INTRODUCTION

Benign paroxysmal positional vertigo (BPPV) is one of the most common causes of vertigo. The cause of BPPV is usually idiopathic (Yimtae et al., 2000). It is characterized by spontaneous remissions and exacerbations with short lived episodic positional vertigo provoked by certain head positions and chronic disequilibrium (Gianoli, 2001).

The two most accepted theories for BPPV at present are cupulolithiasis which proposes that otoconia from the utricle have migrated to the ampulla of the posterior semicircular canal where they have become attached (Gianoli, 2001), and canalithiasis due to the presence of free otoconial debris migrating into one or more semicircular canals (SCCs) during head movements and resulting in abnormal stimulation of the ampullary crest (Giacomoni et al., 2002).

The canalith repositioning procedure (CRP) is designed to treat BPPV through induced out-migration of free moving pathological particles in the endolymph of SCCs using timed head maneuvers and applied vibration (Epley, 1992). The Epley canalith repositioning procedure or Semont maneuver had a significantly higher efficacy rate in patient with BPPV than placebo procedure (Lopez-Escamez et al., 1999).

CRP is the main therapy used for BPPV treatment (Stambolieva and Angov, 2006). Some patients that underwent canalith repositioning maneuver reported improvement in postural stability as well as vertigo. Others still complain of postural instability despite improvement of vertigo. This controversy of patients' outcomes is the rationale of our study.

Aim of the Work

1. To assess the effect of canalith repositioning maneuver on the improvement of postural instability in patients with BPPV.
2. To find factors that would predict improvement in postural instability.

PHYSIOLOGY OF BALANCE

Balance and postural control involves maintenance of alignment of body posture, stability and bodily orientation in the environment and also serves as a mechanical support for action. We should be aware that postural control is a pre requisite for voluntary skills, because almost every movement that an individual makes is made of a postural component that stabilizes the body (Massion and Woollacott, 1996).

Maintaining balance in man occurs largely subconsciously. The sense of balance is not one that the normal individual is aware of, until it goes wrong. Humans have the ability to control posture and movements of the body and eyes relative to the external environment. Most vestibular activity is conducted at a subconscious level. However, in situations producing unusual or novel vestibular stimulation such as wave motion in ships, vestibular perception becomes acute, with subsequent vestibular symptoms (Minor and Zee, 1998).

Standing, reaching for objects, rising from a chair and walking, place the body center of gravity (COG) well above base of support, which is small relative to our body height (Nashner, 2001).

Center of Gravity (COG)

It is the center of area contained within the sway perimeter (Nashner, 1993). It is located in the lower abdominal area and slightly forward of the ankle joint in healthy subjects standing erect (Hullar et al., 2005). When the average person stands erect, the COG is usually positioned directly over a point called the center of foot support.

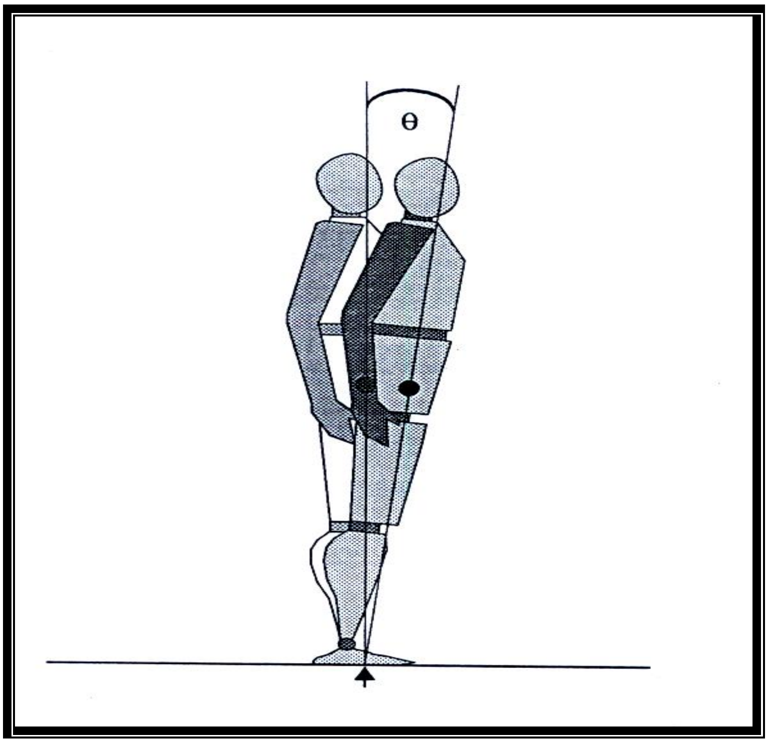

Fig. (1): Center of Gravity sway angel θ

(Quoted from Smart Balance Master® Operator's Manual Version 4, 1994)

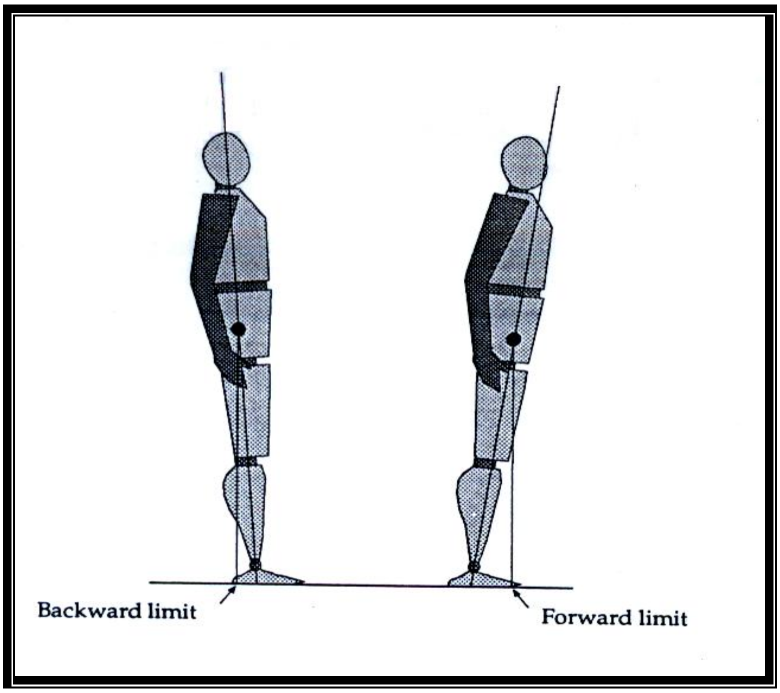

Fig. (2): Limits of stability

(Quoted from Smart Balance Master® Operator's Manual Version 4, 1994)

This point is located slightly forward of the ankle joint, halfway between the front and back boundaries of the feet, and is midway between the lateral borders of the feet. **Fig. (1)** illustrates the (antero-posterior) AP COG sway angle (θ). When a person moves as a rigid mass about the ankles, the AP COG sway angle is the angle between a line extending vertically from the center of foot support and a line extending from the center of foot support through the COG (Smart Balance Master Operator's Manual, 1994).

The goal of human postural control is to maintain sway within the limits of stability for different body positions and activities. Active processes for control of bodies' center of gravity are involved in maintaining postural stability in healthy subjects (Hullar et al., 2005).

Limits of Stability (LOS)

The limits of stability (LOS) refer to the outer most perimeters of the COG positions which maintain the COG over the base of support **(**Nashner, 2001). **Fig. (2)** demonstrates the limits of stability in a normal human subject. In theory, the forward limit of stability places the COG over the toes, and the backward limit places the COG over the back of the heels. In practice, however, the effective limits of stability are less than this, since the foot muscles in most individuals are not strong enough to allow the toes to carry the full body weight (Smart Balance Master Operator's Manual, 1994).

The limits of stability are defined by a horizontal ellipse measuring approximately 12.5 degrees from front to back, for a person 70 inches tall with feet placed 4 inches apart. The lateral dimensions of the limits of stability ellipse are approximately 16 degrees from left to right (Hullar et al., 2005). Height and foot length affect antero-posterior LOS. The LOS is similar for people of various heights because height and foot length co-vary. The lateral dimension of our limits of stability depends on both the person's height and the lateral spacing of the feet (Nashner, 2001).

Base of Support

Our base of support is the area of contact between the feet and the surface. The relationship between the COG and the base of support varies during typical daily life activities. The side-by-side placement of the feet provides an elliptical base of support. During the double support phase of walking, a diagonal foot placement produces a parallelogram-shaped base of support extending forward on one side and backward on the other. Standing or walking with the feet in tandem substantially reduces the width of the support base but not its length (Nashner, 2001).

In humans, a highly sophisticated mechanism for maintaining gaze and balance is present, which is dependent upon visual, vestibular, proprioceptive and superficial sensory information. The vestibular system mediates these activities through a network of receptors and neural elements. The information is integrated in the central nervous system. It is modulated by the activity arising in the reticular formation, extra pyramidal system, the cerebellum and cerebral cortex providing appropriate signal to coordinate relevant muscle movements (Savundra and Luxon, 1997; Dickman, 1997). **Fig. (3)** demonstrates the sensorimotor integration for balance and oculomotor control.

The three main sensory inputs for control of balance are:

- Somatosensory input: derived from the contact forces and motions between the feet and the support surface (tactile, deep pressure, joint receptor and muscle proprioceptive). It is the dominant sensory input to balance under normal (fixed) support surface conditions. When a person stands on a fixed support surface, COG sway deviations are normally very small relative to the dimensions of the LOS. Because of the dominance of the somatosensory input, normal individuals and even patients with vestibular system deficits standing on fixed surfaces experience few if any, functionally significant increases in sway, even when closing their eyes to eliminate the visual input (Nashner, 2001). In contrast, ischemic disruption of somatosensory input from the ankle muscle increases COG sway significantly when the eyes are closed (Diener et al., 1986; Horak et al., 1990).
- Visual input: plays a more significant role in balance when the support surface is unreliable. In contrast to fixed surface conditions, individuals closing their eyes while standing on compliant foam surfaces experience significant increases in sway.
- Vestibular input: it is critical for balance when support surface and visual inputs are both unreliable. When normal individuals attempt to move the head and eyes independently while standing on an unreliable surface, the vestibular input to balance is less reliable, and sway increases significantly.

Because input from the healthy vestibular system is seldom, if ever, misleading (the exception being unusual motion environments), the vestibular input plays a critical role while balancing in environments requiring a person to identify and quickly ignore misleading inputs. This is probably why patients with partial vestibular system deficits, frequently complain of problems with vision and report dizziness, unsteadiness, and unusual sensory illusions when exposed to unusual motion environments (Nashner, 2001).

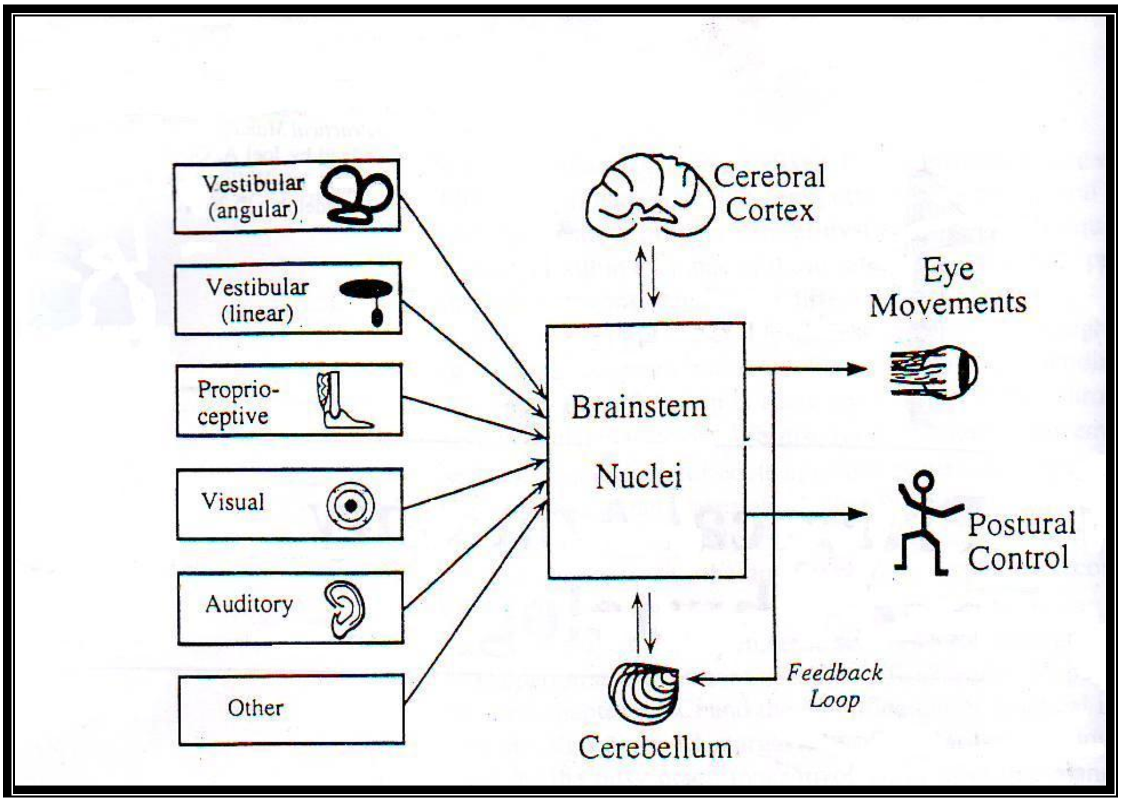

Fig. (3): Sensorimotor integration for balance and oculomotor control

(Quoted from Goebel, 2001)

The vestibular system consists of five distinct end-organs: three semicircular canals, which are sensitive to angular acceleration and two otilith organs, which are sensitive to linear acceleration (Lysakowski et al., 1998). The vestibular system transduces into neural activity forces due to angular acceleration in each of the three planes of motion (Figure 4): **yaw** (horizontal about a vertical axis), **pitch** (flexion and extension about a horizontal axis), **roll** (lateral head tilt about anteroposterior axis) and linear acceleration in all planes. There are three types of response following peripheral vestibular stimulation: the vestibulo-ocular reflexes, the vestibule-spinal reflexes and vestibule-collic reflexes.

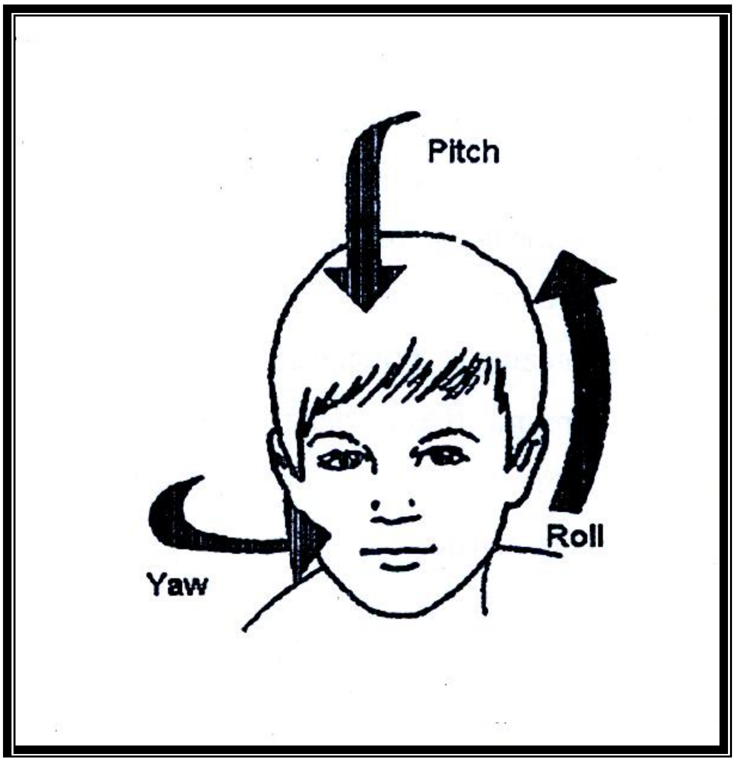

Fig. (4): The three planes of motion

(Quoted from Savundra and Luxon, 1997)

(1) Vestibulo-ocular Reflexes (VOR):

It is often necessary to keep the gaze fixed on an object of interest, while the head is moving. The vestibular system provides this capability by eliciting compensatory eye movements through a network of neural connections. These elicited stabilizing eye movements, are collectively known as the vestibulo-ocular reflexes (VOR).

VOR have traditionally been viewed as gaze-stabilizing systems that produce an eye movement equal in magnitude but opposite in direction to a head movement, thereby maintaining constant eye orientation in space and supporting clear vision during translational and rotational movement of the head and body.

VOR must fulfill two criteria to maintain binocular foveal fixation. First, an eye movement must negate the angle induced by a head movement, between the eye and the point of fixation. Second, the eye must rotate in synchrony with head movement. Although angular and linear motions are detected by separate groups of receptors in the labyrinths, these two classes of VORs are inherently interactive (Minor and Zee, 1998).

The basic structure of the short latency, direct vestibulo-ocular reflex arc is relatively simple. The pathway consists of only three neurons in series; the primary afferent neuron from a labyrinthine receptor, the vestibular nucleus neuron and the motor neuron of the oculomotor complex. Electrical stimulation of the vestibular nerve produces either an excitatory or inhibitory response. Thus, each receptor organ is capable of simultaneously exciting agonists and inhibiting antagonists to produce a reflex turning of the eyes (Brugge, 1991).

Three systems related to vision act in concert to stabilize gaze: a saccadic system, a smooth pursuit system and an optokinetic system. Rapid eye movements (saccades) bring an object quickly to the fovea, maintaining gaze on a moving target is the job of the smooth pursuit system and the optokinetic system is thought to do the same using the entire retina. Stability of image on the retina also involves input from the neck muscle receptors. Like the vestibulo-ocular reflex pathways, the neck-ocular reflex involves synergistic excitatory and inhibitory input to oculo-motor neurons via primarily, the medial and inferior vestibular nuclei.

The interaction of these reflex pathways is the consequence of convergence of vestibular end organs and neck-muscle afferents onto secondary vestibular neurons (Brugge, 1991).

(A) Angular Vestibulo-ocular Reflexes

Models of VOR were initially confined to one dimension and have largely been concerned with defining processing of angular VOR by the semicircular canals. Angular head acceleration is the stimulus for activation of the semicircular canals.

Semicircular Canal Stimulation

The semicircular canals (SCCs) are aligned to form a three-dimensional coordinate system. The plane of the horizontal SCCs makes 30º angles with the horizontal plane. The other two canals are in vertical positions almost orthogonal to each other **(Fig. 5)**. At the dilated end of each semicircular duct is the ampulla, which contains the neuro-epithelium (crista ampullaris).

The hair cells within each crista are oriented so that all their kinocilia point in the same direction. Displacement of hair (or stereocilia) bundle toward the kinocilium is stimulatory to the afferent fibers. On the other hand, displacement of stereocilia away from the kinocilium is inhibitory **(Fig. 6)**.

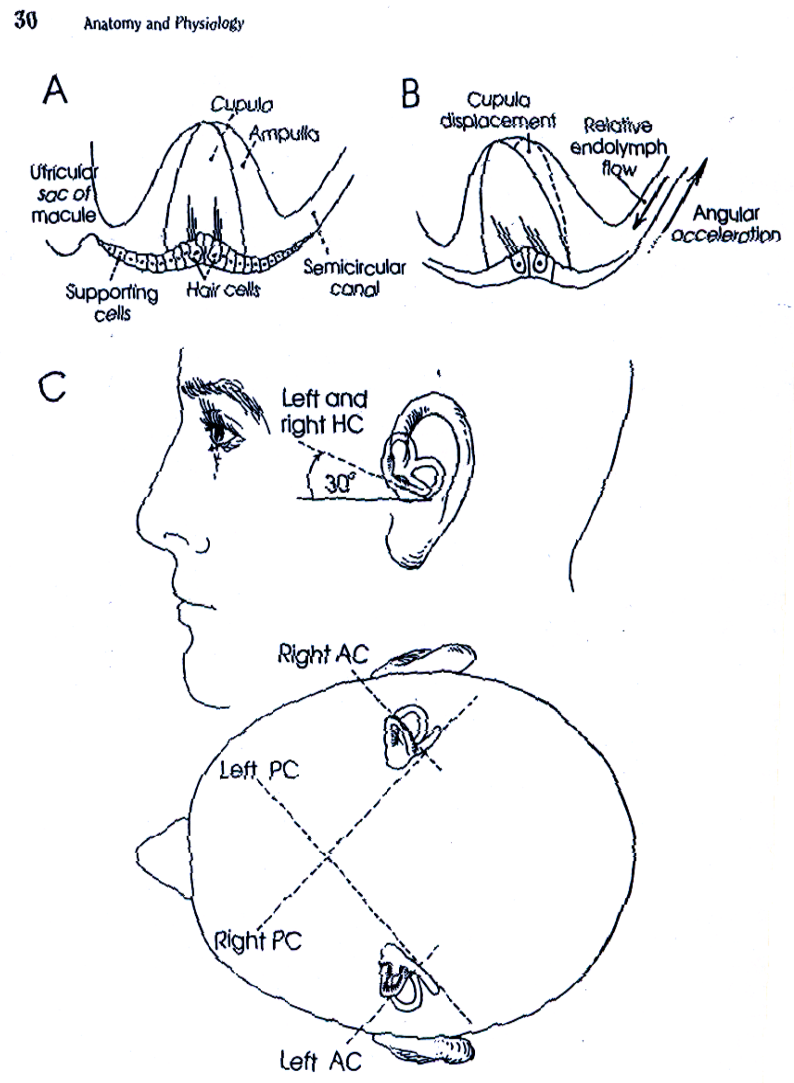

Fig. (5): The crista: (A) anatomy, (B) mechanism of hair cell activation with angular acceleration, and (C) orientation of the semicircular canals within the head. AC, anterior canal; HC, horizontal canal; PC, posterior canal <u>(Quoted from Baloh and Honrubia, 2001a)</u>

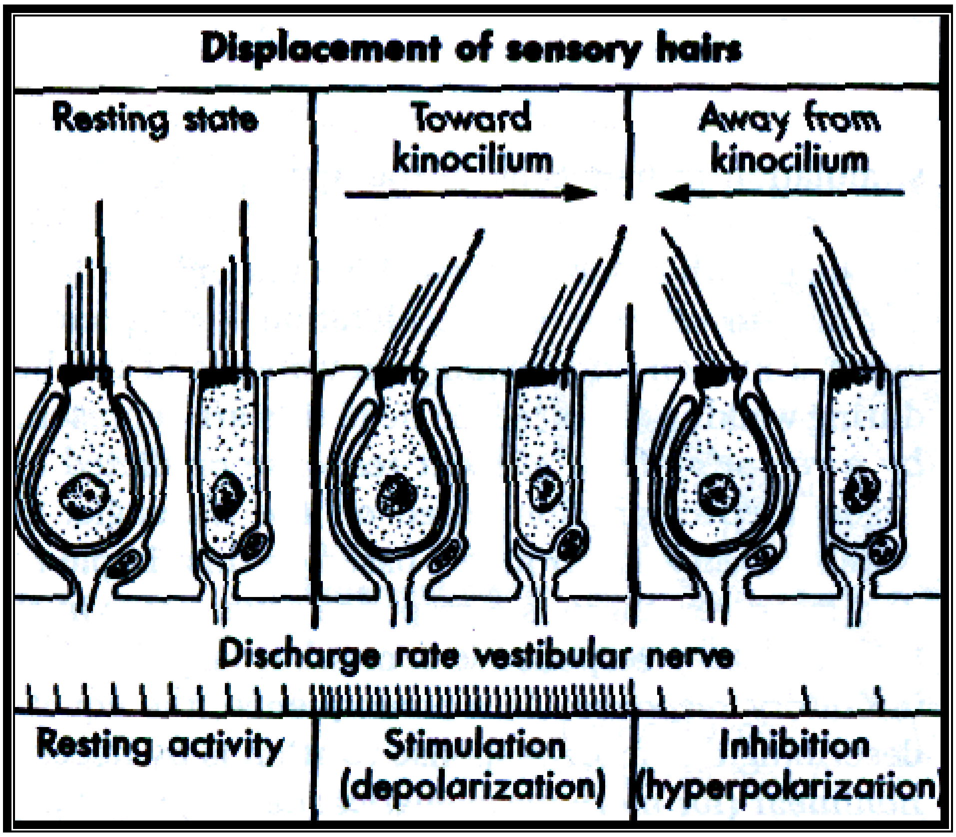

Fig. (6): Diagram of discharge rate of individual vestibular nerve fibers as a result of the displacement of stereocilia (sensory hairs) relative to the kinocilium.

(Quoted from Lysakowski, 2005)

In the vertical canals, the kinocilia are directed toward the canal side of the ampulla, whereas in the horizontal canal they are directed toward the utricular side. The opposite morphologic polarization is the reason for the difference in directional sensitivity between the horizontal and the vertical canals. The afferent nerve fibers of the horizontal canals are stimulated by endolymph movement in the utricular or ampullopetal direction, and those of the vertical canals are stimulated by ampullofugal endolymph flow **(Fig. 7)**.

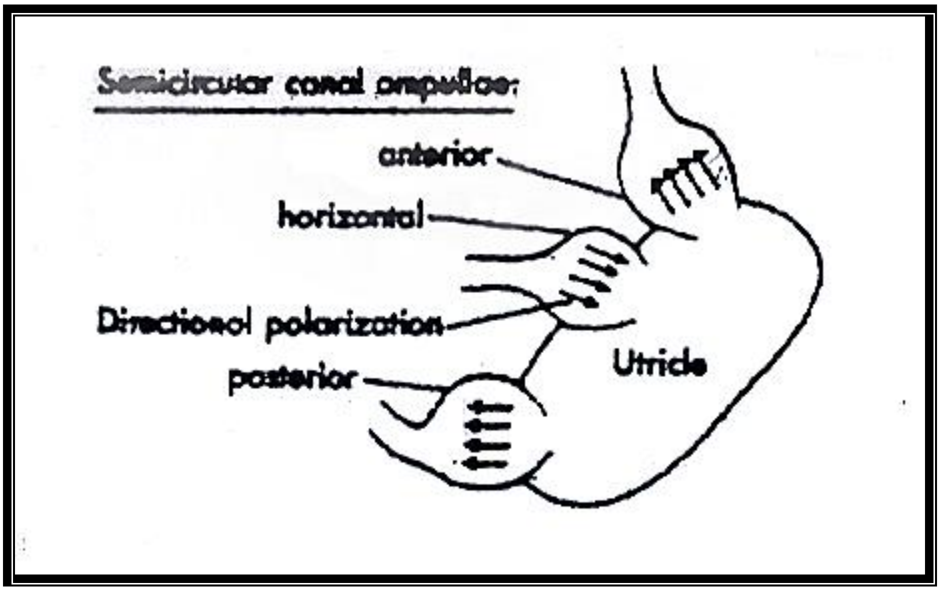

Fig. (7): Morphologic polarization in the SCCs ampullae
(Quoted from Dickman , 1997)

Each semicircular is connected to the eye muscles in such a way that stimulation of a canal nerve results in eye movements approximately in the plane of that canal **(Table. 1)**. There are three types of eye movements: horizontal, vertical and torsional. Each of the six pairs of eye muscles must be controlled in unison to produce the appropriate response (Baloh and Honrubia, 1998; Minor and Zee, 1998).

Table (1): Connection of the semicircular canals with the muscles of the eye

Semicircular canal	Excitation	Inhibition
Horizontal	I------MR C------LR	C-------MR I---------LR
Posterior	I-------SO C-------IR	I---------IO C--------SR
Superior	I-------SR C-------IO	I---------IR C--------SO

N.B: I: Ipsilateral, **C:** Contralateral, **MR:** Medial rectus muscle, **LR:** lateral rectus muscle, **SO:** Superior oblique muscle, **IO:** Inferior oblique muscle, **SR:** Superior rectus muscle, **IR:** Inferior rectus muscle **(Quoted from Baloh and Honrubia, 1990)**

(B) Otolith-ocular Reflexes:

The pathways from the macules to the extra-ocular muscles are less clearly defined than those from the semicircular canals. Di-synaptic pathways also exist from the macules to the extra-ocular muscles (Baloh and Honrubia, 2001 b).

Otolith Organs and its Stimulation

The membranous labyrinth forms two globular cavities within the vestibule; the utricle and the saccule. The saccule lies on the medial wall of the vestibule in a spherical recess inferior to the utricle, with which it is in contact but without direct connection. It communicates with the endolymphatic duct (and thus the utricular duct) by the saccular duct and with the cochlea by the ductus reuniens **(Fig. 8).**