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# Eye Movements Induced by Stimulation to the Otolith Organs

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## Abstract

**Background:** We have been performing a canalith repositioning procedure for benign paroxysmal positional vertigo. When we adopted the Epley maneuver for posterior semicircular canal type, and affected-ear-up 90˚ maneuver for lateral semicircular canal type, we noticed that no nystagmus occurred in the sitting position just after treatment. Despite direct excitation to the utricle by the pathological debris, none of the subjects complained of dizziness. Thus, we hypothesized that nystagmus and dizziness do not occur by stimulation of the otolith organs. **Objective:** The aim of the study was to observe and record the eye movements induced by the otolith organs to confirm our hypothesis. **Materials and Methods:** Twelve healthy humans were tested. In the sitting position, the head was tilted to the right ear by 45˚ and vice versa. Afterward, the head was bent forward by 90˚ (nose-down), and the subject's seat was reclined to the head-hanging position. Each position was kept for five seconds. We interviewed the subjects to assess their dizziness. **Results:** None of the subjects showed nystagmus and complained of dizziness in every position. **Conclusions:** Nystagmus does not occur by the stimulation to the otolith organs; therefore, ocular counter-rolling is a semicircular canal ocular reflex.

## Keywords

Utricle, Saccule, Otolith Ocular Reflex, Ocular Counter-Rolling

## 1. Introduction

The labyrinthine otolith organs are the utricle and saccule. Each macula consists of a sheet of hair cells with their cilia embedded in a gelatinous otolith membrane, to which are attached calcium carbonate crystals (otoconia). In animal experiments, electrical stimulation of the utricular nerve produced various pat-

terns of eye movements. Suzuki *et al.* [1] reported that there was a vertical deviation of the optic axes (skew deviation) and a horizontal deviation, in addition to a torsional component. Moreover, Goto *et al.* [2] reported that horizontal eye movements were evoked. However, there is not a physiological consensus regarding otolith ocular reflex.

We have been performing a canalith repositioning procedure for benign paroxysmal positional vertigo. When we adopted the Epley maneuver [3] for posterior semicircular canal type, and affected-ear-up 90˚ maneuver [4] for lateral semicircular canal type, we noticed that no nystagmus occurred in the sitting position just after treatment. Despite direct excitation to the utricle by the pathological debris, none of the subjects complained of dizziness. Thus, we hypothesized that nystagmus and dizziness do not occur by stimulation of the otolith organs. The aim of the study was to observe and record the eye movements induced by the otolith organs to confirm our hypothesis.

## 2. Materials and Methods

Twelve healthy humans, ranging in age from 20 to 71 years, participated in this study. They had no history of dizziness and no routine medication. We judged that they had no vestibular disorder because they had no gait disturbance, and no spontaneous nystagmus. All subjects gave informed consent to participate in the study. In the sitting position, the head was tilted to the right ear by 45˚ and vice versa. Afterward, the head was bent forward by 90˚ (nose-down), and the subject's seat was reclined to the head-hanging position. Each position was kept for five seconds. We interviewed the subjects to assess their dizziness.

The experiment was performed in the dark with the subjects' eyes open using an infrared charge-coupled device camera. Eye movement was recorded and converted to digital data. Three-dimensional video-oculography was performed using ImageJ (a public domain, Java-based image processing program developed at the National Institutes of Health) and a Macintosh computer. For analysis of horizontal and vertical components, the XY center of the pupil was calculated. For analysis of the torsional component, the whole iris pattern, which was rotated in steps of 0.1˚, was overlaid with the same area of the next iris pattern, and the angle at which both iris patterns showed the greatest match was calculated [5].

## 3. Results

None of the subjects showed nystagmus and complained of dizziness in every position (**Table 1**). Video-oculography of subject 9 is shown in **Figure 1**.

## 4. Discussion

We found that nystagmus does not occur by stimulation to the otolith organs. Previous studies adopted eccentric rotation to stimulate the otolith organs [6] [7]; however, in eccentric rotation not only otolith organs but also semicircular

Table 1. Results.

| Subject | Age (years) | Sex | Left-ear-down | | Right-ear-down | | Head-hanging | | Nose-down | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Nystagmus | Dizziness | Nystagmus | Dizziness | Nystagmus | Dizziness | Nystagmus | Dizziness |
| 1 | 20 | Female | — | — | — | — | — | — | — | — |
| 2 | 24 | Female | — | — | — | — | — | — | — | — |
| 3 | 34 | Male | — | — | — | — | — | — | — | — |
| 4 | 36 | Male | — | — | — | — | — | — | — | — |
| 5 | 38 | Female | — | — | — | — | — | — | — | — |
| 6 | 41 | Male | — | — | — | — | — | — | — | — |
| 7 | 52 | Female | — | — | — | — | — | — | — | — |
| 8 | 58 | Female | — | — | — | — | — | — | — | — |
| 9 | 58 | Male | — | — | — | — | — | — | — | — |
| 10 | 64 | Male | — | — | — | — | — | — | — | — |
| 11 | 67 | Female | — | — | — | — | — | — | — | — |
| 12 | 71 | Female | — | — | — | — | — | — | — | — |

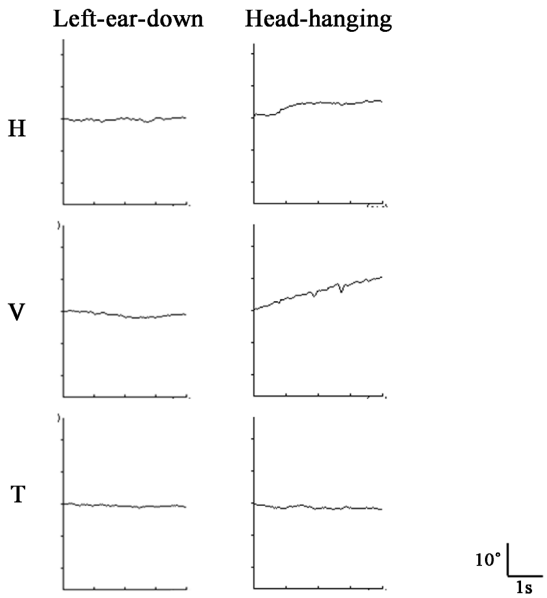


Figure 1. Video-oculography (position trace) in subject 9. No nystagmus occurred in both head positions. Small vertical eye movements in the head-hanging position are due to the shake of camera. The upward deflections in horizontal (H), vertical (V), and torsional (T) eye movements are indicated as being toward the right, upward, and right, respectively.

canals sense the acceleration. Therefore, these studies were unable to excite the otolith organs selectively. In the present study, our methodology was able to stimulate only the otolith organs. In the left-ear-down position, otoconia move toward the left (Figure 2); therefore, the macula of the utricle is excited by grav-

ity constantly. In the head-hanging position, the otoconia move upward (Figure 3); therefore, the macula of the saccule is excited by gravity constantly. We found that no nystagmus occurred and none of the subjects complained of dizziness. Ocular counter-rolling has been considered an otolith ocular reflex; however, our experiments do not support this hypothesis.

Horizontal head rotation (Yaw rotation) produces a lateral semicircular canal ocular reflex. Vertical head rotation (Pitch rotation) produces a vertical semicircular canals ocular reflex. It is not reasonable that only Roll rotation produces otolith ocular reflex. It is natural to consider that semicircular canals are stimulated by Roll rotation.

Structurally (heavy otoconia are on the soft tissue), hair cells of otolith organs

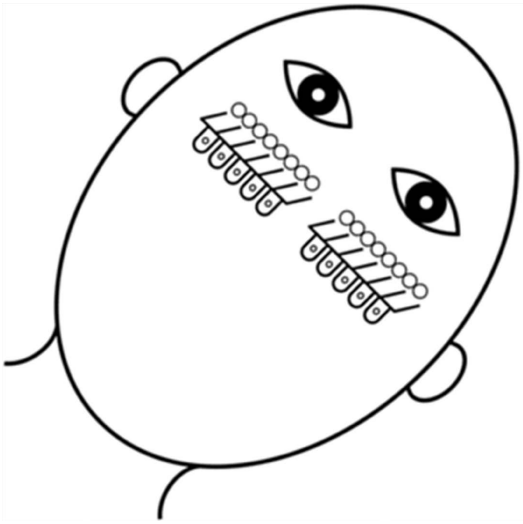

Figure 2. In the left-ear-down position, otoconia move toward the left. Therefore, the macula of the utricle is excited by gravity constantly.

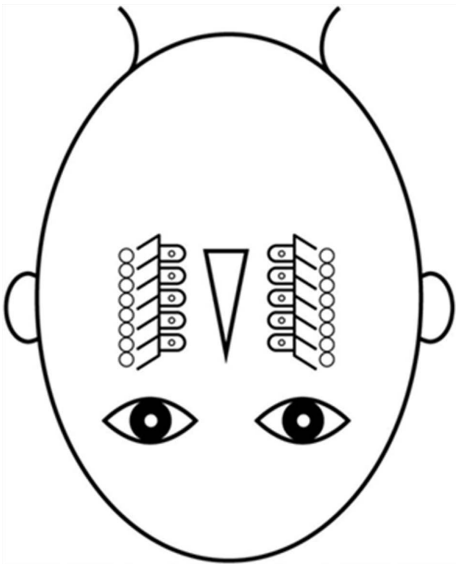

Figure 3. In the head-hanging position, otoconia move upward. Therefore, the macula of the saccule is excited by gravity constantly.

sense not only a gravity but also an angular acceleration. For example, utricles are stimulated in horizontal head rotation (the center of rotation is the second cervical vertebra) by the centrifugal force. Hair cells in semicircular canals sense not only an angular acceleration but also a linear acceleration. When a human takes an elevator, superior canals cupulae are stimulated by the inertial force. Both otolith organs and semicircular canals sense every direction of acceleration, in a coordinated manner. However, our methodology is easy to do, and able to

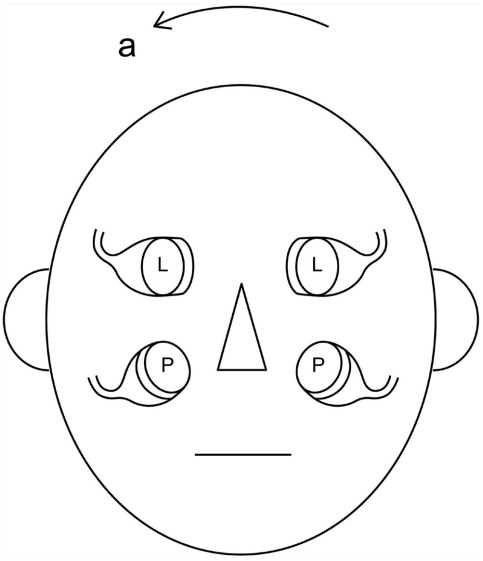


Figure 4. Position of the four cupulae. When the head is tilted toward the right side (Roll rotation), the lateral and posterior canals are stimulated by the inertial force. a = Angular acceleration; L = Lateral canal cupula; P = Posterior canal cupula.

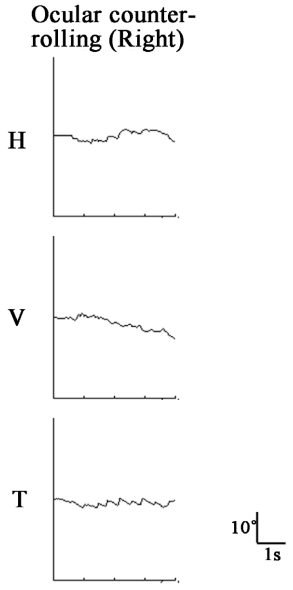


Figure 5. Video-oculography (position trace) in subject 7. Ocular counter-rolling is horizontal/torsional. The upward deflections in horizontal (H), vertical (V), and torsional (T) eye movements are indicated as being toward the right, upward, and right, respectively.

stimulate only the otolith organs because semicircular canals do not sense gravity.

We propose the following mechanism of ocular counter-rolling. David *et al.* reported that the position of the cupula of the lateral canal tilts toward the lateral side by 45˚ [8]. Furthermore, the cupula of the posterior canal is also tilted 45˚. The position of the four cupulae is shown in **Figure 4**. When the head is tilted towards the right side, lateral and posterior canals are stimulated by the inertial force. Theoretically, horizontal/torsional nystagmus occurs. Practical eye movement (horizontal/torsional) is shown in **Figure 5**. Thus, physiologically, we hypothesize that lateral and posterior canals produce ocular counter-rolling.

As mentioned above, our findings suggest that nystagmus does not occur by stimulation of the otolith organs. Moreover, our findings suggest that the function of the otolith organs is to deal with a vestibulospinal reflex.

## 5. Conclusion

Nystagmus does not occur by the stimulation of the otolith organs; therefore, ocular counter-rolling is a semicircular canal ocular reflex.

## Acknowledgements

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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