The Head's Hairy Hula-Hoop: A Three Step Model of the Vestibular System

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April 13, 2004

Abstract

In this study, we constructed a three stage model designed to teach fifth grade students about the vestibular system. The presentation was structured to progress in an increasingly magnified order, from a diagram of the vestibular labyrinth, to a large scale model of a semicircular canal, and finally to an expanded model of a cupula demonstrating the mechanism for neural transmission. The second stage involved a hands-on approach that integrated sensory and conceptual information. These methods proved very effective at teaching the functional and molecular mechanism of vestibular sensation to children. As a whole, the model was well understood by most students, as is evident by the quantity and types of questions and comments received. Individual student evaluations for this project were less impressive; however, these evaluations did not seem to correlate well with overall performance. This study has demonstrated two valuable methods for teaching complex neuroscience topics to children, which can intuitively be extended to teach the general public.

Introduction

Human perception of space and movement is largely detected by a collection of sacks and tubes that make up the sensory organs of the vestibular system. This assortment of structures, called the vestibular labyrinth, is located in the inner ear and composed of two sacks called the utricle and saccule and three tubes called the semicircular canals. The semicircular canals are positioned in three reciprocally orthogonal planes and are responsible for the perception of angular acceleration (i.e. rotating along our vertical axis). These canals will be the focus of this paper.

Each of the semicircular canals is filled with a potassium-rich fluid called endolymph. When the head rotates along the axis of one of the canals, the endolymph tends to rotate more slowly due to its own inertia. As a result, the fluid pushes against a gelatinous diaphragm, the cupula, located in a swelling called the ampulla at the base of each semcircular canal (Goldberg et al. 1971). Hair cells within the cupula transduce this physical stimuli into a neural signal. As the individual hairs, or stereocila, bend in a particular direction, filamentous connections at the tips mechanically open ion channels and depolarize the cell (Assad et al. 1991). Conversely, when the head rotation decelerates, the endolymph will be moving in the opposite direction in relation to the cupula, and the stereocilia will release tension on receptors resulting in a hyperpolarization of the vestibular neuron (Flock 1965). Projections to the vestibular nuclei and other brainstem regions integrate this information and project to other brain regions to be used for functions such as balance and oculomotor reflexes.

Our model will simulate this process in three steps. We will first describe the basic parts of the vestibular labyrinth using an large poster portraying the inner ear so the children can visualize the location of the semicircular canals. The next step involves a circular piece of water-filled tubing with a group of “hairs” projecting into the center representing a single horizontally oriented semicircular canal and ampulla. We then illustrate the mechanical transmission mechanism by magnifying the “ampulla” region of the semicircular canal model using a third model that portrays the activation of hair cells and the subsequent conduction to brain processing areas. It is our hope that separating the various aspects of vestibular sensation into three increasingly magnified stages will help children conceptualize the processes that are occurring at the microscopic level.

We think that this model will help the children understand the vestibular system’s role in balance using an interactive approach. This will demonstrate the basic idea of how our nervous system transforms physical stimuli from our surroundings into information that the brain can interpret. As a supplementary goal, the children will hopefully get a grasp on a type of mechanoreception that is crucial to our perception of our environment. By explaining the sensation of dizziness and balance to the children, we hope to inspire interest in science and foster lasting inquisitiveness.

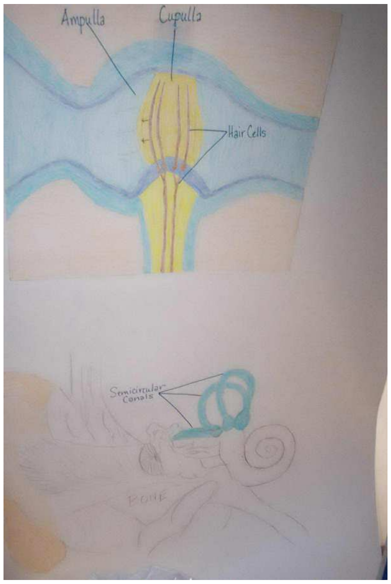
Materials and Methods

Apparatus. Stage 1 of our model was an overview of the vestibular labyrinth portraying its location and various components. In stage 2 of our model (Figure 2), we used a water-filled ring with a diameter of approximately 80cm made from 2.2cm inner diameter transparent hosing to represent a horizontal semicircular canal. At one end of the ring, three small bundles of soft paintbrush bristles were inserted through three separate holes and secured with duct tape to represent the hair cells of the cupula. We found it was important to fray the bristles before inserting them to ensure maximum flexibility. The final stage (Figure 3) represented the cupula and the projections to the primary vestibular areas in the midbrain. The cupula consisted of three protruding pieces of wood of descending lengths attached via hinges to a 40cm wooden board. A piece of string was laced through all three lengths of stripping and fastened to a generic light-switch. This switch was wired to a string of blinking lights leading to the midbrain region of a 3 dimensional replica of the brain composed of newspaper and tissue paper.

Figure 1. Vestibular labyrinth Poster

Figure 2. Semicircular Canal Model With Hair Cells

Figure 3. Expanded Model of Cupula and 3D Brain



Procedure. We presented this model of vestibular function to six groups of children (mean n~7 per group) in the fifth grade. We first gave a general overview of the vestibular labyrinth using the poster in Figure 1, making an effort to help the kids conceptualize the location of the semicircular canals in the inner ear. We then described the various components of the semicircular canal model (Figure 2), relating each back to their respective parts on the poster. After instructing the students to watch the hairs inside the tube, one of the researchers held the tube so that it encircled their waist and proceeded to spin several complete rotations. The individual children were then allowed to repeat this activity and afterwards were asked to describe the way they felt and the action of the hairs inside the tube. We then advanced to the third stage of the model and informed the students that the wooden rods (Figure 3) were synonymous with the hair cells in semicircular canal. Students were asked to move the rods as they had observed the water displacing the hairs in the second model. The light switch was activated by the movement of the rods, and the lights portrayed the path of transmission to the midbrain. Throughout the presentation, we asked the children to comment on what they saw and draw their own conclusions, while constantly referring back to all three models to facilitate linking of the macro and microscopic concepts.

Results

From a qualitative perspective, the presentation seemed to be well received and understood by the children overall. We asked questions throughout the demonstration to ensure that they were absorbing the information, and at each point, most students were able to draw the conclusions that we were trying to elicit. The most important of these conclusions seemed also to be the best understood, this being "I feel dizzy because my brain thinks I'm still moving." The involvement of the children in the interactive activity of spinning with the semicircular model seemed to have a positive effect on the children's ability to learn the concepts because it linked a physical sensation (dizziness) and excitement to the more abstract ideas. The children also asked several good questions during the presentation, most notably "what would happen if there was not enough fluid in the canals" and "what if the [string of lights] was broken." These questions require a fairly in depth understanding of the concepts and demonstrate at least some degree of interest.

Figure 4. Individual Student Evaluations of Models in Our Group. This study is represented in B4.

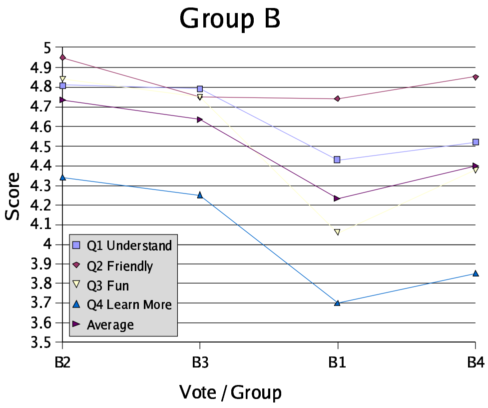


Table 1. Examples of Student Comments

When you get dizzy your brain thinks you’re still moving
Fluid in ears helps balance
If you didn’t have ears you would lose your balance
There are hairs in your ears that can move when fluid passes by
(Fairly detailed picture of the vestibular labyrinth.

Statistically, the presentation placed well for individual characteristics but poorly in the overall voting ranking (see Figure 4, group B4). Although we placed 4th out of 4 in the voting ranking, all of our evaluation rankings were higher than the third place group (B3), and we placed second for the “friendliness” ranking. Our lowest ranking was for “wish to learn more,” at a score of about 3.8 and our highest was for friendliness at about 4.8, both values out of a possible 5. The type and large quantity of student comments received after Brain Awareness Day also suggested that they learned more than was apparent from the voting rank. Some examples are noted in Table 1.

Discussion

There does not seem to be a strong correlation between the individual evaluation rankings and the overall voting rankings. It is important to remember that these ranking statistics are based on the subjective quantifications of fairly vague ideas by fifth grade students. Therefore, it is likely that the written comments and our subjective evaluations of the model’s performance are more illustrative of its educational value than are the students’ ranked voting statistics. For instance, we ranked third for wanting to “learn more” about the vestibular system, but we received the most comments out of any group. Numerous comments usually indicates a high degree of interest in the material and so this data is contradictory. The comments and questions themselves also suggest that most of the children understood the presentation quite well. The statement "when you're dizzy your brain thinks you're still moving" implies that the students made the connection between the moving fluid in the semicircular canals and the transmission to the brain and its subsequent interpretation. There were also relatively few comments denoting misinterpretations of the model, which are usually very common when teaching neuroscience to younger children. The only comment that was not accurate according to our model was "if you didn't have ears you would lose your balance," and even this is close to being correct.

During the presentation we made a strong effort to stop periodically to ascertain if the students were understanding the material. This allowed us to determine the strategies of the model that worked and those that did not. Perhaps the most efficacious aspect of our approach was the step-by-step magnification method. By gradually increasing the "power" on our hypothetical microscope while sporadically reminding them of the specific stage the model represented, we were able to describe mechanical and electrical events occurring at a microscopic level. This sort of conceptualization is notoriously difficult for elementary school-aged children, especially while keeping track of the general function the model represents. The children's apparent ability to retain the basic idea of the model throughout the various steps was probably greatly facilitated by the intermingling of simultaneous perception and conceptualization of the physical sensation (dizziness).

There was a flaw in the light switch portion of our model (Figure 3) which made it difficult to describe and answer questions concerning how the vestibular system distinguishes specific directions of angular motion. The simple on/off nature of a generic light switch made it difficult to simulate the more complicated graded scale of depolarization/hyperpolarization present in the biological system. This could be better simulated using a bipolar switch attached to two different color lights, fastened to the hair cells with a stiff object rather than string, so that movement in each direction would produce a unique response. This, however, was not the only sacrifice of detail that we made in the interest of simplicity.

Another example of such a compromise was the decision to limit the semicircular canal to one horizontal ring as opposed to using all three reciprocally orthogonal canals. We made this compromise because it would be easier to see the movement of the hairs in the ampulla region with one canal, and also because the horizontal canal is involved in detecting dizziness, a sensation that children are already familiar with. The structure of the canal model (Figure 2) also had to be greatly simplified for visibility and construction purposes. The ampulla in our model contained three cupulas as opposed to one in the biological system. These cupulas were also not continuous with the roof of the canal as is the case in the vestibular labyrinth, so water flowed freely through the tubing instead of merely applying pressure. Although these compromises are significant, there are relatively few of them considering the complexity of the ideas we attempted to convey.

Works Cited

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