THE SCIENCE BEHIND BALANCE TRAINING

Balance represents an ability to stabilize and maintain a desired body position. Balance can also be thought of as correct, or efficient, positioning of a body part or the entire body.

Natural and functional movement is directly related to the harmonious work of joints, muscles and the neurological system. The neurological system interacts with the musculoskeletal system in a coordinated and complex manner. Using stability or balance training, and CCE, is the perfect way to stimulate and train this complex interaction of the body. Think about common activities and it quickly becomes apparent that most movements are dependent on coordinated balance and changing force output throughout the body.

Demands placed on the body during stability training, balance training and closed chain exercise vary dramatically, but replicate daily life and sport situations. From moment to moment, the body strives to maintain balance and to integrate the responses into safe, skilled movement. This mirrors daily activities where one must constantly perform in many planes of movement.

body equilibrium

A number of components represent key building blocks that contribute to safe, effective and functional movement, as well as skilled performance. The concept of body equilibrium includes:

1. **Kinesthetic sense.** This feedback mechanism provides awareness of how the body is positioned at any moment. Kinesthetic or proprioceptive sense allows the body to perceive or feel movement, weight-shifts, resistance and position.

2. **Proprioception.** Proprioception, which overlaps with kinesthetic awareness, provides a sense of body symmetry, or necessary balance and positioning between body parts, and specifically refers to a sense of joint position. Proprioception, as mediated by sensory organs such as muscle spindles that are located between muscle fibers, represents an ongoing or normal awareness of the position, balance or movement of the body or any of its parts.

   Note: *The term kinesthesis is used to define a person's awareness of motion or position as it pertains to his/her limbs. Proprioception is defined as one's sense of movement as it relates to movement of the body and how it is oriented in space. Today, current literature uses the terms as though they are synonymous (Plowman and Smith 1997).*

3. **Gradation of force**. An ability to control muscular force production and maintain an equalized, though dynamic, position regardless of the physical task at hand, is critical to any type of human movement. Correct application of force is complex, learned and under the direct influence of neural control. The regulatory control of muscular force is referred to as "gradation of force."

These three components of body equilibrium are important to consider, and train, when used in the context of sport performance and daily movement requirements. Balance, kinesthetic sense, proprioception, body symmetry and proper force application are key aspects of any activity that requires a dynamic, integrated, coordinated and skilled response. Being able to change one's center of gravity to compensate for required movement is the key to moving skillfully. Agility is the technical term for this developed sense that incorporates proprioception and balance, and allows a person to move efficiently, confidently, gracefully and smoothly, while wasting little motion. The smooth fusion and training of all of these elements can represent skillful or functional movement, and reflect the athletic qualities that everyone should seek to develop.

science foundation behind balance training

Balance and stability training have been studied for many years and continue to grow as a mainstay of cutting-edge conditioning training programs. The scientific foundation behind this type of training has a long-standing history that is well researched and documented (Plowman and Smith 1997; Wilmore and Costill 1994; McArdle et al. 1991; Jackson, J.H. 1931).

Postural stability as it relates to balance revolves around the body's ability to maintain center of mass (COM) within specific stability and balance limits. This capacity is the foundation for all movement activity and has become increasingly recognized in the realm of sport and rehabilitation (Anderson, Gregory 2004, unpublished manuscript; Anderson et al. 2005). The benefits of training controlled instability on unstable surfaces are many.

Skilled movement is epitomized by athletes who perform tasks requiring complex degrees of coordination, balance, strength and power – and make them look easy! Yet, skill cannot be developed without a "sharp" neuromuscular system, which only occurs with practice, rehearsal, training and experience. The most basic element of human movement relies solely on the nervous system. Muscles do not get the signal to "go" unless the nervous system directs them to do so!

the nervous system and movement

The brain, spinal cord and nerves make up the basic elements of the nervous system. The nervous system represents the control tower for communication and directs movement for the entire body. In a basic sense, movement occurs because information is received and forwarded via the nervous system and its specialized messengers, the sensory organs, to the skeletal muscles of the body. Quite simply, the brain controls muscular movement and "thinks" in terms of whole motions to attain a synchronized movement pattern (Jackson 1931; Korr 1976; reported in Wolf 2001).

Understanding human movement becomes easier with a realization that "exercise is muscle contraction." More specifically, movement relates to muscular force production rather than muscle contraction. Why? Because not all muscular force development refers to a tension building process of "contraction," which results in a shortening of the muscle and is referred to as a "concentric contraction." A muscle can also produce force where the length of the muscle does not change (isometric force production), where the "contraction" produces an increase in tension but does not cause significant movement at the joint, or where the muscle exerts tension while lengthening, which represents eccentric force production (Plowman and Smith 1997).

Traditional approaches to conditioning, as well as functional types of training incorporate concentric, eccentric and isometric types of force production. One type of training or force production is not superior to the other, but all are essential to a well-rounded program that meets all the requirements of a forward-looking program. In turn, a progressive and complete training program will meet all the requirements that contribute to proficient human movement.

neural control of human movement

The study of neuromuscular control in human movement provides the science that backs functional balance training, and explains why it is important. As mentioned, all human movement, skilled or unskilled, is dependent on muscle contraction or force production, which in turn is one hundred percent dependent on receiving a signal from the nervous system. A muscle that is not activated by the nervous system is a muscle that does not contribute to movement. This fact implies that muscles must "learn" how to contribute to skilled movement patterns through training and repetition that is specific to the movement(s) being undertaken. Activity like this is usually referred to as "skill practice," "sport specific training" or "rehearsal." The principle of skill-rehearsal encompasses specificity – specific practice and repetition – and is the most important fundamental aspect related to motor learning and high-level performance.

As a result of training in a specific manner, for given activities, the nervous system is able to call on and activate groups of muscle fibers (motor units) at the precise moment needed, as well as call into play the correct number of motor units to develop the appropriate amount of force needed for the activity. As an example, removing an eyelash from the surface of the cornea requires a different amount of muscle force production when compared to slam-dunking a basketball or pressing a 1 RM (repetition maximum) amount of weight. An ability to mediate muscular force development is called "rate coding," or as referred to earlier, as a "gradation of force" (Plowman and Smith 1997).

The ability to gradually and progressively control muscular force output, up or down, for a given movement, is obviously a critical aspect of successful and skilled human movement. The ability to regulate force development depends on the nervous system, with the other key aspect being tied to mechanical factors (i.e., length-tension-angle, force-velocity and elasticity-force relationships, as well as architectural design of the muscle) that influence muscle contraction in the body (Plowman and Smith 1997). Human performance – balance responses included – is directly dependent on the correct application of force.

muscle fibers and motor units

The physiologic reason behind the ability to regulate force production lies in the fact that movement is based on contractions of motor units (force production output), and not single muscle fibers, nor entire muscles. A number of muscle fibers make up a motor unit, and many motor units are contained within each muscle. The body's muscles are comprised of both fast and slow twitch muscle fibers. Each type of fiber has a different threshold at which they will fire or activate. Slow twitch muscles have a lower stimulus threshold so they will fire or be called into action sooner, and will continue to perform the work load until the activity demands a more powerful contraction, at which time the fast twitch motor units will be activated (Brooks 2001; Brooks 1997).

Motor units, of which there are many in each muscle, are made up of either all fast or slow twitch fibers. When a motor unit is activated, or in other words the stimulus from the nervous system is great enough to cross its threshold, all of the muscle fibers associated with the motor unit will be called into action. This is known as the "all-or-none" principle of muscle contraction. Mistakenly, many people believe this means that a muscle fires all-or-none. It does not. What is true is that motor units and their associated fibers do fire all-or-none. Each type of motor unit – fast or slow twitch – has a different threshold or point at which it will activate in response to neural stimuli. These facts explain why an athlete can perform explosive physical movement in a skilled fashion, and can also delicately remove a speck of dirt from the eye. This complex and subtle interplay is developed through practice.

reflex control of movement

A discussion of coordinated movement must always include a reference to bodily reflexes, and the systems that govern motor-movement reflex feedback. These systems obviously play an important role. A reflex is a rapid, involuntary response that results in a specific motor response (Plowman and Smith 1997), with that response being dependent on the type and duration of the stimulus received. Skilled movement depends a great deal upon the body's ability to respond to stimuli with an unconscious, or automatic, movement reaction.

Reflexes can be categorized into autonomic or somatic categories. Autonomic reflexes activate cardiac and smooth muscle and glands, whereas somatic (soma refers to the body) reflexes result in skeletal muscle contraction (Plowman and Smith 1997). Somatic reflexes are, of course, most important to a discussion that focuses on movement.

The spinal cord serves as the crucial link between the brain and peripheral nervous system (nerves that serve the extremities or limbs). The spinal cord is involved in both voluntary and involuntary movements, and besides serving as the information conduit between the brain and peripheral nervous system, it is also the site at which reflex integration occurs (Plowman and Smith 1997). In other words, information moves into and out of the spinal cord via spinal nerves that exit from each side and along the length of the cord. Information must be transmitted via the brain and the spinal nerves, and then must be integrated in a manner that results in useful or necessary movement. Along this information highway, data is carried up and down the spinal cord via a series of tracts, or bundles of fibers, in the central nervous system. Some tracts are responsible for transmitting sensory information (i.e., pressure, temperature, visual, sound, changes in equilibrium), whereas others carry motor, or movement information and regulate a continuum of movement that ranges from delicate or fine movement, to gross physical skills that require explosive and maximal force output.

the role of mechanoreceptors

Mechanoreceptors are specialized sensory cells which process a physical stimulus into a neurologic signal that can be interpreted by the central nervous system (CNS), with the end result being the ability to monitor and control joint position and movement. Mechanoreceptors have critical roles in not only providing feedback about joint position sense, but also in controlling muscle tone and impacting reflex response (Laskowski et al. 1997).

Each of four mechanoreceptor sites – currently thought to be key information receptors and to trigger dynamic joint stability – include cutaneous, joint capsule, muscle and ligamentous receptors. All are thought to contribute to joint position sense, and the muscle receptors which are found in the muscle spindle and Golgi tendon organ are important to both proprioception and motor control of the muscles (Laskowski et al. 1997). Mechanoreceptors can be stimulated by a variety of feedback or stimuli.

proprioception, equilibrium, balance and associated reflexes

Proprioception is a term that refers to the normal, ongoing awareness of body position or joint position sense. Automatic adaptations and responses to stimuli, that impact body position and state-of-balance, are ever-present and ongoing in the body. Sensory feedback, which helps discern how the body or a body part is positioned, is regulated by proprioceptors or sensory organs. All senses are important. A host of sensory receptors that include the eyes, ears and specialized sensory receptors located in muscles, tendons and joints provide a constant barrage of information about body motion, position of body parts and their interaction. This feedback gives the nervous system the information to make physical adjustments, if necessary.

Visual senses give immediate feedback about external stimuli, and are extremely important to skilled performance and balance. Try to stand on the Balance Trainer dome with the eyes closed, and it quickly becomes apparent that visual stimulus is very important to balance. Hearing is important as well. For example, the sound created by solid bat contact with a baseball gives information to fielders about the speed of the ball and even ground reaction conditions can be heard (i.e., wet, spongy playing surface or an athlete's shoe sliding and losing contact with the playing surface), which gives the performer insight and feedback into what adjustments will be necessary as movement is continued. It is easy to conclude that movement is complex and influenced by a number of factors.

the vestibular system

The inner ear is equipped with specialized equilibrium receptors and is called the vestibular apparatus. Turn the head one way, then the other, or tip an ear toward one shoulder to experience how sensory receptors in the inner ear attempt to preserve equilibrium and maintain a steady head position. Fluid filled structures and specially arranged semicircular canals in the vestibular apparatus allow information about head movement, and speed of head movement, to be transmitted to the brain via an inner ear nerve (vestibulochoclear nerve). This information is processed in the brain along with any information being received from the visual receptors and the somatic receptors located in the muscles, tendons and joints (Plowman and Smith 1997).

muscle spindles

Proporioceptive sense, and consequently balance, is available largely because of muscle spindles and other sensory organs or proprioceptive receptors. Sensory organs relay information via the central nervous system, and provide a sense of body or limb position in space. This is also referred to as kinesthetic awareness. Sensory organs, located in muscles, tendons or joints, for example, allow a person to predict the degree of elbow flexion or extension even if the individual does not have the advantage of visual feedback. Therefore, balance training should include drills that both allow and discourage the use of sight, as this will challenge the somatic receptors of the body in different ways, which will challenge the body as whole, in a different manner.

The muscle spindle plays an important role in daily posture and has important implications for balance needs in general, for all movement. Muscle spindles are located in skeletal muscles, and lie parallel to and are imbedded in muscle fibers or muscle cells (Plowman and Smith 1997, pg. 491). They are sensitive to the resting length of the muscle, changes in the length of the muscle and the speed at which lengthening occurs, and thus are stimulated by stretch. Information from the spindle is sent directly to the central nervous system via a reflex arc. This sensory feedback loop (the reflex arc) is made up of a sensory receptor (the muscle spindle and afferent neuron) and spinal nerve (efferent neuron). This reflex arc allows a person to regularly adjust body position based on immediate physical demands, as presented by current stimuli, and to do so with little thought. Muscle spindles help the body maintain tone, posture, alignment and balance.

Additionally, when muscle spindles are activated because of changes in the length of the muscle (i.e. when attempting to maintain balance on an unstable surface), associated muscles will alternately contract and relax as a result of muscle spindle activation. This reaction, in turn, directly affects body position, balance and center of gravity. Muscle spindles are involved in both sensory and motor functions. Challenging this automatic "correction factor" through functional balance practice and participation in a specific sport or activity, lays critical groundwork that leads to efficient, functional movement.

In summary, the muscle spindle is an important sensory feedback mechanism of the body. Not only does the spindle normally emit low-level sensory nerve signals that assist in maintaining muscle tone and affect constant postural adjustments throughout the day, feedback from the spindle also helps the muscles and body adjust movement requirements based on load or degree of effort required. Spindles influence skilled movement capabilities because of the spindle's dampening affect on skeletal muscles' agonist/antagonist relationship, which contributes to "smooth" movement (Plowman and Smith 1997).

golgi tendon organ

The golgi tendon organ (GTO) represents the last key sensory organ that impacts somatic reflexes. The GTOs are located within the tendonous attachment area of muscles and are stimulated by stretch or muscle contraction. GTOs transmit information about muscle tension, and if activated, cause associated muscle(s) to relax. This reflex inhibition of the muscle is called the inverse myotatic response.

This reflex action that results in a relaxed muscle is important to movement for several reasons. First, this reflex inhibition can be called into play when the GTOs "sense" that excessive tension in the muscle could cause the tendonous attachment(s) of the muscle to tear away, or rupture, from its bony attachment point. GTOs are responsible for a "muscle giving out" when under too much duress. Finally, sensory information gathered by the GTOs about tension development in the muscle allows for adjustments during movement that require only the needed tension, or force development, to successfully begin and finish movements with smooth transitions (Plowman and Smith 1997).

automatic integration of sensory systems

Many of the responses made by the body to balance challenges (external stimulus, visual affect, points of contact and movement) are referred to as automatic postural reactions. These responses occur before voluntary movement and after reflexes, yet have commonalities with both (Anderson, et al. 2005).

Just as high-level sport performance represents a picture of extraordinary neuromuscular accomplishment, at even its simplest level, so does balance training and its maintenance. The key difference in perspective is that balance training is accessible to all, easy to do, fun and self-gratifying! Yet any skill level, as it relates to movement, is dependent on the intricate and precise participation of the central nervous system as it acts upon muscles, after receiving information. It is only through a complex, automatic integration of several sensory systems of the body, that one can accurately position the body, perceive where and how the body is positioned in space, and easily adjust how much force is developed in the muscles to maintain precise performance boundaries, assure safe execution of the movement and maintain or recover alignment and center of gravity without a second thought.

The neuromuscular system's motor output – maintenance or recovery of body equilibrium – is directly influenced by the somatosensory, visual and vestibular systems. Training the various nervous and sensory receptor systems of the body with functional, balance and sport/activity specific training can lead to more efficient, accurate and highly skilled movement patterns. Skilled movement is more energy efficient, safer and it feels better. Moving gracefully and performing better are just two reasons why functional training is important to all who want to move efficiently and with purpose.

The importance of a broad-ranged plan of attack that includes functional, traditional and specific exercise/practice is apparent. A complete approach should:

1. Teach the nervous system how to regulate muscular force production.
2. Improve proprioception or awareness of the body's position, or any of its parts, and how they are positioned.
3. Develop more skillful and energy efficient movement patterns.
4. Train flexibility, cardiorespiratory endurance, stabilizing strength, muscular strength and endurance – and develop power, which combines an element of strength with speed of movement.

Functional training incorporates the concepts of balance/stability training and closed chain exercise (CCE) by requiring the body's natural motor reflexes to react as an integrated unit. In other words, the whole body is challenged to participate in order to maintain correct posture and balance while moving. The inclusion of activities that involve the entire body in a dynamic and coordinated fashion represents the development of functional fitness. This type of fitness is easily transferred to daily tasks, recreation and sport. Stabilization and functional training can both be integrated into closed chain and open chain exercise. But, remember that functional training ultimately trains movement, not just stabilizing contractions that contribute to effective movement. Stability and balance training represent two aspects of training that fit under the "functional training umbrella."

righting, protective and equilibrium reactions

The antigravity, balance and power producing capacity of the body can be simply thought of, in terms of physical skills, as righting, protective and equilibrium reactions.

Automatic righting reactions maintain or restore body alignment as it relates to the position of the head, trunk and limbs. Muscle spindles monitor the rate at which muscles lengthen and play a big role in maintaining balance at rest. Spindle feedback helps the body stay centered while standing on the Balance Trainer dome and visually tracking one hand from in front of the body to the side, and then to an overhead position. Muscle spindles also play a role when trying to maintain balance over the center of the dome with the eyes closed. When a body part is suddenly displaced, righting reactions come into play. An arm or leg shooting up or out to the side counters the weight displacement and is largely automatic, thanks to sensory feedback coming from the muscle spindles. If weight shifts are slow and controlled, constant muscular activity and adjustment is subtle, rather than dramatic.

Equilibrium reactions can be thought of as an integration of righting and protective reactions as the body fine tunes, through practice, a coordinated, complex and automatic response. The aim of the response is to preserve or restore balance during any type of activity. Reactions and attempts to maintain balance are common whenever the center of gravity of the body is displaced over any base of support. When centered on the Balance Trainer, this displacement is ever present as the properties of the dome provide a dynamic surface that continually attempts to displace the body's center of gravity.

balance training research

An irony of past balance research is that researchers have found it difficult to measure or show balance improvements in individuals who have "normal" balance. However, that does not mean that improvements do not occur. Limited research has been performed on unstable surfaces with healthy or highly conditioned athletes. Data (Behm et al. 2003, 2005) suggest that trunk stabilizer muscles are activated to a greater degree by unstable versus stable exercises and that unilateral resistance exercises cause greater muscle activity in the contra-lateral (opposite) side trunk stabilizers. Exercises that include an overhead shoulder press while seated on a stability ball and squat exercises performed on progressively more unstable surfaces, have demonstrated this increased muscle activation (Anderson and Behm 2005). Both McGill (2001, 2002, 2004) and Vera-Garcia showed increased muscle activity on an unstable surface when compared to a stable surface. It is important to remember that the goal of training on unstable surfaces is to increase muscle activity without necessarily increasing load.

balance research and the older adult

Balance research has historically focused on older adult populations because this group is at an increased risk for fall related fractures. Because proprioceptive feedback capability is often reduce in active or diseased older adult populations, this group can show marked improvement in both balance and physical improvement even with non-specific, or non-balance focused conditioning approaches. Research also shows that specific strength and/or balance exercises enhance stability and reduce the risk of falling, as well as increase overall physical performance (LaStayo et al. 2003; Spirduso 1995; Judge et al. 1993).

balance research in rehabilitation and injury prevention programs

Significant research has focused on injured and disabled populations. Restoring (rehabilitating) or maintaining (prevention) proprioception allows the body to maintain stability and body orientation during static and dynamic activities. During rehabilitation, proprioceptive programs are specifically tailored to each patient, and as is true for any functional rehabilitation program, should include balance training, closed kinetic chain exercise (CCE) like leg presses, single leg balance, hops or jumps, back strengthening exercise and quadruped stabilization (i.e., position on the hands and knees or "all-fours" to stabilize the scapulae in a closed-kinetic chain position), as well as sport specific training and drills (Carmeli et al. 2003; McCurday and Conner 2003; Gauchard et al. 1993; Judge et al. 1993; Laskowski et al. 1997).

It is believed that impaired "joint position sense," when overlooked in a rehabilitation program, may be a leading cause for recurrent injuries. On the other hand, proprioceptive and balance training have been shown to significantly reduce the incidence of anterior cruciate ligament (ACL) injury in soccer players (reported in Laskowski et al. 1997, pg. 97). The goal of proprioceptive training during rehabilitation is to maximize protection from injury and restore one hundred percent, or optimal, function (Laskowski et al. 1997). From this perspective, it would make perfect sense that this type of functional and balance training would be a necessary part of any training or rehabilitation program, and be appropriate for all types of people, regardless of program goals.

Rehabilitation and injury prevention oriented programs can be designed to challenge, enhance and improve the proprioceptive system. By affecting (training) various central nervous system pathways and reflex arcs, "prophylactic" (protective) proprioception training programs may protect against injury (Caraffa et al. reported in Laskowski et al. 1997).

static and dynamic joint stability

A major category of proprioceptive or functional training is balance training. An example of training the proprioceptive system and joint stability in a mostly static way includes one-legged standing balance exercises. The ability of appropriately activated muscles to stabilize a joint during more complex movement defines dynamic joint stability (Laskowski 1997, pg. 98). Progressive and dynamic challenges, for example, hopping from one Balance Trainer dome to another on one leg, jumping vertically and landing on the dome or performing push-ups on the platform side of the Balance Trainer while simultaneously keeping the platform level, changes the nature of the required joint stability to "dynamic."

functional training controversy: science vs. science?

It seems that "two sides" have evolved with regard to whether or not functional training can have an impact on performance. Experts on both sides are in agreement that proprioceptive training is valuable to rehabilitation. Research that is ongoing will soon point to additional training benefits that go beyond what has been discussed in this text. As mentioned, the difficulty as it relates to objective test data, is for researchers to figure out how to measure balance improvements with people who have normal balance capability (Brown, ed. 2002, 2005; Willardson 2004).

How can two sides, which both base their claim on science, be at such odds? Many of the issues will come down to semantics and how we define training result as it relates to performance. This topic will be greatly affected by current testing methods and interest in this type of training. Fitness professionals and consumers are trying to sort through the seemingly contradictory information and it is placing a burden on the scientific community to provide answers and guidelines with regard to what this type of training can and cannot accomplish. This scenario will accelerate research and learning.

Ultimately, for an understanding of the subject to move forward, "both sides" will have to move from all or none positions and identify the value of traditional approaches to training, as well as functional and integrated movement approaches. This would allow and encourage future research to define the possibilities of functional training and its impact on performance improvement (Brown, ed. 2002, 2005; Willardson 2004; IDEA 2003).

It is obvious that functional or proprioceptive training programs work. Functional and balance training teaching methodology should be built on an understanding of the "why, when and how" behind exercise choice, implementation and progression. Rather than taking a haphazard approach to designing functional training programs, or not fully understanding why this type of training is being offered, it is therefore important to identify what is being accomplished with functional training workouts. It is also important to understand why and how functional training dovetails with, and complements other science-based aspects of a general fitness and performance training hierarchy.

Strategies for balance training focus on increasing sensory input in a variety of training environments with different proprioceptive challenges (visual affect, contact points, movement and external stimulus). Ultimately, training like this will improve motor skills, kinesthetic awareness and balance. The BOSU Complete Workout System takes you through this exciting and productive process step-by-step.