# Motor Control, Muscle Function, and the INSTANT REPLAY

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This paper is an exploration of the motor pathways utilized by INSTANT REPLAY protocols. A unique methodology, these protocols can be applied to the subacute and chronically injured patient in rehabilitation settings as well as to the uninjured through training programs. A rapid reduction in pain and improvement in function is often seen with its use; therefore the purpose of this paper is to explore avenues for this sometimes-astonishing response in movement ease and performance.

Athletic movements require coordination, balance, and timed weight-shifts of the various segments of the body. Several neurological systems provide the feedback necessary for a person to accurately move body segments and contract and relax muscles in the smooth ballet of sporting movements. As humans, we all have the same basic anatomical elements yet some are able to use their particular neurological senses in a more effective manner in sport. "Gifted athlete" we often call them; they excel at sports because they are able to move in repetitive patterns of highly coordinated, sequenced movements. They are somehow able to integrate information from these systems better than others. Although it is beyond the scope of this paper to provide an exhaustive discussion of these systems and their pathways, some dialogue of this neuroanatomy and neurophysiology will be necessary if we are to understand the theories of this methodology.

Three subsystems of the central nervous system (CNS) control our ability to maintain balance and equilibrium: the somatosensory system, the vestibular system, and the visual system.1 Although higher CNS centers (cerebral cortex and brain stem) are very much involved, this paper will primarily concern itself with the somatosensory system.

The somatosensory system may most simply be described as a system providing information concerning the orientation of body parts to one another and to the supporting surface for the purpose of maintaining postural equilibrium.2,3 In other words; it controls how we move our center of gravity and body parts in relation to our environment. It includes cells or organs called proprioceptors and tactile sensors. Proprioceptors are receptors spread throughout our muscles, ligaments, joints, and connective tissues that tell us not only where our body parts are in relation to each other and the outside world but also how fast and where they may be moving. The tactile organs detect such things as touch, pressure, and vibration and also influence balance and movement.4

There are two functional groups to which tactile organs and proprioceptors may be further divided: slow and fast adapting to external stimuli. Slowly adapting sensors relay information regarding continuous tension or deformation while fast adapting perceives rapid changes in movement or pressure.5 Mechanoreceptors are specialized proprioceptors that live either within joint ligaments or capsules (articular) or within muscles and tendons (muscular). They may be either fast or slowly adapting as well. Overlap exists between the two as they function to provide seamless control of joint stability via muscle tone changes. Articular mechanoreceptors are of four types: "The function of the slow adapting/non-adapting type I receptors is to continuously transmit impulses as long as the stimulus is present. This keeps the brain aware of the body and its surroundings. They allow the CNS to know the status of muscle contraction and load on tissues at each moment of both static and dynamic activities. The fast adapting receptors (type II) fire only when the strength of the stimulus being applied changes. They react strongly while a change is actually taking place and the impulses are directly related to the rate at which change takes place. These receptors are movement and rate detectors. The type III receptors are completely inactive in immobile joints. They are found in ligaments and are thought to measure tension. They become active at the extreme ranges of motion. Type IV receptors are free nerve endings found throughout the body. Most detect pain, but some detect crude touch, pressure, and tactile sensations." 6,7

Muscular mechanoreceptors are called Golgi tendon organs (GTOs) and muscle spindles. The GTOs, located where tendon blends to muscle, send information about muscle tension or changes in tension to the

CNS and spinal cord. The spindles, however, are located within the muscle belly and transmit information regarding rate and magnitude of muscle length change.4,7 A major role in the phenomenon called alpha-gamma coactivation is played by the muscle spindles as well. The muscle spindles are unique in that they have nerve attachments (innervations) that not only perceive stimulus (afferent) but also cause a motor response (efferent). These motor efferents (also called gamma efferents) adjust the tension of small muscle fibers (intrafusal) within the spindle itself altering its sensitivity to the larger muscle's current state of tone. Large muscle movement is initiated when it receives signals from alpha motor neurons thus changing its current tone. When alpha motor impulses and gamma efferents stimulate the muscle at the same time it is called alpha-gamma coactivation. Often this system is used to fine-tune the movement of a limb when loads are different than we expect .4,8 But since the gamma system may be stimulated by joint and cutaneous mechanoreceptors as well as the brainstem 8,9, it follows that proprioceptor activation in functional movements help increase excitation of the spindles which in turn cause a greater recruitment of motor units and a stronger contraction.11

The last groups of proprioceptors explored are tactile sense organs; they also have the ability to influence movement and posture. Spread throughout the skin as cutaneous receptors as well as in deeper layers, these organs are also either slow or fast adapting. Of particularly importance, are those of the plantar surface of the feet. They have been shown to supply the CNS with information regarding weight distribution upon each foot as well as between the feet. Not only are they an important source of input on static position and body sway, they play a "significant role during dynamic and functional movements as well." 4 p.40-41 These cutaneous receptors provide information that blend with the receptors of muscles and joints to further the overlapping system of neurological input guiding movement and balance.

The INSTANT REPLAY and its methodology rapidly enhance input from these somatosensory components enabling people to learn athletic movements faster as well as improve existing motor skills. Additionally, the device provides a platform for enhanced rehabilitation and strengthening. The constant tension of the elastic component (RNT tubing) helps increase input from those sense organs that are slowly adapting. Type I articular mechanoreceptors for instance function continuously in both dynamic and static situations as well as the tactile sense organs in the plantar surface of the foot. The fast adapting type II mechanoreceptors are triggered as the tension from the RNT changes with the specific movement pattern. In progression, the protocol holds that exercise patterns are done slowly and then faster, further exciting the type II's. The sport-specific swing planes used by the INSTANT REPLAY trigger the type III cells at the end of the pattern further educating the sensory system as to exact positions. Protocol rotation patterns tend to load limbs and feet in a certain order, stimulating the cutaneous receptors of the foot as well as muscular mechanoreceptors of the lower leg. During rapid movements, this input from the legs give us our most sensitive means of feeling postural sway.4 The INSTANT REPLAY encourages loading of the legs in functional patterns at different times as weight shifts are progressively trained. This results in massive sensorimotor input 6,9 and raises the level of excitability and contractility of the nervous system, speeding the rate of muscle shortening.13 In other words, movements and muscle contractions become more responsive and quicker. The importance of this becomes evident when we think of a typical force/time graph. In golf, for instance, typically .20 seconds are required from a full, take-away position to reach impact14 yet absolute maximum force usually requires .60 to .80 seconds in any explosive move.13 So the goal with late stage training is to create more power faster. By focusing on the trunk, hips, and legs the INSTANT REPLAY is in perfect position to do this.19 In this golf example, greater force is directed through the club in a shorter amount of time yielding more club head speed and further shots. This same approach can be applied to nearly any sport. The INSTANT REPLAY, using an optimal combination of open and closed chain maneuvers 10 p. 372, loads the joints of the spine and lower extremity in sport-specific patterns; a requirement for any exercise designed to enhance neuromuscular control of joints or movement patterns.10 p.369 Because these patterns first require the athlete to control his center of gravity and individual body segments against resistance in an "isoeconcentric" (eccentric and concentric contractions punctuated by an isometric hold) fashion and then move those same components with the assistance of the tension, balance is continually challenged. This sort of training will enhance the "responsiveness and sensitivity of mechanoreceptors, thereby increasing proprioceptive input to the CNS." 10 p. 369 Since these inputs and effects are mediated via the nervous system rapid changes may take place. Whereas changing muscle physiology with weight training requires 6-8 weeks12 working with the sensorimotor system allows us the luxury of nearly immediate change as we alter electrical nerve impulses. As has been shown, more input means a better ability to move the body in a coordinated fashion. This mechanoreceptor-based training, "although the most important from a clinical orthopedic perspective" is largely mediated at the spinal cord level.[11] Yet research holds that all 3 levels of motor control need be accessed for optimal training: spinal cord, cortex, and brain stem.[1,10,15]

As has been shown, proprioceptor activity has most of its effects through reflex pathways at the spinal cord level. The brain stem uses the somatosensory systems in conjunction with visual and vestibular systems to maintain balance and posture[10,11] while acting as a relay station between the cortex and spinal cord. From this vantage point it is also a modifier of motor commands.[11] The cerebral cortex is responsible for cognitive programming. Cognitive programming is what happens when one learns a precise movement pattern and is able to repeat it often enough to fashion what is called an engram on the cerebral cortex making the activity automatic, requiring no conscious thought. Cognitive programming or motor programming is the most contemporary of movement learning theories and certainly makes the most sense in the face of current literature.[16] The concept of "feedforward" or mentally visualizing the movement prior to performing it is a function of the cortex and programming.[23] According to Fitts, this programming may be achieved in 3 stages of motor learning: cognitive, associative, and autonomous.[24] The cognitive stage is when initial understanding of the movement takes place. This is beautifully illustrated by the torso-accelerated swing of the INSTANT REPLAY golf protocol. By facilitating the sensation of a proper hip turn and weight shift at impact and follow-through, a golfer is able to grasp (often for the first time) what moving through the ball feels like and means. Therefore, the golfer is subsequently enabled to more effectively use the feedforward process. This stage is marked by rapid improvement and soon the associative stage is reached where the task is fine-tuned. In our example of the golfer, this would be when continued repetition yields better balance or more precise positioning. This is that phase we have all felt while learning a new technique or sport: you can't do it the same each repetition but it's getting closer. Gains are slow in this phase. Once at the autonomous point, the movement has been patterned and is "fairly automatic".

During swing training with the INSTANT REPLAY, the line of the RNT from its wall attachment to the body forms a perfect visual reference to align the hips and feet with the swing plane. Additionally, any swing made that does not control the center of gravity to finish on a firm lead-side will cause the user to lose his balance. So visual input and additional balance perturbations use the brain stem and associated areas. Now the user has a device that calls into play massive sensory input from all 3 levels of motor control. Additionally, the device and methodology of the INSTANT REPLAY allows for multiple repetitions using minimal load (if desired) on the muscular system allowing for daily use and rapid formation of a cognitive program.

Obviously, these same principles apply to the injured user as well with one big exception: the effect is often more dramatic. Consider for a moment the injured athlete. In virtually any injury proprioception may be disrupted. Barrack and Munn detail the specifics of proprioceptor damage following knee ligament injury[17] and the same has been documented in regards to ankle ligaments.[18] But can the same be said for spinal ligaments and soft tissue? Since it has been widely published that 80% to 90% of us will have a back injury at some point in our lives, this question takes on a more personal meaning. Lyons, perhaps, summarizes that answer best: "Intuitively, proprioception deficits would be present if muscle, ligament, capsule, or joint injury is present based on previous work on extremities and neurology of joint receptors. It is beginning to look like proprioception deficits are present in low back pain patients based on joint position and stabilometry studies." [6] Perhaps the best article he sited was published in Spine,[20] and showed statistical significance for low back pain patients demonstrating enhanced sacral-tilt position-sense after a vibratory stimulus was placed over the spinal muscles. Muscle spindles and mechanoreceptors are stimulated by the vibration and send more impulses into the CNS, improving aspects of proprioception. Most certainly, this parallels the empirical experience often shown by injured users of the INSTANT REPLAY. Indeed, as early as 1959, then unidentified encapsulated receptors on the surface of the lumbar disc were thought to be proprioceptors.[21] Now identified, these mechanoreceptors are present not only in the disc but in its surrounding ligaments as well.[6] Imagine how hampered the somatosensory system is when faced with a damaged or degenerated disc. All the tissues that should be taut with twisting or bending motions no longer receive the same tension with a given movement and are therefore unable to trigger the same level of proprioceptor activity or subsequent muscle control. This is what has been termed as "functional instability" [18] and is where the INSTANT REPLAY is incredibly effective.

We know that in order to best enhance joint stability with rehabilitation, the exercise used must be activity-specific or be presented under similar conditions as will be required by function.[10] Ligament damage, disc damage, muscle damage, or joint damage all have the potential to create a functional instability18 and as such will require specific efforts to re-educate the movement patterns. Recovery of muscular stabilization following a low back injury is not spontaneous as shown earlier by Hides et al. and more recently by Evans and Oldreive.22 The reason for this has not been proven to date but it's likely the sensorimotor system is playing the key role. A damaged sensorimotor system will not automatically allow muscles to be used for stabilization, they need to be very specifically retrained in very specific patterns. Without retraining there is poor muscular stabilization and an increased risk of injury or aggravation of an old injury.25,26 Understanding this makes it easier to see the recurrent nature of low back injuries.

Failure of low back rehabilitation to a functional state is not necessarily due to lack of effort but perhaps too much effort in the wrong directions. Richardson et al. have devoted an entire text to this principle and have effectively presented the link between spinal muscles and their neural control as it relates to functional spinal stability. They present data that shows the multifidus acts more as a precise fine-tuner of vertebral position, like a dynamic ligament, than a prime mover.27 Therefore, training of the global or outer trunk muscles before adequate control from this deeper lumbo-pelvic musculature has occurred may well spell long-term failure or damage to other spinal structures as loads are distributed less than optimally.28 Subsequently, INSTANT REPLAY exercises are designed to focus on muscles that are thought to synergistically co-activate to provide a firm foundation for lumbar stability: pubococcygeus (pelvic floor), transversus abdominus, multifidus, and oblique abdominals.29,30 The research to date has shown the importance of engaging the transversus and pelvic floor before all other abdominals but with progression the global muscular system is later called into play for stabilized, functional movements.27 It seems by combining volitional efforts and the sensorimotor influence via the weight-bearing INSTANT REPLAY method, a very efficient technique to facilitate improved function of the core, foundational muscles has been developed.

The INSTANT REPLAY combines forces from several planes at once but torsion about a central axis is a constant. In spinal stabilization this becomes very important, as not only has rotation been shown to be the most appropriate trunk stabilization exercise29 but torsional overload (usually from chronic overuse) is the most common cause of low back injury.33 Here, the "isoeconcentric" idea of using all 3 types of muscle actions at first individually and then in a progressive manner begins to train the tonic function of deep lumbar muscles. In his exhaustive literature review of multifidus biomechanics, Kay summarizes how the multifidus is a poor rotator of spinal segments and functions more as an "anti-flexor" in resisting the flexion component that occurs when the obliques engage isometrically or with movement.31 One of the potential problems in chronic low back dysfunction and pain and subsequent diminished proprioceptive input is a transformation in multifidus muscle fiber from type I to IIa. The normal tonic function is hampered since its timing and sequencing have been altered from lack of proper sensorimotor input and rapid wasting in the presence of low back pain.22 To rectify this, multiple, controlled repetitions over an extended period of time are required to return it to its normal type I fibers. Again the isoeconcentric approach seems ideal for this, as the muscle is required to perform low-level concentric and eccentric efforts punctuated by an isometric hold in controlled, functional patterns. In fact, if the goal is to increase the cross-sectional area (CSA) of the multifidus muscle to aid in stabilization of the lumbar spine via increased lumbodorsal fascia tension as suggested by Farfan31 this is the exercise. When compared to other stabilization programs, this technique was found to be the only method to have a significant effect on multifidus CSA.32 Training superimposed over an axial torsion also helps to improve endurance and coordination of the abdominal muscles, two requirements in avoiding low back injuries.34

As a training modality, the INSTANT REPLAY method focuses its effects on the 3 motor control centers of the body for the purposes of promoting coordinated, sequenced movements as well as fostering a stable, core foundation and spine. This system is geared towards neuromuscular control vs. bulk size and strength. As such its methodology centers upon accepted progressions: from slow to fast speeds, low force to higher force, controlled to uncontrolled movements and from conscious to unconscious, automatic activities.10 Using dynamic, weight-bearing functional postures, closed as well as open chain forces, and "isoeconcentric" contractions, maximizes excitation of proprioceptive pathways providing for coordinated, balanced movement. Training for balance and coordination is recommended for golf35, spinal rehabilitation, and nearly any other sport that requires sequenced weight shifts. This system allows multiple repetitions of specific patterns to be precisely repeated, just like on INSTANT REPLAY.

## BIBLIOGRAPHY

**1.** Rozzi, S., Yuktanandana, P., Pincivero, D., Lephart, S., Role of Fatigue on Proprioception and Neuromuscular Control. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, F., (Eds.) p. 378. Champaign, IL: Human Kinetics, 2000.
**2.** Flores, A. Objective Measures of Standing Balance. Neurology Report-Am Phys Ther Assoc 16: 17-21, 1992.
**3.** Nasher, L., Practical Biomechanics and Physiology of Balance. In Handbook of Balance Function and Testing, Jacobsen, G., Newman, C., Kartush, J., (Eds.), 261-79. St. Louis: Mosby Year Book, 1993.
**4**. Riemann, B., Guskiewicz, KM., Contribution of the Peripheral Somatosensory System to Balance and Postural Equilibrium. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, F., (Eds.) p.39-40. Champaign, IL: Human Kinetics, 2000.
**5.** Martin, J., Jessel, T., Modality Coding in the Somatic Sensory System. Princ Neural Sci pp.340-52, 1991.
**6.** Lyons, C., Review of Proprioception and its Role in Low Back Pain. In The North American Institute of Orthopaedic Manual Therapy Newsletter. Vol. VII, Issue 1, Winter 2002.
**7.** Berry, M., Bannister, LH., Standring, S., (Eds.) Nervous System. In Gray's Anatomy 38th Ed. pp. 964-969. London: Churchill Livingstone, 1999.
**8.** Vander, AJ., Sherman, JH., Luciano, DS., Control of Body Movement. In Human Physiology: The Mechanisms of Body Function. Pp. 539-42. New York: McGraw-Hill 1975.
**9.** Johansson, H., Sjolander, P., Neurophysiology of Joints. In Mechanics of Human Joints, Wright, V., Radin, EL., (Eds.), 243-90. New York: Marcel Dekker, 1993.
**10**. Irrgang, JJ., Neri, R., The Rational for Open and Closed Kinetic Chain Activities for Restoration of Proprioception and Neuromuscular Control Following Injury. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, F., (Eds.) p.365-9 Champaign, IL: Human Kinetics, 2000.
**11.** Lephart, SM., Riemann, BL., Fu. FH., Introduction to the Sensorimotor System. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, FH., (Eds.) p. xvii -xx. Champaign, IL: Human Kinetics, 2000.
**12.** Harris, RT., Dudley, G., Neuromuscular Anatomy and Adaptations to Conditioning. In Essentials of Strength Training and Conditioning, Baechle, TR., Earle, RW., (Eds.) p. 20. Champaign, IL: Human Kinetics, 2000.
**13.** Plisk, SS., Speed, Agility, and Speed-Endurance Development. In Essentials of Strength Training and Conditioning, Baechle, TR., Earle, RW., (Eds.) pp. 472-74. Champaign, IL: 2000.
**14.** Stover, C., Wiren, G., Topaz, S., The Modern Golf Swing and Stress Syndromes. Phys Sportsmed. 4(9): 43, 1976.
**15.** Lephart, S., et al. The Role of Proprioception in the Management and Rehabilitation of Athletic Injuries. J Sports Med. 1997 25(1): 130-7.
**16.** Garrett Jr., WE., Kirkendall, DT., Motor Learning, Motor Control, and Knee Injuries. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, F., (Eds.) p. 53-7. Champaign, IL: Human Kinetics, 2000.
**17.** Barrack, R., Munn, B., Effects of Knee Ligament Injury and Reconstruction on Proprioception. In Proprioception and Neuromuscular Control in Joint Stability, Lephart, S., Fu, F., (Eds.) pp. 197-211. Champaign, IL: Human Kinetics, 2000.
**18.** Freeman, M.A.R., Instability of the Foot after Injuries to the Lateral Ligament of the Ankle. J Bone Joint Surg 47B: 669-77, 1965.
**19.** Leadbetter, D., The Golf Swing. Lexington, MA: Stephen Greene Press, 1990.
**20.** Brumagne, S., et al: The Role of Paraspinal Muscle Spindles in Lumbosacral Position Sense in Individuals With and Without Low Back Pain. Spine 25(8): 989-994, 2000.
**21.** Bogduk, N., Twomey, L., Nerves of the Lumbar Spine. In Clinical Anatomy of the Lumbar Spine. p. 118. Melbourne, Aust.: Churchill Livingstone, 1991.
**22.** Evans, C., Oldreive, W., A Study to Investigate Whether Golfers with a History of Low Back Pain Show a Reduced Endurance of Transversus Abdominis, J Man Manip Ther, vol. 8, #4, pp. 162-74, 2000.
**23.** Shumway-Cook, A., Woollocott, MH. Motor Control: Theory and Practical Application 2nd ed., p.29. Philadelphia, PA: Lippincott Williams and Wilkins, 2001.
**24.** Ibid. p.36.
**25.** Panjabi, MM., The Stabilizing System of the Spine. Part 1. Function, Dysfunction, Adaptation, and Enhancement. J Spine Disorders; 5(4): 383-9, 1992.
**26.** Richardson, C., Jull, G., Hodges, P., Hides, J., Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain: Scientific Basis and Clinical Approach. p. 14-9. London, UK: Churchill Livingstone, 1999.
**27.** Ibid. p.3-164.
**28.** Ibid. p. 163-4
**29.** Ibid. p. 53-4
**30.** Tesh, KM., Shaw Dunn, J., Evans, JH. The Abdominal Muscles and Vertebral Stability. Spine; 12(2): 501-8, 1987.
**31.** Kay, AG. An Extensive Literature Review of the Lumbar Multifidus: Biomechanics. J Man Manip Ther; Vol 9, #1 pp. 17-39, 2001.
**32.** Danneels, LA. Vanderstraeten, GG., Cambier, DC., Witvrouw, EE., Bourgois, J., Dankaerts, W., DeCuyper, HJ., Effects of Three

Different Training Modalities on the Cross Sectional Area of the Lumbar Multifidus Muscle in Patients with Chronic Low Back Pain, Br J Sports Med., Vol 35(3): 186-191, 2001.
**33.** Farfan, HF., Reorientation in the Surgical Approach to Degenerative Lumbar Intervertebral Joint Disease, Orthop Clin North Am. 8(9); 1977.
**34.** Farfan, HF., Biomechanics of the Spine in Sports. In Spine in Sports, Watkins, R., (Ed.) p. 20, St. Louis, MO: Mosby, 1996.
**35**. Watkins, RG. Uppal, SS., Perry, J., Pink, M., Dinsay, JM., Dynamic Electromyographic Analysis of Trunk Musculature in Professional Golfers, Am J Sports Med, 24(4): 535-40, 1996.