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REVIEW

Sensorimotor training: A ''global'' approach for balance training

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Summary Sensorimotor training was developed by Dr. Vladimir Janda as part of a treatment approach to chronic musculoskeletal pain syndromes. He noted that many of these syndromes exhibited characteristic patterns of muscle imbalance, which were manifested with changes to the central nervous system motor programming. Janda emphasized the importance of proprioception in the rehabilitation process. In order to restore normal muscle firing patterns and reflexive stabilization, he developed a specific proprioceptive exercise progression for patients with chronic musculoskeletal pain. Sensorimotor training emphasizes postural control and progressive challenges to the sensorimotor system to restore normal motor programs in patients with chronic musculoskeletal pain. Patients progress through static, dynamic, and functional phases using simple rehabilitation tools such as balance boards, foam pads, and elastic bands. This paper will describe the scientific rationale for the program and describe the clinical progression of sensorimotor training.

Introduction

In the early 1900s, Dr. Charles Sherrington first defined proprioception as a sense of position, posture, and movement (Sherrington, 1906). He noted that special receptors were present to transmit the afferent information into the central nervous system (CNS). During the 1960s, British physician Michael Freeman (1965b) reported chronic instability in the ankles of soldiers who had suffered an ankle injury. He noted that the pathological process for instability was unknown at the time. Further research led Freeman and his colleagues to discover the actual proprioceptive receptors in encapsulated nerve endings in the joints of cats. They found that cats were unable to walk properly after their peripheral afferent joint receptors had been severed from the CNS (Freeman and Wyke, 1966). They termed this ''deafferentation'' and suggested that this was a mechanism for chronic ankle instability, noting that repetitive ankle sprains were most likely a result of impaired proprioceptive information from damaged ankle ligamentous receptors, rather than a mechanical

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Table 1 Postural and phasic groups (adapted from Janda (1987)).

Postural muscles prone to tightness or shortness	Phasic muscles prone to weakness or inhibition
Gastroc-soleus	Peroneus longus, brevis
Tibialis posterior	Tibialis anterior
Hip adductors	Vastus medialis, lateralis
Hamstrings	Gluteus maximus, medius, minimus
Rectus femoris	Rectus abdominus
Iliopsoas	Serratus anterior
Tensor fascia lata	Rhomboids
Piriformis	Lower trapezius
Thoraco-lumbar extensors	Deep neck flexors
Quadratus lumborum	Upper limb extensors
Pectoralis major	
Upper trapezius	
Levator scapulae	
Scalenes	
Sternocleidomastoid	
Upper limb flexors	

instability or loss of strength. In 1965, Dr. Freeman then suggested a simple treatment approach to "compensate for a peripheral sensory deficit" in patients with functional instability of the ankle (Freeman, 1965a). His treatment consisted of balancing on a simple wooden rocker or wobble board. He noted significant decreases in recurrent ankle sprains among the 85 patients completing the training.

The results of Freeman and colleagues helped pioneer proprioceptive rehabilitation not only by identifying the importance of mechanoreceptors in joints, but also by noting the importance of the CNS in rehabilitation of peripheral joints. Researchers and clinicians began to investigate the role of the CNS in chronic musculoskeletal dysfunction.

During the 1950s and 1960s, Dr. Vladimir Janda (1928–2002), a physiatrist and neurologist from the Czech Republic, noted that it was impossible to separate the sensory system and the motor system in the control of human movement, thus he used the term, "sensorimotor system." He emphasized that the sensorimotor system functions as one unit and that changes within one section of the system are reflected by adaptations elsewhere in the system (Janda, 1987). Dr. Janda had done extensive work on the patterns of muscle imbalance and the importance of proper firing patterns in maintaining joint stability, recognizing the importance of the CNS in regulating movement. Rather than emphasizing isolated strength of a joint, Janda noted that the most important aspect of coordinated movements was proprioception.

Janda's approach to chronic musculoskeletal pain was that certain muscle groups, the "postural" and "phasic" (Table 1) are pre-disposed to tightness or weakness, respectively, based on their function and control by the CNS (Janda, 1987). His classification was based on the assertion that these two groups served different functions in human development and movement patterns, and that their balanced function was essential to normal movement. Often, the "postural" muscles would respond to dysfunction with increased tightness, while the "phasic" muscles would respond with weakness, creating characteristic muscle imbalance syndromes he classified as "upper crossed", "lower crossed", and "layer" syndrome (Fig. 1).

Janda believed that these muscle imbalances led to movement impairments and ultimately changed the motor programming within the CNS. He noted that chronic musculoskeletal pain is mediated centrally within the CNS. The only way to correct these impairments was to first normalize the peripheral proprioceptive structures (through joint mobilization or soft tissue mobilization), then correct muscle balance, and finally facilitate a correct motor program. He placed emphasis on restoring function of the nervous system through motor re-learning, rather than emphasizing treatment of isolated structural components.

Janda noted two basic stages of motor learning in rehabilitation of muscle imbalance syndromes (Janda, 1987). The first stage is characterized as "voluntary" control of movement, requiring cortical regulation of movement and much concentration on the part of the patient. This stage requires constant feedback from both positive and negative experiences, and is thus somewhat inefficient.

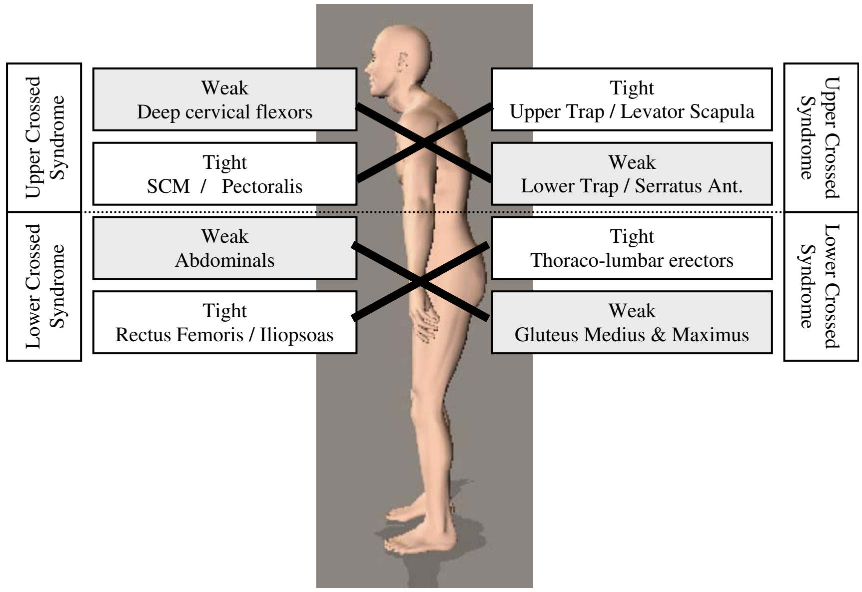

Figure. 1 Janda's muscle imbalance ('crossed') syndromes. Used with permission of the Hygenic Corporation.

As the patient learns, the new coordinated movement pattern is programmed in the subcortical region, becoming more "automatic" and requiring less conscious thought processing, thus becoming much quicker. At this point, "feed-forward" mechanisms become important. Feed-forward mechanisms occur unconsciously and are important in preparing the body for movement by contracting stabilizing muscles prior to initiating the movement. The importance of this mechanism is most noted in the transverse abdominus muscle, which normally contracts prior to extremity movement (Hodges and Richardson, 1997a, b), and becomes delayed in chronic musculoskeletal dysfunction (Hodges and Richardson, 1998).

Janda felt that this automatic level of processing was essential to protect joints for dynamic functional stability throughout the body, and he developed his sensorimotor training (SMT) program in 1970 for rehabilitation of the lower extremities as well as the spine (Janda and VaVrova, 1996).

Influenced by the work of Freeman and colleagues, noting the importance of foot proprioception, Janda focused on providing input into the sensorimotor system "from the ground-up". He emphasized the importance of optimal foot position and sensory stimulation to the sole of the foot to ensure maximal afferent information during stance (Janda and VaVrova, 1996). He suggested that the sensory information coming into the CNS must be optimal at three locations in the body due to their large amounts of proproiceptors: the foot, the sacroiliac (SI) joint, and the cervical spine. The goal of SMT is to increase proprioceptive input of these three areas in order to stimulate subcortial pathways and facilitate automatic coordinated movement patterns. Therefore, it is vital to ensure proper positioning of the joints at these three key points during any exercise movement.

The first postural key point is the foot (Freeman and Wyke, 1967). Proprioceptive exercises are best performed without shoes (barefoot is best) to ensure the maximum amount of appropriate afferent information entering the sensorimotor system. First, stimulate the sole of the foot with tactile input such as a sensory/reflex ball or brush, and the joints of the foot and ankle are mobilized. Most importantly, instruct patients in the concept of the "short foot", used to describe the shortening and narrowing of the foot while the toes remain relaxed. This is accomplished by contracting the intrinsic muscles of the foot, thereby increasing the medial longitudinal arch and effectively "shortening" the length of the foot.

Janda stated that proprioception and postural stability improve when exercises are performed with a short foot (Janda and VaVrova, 1996). Begin training the patient in the short foot in sitting, using "passive modeling" or hand positioning to help facilitate the patient to perform an active short foot (Figs. 2a and b). For patients having difficulty maintaining a short foot, a strip of Thera-Band is sometimes taped to the sole of the foot as an "active-assist" to help patients maintain the short foot position. (Fig. 3).

The next key point in postural stability is the SI joint (Hinoki and Ushio, 1975). The lumbopelvic region must be maintained in a "neutral" position,

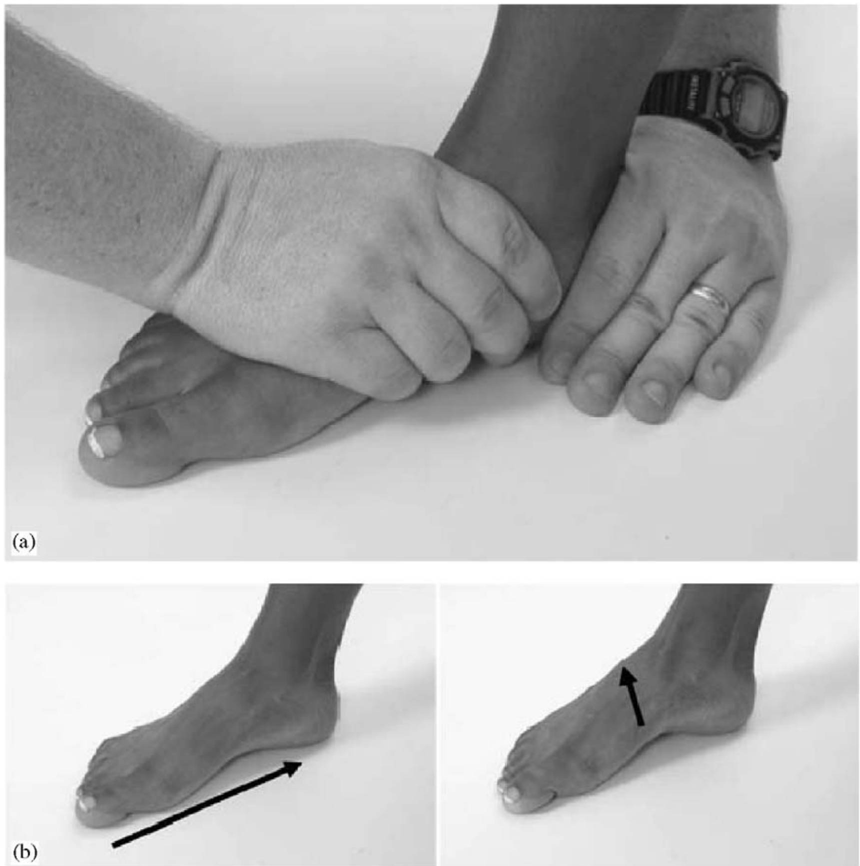

Figure. 2 (a) Passive modeling of the short foot. (b) Active modeling of the short foot. Used with permission of the Hygenic Corporation.

Figure. 3 Thera-Band assist taping for short foot. Used with permission of the Hygenic Corporation.

neither too lordotic nor too kyphotic. It is important that any dysfunction of the SI joint be corrected prior to initiating SMT because of its role in proprioception. This helps ensure proper length-tension relationships of the joint mechanoreceptors sending information on posture to the CNS from the lumbopelvic region. In addition, facilitation of the transverse abdominus is cued by slightly drawing the umbilicus inward.

Finally, the cervical spine plays an important role in posture (Abrahams, 1977). These mechanoreceptors are important in maintaining equilibrium and postural reflexes from birth. Placing the cervical spine in a neutral position with the chin slightly tucked helps activate the deep neck flexors. Once the individual learns the proper positioning of these three proprioceptive points, SMT can begin.

Sensorimotor training progression

Patients progress through three stages of SMT: static, dynamic, and functional (Table 2). Within each stage, patients progress through exercises in different postures, bases of support, and challenges to their center of gravity. Each exercise should elicit automatic and reflexive muscular

Table 2 SMT progression.

Stage	Description	Posture	Base of support	Center of gravity
Static	Maintain postural stability on progressively unstable surfaces	Standing	Firm	Weight shifts
		1-leg balance	Stability trainer	Perturbations
	Progress by shifting weight, closing eyes, or adding head movements	1/2 step	Rocker board	
		Minisquat	Wobble board Minitrampoline	
Dynamic	Add arm and leg movements while maintaining postural stability on progressively unstable surfaces. Use other devices for additional challenge (bands, balls, etc)	(progress above)	(progress above)	Upper extremity → Resisted band
				Lower extremity → Resisted band Weighted ball toss
Functional	Perform functional movements (such as lunge or squat) on progressively unstable surfaces	Walk	Balance sandals	
		Squat Lunge Step Jump Run		

stabilization, challenging the patient to maintain postural control under a variety of situations.

Static phase: In the static phase, emphasis is placed on developing a stable pelvis ("core") from which to build movement in subsequent phases. The pelvis is stabilized by a "pelvic chain" of muscles (Lewit, 1999): the multifidus, transverse abdominus, pelvic floor, and diaphragm. Janda (1987) noted that many movement impairments are caused by, or reflected in the pelvis and hip musculature. Without a stable base at the pelvis, extremity movement will be compensated elsewhere in the kinematic chain. This is the principle of "proximal stability for distal mobility". Distal dysfunction (in the extremities) may be caused by or the result of proximal (lumbopelvic) dysfunction. For example, knee dysfunction has been associated with hip muscle weakness (Jaramillo et al., 1994, p. 2001).

Remembering the importance of Janda's three key proprioceptive joints, patients maintain proper foot, SI, and cervical positioning during each exercise. They progress from bilateral to unilateral stance, and then to a "half-step" position (Fig. 4). In this half-step position, the trunk leans forward over the short foot while the patient maintains a neutral cervical and lumbar spine. Vary the patient's base of support by progressing from a firm surface to a foam surface, and then progress to the rocker and wobble boards (Fig. 5). Using labile surfaces during exercises increases speed of contraction and motor output (Beard et al., 1994; Blackburn et al., 2002; Bullock-Saxton et al., 1993; Ihara and Nakayama, 1986). During the static phase, patients are challenged to maintain their center of gravity using passive weight shifts or challenges to the center of gravity. These weight shifts and perturbations are used to elicit reflexive and automatic postural reactions (Nashner, 1989) that teach the patient pelvic stabilization in a more functional position.

Dynamic phase: Once the patient exhibits the ability to maintain pelvic stability in the half-step position under a variety of conditions, progress the challenges of their center of gravity in the dynamic phase. The patient begins "building" on the stable pelvis by performing movements of the upper and lower extremity, gradually adding resistance to the movements. One of the most effective exercises to elicit automatic muscular contractions of the leg is

Figure. 4 Half-step position. Used with permission of the Hygenic Corporation.

the "T-Band Kick". Several studies have demonstrated reflexive activation of muscles in the stance leg while kicking an elastic band (Cordova et al., 1999; Hopkins et al., 1999; Schulthies et al., 1998) with the other leg. For example, when kicking forward with the left leg, the hamstrings on the stance leg are activated. In addition, movement of the upper or lower extremity reflexively activates the transverse abdominus (Hodges and Richardson, 1997a, b), thus improving pelvic stabilization.

It is important to re-train these feed-forward mechanisms at this point in the rehabilitation. Other techniques which may contribute to the feed-forward mechanism include oscillation training of the extremity or perturbations to the center of gravity. Imparting these additional challenges to postural control may help facilitate these anticipatory muscular stabilizing functions.

Functional phase: The final stage of SMT is functional progression of postures with extremity movement with a stable pelvis. These include walking, squats, lunges, steps, jumps, and running. At this point, patients are ready to begin using Janda's "Balance Sandals". These are simply sandals with a hard rubber ball (cut in half) attached to the mid-sole, providing a very unstable and challenging position for the foot (Fig. 6). Patients are encouraged to maintain a short foot while maintaining correct posture at the pelvis and head. Begin with small steps and progress to forward, retro, and lateral walking in the shoes, while avoiding lateral or vertical shifting of the pelvis. Dr. Joanne Bullock-Saxton et al. (1993) found that patients using Janda's balance sandals five times a day for 3 minutes improved their speed of contraction of the gluteus maximus and medius by as much as 200%, after just 7 days of training. Blackburn et al. (2002) recently reported that the balance shoes produced the same, if not more, EMG activity of the lower leg during other closed-chain exercises.

Advanced SMT activities combine many different challenges to postural stability. For example, patients may perform a lunge onto a wobble board, with a concurrent anterior weight shift using an elastic band (Fig. 7). This would promote eccentric control of posture during the initial stance phase.

Posture is the most important consideration when performing SMT. Patients are progressed through various stages of SMT with progressive challenges to their postural stability through the base of support, center of gravity, or external challenges. It is helpful to remind patients to maintain proper posture at the three key areas of proprioception (neck, low back, and foot). Therefore, *quality* is more important than *quantity* when performing SMT.

SMT exercises are typically performed to fatigue or for a certain amount of time. Rather than prescribe a specified number of repetitions, have the patient perform the exercise under direct supervision to the point of fatigue. Remember that the goal of SMT is to increase muscle reaction and tissue endurance rather than joint strength. At the first sign of fatigue (the initial burning sensation or any compensated movement) the exercise is

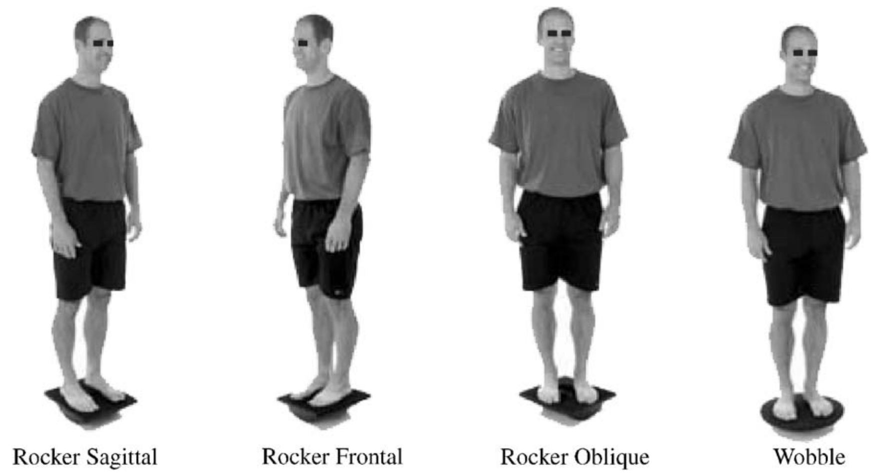

Figure. 5 Balance board progressions. Used with permission of the Hygenic Corporation.

Figure. 6 Janda's balance sandals (avialable in USA from OPTP: (800) 367-7393 or from The Gym Ball Store: (800) 393-7255).

Figure. 7 Squat onto wobble board with anterior weight shift.

stopped to avoid further compensatory movements that may promote dysfunction.

SMT improves proprioception, strength, and postural stability in lower extremity rehabilitation (Beard et al., 1994; Ihara and Nakayama, 1986; Pavlu and Novosadova, 2001). Clinically the author has found SMT to be effective in treating chronic low back pain, fibromyalgia and chronic neck pain. While not appropriate for all chronic pain syndromes, more research is needed in the use of SMT for chronic musculoskeletal pain.

Janda prescribed SMT for chronic pain patients who exhibited his muscle imbalance syndromes in order to re-program the CNS. To treat chronic musculoskeletal pain, it if often necessary to treat the entire sensorimotor system, not just involved structures. The largest advantage to SMT is that this progression can be easily performed as part of a home program with inexpensive equipment, but it is important that the therapist monitor the patient's ability to perform the exercises properly.

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