Proprioception and Balance – Part 1

George lifts his sword over his head, looking to the left in the direction of the blade. He stands high on his right leg and lifts his left knee to chest height and pointing out to the left. Slowly, his left hand sweeps out and, with two fingers, also points to the left. He looks quite grand and, if he can stop wiggling, a little intimidating. Oh, and George, point your toe a bit and hold it right there.

We balance every day with every step. Why is it so difficult to balance on one foot for more than the few seconds it takes to put the other foot down in front of us? Balance, whether we are moving or standing “still”, is a dynamic process filled with movement and signals going back and forth between the body and the brain.

Proprioception in the body is a feedback system that allows us to sense where our head and limbs are situated in space and in relation to the body, whether they are moving or still. Balance is the equilibrium established by the body in response to proprioceptive information gathered in the brain. The response is then sent from the brain to skeletal muscles and joints to make conscious and unconscious corrective adjustments. This controls the body's centre of gravity over its support base. There are basically three centres that provide this sensory input; **the vestibular system** - for vertical and horizontal position and motion, **the oculomotor system** - for the relative position of the body in space and the **somatosensory (proprioceptive) system** - information from skin, muscle, ligament and joint receptors. In this first part of two parts we will examine the vestibular and oculomotor systems and their effect on balance.

'Vestibular' refers to the workings of the inner ear, while 'oculomotor' deals with how the eye moves and fixes images onto the retina. These are not directly related to either hearing or vision, although these do help the body in its orientation. Balance is therefore possible without the aid of hearing or sight.

Sensory Input

In the **vestibular system** proprioception is measured by hair cells located in the bony labyrinth of the inner ear. The semicircular canals are situated on three planes, one straight up and down, a second lying horizontally and the third leaning out to the side, each one at 90° to the next. These make up the dynamic receptors and tell how the head is moving in space. Each canal is filled with a type of lymphatic fluid. At the bulbous part near the opening of each canal is an ampulla that is lined with tiny hair cells. As the head moves in a certain direction, the hair cells are pushed over in that direction by the fluid as it moves past them. Dynamic receptors also detect linear acceleration and deceleration, as

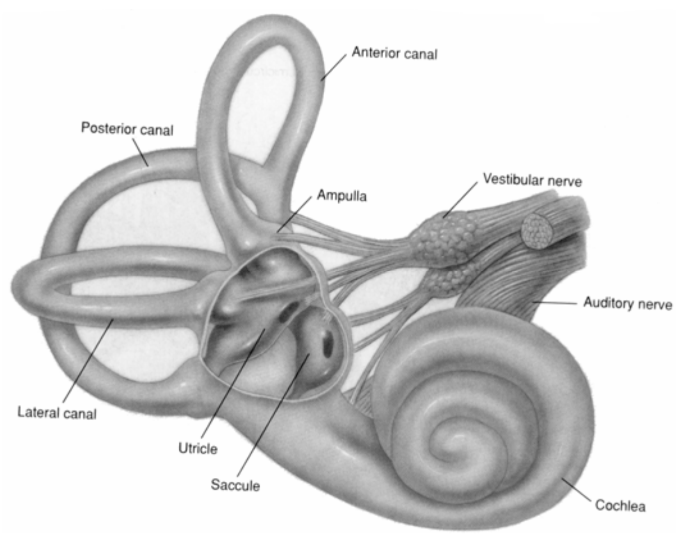

Illustration 1: Vestibular system (inner ear)

experienced in an elevator or car.

In the vestibule just next door are the static receptors. These tell about the position of the head when it is not moving. If anyone has ever told you that you have rocks in your head, well, it's because you do. Inside the vestibule are two pouches called the utricle ("little bag") and the saccule ("little sac") positioned perpendicular to each other. The alignment of the utricles is largely horizontal and the saccules basically vertical. These too are lined with hair cells suspended in fluid and scattered along them are the otoliths (oto = ear; liths = stones), which are deposits of calcium carbonate crystals. These are suspended near the top of the hair cells so that they slide "downhill" in the direction of tilt, exerting a shear force on the hairs. Otolithic organs sense the position of the head in space and are essential for posture and balance.

The position and movement of the eyes play an important role in the function of balance. In the oculomotor system the nerves supplying the muscles around the eye convey impulses for non-visual perception of the movement and position of the head and body. The vestibulo-ocular reflex helps to maintain a steady image on the back of the retina, especially during head movements. This information is sensed "before" signals are sent to move the eyes. Some of the information has simply to do with the eyes' ability to hold a steady gaze in order to sense steadiness in the environment. While reading this page, you can shake your head as if to say 'no' and still focus on the print. This allows us to track with the eyes, independent of head movement. Try this - look from the page to an object to your right. Did you notice that your head moved with your eyes instead of your eyes scanning over independently? At certain times we look at an object separate from its surroundings. In this case the eyes tend to move the head along with them. At other times we look at a specific object within a field of gaze, as when we are driving. Then the eyes move more independently and the entire field is held centrally, as though the face were focussing instead of the eyes. It's difficult to tell sometimes where conscious control of eye movements and some of these involuntary reflexes begin and end.

Proprioceptive information collected from eye movements and vestibular feedback both travel to the vestibular nuclei and from there have a wide-ranging effect on conscious and unconscious balance in the body.

Output Pathways

From the vestibular nuclei, signals are sent to areas that regulate balance in five specific ways:

1. Projections descend from the brainstem into the spinal cord and plug into neurons the entire length of the cord. This ensures muscle tone to the muscles of the back that maintain upright posture.
2. Some of these stop off in the neck to co-ordinate head movements in relation to the body.
3. There is direct output to the muscles surrounding the eyes for co-ordination of eye and head movements. These account for the 'righting reflex' that attempts to keep the eyes level with the horizon when the body is in a non-upright position. The most obvious example is watching a biker take a corner; his body stays with the bike, but his head remains with the horizon.
4. Signals travel through the thalamus at the centre of the brain to the cerebral cortex, a powerhouse of information relay. The cortex holds primary areas that integrate sensory experiences and generate patterns of recognition and awareness (taste, smell, etc.). One of these is the primary somatosensory area (somato = body) which contains a "map" of the entire body. This is a receiving station for the special senses from all kinds of receptors, and can pinpoint the exact location of a sensation's origin. Information to this area from the vestibular nuclei translates into the awareness of balance.
5. Finally there is information passing back and forth from the cerebellum, at the bottom of the brain, to maintain muscle tone at an unconscious level for balance, with the front part of the cerebellum specifically controlling the lower limbs. The cerebellum is the area so easily disturbed by empty wine bottles.

Paired with the primary somatosensory areas (in 4 above) are association areas. Two of interest to us are the somatosensory association area and the premotor area. The role of the somatosensory area is to integrate and interpret sensations. It helps you determine the shape and texture of something without seeing it. For example, sitting in your chair, you can sense clearly in your body the difference between walking on concrete or on dry sand, without setting foot on either one. It also interprets the orientation in space of one object to another (hold one hand out flat, the other at an angle) as well as relationships within the body of one part to another (how far away is one hand from the other?. It puts these sensations into memory so that you can compare current sensations with past experiences.

The premotor area is a motor association area that deals with learned movement that is complex and sequential. Nerve impulses from this area cause specific muscle groups to contract in specific sequences. It also serves as a memory bank for these complex movements. For example, learning Tai Chi, which is usually a long sequence of steps and postures, we engage the brain in memory work and the body in retraining at many levels. We try to remember the steps consciously, but also by direct input from the sensory information through the sequence, as it is repeated over and over. After a while, the conscious involvement of the brain diminishes so that movement may be practised without paying so much attention.

We also rely heavily on proprioceptive information that comes from sensors in the limbs, which will be explored later. But there is an often overlooked chunk of sensory information and interpretation that begins in the neurons surrounding the brain. These work together with the rest of the body's receptors for a complete picture.

Meanwhile, George is beginning to sweat. His eyes are fixed on the horizon, he's steady on his feet with good information back and forth through the cortex. But we should let him relax now, step down behind and left, and turn back, pulling his sword out of the air for a strike to the right. Then he'll try to remember the next move.