Balance and Coordination

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LEARNING OBJECTIVES
1. Define and contrast balance and coordination.
2. Discuss the mechanoreceptor system and define four mechanoreceptors.
3. List static and dynamic balance and coordination tests and activities.
4. Define proprioception and kinesthetic awareness.
5. Discuss several factors that contribute to balance dysfunction.
7. Discuss the rationale for proprioceptive training for the upper extremity.

KEY TERMS
Balance  Golgi tendon organs  Neuromuscular control
Base of support  Mechanoreceptors  Postural equilibrium
Coordination  Muscle spindles  Proprioception

CHAPTER OUTLINE
Learning Objectives  Specific Balance Tasks in Orthopedics
Key Terms  Balance and Proprioceptive Training
Chapter Outline  for the Upper Extremity
Exercise in Orthopedic Disorders  Summary
Definitions of Balance, Proprioception,
Neuromuscular Control, and
Coordination  Glossary
Mechanoreceptors  References
Balance and Coordination Tests  Review Questions
Balance Training in Orthopedics  Short Answer
True/False
EXERCISE IN ORTHOPEDIC DISORDERS

Rehabilitation after an acute injury, surgery, immobilization, or chronic orthopedic condition must address all the components of normal function. Regaining lost strength, reducing pain and swelling, improving flexibility, enhancing local muscular endurance, and building cardiovascular fitness are obvious and vital areas requiring specific therapeutic interventions. Sometimes less apparent, but equally important, is the need to address the motor control and neuromuscular elements to promote synchronous, fluid, and stable motor function of the injured part within the context of the distal and proximal body parts. Furthermore, secondary to the interdependence of coordination, posture, and balance to gait and functional movements, attention must also be placed on these elements for complete recovery from injury. Long-term convalescence reduces strength, flexibility, and cardiorespiratory fitness, as well as the use of vestibular and afferent neural input needed for balance and coordination.

DEFINITIONS OF BALANCE, PROPRIOCEPTION, NEUROMUSCULAR CONTROL, AND COORDINATION

Balance is often considered as the ability to maintain the center of mass (COM) over the base of support. This definition is only appropriate, however, when the base of support is fixed, such as standing in a constant location on two feet. The base of support is defined as the area contained within the parts of the body making physical contact with the external environment (Fig. 6-1). During dynamic situations, such as gait and functional activity, the base of support does not remain fixed to a constant location. Rather, as part of locomotion, the base of support moves, increasing the challenge to the elements responsible for maintaining balance. For this reason, the concept of balance also needs to include consideration to these circumstances. Postural equilibrium is a broader term that refers to balancing all forces acting on the body’s COM to maintain COM within the limits of stability with optimal joint segment alignment. Forces that challenge postural equilibrium arise from gravity, unexpected perturbations (i.e., stumbling over an unforeseen obstacle), or performance of voluntary motor activities (i.e., picking up a bag of groceries). Maintaining postural equilibrium is accomplished by the postural control system, the collection of sensory sources (somatosensory, vision, and vestibular), central nervous system, and the musculoskeletal system, all serving to maintain postural equilibrium. The somatosensory sources relevant to postural equilibrium are the mechanoreceptor populations residing in joint, muscle, connective, and ligamentous tissues. Because these tissues are often damaged during orthopedic injury, postural equilibrium may be disturbed following injury because of sensory disruptions, musculoskeletal disruptions, or both.

Performing motor tasks effectively and efficiently requires not only postural equilibrium, but also effective coordination of the many muscles serving to move and stabilize the joints upon which they cross. Coordination has been defined as the ability to produce patterns of body and limb motions in the context of environmental objects and events. For example, picking up an object from a table requires coordinating the shoulder, elbow, and wrists joints to put the hand and fingers into position so the object can be grasped. Essential to coordinating joint positions is sufficient sensory (afferent) information regarding joint position, movement (kinesthesia), and movement resistance/tension. The afferent information contributing to these three elements, joint position, movement (kinesthesia), and movement resistance/tension, is referred to as proprioception. When the proprioception elements are consciously perceived, they are referred to as the conscious perceptions of proprioception. Proprioception is vital for neuromuscular control. From a joint stability perspective, neuromuscular control refers to the subconscious activation of muscles occurring in preparation for and in response to joint motion and loading.

Mechanoreceptors

Mechanoreceptors are the sensory receptors that are responsible for converting mechanical events (e.g., movement, tension) into neural signals that can be conveyed to the central nervous system. As mentioned previously, mechanoreceptors are located in muscle,
tendon, ligament, joint capsules, and in skin and connective (fascial) tissues. Each mechanoreceptor has specific stimuli (e.g., light touch versus tissue lengthening) and thresholds (e.g., magnitude of stimuli required) to which it will respond. Mechanoreceptors most susceptible to disruption during orthopedic injury include the receptors located in the musculotendinous, ligaments, and joint capsules. Mechanoreceptors located in the musculotendinous tissues include the muscle spindles and Golgi tendon organs. Muscle spindles are responsible for conveying information regarding muscle length and rate of length change. Unique to muscle spindles is their adjustable sensitivity via the gamma motor neurons. Golgi tendon organs, located across a musculotendinous junction are responsible for conveying information regarding muscle tension. Located in the ligaments and joint capsules are Ruffini receptors, Pacinian corpuscles, Golgi tendon-like endings and free nerve endings. Collectively, based on their threshold and adaptation characteristics, these four mechanoreceptors provide the central nervous system with information regarding speed of joint position and movement and host tissue load levels.

**BALANCE AND COORDINATION TESTS**

To prescribe appropriate balance and coordination exercises, it is essential to have data related to present balance and coordination status. Most often, coordination is evaluated by using the simple tests such as those outlined in Box 6-1. Although quantifying a patient’s coordination abilities can be easily accomplished by counting the number of repetitions completed in a given time frame or the number or percentage of successes per number of attempts, qualitatively examining and describing the patient’s abilities and difficulties (e.g., steadiness, control, speed) can also be useful.

Interestingly, balance tests and specific balance treatment activities are rarely separated, and the same movements are used for fundamental balance exercises and clinically relevant balance tests. Recall that three sensory sources, somatosensory, visual, and vestibular, contribute afferent information to the central nervous system so that appropriate muscle actions can be selected. By manipulating the conditions in which balance tasks are conducted, different aspects of the postural control system may be more selectively challenged. For example, having a patient stand with eyes closed heightens their reliance on somatosensory and vestibular information. In addition, manipulating the base of support and support surface characteristics can also change the challenge imposed upon the postural control system. For example, compared to double-leg stance, single-leg stance requires that the postural control system reorganize itself over a narrow and short base of support, with the additional advantage that bilateral comparisons can be made.

### BOX 6-1

**Coordination Tests**

- **Finger to nose**: A reciprocal motion test in which the patient touches the tip of the index finger to the tip of the nose.
- **Finger opposition**: A reciprocal motion test in which the patient alternately touches the tip of each finger with the tip of the thumb.
- **Fixation-position hold**: A static position test in which the arms are held horizontally or the knees extended.
- **Heel on shin**: A reciprocal motion and accuracy test in which the patient is supine and is asked to slide the heel of one leg from the ankle to the knee of the opposite leg.
- **Pronation-supination**: A reciprocal motion test in which the palms are rotated up and down.
- **Tapping foot or hand**: A reciprocal motion test in which the patient is asked to repeatedly tap the ball of one foot while keeping the heel in contact with the floor. With the hand, the patient is asked to tap hand on knee.
- **Throwing and catching a ball**: A reciprocal motion test in which the patient is asked to receive and deliver a ball.

Functionally, periods of single-leg stance are often interspersed in many activities of daily living, such as walking, turning, climbing stairs, and putting on a pair of pants. Further, during activities of daily living, one does not usually solely concentrate on maintaining balance, but rather on the details of the task (e.g., reaching up to remove the correct book from a shelf). Additionally, during activities of daily living, situations arise where unexpected challenges (perturbations) to postural equilibrium occur. Thus comprehensive balance assessment and training frequently call for a progressive battery of specific tasks of incremental difficulty and should include not only static stances with varying bases of support and support surface characteristics, but also tasks that involve voluntary movement and task completion and unexpected perturbations. Close observation of the patient’s protective reactions during loss of balance is a critical component of all balance tests and training activities. Immediate corrective action by the patient to maintain balance is necessary to move the patient from low-level balance activities to more challenging, complex maneuvers.

Box 6-2 summarizes common progressions used with respect to stances, support surfaces, and vision. For example, the static double-leg stance test with the eyes open is often the first test performed. This very simple test is made more challenging by having the patient maintain balance on both legs with his or her eyes closed. Next, the patient can then stand on a high-density foam
surface with eyes open and closed, followed by standing on low-density foam with eyes open and closed. After that, the patient can stand on inclined or declined surfaces and unstable surfaces such as minitrampolines, rocker boards, and wobble boards, again using the eyes open to eyes closed progression. Similar eyes open to eyes closed and support surface progressions can be used with the patient using single-leg and tandem stances.

After a patient has mastered static stances under a variety of visual and support surface conditions, balance tasks can be progressed to include concurrent voluntary movements and tasks. Reaching tasks are very practical and functional test that determine a patient’s ability to perform simple daily tasks. Tests can be performed with the patient seated or standing using the upper or lower extremity (Fig. 6-2). Patients are offered a target that is slightly out of reach to test their ability to shift their center of mass to their limits of stability. Automatic activities, such as catching a ball, can also be performed in sequence from a seated to a standing position. The velocity, angle, and direction of throwing the ball to the patient challenges the patient’s ability to rapidly move arms and trunk out of static balance state, and back to equilibrium.

More dynamic balance tests requiring the patient to maintain a base of support, negotiate a single plane or multidirectional movement, and keep the body in motion are also useful. Walking in a straight line for a prescribed functional distance (e.g., from a chair to the bathroom) is a simple test to administer. Adding directional changes, such as turning a corner or negotiating a random series of obstacles provides information concerning the patient’s dynamic balance.

Quantifying performance during many of the previously mentioned tasks can be done using noninstrumented or instrumented measures. Noninstrumented measures include variables such as length of time in equilibrium, error scoringsystems, and distances reached with arms or legs. During the dynamic tests, such as tandem walking (straight line, heel-to-toe sequencing), the distance traveled during a specified time period can be recorded. Instrumented measures often involve technology that record the forces exerted on a support surface (force platforms) or sensors that detect movement and position of the support surface. In addition to providing objective measures of balance performance, some also provide real time biofeedback to facilitate weight transfer within base of support boundaries.

As an additional objective measurement of static balancing abilities, Wolfson and associates designed the postural stress test (PST) to help quantify static balance. This test measures a patient’s ability to maintain balance during a series of progressive graded destabilizing forces. It is clinically cumbersome in that it involves applying a belt to the patient’s waist and attaching a weight-pulley system behind the patient. Without the patient’s knowledge, a weight is applied to the pulley system, which provides a sudden posterior force necessitating rapid correction of the postural interference. The test is graded on a scale from 0 to 9, with 0 representing a total inability to correct balance, and 9 representing no loss of balance. In addition

**Fig. 6-2** The functional reach test. A, Starting position. B, Normal functional reach of more than 10 inches. (From Cameron MH, Monroe LG: Physical rehabilitation: evidence-based examination, evaluation, and intervention, St Louis, 2008, Saunders.)
to assessing a patient’s ability to withstand destabilizing perturbations, the PST may also serve as a training task.

**BALANCE TRAINING IN ORTHOPEDICS**

In concert with regaining strength and motion, specific functional tasks must be incorporated into the rehabilitation plan to accentuate muscular coordination, neuromuscular control, and postural equilibrium during dynamic activities. Duncan\(^4\) has identified several factors that may significantly contribute to balance dysfunction:

- Perception
- Behavior
- Range of motion
- Biomechanical alignment
- Weakness
- Sensory
- Synergistic organization strategy
- Coordination
- Adaptability

Many studies have demonstrated how injury, surgery, immobilization, and rehabilitation programs without specific balance and proprioceptive training can have a profound negative effect on balance and neuromuscular control. It can be concluded from these studies that the physical therapist assistant must (PTA) clearly recognize that injury, surgery, and non-weight-bearing immobilization negatively affect the proprioceptive pathways, as well as use of proprioceptive information by the central nervous system for neuromuscular control and balance. Functional balance and coordination training combined with closed kinetic chain (CKC) resistive exercises allows for afferent neural input from peripheral joint mechanoreceptors, which in turn may promote restoration proprioception, neuromuscular control, and balance.

**Specific Balance Tasks in Orthopedics**

As described in the testing section, many of the tasks used as balance tests are also used for balance training, using the same progression principles. This section will describe some additional balance tasks that are used for training. It is important to recognize that a rehabilitation protocol rarely suggests a comprehensive, specific sequence using the balance activities described in this chapter. Generally, tasks and drills are initiated and progressed according to the abilities and desired goals of the patient.

In cases of lower extremity injury with long-term, bedbound convalescence, manual resistive hip and knee extension with varying joint positions may be appropriate to initiate restoration of normal proprioceptive pathways. Once a patient may assume an upright position, progressive balance training may begin in a seated position. Similar progressive sequencing as with the standing tasks can be used, with the patient first attempting to maintain balance with the eyes open, then with the eyes closed. Progressions can include movements such as reaching tasks and the lifting of objects. Manually applied external forces (perturbations) can be applied while the patient’s eyes are closed to initiate reflexive balance training. Comparable to using foam and unstable surface for standing progressions, a large physioball or Swiss ball can be used as part of a seated static and dynamic balancing program to increase the challenge to the postural control system (Fig. 6-3, A). The physioball, which is a rather demanding exercise apparatus, has many applicable and creative uses in balancing and strengthening programs for various orthopedic patients. One very challenging exercise is the performance of support sit-ups on the physioball (Fig. 6-3, B). Obviously this particular exercise is for a rather active population, and not for all patients.

![Fig. 6-3](image)

**Fig. 6-3**  
A. Sitting trunk balance can be progressed using a physioball (Plyoball) to challenge and test a patient’s ability to demonstrate protective reactions and appropriate muscular corrective action while seated.  
B. Supported partial direct sit-ups for improving trunk balance and strength on a large diameter physioball (Plyoball).
Once a patient is weight bearing, progressive balance training can begin with vertical weight bearing (double-leg standing). For proper gait mechanics, weight shifting (changing base of support from one leg to another) is critical. Thus, after the patient masters double-leg standing static balance, the physical therapist assistant should begin training the patient to shift balance from one leg to the other. The next progressions can include the aforementioned visual, support surface, and base of support progressions. For teaching and safety purposes, all single-leg balance drills should be initiated on the uninvolved limb. As confidence and motor learning progress, the patient then performs the balance activity on the involved limb. In all cases of balance training, manual support and spotting is provided as required. As a means to document progress, the length of time the patient can maintain equilibrium can be recorded.

Other functional CKC exercises that replicate the specific demands of daily activities or athletic skills serve to restore coordination and balance, as well as the factors contributing to balance dysfunction listed in the previous section. Unfortunately, progressively demanding tasks are sometimes omitted from rehabilitation programs, with reliance put on increased clinical strength tests, greater range-of-motion grades, and reduced pain and swelling, as objective data leading to discharge from formal therapy. Examples of functional CKC exercises include double- and single-leg squats on stable and unstable surfaces, forward and backward gait, sidestepping (lateral steps), heel-to-toe walking, and braiding steps (carioca). Progressively challenging tasks that stimulate the patient’s ability to safely and accurately negotiate obstacles and make multidirectional changes while in motion are important.

It is important that advanced functional balance drills, such as hopping, be included in the programs of patients returning to high levels of physical activity. Hopping drills can range from simple vertical leaps to quite challenging combinations of vertical and horizontal patterns. Hopping is useful with an athletic population and can be done on a flat, hard surface or on a minitrampoline (Fig. 6-4, A). The forgiving, uneven rebound surface of the minitrampoline adds an appropriate challenge for progressive balance training. Additionally, a wobble board (Fig. 6-4, B) or the kinesthetic ability trainer (Fig. 6-5) can be used to challenge single- or double-leg proprioception. Using the minitrampoline after hip, knee, or ankle injury for static standing balance and for single-leg or double-leg hopping is unique and challenging for many patients. As with other balance drills, single-leg or double-leg standing or hopping can progress from eyes open to eyes closed.

Inclusions of tasks in which sudden perturbations challenge balance are also important components of a balance training program. For example the clinician can apply sudden force to the patient while the patient is standing on one leg with the eyes closed (Fig. 6-6). Applying the manual postural stresses in different directions and with varying degrees of force can further challenge the ability to “right” or correct balance. Another method of perturbing balance is to use elastic tubing secured to a patient. The clinician begins the task...
by applying tension through the tubing. By suddenly releasing the tubing, the patient is suddenly presented with an immediate challenge to postural equilibrium.

Many commercial training devices have been developed to assist with balance training. Most commonly used is the biomechanical ankle platform system (BAPS). The name is misleading because this unit can be used for a wide variety of lower extremity conditions. The generic names for this tool are wobble board and balance board (Fig. 6-7). This device is very adaptable, portable, and affordable for many physical therapy environments. Initially, double-leg support progresses to single-leg standing. One of the most challenging balance drills is performing single-leg standing on a balance board with the eyes closed.

**Balance and Proprioceptive Training for the Upper Extremity**

Many household chores involve the repetitive use of the arms and shoulders to lift, pull, and carry. Industrial workers, manual laborers, and assembly line workers all use their arms and shoulders in vigorous weight-bearing positions (weight bearing in these instances refers to overhead lifting, pulling, and climbing maneuvers). Athletes in particular use their arms and shoulders to perform sports skills. Gymnasts require extraordinary flexibility, strength, and glenohumeral stability during demanding upper-body, weight-bearing activities. With the upper extremity in contact with a secure surface, it is incorporated into defining the base of support.

As mentioned, injury, surgery, and immobilization lead to significant alterations in proprioception. Specific proprioceptive exercises have been proposed that, when used in conjunction with proprioceptive neuromuscular facilitation exercises, rhythmic stabilization strengthening exercises, and general range of motion, may contribute to improved proprioception in the upper extremity.

The upper extremities can be progressed in much the same way as the lower extremities. Although many of these exercises are often considered to be specific for an athletic population, they can be adapted to the general orthopedic population who must rely on dynamic vigorous weight-bearing shoulder and arm activities to accomplish tasks of daily living. With both arms in contact with the ground, weight shifting between the arms can be conducted on firm and unstable surfaces. In addition, while in a similar position, eyes open and eyes closed, balancing can be conducted on the same support surfaces used for standing balance (Figs. 6-7, 6-8, A1-A2). Beginning with two arms, this exercise can be intensified by having the patient use one arm with the eyes open and closed. Global stability of the glenohumeral joint can be enhanced effectively with the use of medicine balls and physioballs (Fig. 6-8, B1-B2). The patient begins the progression of this exercise by kneeling in front of the ball and placing both hands on the ball. As the exercise progresses, extraordinary joint stability, strength, and balance are required to maintain equilibrium.
Summary
Underlying all motor activities are specific processes to ensure that postural equilibrium is maintained. Disruptions to balance, postural equilibrium and coordination often accompany orthopedic pathology. Additionally, orthopedic conditions often produce alterations in proprioception, motor control, coordination and neuromuscular control thereby requiring specific elements to be incorporated into rehabilitation programs to promote their restoration. Often the same tasks used for balance assessments can be used for training. Progressions can be made by changing stances, support surfaces, visual conditions and tasks. Similar progressions can also be incorporated into upper extremity rehabilitation programs.

GLOSSARY
Balance: The ability to maintain the center of mass (COM) over the base of support.\textsuperscript{12}
Base of support: The area contained within the parts of the body making physical contact with the external environment.\textsuperscript{9}
Coordination: The ability to produce patterns of body and limb motions in the context of environmental objects and events.\textsuperscript{13}
Golgi tendon organs: Fibers responsible for conveying information regarding muscle tension.

Mechanoreceptors: Sensory receptors responsible for converting mechanical events into neural signals that can be conveyed to the central nervous system.

Muscle spindles: Fibers responsible for conveying information regarding muscle length and rate of length change.

Neuromuscular control: Subconscious activation of muscles occurring in preparation for and in response to joint motion and loading.

Postural equilibrium: The balance of all forces acting on the body’s COM to maintain it within the limits of stability with optimal joint segment alignment.

Proprioception: The afferent information contributing to joint position, joint movement (kinesthesia), and movement resistance/tension.

REFERENCES


REVIEW QUESTIONS

Short Answer

1. Name two ways to increase the intensity of the double-leg stance test (DLST).
2. Studies have demonstrated that many elderly people fall during walking, ascending and descending stairs, and turning. Which activity or test is most appropriate for developing single-leg stance equilibrium?
3. List three Plyoball exercises that can be used to increase dynamic trunk balance, proprioception, and strength.

True/False

4. The joint mechanoreceptor system (afferent neural input system) is important in regulating changes related to joint movement and body position.
5. Single-leg stance test (SLST) and DLST are examples of balance tests and are never used as treatment activities.
6. High-density foam padding is used for patients to stand and walk on during the final phase of balance training.
7. A high degree of balance is necessary to maintain equilibrium while standing and walking on low-density foam.
8. The reach test shows the patient’s ability to reach and challenge the limits or borders of the base of support.
9. Injury, surgery, immobilization, and non-weight-bearing convalescence have a profoundly negative effect on the afferent neural input system.
10. Rehabilitation programs that do not address balance, coordination, and proprioception can result in poor restoration of function and increase the risk of reinjury.
11. Postoperative shoulder patients do not require proprioception exercises because the shoulder is a non–weight-bearing structure.