Proprioception and Balance - Part 2

George is improving his balance. Because of a previous sprain to his left ankle, he wants to reconnect some of the proprioceptors torn away along with the ligament. Sometimes he works extra slowly (even for Tai Chi!) so that the signals may be strengthened. Often, he does “River Walking” just for this reason. He opens his right foot to 45 degrees, bends his knees and picks up his left foot to rest near the right ankle. Slowly he steps out “empty” with the left foot, so that his weight is not committed to that side yet, and places his foot down, toes pointing straight ahead. Just to prove to himself that the foot is empty, he picks it up again and puts it back beside his ankle, then steps out again and allows his weight to shift to the left foot. Rocking back, he now opens his left foot to 45 degrees and picks up his right foot, letting it hover near his left ankle...

Proprioception is information coming into the brain from various parts of the body. This allows us to know where the head and limbs are located and how they are moving. Much of this information originates in the head through the oculomotor and vestibular systems. While these are part of the Central Nervous System (CNS), the proprioceptors discussed here are located throughout the body. They form part of the Peripheral Nervous System (PNS) and are linked to the brain via nerve fibres running through the spinal cord. Information going to the brain is *afferent*, and carry sensory signals only, where information in response from the brain to the body part is *efferent*, carrying both sensory and motor responses. This creates a feed forward/feed back system that influences reflex reactions, such as pulling away from a hot stove, as well as consciously controlled actions like changing the position of a muscle or joint.

Afferent receptors feed information of different types and at different speeds. These include cutaneous (skin) mechanoreceptors for touch sense, thermoreceptors for temperature, nociceptors for pain and proprioceptors, which are deep mechanoreceptors located in the muscles and tendons and in the joint capsules and ligaments surrounding each joint. Proprioceptors allow us to experience joint position as well as the perception of motion, or kinesthesia. We experience the rate of movement of one part of the body in relation to others, acceleration and deceleration and the overall speed of movement. They allow us to estimate the weight of objects and determine how much effort to use if we want to lift or push them. Proprioceptors tend to be most active while we are moving, even slightly. It becomes harder to sense what position we are in when we are resting and extremely still.

Somatic Sensory (Afferent) Pathways

Cutaneous mechanoreceptors are broadly classified as two types and are located both close to the skin's surface and deep in the dermal layer. Type I sensors measure touch and the degree of pressure being exerted on the skin. For our discussion, these are most important in the feet, in reading pressure signals to report position of the foot, centre of mass, weight shifts, surface contours, etc. Type II measure the amount of stretch undergone by that part of the skin, either as a result of lengthening - stretching the skin surface - or from pressure on it, rather like bending a note on a guitar string. Type II receptors are also found in ligaments and tendons.

Muscle spindles are located in the skeletal muscles. Each spindle is made up of nerve endings that wrap around muscle fibres. These respond continuously to stretching and shortening, measuring the length of a muscle. How vigorously they respond to stretch allows the brain to set the overall tone of the muscle in action, and even when it is at rest. Reactions to stretch sensations are sent back to the body part to adjust the movement. This might be a gross (large) movement such as swinging a leg out in front of you, or a fine movement such as tapping a finger. The more finely controlled the movement in an area, the greater the number of spindles and receptors there are present. The sensory information is picked up by receptors deeper inside the muscle and sent via afferent nerve fibres along the spinal cord to the cerebral cortex of the brain. The response is given along efferent fibres to more surface muscle fibres which control contraction of the muscle as a whole. The only skeletal muscles in the body that lack these muscles spindles are the tiny muscles in the middle ear. Otherwise they are in every muscle that is under voluntary control.

Golgi tendon organs are located in the tendons, right at the junction with the muscle. These measure the amount of tension put onto the tendon by the force of the muscle contracting. Tendons form the anchor between a muscle and a bone and have the ability to stretch somewhat. However, because their job is anchoring, stretch is limited, so the receptors measure tension being created between muscle and bone. Their task is to protect the muscle against excessive stretch so their response is usually to decrease or limit the muscle force, causing the muscle to either relax or give out altogether to protect it from damage.

Ligaments also have the job of anchoring, but they act around joints to limit excessive bending. Ligaments, however, do not stretch. Their function is basically to strap down the articular capsule that surrounds a moving joint and anchor it to bone. A ligament may be attached to the joint capsule or independent of it. This allows a joint to move freely until it is restricted at the end of its range by the outer layer of the capsule and the surrounding ligaments.

Moving joints are generally synovial articulations, meaning that two bones meet end to end and move in partnership. Each end is covered with smooth articular cartilage and the joint is mummy-wrapped on all sides by a tough, fibrous capsule. Joint kinesthetic receptors on the capsule send information to the brain that tell about the angle of the joint, the degree of tension, stretch and compression it is experiencing as well as the amount of change (acceleration or rotation) it may be going through. There are four types of receptors surrounding all joints which help not only in controlling movement but which send signals about the relative strain the joint is experiencing.

Type I receptors tend to be found in higher numbers near the core of the body (think vertebrae). They sense the angle of a joint through its range and report its position. These receptors, called Ruffini endings, are found in the superficial layers of a joint capsule. They are low-threshold (it doesn't take much to stimulate them) and are slow adapting, meaning that the afferent fibres are continuously measuring angles are constantly feeding signals into the spinal cord. Efferent messages stimulate minute adjustments for balance and coordination.

Type II receptors on the other hand are fast adapting and are most active at the onset and termination of a joint's movement. These are the ones that sense any change in position and are found in the deep layers of the joint capsule. They are also easily excited (low threshold) but when the joint is not moving they're not active. Type II receptors (Pascinian corpuscles) are found in high densities at the end of limbs and help the brain to control fine movements, adjusting quickly for coordination and precision.

Type III are high threshold, so it takes a lot to upset them. These Ruffini corpuscles are found in the individual ligaments surrounding joints and can inhibit the action of surrounding muscles by relaying the message of excessive stretch when the joint reaches the end of its range. At that point the capsule and ligaments on the stretched side pull tight and send a "that's enough" signal. In this way they serve to protect the joint from damage caused by overstretch, as long as there is no sudden impact force applied.

Type IV are nociceptors. Found in all the tissues of the body except the brain, these are free nerve endings that respond to pain (noci = harmful). Rather than causing a fine adaptive reaction, nociceptors create an intense, non-adapting response in all the structures surrounding an injured part. This creates protective reactions in muscles to either pull quickly back or restrict movement at a joint. These are at work when we instinctively guard an injury. Nociceptors also stimulate the release of noxious chemicals that irritate structures when they are moved. This can work against us later on when an injury has healed to the point where it needs to be moved, stretched and strengthened.

Somatic Motor (Efferent) Control

Bearing in mind that sensory input originates at the various types of mechanoreceptors and feeds from the PNS to the CNS, the CNS must respond either by finely adjusting movement or inhibiting it. This response happens at three distinct levels in the CNS.

In the **spine**, this system operates below the conscious level. Here, reflexes are able to engage quickly, without reference to higher levels and yet may be inhibited either by conscious control or by pain. Some inhibitory messages are sent by muscle spindles and act to smooth out control of muscular movement. This helps to coordinate rhythmic movements such as walking.

The second level of control comes from the **brain stem**, which includes the cerebellum and the basal ganglia which balance one another with excitatory and inhibitory signals respectively. The cerebellum measures the difference between intended movements and movements that are actually performed. It is a powerful coordinator of complex muscle contractions, as well as a maintainer of posture and balance. The basal ganglia is a collection of three complex nuclei (masses of grey matter) whose circuits connect with other areas of the brain, notably the cerebral cortex, the powerhouse of information relay. The task of the basal ganglia is to help initiate and terminate movements, inhibit unwanted movement, cleaning up the excitatory signals of the cerebellum, and help maintain normal muscle tone. It is also a link between movements anticipated but not yet initiated by the body. This, then influences planning, attention and memory. It is also thought to interact with the limbic system to affect emotional behaviour.

Finally, the **cerebral cortex** holds the maps for sensory input and conscious motor control of the body, linking (as previously discussed) the primary somatosensory and primary motor areas in the brain. This pinpoints the exact location of static and dynamic sensation. It is the major area for planning and initiating voluntary movement, which allows for proper muscle function for daily living, sport, etc. It is interesting to note that movement patterns that are repetitive and those practised over a long period of time are no longer coordinated here, but are stored elsewhere in the brain as subconscious control commands. This means they can be performed without deliberate attention to the movements.

Though the sensory and motor pathways are generally well understood, there has been little testing of functional proprioception. Studies that do exist pay most attention to shoulder, hip, knee and ankle joints, which, as we have seen have far less going on in terms of sensory fibre activity and sensory or motor response due to the small number of connecting structures. One can only imagine the level of activity in the foot, with 26 bones (and a joint for each), more than 30 muscles and over 100 ligaments, each one equipped with the receptors mentioned above. Each vertebra also forms multiple joints, as we begin to discover when we begin to mobilize them so that Tai Chi movements come from the core of the body, and the practitioner is not just waving his hands around.

Understanding how these receptors function can also help us to understand post-injury recovery. When muscles are strained, ligaments sprained or joints injured, afferent nerve fibres are also usually torn away. For this, there is the lovely term deafferentation (a great word, which now needs no explanation). It becomes clear how important proprioceptive training / re-training is alongside traditional physiotherapy to restore nerve pathways to and from the brain. This is not only for regaining the balance and finesse of previous movements, but also in preventing re-injury.

George will eventually step out to exercise his efferent nerve signals. These signals tell the joint how to land, how fast to move, and how much tension should be maintained. These are distorted (or completely torn away) after a sprain, leaving the joint poorly aligned and therefore vulnerable to re-injury. He uses this technique along with his physiotherapy. Poor joint alignment is also blamed for various osteo-arthritic problems later in life.

In developing a rehabilitation program that addresses proprioceptive deficiencies, the focus would be on stimulating receptors to maximize afferent signals. This is often done with one foot stances and the use of wobble boards. It is found that balance and postural activities stimulate reflex stabilization (efferent signals) and so enhance motor function at the brain stem with conscious postural correction. After a while, of course, this is transferred to other areas in the brain so that alignment as well as movements become internalized in the body.

George's practice is therefore a powerful tool for gaining or regaining the clarity of proprioceptive signals to the brain, for balance control and postural change.