Developing or re-establishing proprioception and neuromuscular control is a critical component in motor performance and rehabilitation. Proprioception can be defined as a special variation of sensory modality that encompasses the sensation of joint movement (kinesthesia) and joint position.

Proprioception involves integrating peripheral sensations from afferent pathways while neuromuscular control helps process these signals into coordinated motor responses through efferent pathways (Figure 1).

Both the afferent and efferent pathways comprise the sensory-motor system. Basic science research has provided insight on the sensory and motor characteristics of structures that regulate proprioception and neuromuscular control.

This paper gives an overview of the sensory receptors that provide joint motion and position awareness. It addresses the neural pathways that integrate peripheral receptors and motor responses, and uses theoretical models to describe the processing of sensory information for neuromuscular control. The other theme articles will discuss practical ways to improve neuromuscular control in injured athletes.

**Key Points**

- Proprioception gives us the sense of joint movement and position, due to special nerve endings called mechanoreceptors.
- Increased numbers and diversity of stimulated receptors enhances the information about mechanical events in muscles and joints.
- Feed-forward and feedback muscular control can be enhanced through practice.

**Mechanoreceptors**

**Anatomy and Function**

Peripheral receptors for proprioception, called mechanoreceptors, are located in articular structures, tendons, muscle, and skin. Mechanoreceptors are special nerve endings that depolarize in response to tissue deformation. Therefore, mechanical deformation of tissue is transduced into neural signals (Grigg, 1994).

As tissue deformation increases, so does the frequency of discharge and number of mechanoreceptors stimulated. These signals provide sensory information on intrinsic and extrinsic joint loads. Mechanoreceptors vary in shape, location, and function and can be classified according to their responses to mechanical stimuli. They are either slow-adapting (SA) or quick-adapting (QA), and either low-threshold or high-threshold.

QA mechanoreceptors decrease their discharge rate to extinction within milliseconds of the onset of a continuous stimulus,
while SA mechanoreceptors continue to discharge. QA's are very sensitive to changes in stimulation and are therefore thought to mediate the sensation of joint motion, while SA's are maximally stimulated at specific joint angles and are thought to mediate the sensation of joint position.

Articular Mechanoreceptors
Four types of mechanoreceptors are found in the knee joint: (a) Pacinian corpuscles; (b) Ruffini endings; (c) Golgi tendon organs; and (d) free nerve endings.

Pacinian corpuscles are low-threshold, QA located in the medial meniscus, extra- and intra-articular fat pad, cruciate, meniscofemoral, and collateral ligaments. They are thought to mediate the sensation of joint motion.

Ruffini endings are low-threshold, SA found in the superficial layer of the cruciate, meniscofemoral, and collateral ligaments. Ruffini endings mediate the amplitude and velocity of joint rotation and position.

Golgi tendon organ-like endings are high-threshold, SA found in cruciate, collateral ligaments, and menisci. These receptors remain silent when the joint is immobile but are stimulated at the extremes of joint motion.

Free nerve endings are widely distributed throughout most articular structures. During normal conditions they are inactive, but they become active when articular tissues are subjected to damaging mechanical deformation. Free nerve endings are also sensitive to certain chemical by-products of the inflammatory process.

Tenomuscular Mechanoreceptors
Muscle spindles, SA mechanoreceptors located in skeletal muscle, are sensitive to length and rate of length changes. They have the distinction of being innervated by gamma motor nerves. Increased signals from the gamma motor nerves do not initiate muscle contraction but they do heighten the sensitivity of muscle spindles to stretch. When stimulated, muscle spindles convey information about joint motion and position caused by or due to changes in muscle length. They can also elicit a reflex contraction of the agonist muscles. This is the mechanism, known as the stretch reflex, whereby muscle spindles have the capacity to mediate muscle activity.

Golgi tendon organs are SA mechanoreceptors found near the musculotendinous junction; they function by monitoring muscle tension. When stimulated by high muscle tension, they cause reflexive inhibition (relaxation) of the involved muscle.

Cutaneous Mechanoreceptors
The primary role of skin afferents is to enhance the effects of other proprioceptive inputs. We know, for example, that receptors located in the dorsal skin of the wrist and fingers can provide information on wrist and finger movements. The contribution of cutaneous mechanoreceptors to joint motion and position sense continues to be explored.

FIGURE 1  Afferent and efferent pathways linking peripheral receptors with muscle spindles and motor responses.