Rapid Interpretation of Balance Function Tests

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Preface

I often give "chalk talks" to my residents—spontaneous lectures on a topic of their choice. When I ask for a topic, they invariably request a review of balance function testing. After being asked to review this topic for many consecutive years, it finally dawned on me that they would likely benefit from a short, practical monograph that provides a solid overview on the topic. This book is our attempt to provide them with such a reference. We have designed it to be a useful and practical review on the subject for students of otolaryngology, audiology, neurology, and physical therapy.

I want to express my heartfelt thanks and appreciation to my colleague Sherrie Davis, AuD, FAAA, who agreed to coauthor this book with me. Sherrie is a true professional in every sense of the word and is a joy to work with. I would also like to thank the many individuals at Plural, including Valerie Johns, who have put up with our delays and revisions and despite it all have put together an outstanding book.

—MJR

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Vestibular Physiology—Yes You Can Understand This!

The subject of vestibular physiology has typically fallen to researchers with backgrounds in engineering. These biomedical engineers have furthered the science in many ways as they have developed sophisticated vestibular testing and even prostheses that will mimic vestibular function. That said, their explanations of vestibular function typically employ multiple equations that model vestibular function. For those of us not gifted enough to view the world through this quantitative prism, the subject of vestibular physiology can devolve into a blurry mixture of confusion and frustration. The purpose of this brief chapter is to offer readers a qualitative review of vestibular physiology that will provide a sufficient background to understand vestibular testing. For those interested in more advanced reading, some references are provided at the end of this chapter that offer greater detail.

The Function of the Peripheral Vestibular System

The peripheral vestibular system can be defined as the vestibular portion of the inner ear (the vestibular labyrinth), the vestibular branch of the eighth cranial nerve, and the blood vessels that feed and drain these structures. The function of the peripheral vestibular system is to transduce the forces causing head acceleration into a biologic (electrical) signal that is carried to the central nervous system. To complement the information sent to it by the peripheral vestibular system, the brain also receives *visual inputs* and *data from the proprioreceptors* in the major joints of the lower limbs. The brain then integrates this information and uses it to:

- Develop a subjective awareness of head-body relation
- Control equilibrium by effecting a motor response
- Stabilize the visual image on the retina

Thus, the "system" that is responsible for maintaining balance and orientation is composed of a *sensory component* (the inner ear, eyes, proprioreceptors) that sends information to the brain that *integrates* these inputs and then effects *motor responses* via the cranial and spinal nerves that allow for the maintenance of balance and visual fixation.

The Peripheral Vestibular System

The Sensory Hair Cells

The basic sensory receptors of the inner ear are the hair cells (Figure 1–1). The vestibular hair cells are classified morphologically as Type 1 cells that are chalice shaped and possess a single, large nerve terminal (calyx) that surrounds the base. Type 2 hair cells are cylindrical in shape and possess multiple small nerve termi-

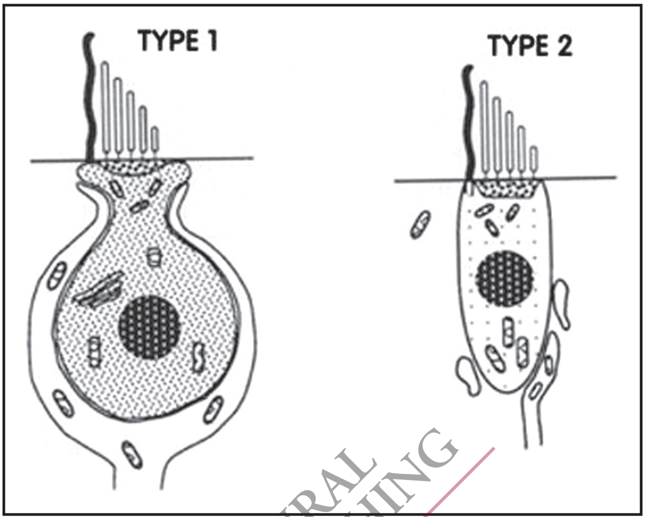

Figure 1–1. Schematic diagram of vestibular hair cells (from Baloh and Kerber, *Clinical Neurophysiology of the Vestibular System*, *Fourth Edition*, Oxford University Press 2011, Figure 1–1, p. 5. Used with permission.).

nals (boutons) at their base. Type 1 and 2 hair cells differ in their shape, distribution within the vestibular end organs, response characteristics, and synaptic connections with afferent fibers. That said, the exact roles of these two different types of hair cells have yet to be delineated. Hair cells are so-called because of the stereocilia (SC) that protrude from their apices. At one side of the hair cell apex is the long and distinct kinocilium (KC). The longest stereocilia are situated closest to the KC whereas the shortest stereocilia are farthest from the KC. The stereocilia are linked to each other via tip links.

Hair cells are the structures charged with transducing the kinetic forces associated with motion into an electrical signal that can be conducted to the brain, and it is the stereocilia that are critical to this function (Figure 1–2). A *shearing force* applied across the surface of the hair cell causes the SC to bend *toward the KC* and results in an influx of potassium (K^+) into the hair cell via channels that are opened in the stereocilia by the tip links. This influx

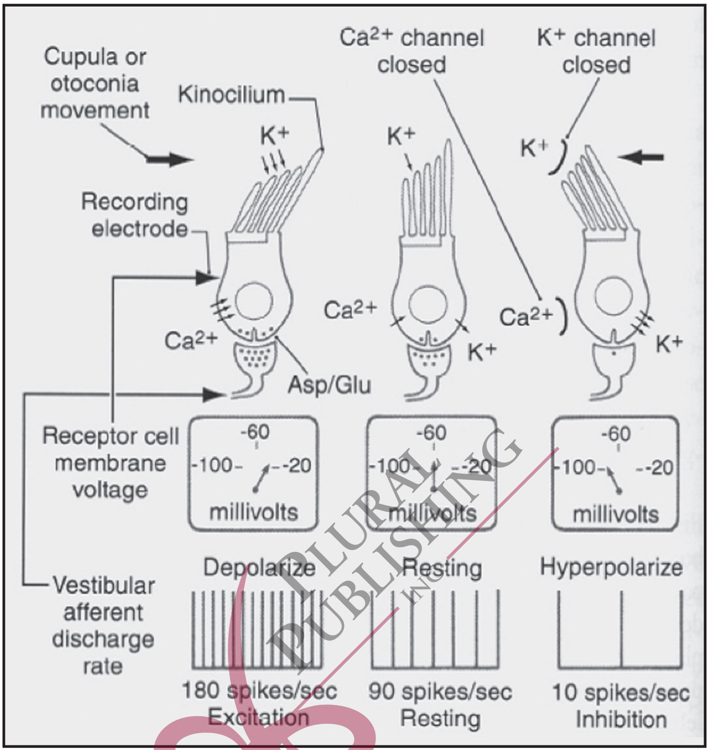

Figure 1–2. Vestibular hair cell depolarization and repolarization (modified from Baloh and Kerber, *Clinical Neurophysiology of the Vestibular System, Fourth Edition*. Oxford University Press 2011, Figure 1–2, p. 7. Used with permission.).

of K^+ results in a depolarization of the hair cell and a secondary increase in intracellular calcium (Ca^{2+}) concentration at the base of the cell. This increase in Ca^{2+} results in release of neurotransmitter (glutamate) from the base of the hair cell that crosses the synapse and binds to the afferent nerve terminal resulting in an *increase* in the firing rates of the afferent nerve fibers innervating those hair cells. Conversely, a shearing force that bends the SC *away* from the KC results in a *decrease* in afferent firing rate when compared with its baseline frequency. As we shall see, activation or inhibition of these hair cells can have dramatically different physiologic effects depending on where they are situated within the vestibular end organs. It is important to recognize that the afferent nerve fibers have a **baseline firing rate** of 50 to 100 spikes/second, and that activity in the hair cells will either increase or decrease this baseline firing rate. This is a very important factor in understanding the consequences of an acute loss of vestibular function. There is also an **asymmetry** in the magnitude of excitation and inhibition of the afferent nerve fibers (Ewald's second law). The potential magnitude of excitation is greater than the potential magnitude of inhibition. An inhibitory stimulus can, at most, decrease the baseline activity to 0 spikes/second (a decrease of 50–100 spikes/second), but an excitatory stimulus may result in spike rates of up to 400 spikes/second.

The Vestibular Labyrinth

The vestibular labyrinth is composed of the semicircular canals and the otolith organs. They are contained within a hard bony otic capsule. Within these bony walls, the vestibular labyrinth is further divided into separate compartments by thin membranes. These compartments are filled with fluids (perilymph or endolymph) that differ in their ionic concentrations. **Perilymph** contains an ionic concentration that is analogous to extracellular fluid (high in sodium and low in potassium), whereas **endolymph** has high potassium and low sodium concentrations. These ionic concentration gradients are maintained by active processes and are critical for inner ear function.

The Otolith Organs

The otolith organs, known as the superior **utricle** and the inferior **saccule**, are designed to detect *linear accelerations* (Figure 1–3). They lie within a central region of the inner ear known as the **vestibule**. Each otolith contains a sensory structure known as a **macule**, with the utricular macule oriented in a *horizontal plane* and the saccular macule oriented in the *vertical plane*. This geometric orientation is critical in allowing the otoliths to respond to linear