radioulnar pronation and supination. Pronation of the foot is a multiplanar movement consisting of the combination of eversion, dorsiflexion, and ankle abduction. Supination of the foot is then the combination of inversion, plantar flexion, and ankle adduction. During gait (walking and running), the foot and ankle complex moves between pronation during force reduction (when the foot lands) and supination during force production (when the foot pushes off the ground) with every step.

**Scapular motion**

Motions of the scapulae (i.e., the shoulder blades) are important for the fitness professional to be familiar with to ensure proper movement of the shoulder complex. Isolated scapular movements— termed *translations*, because they do not rotate around a fixed axis—are primarily retraction, protraction, elevation, and depression (Levangie et al., 2019).

Scapular retraction occurs when the shoulder blades come closer together. Scapular protraction occurs when the shoulder blades move further away from each other. Scapular depression occurs when the shoulder blades move downward, and scapular elevation occurs when the shoulder blades move upward toward the ears (Levangie et al., 2019).

STRETCH YOUR KNOWLEDGE

Scapular retraction requires several muscles, including the middle trapezius and rhomboids. Scapular protraction primarily requires the serratus anterior muscle, with some assistance from the pectoral muscles.

**Movement attributes**

The HMS is complex and requires not only the integrative function of different systems but also cooperative efforts within the systems. Generally speaking, movement can be described in terms of the predominant movement plane and the specific motions at the joints; however, movement can also be classified as being normal or dysfunctional. Normal movement represents efficient, cooperative functioning of the skeletal, nervous, and muscular systems (Kendall et al., 2005). Normal movement requires a joint to be able to move through its full ROM, which requires normal osteo- and arthrokinematics (Levangie et al., 2019).

The amount of movement determined to be normal would depend on the activity of interest. For example, certain sports require greater joint ROMs than standard activities of daily living, as is seen in the difference between the motion of the shoulders when pitching a baseball and simply washing one’s hair. Full ROM requires normal elasticity of the capsule and ligaments surrounding the joint and normal muscle length and flexibility, as well as normally functioning neurological and muscular systems. Clients with hypermobility (excessive ROM at a joint) generally would be expected to have a lack of firm ligamentous support, whereas those with hypomobility (limited ROM at a joint) generally have restricted length of the muscular structures that cross the joint (Kendall et al., 2005).

**Isokinetic**

During isokinetic muscle actions, the muscle shortens at a constant speed over the full ROM. An isokinetic muscle action requires the use of expensive and sophisticated equipment that measures the amount of force generated by the muscles and adjusts the resistance (load) so that no matter how much muscular tension is produced, movement speed remains constant. In other words, the harder an individual pushes or pulls, the more resistance they feel. During a full isokinetic contraction, the tension in the muscle is at its maximum throughout the whole ROM, which is believed to improve strength and endurance. However, the types of movements that are able to be performed on isokinetic machines are rather limited, and these machines often are only seen in rehabilitation clinics or exercise physiology laboratories.

**The muscle action spectrum**

Because practically every exercise consists of an eccentric, isometric, and concentric muscle action to complete one repetition, the movement through those muscle actions is referred to as the muscle action spectrum. A dumbbell curl exercise is a clear example to illustrate this concept. The initial movement requires the biceps brachii to shorten to generate enough force to overcome the weight of the dumbbell in the individual’s hand (i.e., the force of gravity pulling the dumbbell’s mass toward the ground), causing the elbows to flex and the dumbbells to move up toward the front of the shoulder (Figure 7-9). This is the concentric phase of the exercise.

Once the dumbbells are raised to the front of the shoulder, the individual holds this position. Because the length of the muscle does not change while generating force to hold this position, it is considered the isometric portion of the exercise. As the individual lowers the dumbbells back to the starting position, the biceps muscles must now generate forces while lengthening to decelerate the force of the dumbbells against the pull of gravity; this is the eccentric portion of the exercise (Figure 7-10).

GETTING TECHNICAL

When performing a biceps curl exercise with the palm facing up, the biceps brachii is the primary muscle targeted. Changing the hand position to palm down targets the brachialis to a greater degree, whereas performing the exercise with the thumb up (hammer curls) targets the brachioradialis muscle to a greater extent. During all three versions of the curl exercise, all of the elbow flexors are recruited concurrently; however, the degree of recruitment for each muscle differs with each hand and forearm position (Kendall et al., 2005; Levangie et al., 2019).

A second example to help illustrate muscle actions is the squat exercise. To initiate the squat from a standing position, the individual squats down, flexing at the hips, knees, and ankles (Figure 7-11). As the individual squats downward, the gluteal muscles and quadriceps mechanically lengthen while simultaneously decelerating the force of the individual’s bodyweight; this is the eccentric muscle action of the squat exercise. The isometric muscle action occurs when the individual pauses at the bottom position and no joint motion is visible. Lastly, the concentric muscle action occurs when the individual extends at the ankles, knees, and hips to return to the starting position, concentrically contracting the gluteal muscles and quadriceps (i.e., the lifting phase) (Figure 7-12).

**Figure 7-12**Back squat— concentric motion

TRAINING TIP

The integrated function of the HMS can be recognized during a squat. Clients with limited dorsiflexion of the ankle will be limited in the depth of their squat during the eccentric phase. A quick method for these individuals to gain a deeper squat ROM is to place a small board (or weight plates) under their heels. A longer-term solution would be to address the stiffness of the ankle joints by performing routine stretching (Macrum et al., 2012).

## Functional anatomy of muscles

To more effectively understand human movement and to design efficient exercise programs, it is important to view muscles’ capacities to function in all planes of motion and through the entire muscle action spectrum (eccentric, isometric, concentric). In addition, muscles can also work synergistically to produce force, stabilize the body, and reduce force under direct control of the nervous system. The more that functional anatomy is understood, the more specific an exercise program can become. To explore the muscles of the body in more detail, refer to Appendix C.

**Muscles as movers**

Muscles provide the human body with a variety of functions that allow for the manipulation of forces placed on the body to either produce, stabilize, or resist movement. During functional movements, a muscle can be categorized as either an agonist, synergist, stabilizer, or antagonist depending on the joint motion being performed.

Agonists are muscles that act as the prime movers for a joint motion; in other words, they are the muscles most responsible for generating the primary forces for a particular movement. For example, the gluteus maximus is the agonist for hip extension, the quadriceps are the agonists for knee extension, the anterior deltoid is the agonist for shoulder flexion, the biceps brachii is the agonist for elbow flexion, and the triceps brachii is the agonist for elbow extension (Kendall et al., 2005; Levangie et al., 2019).

Synergist muscles create forces to assist prime movers but are not intended as the primary force producer for a given joint motion. For example, the hamstring complex and the erector spinae (muscles of the back) are synergistic with the gluteus maximus during hip extension (Kendall et al., 2005), whereas the brachioradialis and brachialis (forearm muscles) assist the biceps brachii during a biceps curl. Additional examples include the triceps brachii assisting the pectoral muscles during a chest press and the biceps brachii assisting the latissimus dorsi during a pull-up.

Stabilizer muscles contract isometrically to support and stabilize the joints, while the prime movers and synergists move through the entire muscle action spectrum to perform a movement. For example, the transversus abdominis (a deep abdominal muscle), internal obliques, and multifidus (deep muscles of the spine) stabilize the LPHC during hip extension. Another example is the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis), which stabilize the shoulder during upper extremity movements (Day et al., 2012).

GETTING TECHNICAL

An interesting fact regarding stabilization is that certain muscles have the ability to stabilize a joint by contracting automatically in anticipation of movement (Day et al., 2012; Masse-Alarie et al., 2012). This anticipatory stabilization effect is referred to as feed-forward activation.

Lastly, antagonist muscles perform the opposite action of the prime mover. For example, the biceps brachii (an elbow flexor) is an antagonist to the triceps brachii during elbow extension. Conversely, during elbow flexion, the triceps become the antagonist to the biceps. Another example includes how the hip flexor complex is antagonistic to the gluteus maximus during hip extension, whereas the gluteus maximus is antagonistic to the hip flexor complex during hip flexion.

STRETCH YOUR KNOWLEDGE

As previously mentioned, muscles can often take on different roles depending on the joint motion that is being performed. For example, the infraspinatus muscle of the rotator cuff takes up the role of agonist (prime mover) for shoulder external rotation, the role of synergist when abducting the shoulder to reach overhead, and the role of stabilizer during other joint motions of the shoulder (Day et al., 2012; Kisner & Colby, 2007;Levangie et al., 2019).

**Open- versus closed-chain movements**

In the health and fitness industry, exercises are often classified based on different load- or weight-bearing characteristics. One such classification is to describe an exercise as being either open- or closed-chain. Classifying an exercise in this manner may provide insight into muscle recruitment patterns, the degree of weight-bearing, and the number of joints involved (Kisner & Colby, 2007).

Closed-chain movements

The primary characteristic of closed-chain movements is that the distal segments, such as a person’s hands or feet, are fixed and remain in contact with a stationary surface. Additionally, closed-chain exercises often require the movement of multiple joints in a predictable manner with the contraction of multiple muscle groups (Kisner & Colby, 2007).

While not required, a majority of closed-chain activities are weight-bearing. Examples of closed-chain exercises include push-ups, squats, pull-ups, or lunges.

During a squat or lunge, the distal segments (the legs) are fixed on a stable surface and movement occurs at the hips, knees, and ankles; multiple muscles are activated, including the entire gluteal and quadriceps groups. The resistance of bodyweight or a weighted bar is applied simultaneously to all the joints of the lower extremity. The same can be said for the upper extremities during push-ups or pull-ups, with the hands fixed either on the floor or on a static bar. During these movements, the body is moving while transferring the force back into the fixed, stable surface, with multiple joints in the kinetic chain dealing with the resistance (Figure 7-13).

Open-chain movements

The primary characteristic of open-chain movements is that the distal segments (hands and feet) are not fixed, and they are free to move in space. Additionally, open-chain exercises have independent joint movement of only the segments distal to the moving joint itself (Kisner & Colby, 2007). While not required, a majority of open-chain activities are nonweight-bearing.

Examples of open-chain exercises include lat pulldown, biceps curl, bench press, leg curl, and leg extension exercises (Figure 7-14). Unlike closed-chain exercises, which activate multiple muscles, open-chain exercises tend to focus on isolating the prime mover muscles (Kisner & Colby, 2007).

Helpful Hint

Closed-chain exercises involve applying force into an immovable object, such as the floor, wall, or pull-up bar. In other words, the hands or feet are typically fixed and do not move.

Open-chain exercises involve the ability to freely move the limbs, such as the hands and feet.

For example, a pull-up is a closed-chain exercise for the back musculature, whereas the lat pulldown is an open-chain exercise for the same muscle group.

### Muscular force

Force is defined as the interaction between two entities or bodies that results in either the acceleration or deceleration of an object. Forces are characterized by magnitude (how much) and direction (which way they are moving) (Hamill & Knutzen, 2003; Levangie et al., 2019). The HMS is designed to manipulate variable forces from many directions to effectively produce movement. As such, the fitness professional must gain an understanding of some of the more pertinent forces that the HMS must deal with and how they affect motion.

**Length-tension relationships**

A length-tension relationship refers to the association between the resting length of a muscle and the amount of internal tension it can produce at that resting length (Levangie et al., 2019). Each muscle in the body has an optimal muscle length at which the actin and myosin filaments within the sarcomere have the greatest degree of overlap (Figure 7-15). At that optimal length, the ability of myosin to make a maximal amount of connections with actin results in the potential for maximal force production of that muscle.

At both extremes of muscle shortening or lengthening there is a diminished ability to produce force. When a muscle has chronically low neural activation and is longer than it should be, there is a reduced amount of actin and myosin overlap, reducing the amount of force that can be produced at that length. When a muscle has chronically high neural activation and is regularly held in a contracted (shortened) state, it places the actin and myosin in a state of maximal overlap and allows for no further movement to occur between the filaments, also reducing its force output potential (Levangie et al., 2019).

**Muscle balance**

Length-tension relationships relate closely to the concept of muscle balance. Recall that on each side of a joint there are agonist and antagonist muscles; when one contracts and shortens, the other has to relax and lengthen if movement is to occur. When all muscles surrounding a joint have optimal length-tension relationships, neither side is pulling harder than the other, and they will hold that joint in an optimal position for the most efficient movement.

If a muscle’s resting length is either too long or too short on one side of a joint, however, it has an altered length-tension relationship. This creates imbalance around the joint, where one side is contracted and pulling more than it should be and the other side is allowing to be pulled into a lengthened state with reduced actin/myosin overlap, putting the joint into a suboptimal resting position (Figure 7-16).

A joint being held in a suboptimal position like this is the basis for poor posture. For example, if a person’s adductor muscles on the inside of the thighs are in a contracted/shortened position and consequently the abductor muscles on the outside of the hips (i.e., gluteus medius) are in a lengthened position, a knock-kneed posture will be created, which puts unnecessary stress on the joints and can lead to discomfort and increased risk of injury (Ford et al., 2015; Padua et al., 2012).

GETTING TECHNICAL

The scientific term that describes the nervous system’s role in the contract-relax relationship between agonists and antagonists is called reciprocal inhibition. When the agonist for a movement receives a signal (a motor neuron impulse) to contract, the central nervous system also sends a signal that inhibits the antagonist’s activation signals at the same time, causing it to relax. For example, to perform the biceps curl exercise, the biceps brachii (agonist) must contract, while simultaneously, the triceps brachii (antagonist) must relax for the movement to occur.

When muscles have altered length-tension relationships, the normal process of reciprocal inhibition becomes altered. Altered reciprocal inhibition is when an agonist muscle chronically receives an activation signal causing the functional antagonist to chronically receive the inhibitory signal.

When a muscle is chronically overactive, it is in a state of elevated neural activity, which causes the muscle to be in a constant state of contraction. When a muscle is chronically underactive, it is in a state of inhibited neural drive. In this situation, the overactive muscle pulls the joint too much in one direction, while the underactive muscle does not activate enough to resist that pull. The result is that the joint is held in a suboptimal position (poor postural alignment) due to a muscle imbalance.

Formal assessments of a client’s posture will help identify muscle imbalances. Then, flexibility techniques can be used to calm down muscle overactivity, and strengthening techniques can be used to improve the neural activation of underactive muscles. This helps restore optimal length-tension relationships within the muscles, restores balance around the joint, and allows the joint to be held in its most efficient neutral position.

### Stretch-shortening cycle

The stretch-shortening cycle is a term used to describe a loaded eccentric muscle action that prepares muscles and tendons for a rapid concentric contraction. The eccentric muscle action represents the *stretch* component, which stores elastic energy from the springlike nature of contractile tissue. The stored energy is a result of the series elastic component of muscle and tendon (mostly tendon) (Kisner & Colby, 2007).

HELPFUL HINT

The stretch-shortening cycle is similar to stretching a rubber band. Stretching the rubber band stores elastic energy. Once the rubber band is released, the elastic energy is transformed into kinetic energy, and the rubber band flies through the air. The same sort of principle applies to our body’s muscle and connective tissue. When a person needs to jump, they will first perform a shallow squat prior to initiating the jump—this is the body’s version of pulling on the rubber band.

After energy is stored, the contractile tissue releases this elastic energy during the concentric phase. The storage and release of this elastic energy increases force production if the time between the eccentric and concentric phase is rapid. Specifically, the amortization phase is used to describe this transition (Kisner & Colby, 2007). The goal of increased force production, hence, improved performance, depends on a rapid amortization phase. A rapid amortization phase requires both contractile tissue storage of energy and the neurological stretch reflex (Kisner & Colby, 2007).

Use of the stretch-shortening cycle in exercise is the basis for plyometric training, in which jump-landing tasks eccentrically load the muscles (the landing) to achieve a more explosive concentric contraction (the jump). The more rapidly a client can move through the amortization phase, the more powerful the concentric contraction will be, which is known as the integrated performance paradigm. When executed properly, this type of training helps produce the necessary neural and muscular adaptations to improve speed, power, and sport-specific improvements (McArdle et al., 2016).

For example, the appropriate implementation of a depth-jump exercise involves jumping off a box and dropping immediately into a squat position for the landing. Moving into this squat position stores elastic energy via the series elastic component, then the release of that stored elastic energy combines with the concentric contraction to more powerfully drive the jump. If the amortization phase is prolonged, stored energy will dissipate, the neurological stretch reflex will not be optimally activated, and the concentric unloading phase will be less powerful.

The concept of the stretch-shortening cycle can also be applied within the context of agility drills, which require repeated switching from deceleration to acceleration. This switch is the stretch-shortening cycle in action, requiring a rapid reversal of muscle action from eccentric (loading) to isometric (amortization) to concentric (unloading). Essentially, any time a muscle is eccentrically loaded, those elastic forces can be amortized and released to provide a more powerful concentric contraction.

STRETCH YOUR KNOWLEDGE

In the powerlifting world, athletes competing in the bench press will often rapidly lower the bar toward their chest before pressing it back up. This technique, while not recommended for everyday exercisers because it is potentially dangerous, uses the integrated performance paradigm to add a bit of extra force to the concentric phase of the lift.

**Force-velocity curve**

The force-velocity curve describes the inverse relationship between force and velocity and refers to a muscle’s ability to produce tension at differing contraction velocities. As the velocity of a concentric muscle action increases, its ability to produce force decreases, while the ability to produce force increases as the velocity of a concentric contraction decreases (Levangie et al., 2019).

For example, during a heavy barbell back squat, the muscles produce a high amount of force; however, the movement is rather slow. Conversely, during a squat jump exercise, the velocity of movement is high; however, the force output is low (when compared to a heavy barbell back squat).

During an eccentric muscle action, as the contraction velocity increases, the ability to develop force also increases. This is believed to be the result of the use of the elastic component of the connective tissue surrounding and within the muscle—similar to the loading phase of the stretch-shortening cycle (Hamill & Knutzen, 2003; Radnor et al., 2017). Simply put, the faster the eccentric contraction, the more force the muscle is capable of decelerating. When plotted on a graph, the inverse relationship between eccentric and concentric contraction velocities and the amount of force they produce displays the force-velocity curve (Figure 7-17).

**Force-couple relationships**

Muscles produce a force that is transmitted to bones through their connective tissues, known as tendons. Because muscles are recruited as groups, many muscles will transmit force onto their respective bones, creating movement at the joints. This synergistic action of multiple muscles to produce movement around a joint is known as a force-couple relationship (Levangie et al., 2019).

Muscles in a force-couple provide divergent pulls on the bone or bones they connect with. That is to say, each muscle has different attachment sites, pulls at a different angle, and creates a different force on that joint. The motion that results from the combination of differing forces is dependent on the structure of the joint and the collective pull of each muscle involved (Levangie et al., 2019). For example, the middle trapezius, lower trapezius, and serratus anterior all pull on the scapula (shoulder blade) in different directions to assist with shoulder abduction (Figure 7-18).

CRITICAL

Muscles are connected to bones via tendons. When a muscle contracts, the muscle’s tendon pulls on its respective bone(s) to create joint motion. Muscles can only pull on their respective bones—muscles cannot actively push.

In reality, however, every movement produced must involve all muscle actions (eccentric, isometric, concentric) and all functions (agonists, synergists, stabilizers, and antagonists) to ensure proper joint motion as well as to eliminate unwanted or unnecessary motion. Thus, all muscles working in unison to produce a desired movement are said to be working in a force-couple relationship (Levangie et al., 2019).

To ensure that the HMS moves properly, it must have proper force-couple relationships around its joints, which can only happen if the muscles are at the right length-tension relationships and the joints have proper arthrokinematics. Collectively, proper length-tension relationships in the muscles allow for proper posture and motion at the joints, which in turn allow for optimal force-couple relationships that produce the most efficient movement (Levangie et al., 2019).

### Muscular systems of the body

Not only do muscles work together in force-couple relationships around the joints but they also work together throughout the body forming a network of interworking systems that work to both stabilize and create movement in all three planes of motion. There are two overarching categories of these systems, known as the local and global muscular systems.

**Local muscular system**

Local muscles generally attach on or near the vertebrae and serve the primary purpose of stabilizing the trunk of the body. The local muscular system is composed of the *inner unit* of the core and includes the rotatores, multifidus, transversus abdominis, diaphragm, pelvic floor, and quadratus lumborum. Many of these muscles can be actively contracted and may also activate automatically in anticipation of limb or trunk movements, a neurological process known as the feed-forward activation (Masse-Alarie et al., 2012; Okubo et al., 2010). The local muscular system is thought to offer a segmental stabilization effect on the spine (Okubo et al., 2010). Due to this, some commonly refer to it simply as the stabilization system of the core.

STRETCH YOUR KNOWLEDGE

Evidence has shown that the feed-forward stabilization effect from the transversus abdominis and internal oblique musculature is delayed among people with lower back pain (Masse-Alarie et al., 2012). These intrinsic, core stabilizer muscles are often underactive in individuals with overactive hip flexors, causing an anterior tilting of the pelvis and low-back arch.

It should be noted, however, that there are also stabilization force-couples working together systematically in other regions of the body, known as joint support systems. For example, the rotator cuff of the shoulder is a group of muscles functioning in a similar manner to provide stabilization support for the glenohumeral (shoulder) joint (Day et al., 2012).

**Global muscular system**

The global muscular system is comprised of larger muscles that initiate movements and tend to function across one or more joints (Okubo et al., 2010). These muscles are generally larger and act as prime movers during many functional tasks, such as pushing, pulling, squatting, and walking. Because of this, the global muscular system is commonly referred to as the movement system. Examples of global muscles include the rectus abdominis, erector spinae, and latissimus dorsi.

The global muscular system’s main interconnected function is to transfer forces through the LPHC to create the most efficient movement possible while also providing additional support to protect the trunk and spine as the body moves. To better illustrate how muscles of the movement system work together in synchrony, the global muscles can be categorized into subsystems, which include the deep longitudinal, posterior oblique, anterior oblique, and lateral subsystems. These muscular subsystems highlight the functional elements of regional interdependence, as well as the necessary extensions of force-couple relationships. Without these subsystems, normal movement would be impaired, and the risk of injury and reduced performance would increase. Each of the subsystems is mirrored on the left and right sides of the body.

**Deep longitudinal subsystem**

The deep longitudinal subsystem (DLS) includes muscles of the lower leg, hamstrings, and lower back region (Figure 7-19). Working together synergistically, these muscles create a contracting tension to absorb and control ground reaction forces during gait (walking, running). For example, during or just prior to the heel strike phase of running, the long head of the biceps femoris (hamstring) contracts eccentrically to decelerate knee extension. Because the hamstrings attach at the pelvis, forces are transmitted up to the lower back muscles (erector spinae). Thus, the regional interdependence between the lower extremity ankle musculature, the hamstrings, and lower back is highlighted.

**Posterior oblique subsystem**

The posterior oblique subsystem (POS) is made up of the latissimus dorsi, thoracolumbar fascia (connective tissue of the low-back), and contralateral gluteus maximus. Figure 7-20 shows how the latissimus dorsi and contralateral gluteus maximus create a nearly straight line with each other across the sacroiliac joint (a joint between the sacrum and the ilium bones).

When the muscles of the POS contract, they produce a pulling force across the thoracolumbar fascia and a stabilization force at the sacroiliac joint. When mirrored for both the left and right sides of the body, the POS can be seen to form an X across the sacroiliac joint, creating the divergent tensions that lead to its stabilization effect.

This system works together with the DLS during gait just prior to or during heel strike as the gluteus maximus and latissimus dorsi are eccentrically loaded (Levangie et al., 2019). The force-couple relationship of the gluteus maximus and latissimus dorsi are highlighted here, which together provide a functional element of stability to the LPHC as a whole. Further to this point, the regional interdependence of the LPHC, middle, and upper back is highlighted by the interaction of the POS musculature.

**Anterior oblique subsystem**

The anterior oblique subsystem (AOS) is similar to the POS, just on the anterior side of the body. The muscles include the obliques, the adductor (inner) thigh muscles, and the hip external rotators. The obliques and contralateral (opposite) adductors are the most common visualization of this subsystem because of the X pattern made across the front of the body (Figure 7-21). The AOS creates stability from the trunk, through the pelvis, and to the hips and contributes to rotational movement. The AOS and POS work together as a global force-couple in enabling rotational force production in the transverse plane.

STRETCH YOUR KNOWLEDGE

During normal walking and running, the pelvis rotates in the transverse plane to facilitate the necessary momentum for the swing phase of gait where leg and thigh are advanced forward in the sagittal plane.

**Lateral subsystem**

The lateral subsystem (LS) is made up of the lateral hip (gluteus medius) and medial thigh muscles (adductors) and the contralateral quadratus lumborum, all of which provide movement in the frontal plane (Figure 7-22). Together, these muscles are tasked with creating and maintaining frontal plane (side-to-side) stabilization of the LPHC during movement.

The LS functions during numerous activities, which include movements that require a single-leg stance phase, such as seen during gait, running, and lunges. Furthermore, the LS provides stability of the lower extremities to prevent abnormal or unwanted frontal plane movement patterns during activities. For example, the LS prevents unwanted hip and thigh adduction during the squat (Kolber et al., 2017). An improperly working LS may be evident among those individuals who are unable to maintain appropriate lower-extremity alignment in the frontal plane (knees collapsing inward during a squat) (Kolber et al., 2017).

**Subsystem coordination**

While these subsystems have been described individually, it is important to recognize their coordinated and complex actions during movements. During physical activity, the subsystems work synergistically to perform efficient movements and stabilize the spine and pelvis.

Although the subsystems have been described only in the context of muscle activity, fitness professionals must remember that all movement relies on the nervous and skeletal systems as well. A deficit in joint function or failure of the nervous system to supply the appropriate signal can potentially lead to improper movement patterns, even if all muscles in a subsystem have proper length-tension relationships.

### Muscular leverage and Arthrokinematics

The amount of force that the HMS can produce relies on not only motor unit recruitment and muscle size but also the lever system of the joint. The musculoskeletal system is composed of bones, muscles, tendons, and ligaments, all of which create a series of levers and pulleys that generate force against external objects.

Skeletal muscles are attached to bones by tendons and produce movement by bending the skeleton at movable joints. Recall that joint motion is caused by muscles pulling on bones; muscles cannot actively push. Particular attachments of muscles to bones will determine how much force the muscle is capable of generating. For example, the quadriceps muscles can produce more force than muscles of the hand.

Most motion uses the principle of levers. A lever consists of a rigid bar that pivots around a stationary pivot point (fulcrum). In the human body, the fulcrum is the joint axis, bones are the levers, muscles create the motion (effort), and resistance can be the weight of a body part, or the weight of an object (Hamill & Knutzen, 2003; Levangie et al., 2019).

Levers are classified as first, second, and third class, depending on the relations among the fulcrum, the effort, and the resistance (Figure 7-23). First-class levers have the fulcrum in the middle, like a seesaw. Nodding the head is an example of a first-class lever, with the top of the spinal column as the fulcrum (Levangie et al., 2019).

Second-class levers have a resistance in the middle with the fulcrum and effort on either side, similar to a load in a wheelbarrow where the axle and wheel are the fulcrum points. The body acts as a second-class lever when one engages in a full-body push-up or calf raise. Using the calf raise exercise as an example, the ball of the foot is the fulcrum, the body weight is the resistance, and the effort is applied by the calf musculature (Levangie et al., 2019).

Third-class levers have the effort placed between the resistance and the fulcrum. The effort always travels a shorter distance and must be greater than the resistance. Most limbs of the human body operate as third-class levers. An example of a third-class lever is the human forearm; the fulcrum is the elbow, the effort is applied by the biceps brachii muscle, and the load is in the hand, such as a dumbbell when performing a biceps curl. Another example of a third-class lever is the standing hamstring curl, whereby the knee joint is the fulcrum, hamstring muscle is the effort, and resistance is at the ankle.

HELPFUL HINT

When trying to remember the levers, think of the pneumonic F-R-E-1-2-3. This means that fulcrum is in middle for a first-class lever (F, 1), resistance is in the middle for the second-class lever (R, 2), with the effort in middle for a third-class lever (E, 3).

Applying the concept of levers to the principles of the HMS, bones act as lever arms that move a load from the force applied by the muscles. This movement around an axis can be termed rotary motion and implies that the bones rotate around joints (Hamill & Knutzen, 2003; Levangie et al., 2019). This turning effect of the joint is often referred to as torque (Hamill & Knutzen, 2003; Levangie et al., 2019). Torque is a measurement of the amount of force that can cause an object to rotate around an axis. Torque relies on force, the length of the lever arm, and the angle between the force application and the lever arm.

HELPFUL HINT

An example of torque is using a wrench to loosen a bolt. The wrench serves as a lever, and torque would be a product of the force applied to the wrench and the length of the wrench’s handle. Increasing the length of the wrench’s handle would increase the torque applied to the bolt.

In resistance training, torque is applied so we can move our joints. Because the neuromuscular system is ultimately responsible for manipulating force, the amount of leverage the HMS will have (for any given movement) depends on the leverage of the muscles in relation to the resistance. The difference between the distance from the weight to the center of the joint, the muscle’s attachment, and the line of pull determines the efficiency with which the muscles manipulate the movement (Hamill & Knutzen, 2003; Levangie et al., 2019).

Because we cannot alter the attachment sites or the line of pull of our muscles through the tendon, the easiest way to alter the amount of torque generated at a joint is to move the resistance. In other words, the closer the weight is to the point of rotation, the less torque it creates (Figure 7-24). The farther away the weight is from the point of rotation, the more torque it creates. From a biomechanical perspective, the distance a weight is from the joint it is acting on directly determines the effort required of a muscle to move the weight (Levangie et al., 2019). Meaning, the farther the distance, the harder the muscle must work, thus, the greater activation of the muscle.

For example, when holding a dumbbell straight out to the side at arm’s length (shoulder abduction), the weight may be approximately 24 inches from the center of the shoulder joint. The prime mover for shoulder abduction is the deltoid muscle. If its attachment is approximately 2 inches from the joint center, there is a difference of 22 inches (11 times greater). However, if the weight is moved closer to the joint center, to the elbow, the resistance is only approximately 12 inches from the joint center. Now the difference is only 10 inches or 5 times greater. Essentially, the weight was reduced by half.

Many people performing side lateral raises with dumbbells do this inadvertently by bending their elbow and bringing the weight closer to the shoulder joint. Fitness professionals can use this principle as a regression to exercises that are too demanding by reducing the torque placed on the HMS or as a progression to increase the torque and place a greater demand on the HMS.

TRY THIS

Lie on your side with a weight wrapped around the ankle joint of your top leg and abduct your thigh. Now, repeat with the weight wrapped around your knee. Notice how much easier it was to abduct the hip when moving the resistance closer to the center of the moving joint (hip). That is because moving the weight closer to the joint reduces the amount of torque required.