CHAPTER 3

Motor Control and Motor Learning

OBJECTIVES After reading this chapter, the student will be able to

1. Define motor control and motor learning.
2. Understand the relationship among motor control, motor learning, and motor development.
3. Distinguish between the hierarchic and systems models of motor control.
4. Explain the development of postural control and balance.
5. Describe the role of experience and feedback in motor control and motor learning.
6. Relate motor control and motor learning theories to therapeutic intervention.

INTRODUCTION

Motor abilities and skills are acquired during the process of motor development through motor control and motor learning. Once a basic pattern of movement is established, it can be varied to suit the purpose of the task or the environmental situation in which the task is to take place. Early motor development displays a fairly predictable sequence of skill acquisition through childhood. However, the ways in which these motor abilities are used for function are highly variable. Individuals rarely perform the movement exactly the same way every time. This variability must be part of any model used to explain how posture and movement are controlled.

Any movement system must be able to adapt to the changing demands of the individual mover and environment in which the movement takes place. The individual mover must be able to learn from prior movement experiences. Different theories of motor control emphasize different developmental aspects of posture and movement. Development of postural control and balance is embedded in the development of motor control. Understanding the relationship among motor control, motor learning, and motor development provides a valuable framework for understanding the treatment of individuals with neurologic dysfunction at any age.

Motor development is a product as well as a process. The products of motor development are the milestones of the developmental sequence and the kinesiologic components of movement such as head and trunk control necessary for these motor abilities. These products are discussed in Chapter 4. The process of motor development is the way in which those abilities emerge. The process and the product are affected by many factors such as time (age), maturation (genes), adaptation (physical constraints), and learning. Motor development is the result of the interaction of the innate or built-in species blueprint for posture and movement and the person’s experiences with moving afforded by the environment. Sensory input is needed for the mover to learn about moving and the results of moving. Motor development is the combination of the nature of the mover and the nurture of the environment. Part of the genetic blueprint for movement is the means to control posture and movement. Motor development, motor control, and motor learning contribute to an ongoing process of change throughout the life span of every person who moves.

MOTOR CONTROL

Motor control, the ability to maintain and change posture and movement, is the result of a complex set of neurologic and mechanical processes. Those processes include motor, cognitive, and perceptual development. “The development of motor control begins with the control of self movements, and proceeds to the control of movements in relationship to changing conditions” (VanSant, 1995). Control of self-movement largely results from the development of the neuromotor systems. As the nervous and muscular systems mature, movement emerges. Motor control allows the nervous system to direct what muscles should be used, in what order, and how quickly, to solve a movement problem. The infant’s first movement problem relates to overcoming the effect of gravity. A second but related problem is how to move a larger head as compared with a smaller body to establish head control. Later, movement problems are related to controlling the interaction between stability and mobility of the head, trunk, and limbs. Control of task-specific movements such as stringing beads or riding a tricycle...
depends on cognitive and perceptual abilities. The task to be carried out by the person within the environment dictates the type of movement solution that is going to be needed.

Because the motor abilities of a person change over time, the motor solutions to a given motor problem may also change. The motivation of the individual to move may also change over time and may affect the intricacy of the movement solution. An infant encountering a set of stairs sees a toy on the top stair. The infant creeps up the stairs but then has to figure out how to get down: cry for help, bump down on the buttocks, creep down backward, or even attempt creeping down forward. A toddler faced with the same dilemma may walk up the same set of stairs one step at a time holding onto a railing, and descend in a sitting fashion holding the toy, or may be able to hold the toy with one hand and the railing with the other and descend the same way as walking up the stairs. The child will walk up and down without holding on, and an even older child may run up those same stairs. The relationship among the task, the individual, and the environment is depicted graphically in Figure 3-1. All three components must be considered when thinking about motor control.

**Motor Control Time Frame**

*Motor control* happens not in the space of days or weeks, as is seen in motor development, but in fractions of seconds. Figure 3-2 illustrates a comparison of time frames associated with motor control, motor learning, and motor development. *Motor control* occurs because of physiologic processes that happen at cellular, tissue, and organ levels. Physiologic processes have to happen quickly to produce timely and efficient movement. What good does it do if you extend an outstretched arm after having fallen down? Extending your arm in a protective response has to be quick enough to be useful, that is, to break the fall. Individuals with nervous system disease may exhibit the correct movement pattern, but they have impaired timing, producing the movement too slowly to be functional, or they have impaired sequencing of muscle activation, producing a muscle contraction at the wrong time. Both of these problems, impaired timing and impaired sequencing, are examples of deficits in motor control.

**Role of Sensation in Motor Control**

Sensory information plays an important role in motor control. Initially, sensation cues reflexive movements in which few cognitive or perceptual abilities are needed. A sensory stimulus produces a reflexive motor response. Touching the lip of a newborn produces head turning, whereas stroking a newborn’s outstretched leg produces withdrawal. Sensation is an ever-present cue for motor behavior in the seemingly reflex-dominated infant. As voluntary movement emerges during motor development, sensation provides feedback accuracy for hand placement during reaching and later for creeping. Sensation from weight bearing reinforces maintenance of developmental postures such as the prone on elbows position and the hands and knees position. Sensory information is crucial to the mover when interacting with objects and maneuvering within an environment. Figure 3-3 depicts how sensation provides the necessary feedback for the body to know whether a task such as reaching or walking was performed and how well it was accomplished.

**Theories of Motor Control**

Many theories of motor control have been posited, but only those most closely related to early motor development are discussed in this chapter. The first theoretic model of motor control presented is the traditional hierarchic one. Second, a systems model of motor control is outlined.
Hierarchic Theory

Many theories of motor control exist, but the most traditional one is that of a hierarchy. Characteristics of a hierarchic model of motor control include a top-down perspective. The cortex of the brain is seen as the highest level of control, with all subcortical structures taking orders from it. The cortex can and does direct movement. A person can generate an idea about moving in a certain way and the nervous system carries out the command. The ultimate level of motor control, voluntary movement, is achieved by maturation of the cortex.

In the hierarchic model, a relationship exists between the maturation of the developing brain and the emergence of motor behaviors seen in infancy. One of the ways in which nervous system maturation has been routinely gauged is by the assessment of reflexes. The reflex is seen as the basic unit of movement in this motor control model. Movement is acquired from the chaining together of reflexes and reactions. A reflex is the pairing of a sensory stimulus with a motor response, as shown in Figure 3-4. Some reflexes are simple and others are complex. The simplest reflexes occur at the spinal cord level. An example of a spinal cord level reflex is the flexor withdrawal. A touch or noxious stimulus applied to the bottom of the foot produces lower extremity withdrawal. These reflexes are also referred to as primitive reflexes because they occur early in the life span of the infant. Another example is the palmar grasp. Primitive reflexes are listed in Table 3-1.

The next higher level of reflexes comprises the tonic reflexes, which are associated with the brain stem of the
TABLE 3-1  Primitive Reflexes

<table>
<thead>
<tr>
<th>Reflex</th>
<th>Age at Onset</th>
<th>Age at Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suck-swallow</td>
<td>28 weeks' gestation</td>
<td>2–5 months</td>
</tr>
<tr>
<td>Rooting</td>
<td>28 weeks' gestation</td>
<td>3 months</td>
</tr>
<tr>
<td>Flexor</td>
<td>28 weeks' gestation</td>
<td>1–2 months</td>
</tr>
<tr>
<td>Crossed extension</td>
<td>28 weeks' gestation</td>
<td>1–2 months</td>
</tr>
<tr>
<td>Moro</td>
<td>28 weeks' gestation</td>
<td>4–6 months</td>
</tr>
<tr>
<td>Plantar grasp</td>
<td>28 weeks' gestation</td>
<td>9 months</td>
</tr>
<tr>
<td>Positive support</td>
<td>35 weeks' gestation</td>
<td>1–2 months</td>
</tr>
<tr>
<td>Asymmetric tonic neck</td>
<td>Birth</td>
<td>4–6 months</td>
</tr>
<tr>
<td>Palmar grasp</td>
<td>Birth</td>
<td>9 months</td>
</tr>
<tr>
<td>Symmetric tonic neck</td>
<td>4–6 months</td>
<td>8–12 months</td>
</tr>
</tbody>
</table>


Motor Control and Motor Learning  =  CHAPTER 3  31

central nervous system. These reflexes produce changes in muscle tone and posture. Examples of tonic reflexes exhibited by infants are the tonic labyrinthine reflex and the asymmetric tonic neck reflex. In the latter, when the infant’s head is turned to the right, the infant’s right arm extends and the left arm flexes. The tonic labyrinthine reflex produces increased extensor tone when the infant is supine and increased flexor tone in the prone position. In this model, most infantile reflexes (sucking and rooting), primitive spinal cord reflexes, and tonic reflexes are integrated by four to six months. Exceptions do exist. Integration is the mechanism by which less mature responses are incorporated into voluntary movement.

In the hierarchic model, nervous system maturation is seen as the ultimate determinant of the acquisition of postural control. As the infant develops motor control, brain structures above the spinal cord begin to control posture and movement until the ultimate balance reactions are achieved. The ultimate balance reactions are the righting, protective, and equilibrium reactions.

Righting and equilibrium reactions are complex postural responses that continue to be present even in adulthood. These postural responses involve the head and trunk and provide the body with an automatic way to respond to movement of the center of gravity within and outside the body’s base of support. Extremity movements in response to quick displacements of the center of gravity out of the base of support are called protective reactions. These are also considered postural reactions and serve as a back-up system should the righting or equilibrium reaction fail to compensate for a loss of balance. According to the hierarchic model of motor control, automatic postural responses are associated with the midbrain and cortex (Fig. 3-5).

The farther up one goes in the hierarchy, the more inhibition there is of lower structures and the movements they produce, that is, reflexes. Tonic reflexes inhibit spinal cord reflexes, and righting reactions inhibit tonic reflexes. Inhibition allows previously demonstrated stimulus-response patterns of movement to be integrated or modified into more volitional movements. A more complete description of these postural responses is given as part of the development of postural control from a hierarchic perspective.

Development of Motor Control. Development of motor control can be described by the relationship of mobility and stability of body postures (Sullivan et al., 1982) and by the acquisition of automatic postural responses (Cech and Martin, 2002). Initial random movements (mobility) are followed by maintenance of a posture (stability), movement within a posture (controlled mobility), and finally, movement from one posture to another posture (skill). The sequence of acquiring motor control is seen in key developmental postures in Figure 3-6. With acquisition of each new posture comes the development of control within that posture. For example, weight shifting in prone precedes rolling prone to supine; weight shifting on hands and knees precedes creeping; and crawling, or sideways weight shifting in standing, precedes walking. The actual motor accomplishments of rolling, reaching, creeping, cruising, and walking are skills in which mobility is combined with stability and the distal parts of the body, that is, the extremities, are free to move. The infant develops motor and postural control in the following order: mobility; stability; controlled mobility; and finally, skill.

Stages of Motor Control

Stage One. Stage one is mobility, when movement is initiated. The infant exhibits random movements within an available range of motion for the first three months of development. Movements during this stage are erratic. They lack purpose and are often reflex based. Random limb movements are made when the infant’s head and trunk are
supported in the supine position. Mobility is present before stability. In adults, mobility refers to the availability of range of motion to assume a posture and the presence of sufficient motor unit activity to initiate a movement.

**Stage Two.** Stage two is stability, the ability to maintain a steady position in a weight-bearing, antigravity posture. It is also called *static postural control*. Developmentally, stability is further divided into tonic holding and co-contraction. Tonic holding occurs at the end of the shortened range of movement and usually involves isometric movements of antigravity postural extensors (Stengel et al., 1984). Tonic holding is most evident when the child maintains the pivot prone position (prone extension), as seen in Figure 3-6. Postural holding of the head begins asymmetrically in
prone, is followed by holding the head in midline, and progresses to holding the head up past 90 degrees from the support surface. In the supine position, the head is turned to one side or the other; then it is held in midline; and finally, it is held in midline with a chin tuck while the infant is being pulled to sit at four months (Fig. 3-7).

Co-contraction is the simultaneous static contraction of antagonistic muscles around a joint to provide stability in a midline position or in weight bearing. Various groups of muscles, especially those used for postural fixation, allow the developing infant to hold such postures as prone extension, prone on elbows and hands, all fours, and semi-squat. Co-contraction patterns are shown in Figure 3-6. Once the initial relationship between mobility and stability is established in prone and later in all fours and standing, a change occurs to allow mobility to be superimposed on the already established stability.

**Stage Three.** Controlled mobility is mobility superimposed on previously developed postural stability by weight shifting within a posture. Proximal mobility is combined with distal stability. This controlled mobility is the third stage of motor control and occurs when the limbs are weight bearing and the body moves, such as in weight shifting on all fours or in standing. The trunk performs controlled mobility when it is parallel to the support surface or when the line of gravity is perpendicular to the trunk. In prone and all fours positions, the limbs and the trunk are performing controlled mobility when weight shifting weight.

The infant’s first attempts at weight shifts in prone happen accidentally with little control. As the infant tries to reproduce the movement and practices various movement combinations, the movement becomes more controlled. Another example of controlled mobility is demonstrated by an infant in a prone on elbows position who sees a toy. If the infant attempts to reach for the toy with both hands, which is typical before reaching with one hand, the infant is likely to fall on her face. If the infant perseveres and learns to shift weight onto one elbow, the chance of obtaining the toy is better. Weight bearing, weight shifting, and co-contraction of muscles around the shoulder are crucial to the development of shoulder girdle stability. Proximal shoulder stability supports upper-extremity function for skilled distal manipulation. If this stability is not present, distal performance may be impaired. Controlled mobility is also referred to as **dynamic postural control**.

**Stage Four.** Skill is the most mature type of movement and is usually mastered after controlled mobility within a posture. For example, after weight shifting within a posture such as in a hands-and-knees position, the infant frees the opposite arm and leg to creep reciprocally. Creeping is a skilled movement. Other skill patterns are also depicted in Figure 3-6. Skill patterns of movement occur when mobility is superimposed on stability in non–weight bearing; proximal segments stabilize while distal segments are free for movement. The trunk does skilled work when it is upright or parallel to the force of gravity. In standing, only the lower extremities are using controlled mobility when weight shifting occurs. If the swing leg moves, it performs skilled work while the stance limb performs controlled mobility. When an infant creeps or walks, the limbs that are in motion are using skill, and those in contact with the support surface are using controlled mobility. Creeping and walking are considered skilled movements. Skilled movements involve manipulation and exploration of the environment.

**Development of Postural Control.** Postural control develops in a cephalocaudal direction in keeping with Gesell’s developmental principles, which are discussed in Chapter 4. Postural control is demonstrated by the ability to maintain the alignment of the body—specifically, the alignment of body parts relative to each other and the external environment. “The functions that maintain or preserve alignment have been called ‘equilibrium’ or ‘balance’” (VanSant, 1995). The infant learns to use a group of automatic postural responses to attain and maintain an upright erect posture. These postural responses are continuously used when balance is lost in an effort to regain equilibrium.

The sequence of development of postural reactions entails righting reactions, followed by protective reactions, and last, equilibrium reactions. In the infant, head righting reactions develop first and are followed by the development of trunk righting reactions. Protective reactions of the extremities emerge next in an effort to safeguard balance in higher postures such as sitting. Finally, equilibrium reactions develop in all postures beginning in prone. One way of looking at these postural reactions is based on a hierarchic view of how the nervous system works, as seen in Figure 3-5. As the nervous system matures, ever higher centers are responsible for coordinating the infant’s postural responses to shifts of center of mass within the base of support. Figure 3-8 shows a hierarchic representation of how muscle tone, reflexes, and reactions are related to attainment of selective voluntary movement, postural control,
and equilibrium reactions. Traditionally, posture and movement develop together in a cephalocaudal direction, so balance is achieved in different positions relative to gravity. Head control is followed by trunk control; control of the head on the body and in space comes before sitting and standing balance.

**Righting Reactions.** Righting reactions are responsible for orienting the head in space and keeping the eyes and mouth horizontal. This normal alignment is maintained in upright vertical position and when the body is tilted or rotated. Righting reactions involve head and trunk movements to maintain or regain orientation or alignment. Some righting reactions begin at birth, but most are evident between four and six months of age, as listed in Table 3-2. Gravity and change of head or body position provide cues for the most frequently used righting reactions. Vision cues the optical righting reaction, gravity cues the labyrinthine righting reaction, and touch of the support surface to the abdomen cues the body-on-the-head reaction. These three head righting reactions assist the infant in developing head control.

Head turning can produce neck-on-body righting, in which the body follows the head movement. If either the upper or lower trunk is turned, a body-on-body righting reaction is elicited. Either neck-on-body righting or body-on-body righting can produce log rolling or segmental rolling. Log rolling is the immature righting response seen in the first three months of life; the mature response emerges at around four months of age. The purpose of righting reactions is to maintain the correct orientation of the head and body in relation to the ground. Head and trunk righting reactions occur when weight is shifted within a base of support; the amount of displacement determines the degree of response. For example, in the prone position, slow weight shifting to the right produces a lateral bend or righting of the head and trunk to the left. If the displacement is too fast, a different type of response may be seen, a protective response. Slower displacements are more likely to elicit head and trunk righting. These can occur in any posture and in response to anterior, posterior, or lateral weight shifts.

Righting reactions have their maximum influence on posture and movement between 10 and 12 months of age, although they are said to continue to be present until the child is five years old. Righting reactions are no longer considered to be present if the child can come to standing from a supine position without using trunk rotation. The presence of trunk rotation indicates a righting of the body around the long axis. Another explanation for the change in motor behavior could be that the child of five years has sufficient abdominal strength to perform the sagittal plane movement of rising straight forward and attaining standing without using trunk rotation.

**Protective Reactions.** Protective reactions are extremity movements that occur in response to rapid displacement of

<table>
<thead>
<tr>
<th>TABLE 3-2 Righting and Equilibrium Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction</strong></td>
</tr>
<tr>
<td><strong>Head righting</strong></td>
</tr>
<tr>
<td>Neck (immature)</td>
</tr>
<tr>
<td>Labyrinthine</td>
</tr>
<tr>
<td>Optical</td>
</tr>
<tr>
<td>Neck (mature)</td>
</tr>
<tr>
<td><strong>Trunk righting</strong></td>
</tr>
<tr>
<td>Body (immature)</td>
</tr>
<tr>
<td>Body (mature)</td>
</tr>
<tr>
<td>Landau</td>
</tr>
<tr>
<td><strong>Protective</strong></td>
</tr>
<tr>
<td>Downward lower extremity</td>
</tr>
<tr>
<td>Forward upper extremity</td>
</tr>
<tr>
<td>Sideways upper extremity</td>
</tr>
<tr>
<td>Backward upper extremity</td>
</tr>
<tr>
<td>Stepping lower extremity</td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
</tr>
<tr>
<td>Prone</td>
</tr>
<tr>
<td>Supine</td>
</tr>
<tr>
<td>Sitting</td>
</tr>
<tr>
<td>Quadruped</td>
</tr>
<tr>
<td>Standing</td>
</tr>
</tbody>
</table>

The infant is always working on more than one postural change at 9 to 12 months, and standing at 12 to 21 months. Supine at 7 to 8 months, sitting at 7 to 8 months, on all fours at 9 to 12 months, and standing at 12 to 21 months. The three expected responses to a lateral displacement of the body by diagonal or horizontal forces. They have a predictable developmental sequence, which can be found in Table 3-2. By extending one or both extremities, the individual prepares for a fall or prepares to catch himself. A four-month-old infant’s lower extremities extend and abduct when the infant is held upright in vertical and quickly lowered toward the supporting surface. After six months, the upper extremities show forward protective extension, followed by sideways extension at seven to eight months and backward extension at nine months. Protective staggering of the lower extremities is evident by 15 to 17 months (Barnes et al., 1978). Protective reactions of the extremities should not be confused with the ability of the infant to prop on extended arms, a movement that can be self-initiated by pushing up from prone or by being placed in the position by a caregiver. Because the infant must be able to bear weight on extended arms to exhibit protective extension, propping or pushing up can be useful as a treatment intervention.

Equilibrium Reactions. Equilibrium reactions are the most advanced postural reactions and are the last to develop. These reactions allow the body as a whole to adapt to slow changes in the relationship of the center of gravity with the base of support. By incorporating the already learned head and trunk righting reactions, the equilibrium reactions add extremity responses to flexion, extension, or lateral head and trunk movements to regain equilibrium. In lateral weight shifts, the trunk may rotate in the opposite direction of the weight shift to further attempt to maintain the body’s center of gravity within the base of support. The trunk rotation is evident only during lateral displacements. Equilibrium reactions can occur if the body moves relative to the support surface, as in leaning sideways, or if the support surface moves, as when an individual is on a tilt board. In the latter case, these movements are called tilt reactions. The three expected responses to a lateral displacement of the center of gravity toward the periphery of the base of support in standing are as follows: (1) lateral head and trunk righting occurs away from the weight shift; (2) the arm and leg opposite the direction of the weight shift abduct; and (3) trunk rotation away from the weight shift may occur. If the last response does not happen, the other two responses can provide only a brief postponement of the inevitable fall. At the point at which the center of gravity leaves the base of support, protective extension of the arms may occur, or a protective step or stagger may reestablish a stable base. Thus, the order in which the reactions are acquired developmentally is different from the order in which they are used for balance.

Equilibrium reactions also have a set developmental sequence and timetable (see Table 3-2). Because prone is a position from which to learn to move against gravity, equilibrium reactions are seen first in prone at 6 months, then supine at 7 to 8 months, sitting at 7 to 8 months, on all fours at 9 to 12 months, and standing at 12 to 21 months. The infant is always working on more than one postural level at a time. For example, the eight-month-old infant is perfecting supine equilibrium reactions while learning to control weight shifts in sitting, freeing first one hand and then both hands. Sitting equilibrium reactions mature when the child is creeping. Standing and cruising are possible as equilibrium reactions are perfected on all fours. The toddler is able to increase walking speed as equilibrium reactions mature in standing.

Systems Models of Motor Control

A systems model of motor control is currently used to describe the relationship of various brain and spinal centers working together to control posture and movement. However, because more than one “systems” theory of motor control exists, some of the features that make these approaches different from the traditional top-down hierarchic model are identified. Inherent in any systems theory is the view that motor control is accomplished by the complex interaction of many systems of the body, not just the nervous system. The musculoskeletal system and the cardiopulmonary system as well as the nervous system are involved in motor control. If movement were to be considered a system of the body such as the pulmonary system, posture would be listed as one of the components. Posture should be considered its own system. Depending on the task to be carried out, such as playing the piano or walking, different postures would be required, such as sitting or standing, respectively. Certain activities such as walking can be done only in certain postures. The complex interaction of postural control’s component processes is discussed in further detail in the next section.

A second characteristic of systems theories of motor control is that posture and movement are thought to be self-organizing. As the body grows and various body systems mature, the speed of nervous system responses increases, and the changing relationship among the body systems produces different motor responses. The basic functional unit in the systems theories is the movement pattern. Movement emerges from this complex interaction of the changing body’s systems. Prior to attaining upright standing, other means of mobility are generated in movement patterns such as rolling or creeping. Erect standing is the body’s answer to how to achieve mastery over gravity, and walking is the logical solution to finding an efficient means of mobility.

Feedback is a third fundamental characteristic of systems models of motor control. To control movements, the individual needs to know whether the movement has been successful in the past. In a closed-loop model of motor control, sensory information is used as feedback to the nervous system to provide assistance with the next action. A person engages in closed-loop feedback when playing a video game that requires guiding a figure across the screen. This type of feedback provides self-control of movement. A loop is formed from the sensory information that is generated as part of the movement and is fed back to the brain. This sensory information influences future motor actions. Errors
that can be corrected with practice are detected, and performance can be improved. This type of feedback is shown in Figure 3-9.

By contrast, in an *open-loop model* of motor control, movement is cued either by a central structure, such as a motor program, or by sensory information from the periphery. The movement is performed without feedback. When a baseball pitcher throws a favorite pitch, the movement is too quick to allow feedback. Errors are detected after the fact. An example of action spurred by external sensory information is what happens when a fire alarm sounds. The person hears the alarm and moves before thinking about moving. This type of feedback model is also depicted in Figure 3-9 and is thought to be the way in which fast movements are controlled. Another way to think of the difference between closed-loop and open-loop motor control can be exemplified by someone who learns to play a piano piece. The piece is played slowly while the student is learning and receiving feedback, but once it is learned, the student can sit down and play it through quickly, from beginning to end.

**Components of the Postural Control System.** In the systems models, both posture and movement are considered systems that represent the interaction of other biologic and mechanical systems and movement components. The relationship between posture and movement is also called *postural control*. As such, posture implies a readiness to move, an ability not only to react to threats to balance but also to anticipate postural needs to support a motor plan. A motor plan is a plan to move, usually stored in memory. Seven components have been identified as part of a postural control system, as depicted in Figure 3-10. These are limits of stability, environmental adaptation, the musculoskeletal system, predictive central set, motor coordination, eye-head stabilization, and sensory organization. Postural control is a complex process that must be ongoing.

**Limits of Stability.** Limits of stability are the boundaries of the base of support of any given posture. As long as the center of gravity is within the base of support, the person is stable. An infant’s base of support is constantly changing relative to the body’s size and amount of contact the body has with the supporting surface. Supine and prone are more stable postures by virtue of having so much of the body in contact with the support surface. However, in sitting or standing, the size of the base of support depends on the position of

---

the lower extremities and on whether the upper extremities are in contact with the supporting surface. In standing, the area in which the person can move within the limits of stability or base of support is called the cone of stability, as shown in Figure 3-11. The central nervous system perceives the body’s limits of stability through various sensory cues.

**Environmental Adaptation.** Our posture adapts to the environment in which the movement takes place in much the same way as we change our stance if riding on a moving bus and have nothing stable to grasp. Infants have to adapt to moving in a gravity-controlled environment after being in utero. The body’s sensory systems provide input that allows the generation of a movement pattern that dynamically adapts to current conditions. In the systems model, this movement pattern is not limited to the typical postural reactions.

**Musculoskeletal System.** The two major systems that contribute most to postural control and therefore to balance are the musculoskeletal and neurologic systems. The musculoskeletal system provides the mechanical structure for any postural response. This response includes postural alignment and musculoskeletal flexibility of all body segments such as the neck, thorax, pelvis, hip, knee, and ankle. The neurologic system processes vital sensory information to choose the correct postural and motor response, to plan for the response, and to execute the response. When both the nervous and muscular systems are functioning optimally, postural responses are appropriate and adequate to maintain balance.

**Predictive Central Set.** Predictive central set is that component of postural control that can best be described as postural readiness. Sensation and cognition are used as an anticipatory cue prior to movement as a means of establishing a state of postural readiness. This readiness or postural set must be present to support movement. Think of how difficult it is to move in the morning when first waking up; the body is not posturally ready to move. Contrast this state of postural unpreparedness with an Olympic competitor who is so focused on the motor task at hand that every muscle has been put on alert, ready to act at a moment’s notice. Predictive central set is critical to postural control. Mature motor control is characterized by the ability of the body, through the postural set, to anticipate what movement is to come, such as when you tense your arm muscles prior to picking up a heavy weight. Anticipatory preparation is an example of feedforward processing, in which sensory information is sent ahead to prepare for the movement to follow, in contrast to feedback, in which sensation from a movement is sent back to the nervous system for comparison and error detection. Many adult patients with neurologic deficits lack this anticipatory preparation, so postural preparedness is often a beginning point for treatment. Children with neurologic deficits may never have experienced using sensation in this manner.

**Motor Coordination.** Motor coordination is the ability to sequence muscle responses in a timely fashion to respond to displacements of the center of gravity within the base of support. According to Maki and McIlroy (1996), the process by which the central nervous system generates the patterns of muscle activity required to regulate the relationship between the center of gravity and the base of support.
is postural control. Postural sway in standing is an example of such motor coordination. Sway strategies have been described by Nashner (1990) in his systems model of postural control.

**Eye-Head Stabilization.** The visual system must provide accurate information about the surrounding environment during movement and gait. The vestibular system also coordinates with the visual system, so if the head is moving either with or without the body’s moving, a stable visual image of the environment continues to be transmitted to the brain. If the head or eyes cannot be stable, movement can be impaired. Clinical examples can be seen in the individual with nystagmus or lack of head control.

**Sensory Organization.** Sensory organization is the province of the nervous system. Three sensory systems are primarily used for posture and balance and therefore motor control: visual, vestibular, and somatosensory. Vision is critical for the development of balance during the first three years of life. Development of head control is impeded in infants with inaccurate visual input. Researchers have also demonstrated how powerful vision is in directing movement by using a visual cliff. A baby will stop creeping across a floor because of the visual illusion that the depth of the surface has changed.

Vestibular input is relayed to the brain by the structures within the middle ear whenever the head moves. The tonic labyrinthine reflex is cued by the labyrinths within the ear that detect the head’s relation to gravity. Head lifting behavior in infants is related to maintaining the correct orientation of the head to gravity. Early motor behaviors stimulate vestibular receptors. A close relationship also exists between eye and head movements, to provide a stable visual image even when the body or head is moving. The eyes have to be able to move separately from the head, to dissociate, and to scan the surroundings to assess environmental conditions. In adults, information from the vestibular system can resolve a postural response dilemma when sensory data are conflicting about whether the body is moving.

Somatosensation is the combination of touch and proprioceptive information the body receives from being in contact with the support surface and from joint position. The ability of an individual to use this information for postural responses occurs first in the form of reflexes and then as more sophisticated input from the unconscious movement of weight-bearing joints in contact with the support surface. Not until middle to late childhood is this source of information consistently used for balance.

**Nashner’s Model of Postural Control.** Nashner’s (1990) model for the control of standing balance describes three common sway strategies seen in quiet standing: the ankle strategy, the hip strategy, and the stepping strategy. An adult in a standing position sways about the ankles. This strategy depends on having a solid surface in contact with the feet and intact visual, vestibular, and somatosensory systems. If the person sways backward, the anterior tibialis fires to bring the person forward; if the person sways forward, the gastrocnemius fires to bring the person back to midline.

A second sway strategy, called the hip strategy, is usually activated when the base of support is narrower, as when standing crosswise on a balance beam. The ankle strategy is not effective in this situation because the entire foot is not in contact with the support surface. In the hip strategy, muscles are activated in a proximal-to-distal sequence, that is, muscles around the hip are activated to maintain balance before those muscles at the ankles. The last sway strategy is that of stepping. If the speed and strength of the balance disturbance are sufficient, the individual may take a step to prevent loss of balance or a fall. This stepping response is the same as a lower extremity protective reaction. The ankle and the hip strategies are shown in Figure 3-12.

The visual, vestibular, and somatosensory systems previously discussed provide the body with information about movement and cue-appropriate postural responses in standing. For the first three years of life, the visual system appears to be the dominant sensory system for posture and balance. Vision is used both as feedback as the body moves and as feedforward to anticipate that movement will occur. Children as young as 18 months demonstrate an ankle strategy when quiet standing balance is disturbed (Forssberg and Nashner, 1982). However, the time it takes for them to respond is longer than in adults. Results of studies of four- to six-year-old children’s responses to disturbances of standing balance were highly variable, almost as if balance was worse in younger children. Sometimes the children demonstrated an ankle strategy, and sometimes they demonstrated a hip strategy (Shumway-Cook and Woollacott, 1985). Not until 7 to 10 years of age were children able to demonstrate consistent ankle strategies as quickly as adults (Shumway-Cook and Woollacott, 1985). This finding is in keeping with the knowledge that the nervous system appears to be mature.

Comparison of Hierarchic and Systems Models of Motor Control

**Motor control** is the control of posture and movement that supports the initial acquisition of motor abilities and their continual adaptation to the changing physical demands encountered throughout the life span. Without appropriate motor control, motor development would not proceed normally. Children and adults with neuromuscular disorders exhibit abnormal motor control and subsequent abnormal patterns of movement. Whether these abnormal patterns of movement are learned or are the result of factors that hinder (constraint) movement because of existing disease remains to be proven. Constraints can be such things as lack of strength, endurance, and range of motion. Constraints to developmental change are further discussed at the end of the next section on motor learning.

Two views of motor control and their relation to the development of posture and movement have been presented. Although the two views of postural control, the classic hierarchic-maturational view and the action-oriented systems view, may seem to be in conflict, they are not. The infant may initially learn the automatic postural system through maturation and the action system through experience, so both possibilities are available to the mover. We know that the nervous system is organized in many different ways to respond to varying movement demands.

Which model of motor control, **hierarchic or systems**, best explains changes in posture and movement seen across the life span depends on the age and experience of the mover, the physical demands of the task to be carried out, and the environment in which the task is to be performed. The way in which a 2-year-old child may choose to solve the movement problem of how to reach the cookie jar in the middle of the kitchen table will be different from the solution devised by a 12-year-old child. The younger the child, the more homogenous the movement solutions are. As the infant grows into a child, the movement solutions seem to become more varied, and that, in and of itself, may reflect the self-organizing properties of the systems of the body involved in posture and movement. A comparison of the two models of control is found in Table 3-3.

Posture has a role in movement before, during, and after a movement. Posture should be thought of as preparation for movement. A person would not think of starting to learn to in-line skate from a seated position. The person would first stand with the skates on and try to balance while standing before taking off on the skates. The person’s body tries to anticipate the posture that will be needed before the movement. Therefore, with patients who have movement dysfunction, the clinician must prepare them to move before movement is initiated.

When learning to in-line skate, the person continually tries to maintain an upright posture. Postural control maintains alignment while the person moves forward. If the person loses balance and falls, posture is reactive. When falling, an automatic postural response comes from the nervous system—arms are extended in protection. Stunt performers have learned to avoid injury by landing on slightly bent arms, then tucking and rolling. Through the use of prior experience and knowledge of present conditions, the end result is modified and a full-blown protective response is prevented. In many instances, automatic postural responses must be unlearned to learn and perfect fundamental motor skills. Think of a broad jumper who is airborne and moving forward in a crouch position. To prevent falling backward he must keep his arms forward and counteract the natural tendency to reach back.

**Motor Learning**

**Motor learning** is defined as the process that brings about a permanent change in motor performance as a result of practice or experience (Schmidt and Lee, 1999). Infants practice many movements during the first year of life to achieve upright locomotion. Part of learning tasks that involve self-movement is to learn the rules of moving. Motor learning occurs when the rules and the tasks are perfected. Early in life, these tasks are the motor milestones, whereas later in life, these tasks involve other motor skills. Task-specific abilities, other than walking, that must be learned in infancy include self-feeding and object play. Fundamental motor patterns such as running, hopping, throwing, and catching are learned in childhood. Many sports-related skills begun in childhood are often carried over into leisure activities. Motor tasks in adolescence and adulthood are primarily related to jobs and leisure. These tasks may require manipulation of a computer keyboard, driving a car, or playing golf.

**Motor Learning Time Frame**

The process by which a person learns the skills that make up the developmental sequence and learns how to execute and

---

**TABLE 3-3** Comparison of Hierarchic and Systems Models of Motor Control

<table>
<thead>
<tr>
<th>Features</th>
<th>Hierarchic Model</th>
<th>Systems Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis of control</td>
<td>CNS maturation</td>
<td>Self-organizing systems (MS, CNS, CP)</td>
</tr>
<tr>
<td>Type of postural response</td>
<td>Reactive</td>
<td>Steady state and anticipatory</td>
</tr>
<tr>
<td>Examples of postural response</td>
<td>Righting, equilibrium, protective reactions</td>
<td>Standing sway strategies, postural readiness</td>
</tr>
</tbody>
</table>

CNS, central nervous system; CP, cardiopulmonary; MS, musculoskeletal.
Phases of Motor Learning

Three phases of motor learning have been identified by Fitts and Posner (1967). They are the cognitive phase, the associative phase, and the autonomous phase. From the previous discussion of motor control, it may be apparent that these three phases of learning may be linked to different types of motor control. The phases of motor learning are found in Table 3-4.

<table>
<thead>
<tr>
<th>TABLE 3-4 Phases of Motor Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features</strong></td>
</tr>
<tr>
<td>Degree of attention to task</td>
</tr>
<tr>
<td>Sensory assistance used for learning</td>
</tr>
<tr>
<td>Gestalt of the task</td>
</tr>
<tr>
<td>Visually guided</td>
</tr>
<tr>
<td>Type of feedback</td>
</tr>
</tbody>
</table>

Cognitive Phase

When a task is completely new to a learner, cognition has to play a major role in learning what the task entails. The first phase of motor learning can be associated with a closed-loop model of control because sensory input is used by the nervous system to learn about moving and about the desired movement. To learn any new movement, such as driving a car or knitting, the task must be thought about; hence, the phase is called cognitive. Others refer to this as the verbal-cognitive stage because verbal directions are given in the form of instructions to someone old enough to understand them. Remember being taught to ride a bike or swing on a swing; verbal directions were useful regarding the speed to pedal or when to pump the legs. Children with cognitive deficits acquire motor milestones at a slower rate. Patients who have difficulty thinking and processing verbal information such as after a traumatic brain injury or a cerebrovascular accident have difficulty in this stage of motor learning. You cannot be thinking about what your name is when trying to learn to transfer. In this stage, a great deal of attention must be devoted to learning a new motor task or relearning a previously known task. The ability to attend may be lacking in a person after a traumatic brain injury or cerebrovascular accident. Consider the look of concentration on an infant’s face when trying to turn over, reach for an object, or walk for the first time. The slightest distraction can interrupt concentration and may result in an unsuccessful attempt. Consider, too, how much a patient with a neurologic deficit must concentrate to try to relearn a movement that was once performed easily. Mastery of the task is not the goal of this first stage of motor learning. The learner must understand “what to do,” so visually guided movements may be helpful during this phase. The goal is to obtain an overall idea or gestalt of what the task is all about, and again, this goal may be difficult in individuals with cognitive deficits.

Associative Phase

The second stage of motor learning is the associative phase. Cognition is still important, but now the person associates aspects of the motor performance of the task with success or failure. Learning takes place with each new trial, and errors are detected and corrected with the next attempt. Sensory feedback is a crucial part of this phase. Schmidt (1991) called this the motor stage of motor learning. Success comes with practice and the ability of the person to detect errors.
and to correct them. As small details of the movement task are perfected, speed and efficiency of movement improve. For example, once an infant learns to creep forward on hands and knees, it may appear that the baby is quicker than the adult who is racing across the living room before some knickknack can be reached. Further improvement in movement efficiency comes through practice in a variety of settings. This stage of motor learning lasts longer than the first one. Now the learner is concentrating on “how to do” the task. Difficulties may arise in this stage of motor learning when the person has a low frustration tolerance for failure or has problems detecting or correcting errors because of sensory or motor deficits.

**Autonomous Phase**

The third and last phase of motor learning is the autonomous phase. Once the task is mastered, it can be carried out with little attention to the details. For instance, have you ever driven home and arrived at your destination only to realize that you did not recall what occurred en route because you were thinking of other things? Your driving was autonomous, independent of outside interference. Although this may not be the safest example of an autonomous motor skill, it is relevant because almost everyone has done it. Walking becomes autonomous or automatic; the recital piano piece you endlessly practiced as a child can be played through to completion without your thinking about it. Once you have learned to ride a bike, you do not forget. The autonomous phase is more like an open-loop model of feedback in which the action, once started, is completed without conscious feedback. The learner is not concentrating on “how to succeed.” It is possible to make changes in an individual’s performance during this stage, but these changes come much more slowly because there is less attention to detail. Once the autonomous stage is reached, the performer can direct attention to other higher-order cognitive activities.

**Open and Closed Tasks**

Movement results when an interaction exists among the mover, the task, and the environment. We have discussed the mover and the environment, but the task to be learned can be classified as either open or closed. *Open skills* are those done in environments that change over time, such as playing softball, walking on different uneven surfaces, and driving a car. *Closed skills* are skills that have set parameters and stay the same, such as walking on carpet, holding an object, or reaching for a target. These skills appear to be processed differently. Which type involves more perceptual information? Open skills require the mover to update constantly and to pay attention to incoming information about the softball, movement of traffic, or the support surface. Would a person have fewer motor problems with open or closed skills? Closed skills with set parameters pose fewer problems. Remember that open and closed skills are different from open-loop and closed-loop processing for motor control or motor learning.

**Theories of Motor Learning**

**Adams’ Closed-Loop Theory**

The closed-loop theory of motor learning was generated based on computer models in which feedback plays a role in either triggering or modifying an initial movement (Adams, 1971). A closed-loop model of feedback was presented earlier as part of motor control theories. This concept can also affect a mover’s ability to learn new movements. Sensory feedback helps us to learn the “feel” of new movements. Intrinsic feedback comes from the feel of the movement; for example, a good shot in tennis feels right. Present performance is compared with an internal reference of correctness, according to Adams. How this internal reference of correctness develops is unclear, but the cerebellum is probably involved. Is the ability of the nervous system to recognize “normal movement” genetically programmed? We do not know. Some children appear to be able to recognize and repeat motor actions only after having them guided by the therapist. Intrinsic and extrinsic feedback plays an important role in motor learning.

The sound of the ball when it hits the “sweet spot” on the racquet is a form of extrinsic feedback. Feedback that comes from the learner is intrinsic. If feedback comes from an external source such as the sound of the ball hitting the racquet, it is extrinsic or external. Seeing where the ball lands—cross court or down the line—and the verbal encouragement of your doubles partner are examples of extrinsic feedback. External feedback is called knowledge of results in motor learning. Adams views knowledge of results as not merely supplying the learner with feedback to reinforce correct performance but also assisting the learner to solve the movement problem. Intrinsic and extrinsic feedback is needed for both motor control and motor learning. Adams’ theory provides a good explanation for how slow movements are learned, but it does not explain how fast movements are controlled and learned.

**Schmidt’s Schema Theory**

Schmidt (1975) developed his schema theory to address the limitations of Adams’ theory. Once a movement, such as walking, is learned, it is called a *motor program* and can be called up with little cognitive or cortical involvement. The rules and relationships for a movement are stored in memory. Feedback is not needed when a motor program is performed unless the external or internal conditions pertaining to the movement change. The open-loop theory proposes that muscle commands are preprogrammed and, once triggered, proceed to completion with no sensory interference or feedback, as seen in the closed-loop control model. Open-loop control is helpful when an individual is performing fast movements in which there may be no time for feedback (see Fig. 3-9, B). Most actions after they are learned are combinations of open-loop and closed-loop control.

Schmidt and Lee (1999) describe three types of feedback that may occur when a movement takes place. One type of
feedback comes from the muscles as they contract during the movement, one type comes from the parts of the body moving in space, and one type comes from the environment in which the movement occurs. All of this information is briefly stored when a person moves, along with the knowledge of the results, in the form of a schema. Schemas are used to adjust and evaluate the performance of a motor program. Researchers do not know how these motor programs are formed.

How much knowledge of results is good for optimal learning of a motor task? Unlike in many situations in which more is usually considered better, such is not the case in motor learning. Although continuous feedback may improve present performance, some researchers have found immediate knowledge of results to be detrimental to learning (Shumway-Cook and Woollacott, 2001). When knowledge of results was given only half the trials, performance was poorer initially but improved later, with findings showing a greater retention of the motor task than would have been expected (Schmidt, 1991). Common sense dictates that as the learner becomes better at the task, feedback should be able to be withdrawn. Such a withdrawal of feedback is called fading and has been shown to have a positive effect on learning (Nicholson and Schmidt, 1989).

Effects of Practice
Motor learning theorists have also studied the effects of practice on learning a motor task and whether different types of practice make initial learning easier. Some types of practice make initial learning easier but make transferring that learning to another task more difficult. The more closely the practice environment resembles the actual environment where the task will take place, the better the transfer of learning will be. Therefore, if you are going to teach a person to walk in the physical therapy gym, this learning may not transfer to walking at home, where the floor is carpeted. Many facilities use an Easy Street (a mock or mini home, work, and community environment) to help simulate actual conditions the patient may encounter at home. Of course, providing therapy in the home is an excellent opportunity for motor learning.

Part-whole Training
Part-whole training is another facet of the practice issue in motor learning. Should a person practice the entire task, or is it easier to learn if it is broken down into its components? Research has shown that if the parts are truly subunits of the task, then working on them individually does enhance the performance of the task as a whole. However, working on weight shifting prior to walking may improve the quality of the task, something that clinicians are also interested in as an end result of therapeutic intervention. Again, it may not be possible for people who have cognitive difficulties to understand all the steps involved in the task because of memory deficits or an inability to plan or execute movement sequences. In such a case, the entire task may need to be tackled at once.

RELATIONSHIP OF MOTOR LEARNING WITH MOTOR DEVELOPMENT

Motor learning is the functional connection between motor control and motor development. Motor learning is an essential part of motor development. The ability of the body to generate and control movement depends on a genetic blueprint for species-specific movement and on the adaptation of those movements to meet ever-changing demands from the mover and the environment. Infants have not previously moved against gravity even though they have practiced some motor patterns in utero (Milani-Comparetti, 1981). Without the ability to learn how to move against gravity, they would not acquire the ability to walk. Further refinement of bipedal locomotion leads to learning to ride a bike and to skip in childhood. Think of the developmental sequence as a road trip that in its early time course has an established route from point A to point B. During the first year, few side trips or detours are possible; after childhood, different routes are more possible. Most children learn fundamental motor skills such as running, jumping, hopping, skipping, throwing, catching, and striking during childhood. Sports-related skills usually build on these fundamental motor patterns, but in some instances, a child’s participation in sports teaches the child these abilities. After childhood, the level of performance of motor skills varies greatly from person to person. Few people are able to perform at the level of an elite athlete.

Constraints to Motor Development, Motor Control, and Motor Learning
Our movements are constrained or limited by the biomechanical properties of our bones, joints, and muscles. No matter how sophisticated the neural message is or how motivated the person is, if the part of the body involved in the movement is limited in strength or range, the movement may occur incorrectly or not at all. If the control directions are misinterpreted, the intended movement may not occur. A person is only as good a mover as the weakest part. For some, that weakest part is a specific system, such as the muscular or nervous system, and for others, it is a function of a system, such as cognition.

Development of motor control and the acquisition of motor abilities occur while both the muscular and skeletal systems are growing and the nervous system is maturing. Changes in all the body’s physical systems provide a constant challenge to the development of motor control. Thelen and Fisher (1982) showed that some changes in motor behavior, such as an infant’s inability to step reflexively after a certain age, probably occur because the infant’s legs become too heavy to move, not because some reflex is no longer exhibited by the nervous system. We have already discussed that
the difficulty an infant encounters in learning to control the head during infancy can be attributed to the head’s being too big for the body. With growth, the body catches up to the head. As a linked system, the skeleton has to be controlled by the tension in the muscles and the amount of force generated by those muscles. Learning which muscles work well together and in what order is a monumental task.

Adolescence is another time of rapidly changing body relationships. As children become adolescents, movement coordination can be disrupted because of rapid and uneven changes in body dimensions. The most coordinated 10- or 12-year-old can turn into a gawky, gangly, and uncoordinated 14- or 16-year-old. The teenager makes major adjustments in motor control during the adolescent growth spurt.

Age-Related Systems Changes Affecting Motor Control

As the muscular system matures, it becomes stronger and adapts to changes in growth of the skeletal system spurred by weight bearing. The cardiopulmonary system provides the basic energy for musculoskeletal growth, neuromuscular maturation, and muscular work. All systems of the body support movement. Movement responses can be limited by the size and weight of the whole body or the relationship of the size and weight of various parts. An infant may be able to crawl up the stairs at home before walking up them because of the biomechanical limitations of her size relative to the size of the stairs. Typically, the inability of an infant to perform this activity is attributed to a lack of trunk control. Changes seen during motor development are a result of neuromuscular maturation and learning.

The brain does not function in a rigid top-down manner during motor development but instead is flexible in allowing other parts of the nervous system to initiate and direct movement. This concept of flexibility when it is applied to motor control is called distributed control. Control of movement is distributed to the part or parts of the nervous system that can best direct and regulate the motor task. What we do not know is whether the central nervous system works in a top-down manner as it is learning movement and then switches to a more distributed control at some age or level of nervous system maturation. Once movement patterns are learned, the body can then call up a motor program, providing us with yet another perspective on motor control. “A motor program is a memory structure that provides instructions for the control of actions” (VanSant, 1995). These motor programs can be initiated with little conscious effort. The systems of the body involved in movement always seem to be seeking the most efficient way to move and ways that do not require a lot of thought, thus leaving the brain free to do other, more important things such as think.

Relationship of Motor Control with Therapeutic Exercise

Physical therapists evaluate whether a child’s development is typical or atypical based on the acquisition of movement. Results of developmental testing are used to plan treatment interventions. The developmental sequence is more closely followed when intervening with infants and children than with adults. Most standardized tests of motor development evaluate a child’s performance of certain skills relative to chronologic age. Therefore, age has always been seen as a natural way to gauge a child’s progress in acquiring motor skills. Assessing an adult’s ability to perform certain skills has always been part of a physical therapy evaluation. Use of standardized functional tools is becoming more prevalent. The physical therapist’s and the physical therapist assistant’s view of motor development, motor control, and motor learning influence the choice of approach to therapy with children and adults with neuromuscular problems. Some physical therapists may utilize interventions taken from a number of neurophysiologic perspectives such as proprioceptive neuromuscular facilitation (Chapter 9), neurodevelopmental treatment (Chapters 6 and 10), and Brunnstrom’s approach (Chapter 10). These therapists may also incorporate recent knowledge of motor control and motor learning principles into their clinical practice. No longer is the emphasis only on controlling spasticity or inhibiting primitive and tonic reflexes. Function is the common goal and the common denominator when choosing interventions. Many therapists who previously used only used the neurophysiologic approaches are now incorporating more and more ideas from the motor control and motor learning literature into patients’ plan of care. Many interventions used by the neurophysiologic approaches are still valid, but the rationale for their use has been tempered by new knowledge of motor control and learning.

If a hierarchic model is applied therapeutically, interventions will be focused on inhibiting reflexes and facilitating higher-level postural reactions in an effort to gain the highest level or cortical control of movement. Although attainment of postural reactions is beneficial to individuals with movement dysfunction, these responses should always be practiced within the context of functional movement. Children with neuromotor problems need to learn these responses, and adults with neurologic deficits need to relearn them.

Some interventions used in treating children with neurologic dysfunction focus only on developing normal protective, righting, and equilibrium reactions. Children need to be safe within any posture that they are placed in or attain on their own. Use of movable equipment, such as a therapy ball, may give the child added sensory cues for movement but should not be the entire focus of the plan of care. It may not always be necessary to spend the majority of a therapy session eliciting postural responses in a situation (such as on a ball) that the child may never find himself in during normal, everyday life. Movement experiences should be made as close to reality as possible. Using a variety of movement sequences to assist the infant or child to change and maintain postures is of the utmost importance during therapy and at home. Setting up situations in which the child has to
try out different moves to solve a movement problem is ideal and is often the best therapy.

Motor control and motor learning theorists recognize that the developing nervous system may function in a top-down manner. They also know that the developed or mature nervous system is probably controlled by many different neuroanatomic centers, with the actual control center determined by the type of task to be accomplished. Early on, an infant’s movements seem to be under the control of spinal or supraspinal reflexes such as the crossed extension or asymmetric tonic neck reflex. Once the nervous system matures, the cortex can direct movement, or it can delegate more automatic tasks, such as walking, to subcortical structures. However, when a person is walking and carrying a tray of food in a crowded galley on a rolling ship, the cerebellum, visual system, and somatosensory system all have to work together to convey the person and the contents of the tray safely to a seat. The cortex does not always give up control, but it can engage in distributing the control to other areas of the nervous system. Any time a familiar task is performed in a new environment, attention must be directed to how the execution of the task has to be changed to accommodate different information.

How a therapy session is designed depends on the type of motor control theory espoused. Theories guide clinicians’ thinking about what may be the reason that the patient has a problem moving and about what interventions may remEDIATE the problem. Therapists who embrace a systems approach may have the patient perform a functional task in an appropriate setting, rather than just practice a component of the movement thought to be needed for that task. Rather than having the child practice weight shifting on a ball, the assistant has the child sit on a bench and shift weight to take off a shoe. Therapists who use a systems approach in treatment may be more concerned about the amount of practice and the schedule for when feedback is given than about the degree or normality of tone in the trunk or extremity used to perform the movement. Using a systems approach, an assistant would keep track of whether the task was accomplished (knowledge of results), as well as how well it was done (knowledge of performance). Knowledge of results is important for learning motor tasks. The goal of every therapeutic intervention, regardless of its theoretic basis, is to teach the patient how to produce functional movements in the clinic, at home, and in the community.

Interventions must be developmentally appropriate regardless of the age of the person. Although it may not be appropriate to have an 80-year-old creeping on the floor or mat table, it would be an ideal activity for an infant. All of us learn movement skills better within the context of a functional activity. Play provides a perfect functional setting for an infant and child to learn how to move. The physical therapist assistant working with an extremely young child should strive for the most typical movement possible in this age group while realizing that the amount and extent of the neurologic damage incurred will set the boundaries for what movement patterns are possible. Remember that it is also during play that a child learns valuable cause-and-effect lessons when observing how her actions result in moving herself or moving an object. Movement through the environment is an important part of learning spatial concepts.

When a therapist is working with an extremely young child, typical motor development is an appropriate goal within the limits of the child’s disorder. Progression within the plan of care can follow the typical developmental sequence, with emphasis on establishing head control, attaining trunk control in rolling, attaining sitting, attaining trunk control in sitting, attaining a hands-and-knees position, moving on hands and knees, attaining upright standing, and finally, walking. Early in the intervention process, quality of movement should be stressed when trying to promote achievement of general developmental milestones. As a child grows older, more and more treatment emphasis should be placed on functional movement, with less emphasis placed on quality. This does not imply that abnormal movement patterns should be encouraged, because they can certainly increase a child’s likelihood of developing contractures. It does mean, however, that it is more important for the child to be able to perform an activity and to function within an appropriate environment than to look perfect when doing the activity. Therapists are just beginning to realize that in all but the mildest neuromuscular problems, motor patterns may not be able to be changed, but motor behaviors can be changed. The child with a specific neuromotor disability may have only certain patterns of movement available to her but may be able to learn to use those patterns to move more effectively and efficiently. An example is a child with cerebral palsy who walks with a bilateral Trendelenburg gait. The gait pattern is abnormal, but it may be efficient. If the focus in therapy is to teach the child to walk without the Trendelenburg gait because it may improve the quality of the gait, but the therapist does not consider or recognize that in doing so the overall gait efficiency decreases, no positive functional change has occurred. If, however, by changing the gait pattern, the efficiency of the task is improved, then a positive functional outcome has occurred, and the treatment was warranted. Judgments about appropriate therapeutic goals cannot and should not always be made solely on the basis of quality of movement.

By stressing normal movement, the therapist encourages normal motor learning. Normal movement is what results when all body systems interact together during the process of overall human development. Motor learning must always occur within the context of function. It would not be an appropriate context for learning about walking to teach a child to walk on a movable surface, for example, because this task is typically performed on a nonmovable surface. The way a task is first learned is usually the way it is remembered best. When stressed or in an unsafe situation, individuals often revert to this way of moving. For example, I had on many occasions observed the daughter of a friend go up and down the long staircase in her parents’ home foot
over foot, without using a railing. While I filmed the motor skills of the same child in a studio in which the only stairs available were ones that had no back, she reverted to stepping up with one foot and bringing the other foot up to the same step (marking time) to ascend and descend. She perceived the stairs to be less safe and chose a less risky way to move. Infants and young children should be given every opportunity to learn to move correctly from the start. This is one of the major reasons for intervening early when an infant exhibits motor dysfunction. Motor learning requires practice and feedback. Remember what had to be done to learn to ride a bicycle without training wheels. Many times, through trial and error, you tried to get to the end of the block. After falls and scrapes, you finally mastered the task, and even though you may not have ridden a bike in a while, you still remember how. That memory of the movement is the result of motor learning.

Therapeutic exercise techniques based on older neurophysiologic approaches can be valuable adjuncts to interventions for patients with neurologic dysfunction. However, they must be combined with new knowledge of how to provide feedback, so the person will have the best chance of learning or relearning a motor skill. How much practice is enough to learn a new skill as compared with an already learned skill? The answer is unknown; therefore, the patient continues to practice until no changes occur and a plateau is recognized. Typically developing infants repeat seemingly non-task-oriented movements over and over again before moving on to some new skill. In fact, Thelen’s research (1979) suggests that repetitive flexion and extension movements of the extremities and trunk, observed in typically developing infants, appear to be a prerequisite for attaining postural control within a position or as a precursor to moving on to a more demanding posture or developmental task. For example, infants may rock repetitively on their hands and knees prior to moving in the hands and knees position. Once upright posture and movement are attained, less practice may be needed in this position because most complex movements are variations of simpler movements, differing only in timing, sequencing, and force production. An adolescent or young adult may need less practice to learn a motor skill than an older adult. Learning any new skill as an older adult is more difficult but still possible. However, when nervous system disorders impair cognitive function, learning is more difficult. The amount of nervous system recovery possible after nervous system injury plays a large role in determining functional movement outcomes in any person who has movement impairment.

Assessing functional movement status is a routine part of the physical therapist’s examination and evaluation. Functional status may provide cues for planning interventions within the context of the functional task to be achieved. Therapeutic outcomes must be documented based on the changing functional abilities of the patient. When the physical therapist re-examines and reevaluates a patient with movement dysfunction, the physical therapist assistant can participate by gathering objective data about the number of times the person can perform an activity, what types of cues (verbal, tactile, pressure) result in better or worse performance, and whether the task can be successfully performed in more than one setting, such as the physical therapy gym or the patient’s dining room. Additionally, the physical therapist assistant may comment on the consistency of the patient’s motor behavior. For instance, does the infant roll consistently from prone to supine or roll only occasionally, when something or someone extremely interesting is enticing the infant to engage in the activity?

CHAPTER SUMMARY

Motor control is ever-present. It directs posture and movement. Without motor control, no motor development or motor learning could occur. Motor learning provides a mechanism for the body to attain new skills regardless of the age of the individual. Motor learning requires feedback in the form of sensory information about whether the movement occurred and how successful it was. Practice and experience play major roles in motor learning. Motor development is the age-related process of change in motor behavior. Motor development is also the tasks acquired and learned during the process. A neurologic deficit can affect an individual’s ability to engage in age-appropriate motor tasks (motor development), to learn or relearn motor skills (motor learning), or to perform the required movements with sufficient quality and efficiency to be effective (motor control). Purposeful movement requires that all three processes be used continually and contingently across the life span.

REVIEW QUESTIONS

1. Define motor control and motor learning.
2. How does sensation contribute to motor control and motor learning?
3. How can the stages of motor control be used in treatment?
4. How do the components of the postural control system affect balance?
5. How is a postural response determined when visual and somatosensory input conflict?
6. When in the life span can “adult” sway strategies be consistently demonstrated?
7. How much attention to a task is needed in the various phases of motor learning?
8. Give an example of an open task and of a closed task.
9. Which type of feedback loop is used to learn movement? To perform a fast movement?
10. How much and what type of practice are needed for motor learning?
REFERENCES


