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Electro-Otolithography: New Insight into Benign Paroxysmal Positioning Vertigo

Burkhard Franz

Tinnitus Research and Balance Clinic, Wantirna, Australia

Abstract: Early vestibular evoked potentials were recorded with an extratympanic electrode. The recording principle was adding responses that were phase-locked to a recording frequency. The recording frequency was empirically determined to match harmonically an individual response frequency, thus allowing averaging. This new technique was evaluated in benign paroxysmal positioning vertigo. Normal data were obtained from 12 patients without vestibulocochlear symptoms and were compared with data from 18 symptomatic patients with diagnoses of benign paroxysmal positioning vertigo. All symptomatic patients were treated with a canalith repositioning maneuver, and all responded, in that they no longer had attacks of vertigo. Of the five patients who could be reassessed, all five no longer had attacks of vertigo, but three complained of persisting postural imbalance. Repeat electro-otolithography results continued to be abnormal in these patients, whereas in the remaining two patients responses were normal, consistent with the treatment outcome. The results suggest that electro-otolithography is a valuable addition to the otoneurological test battery. Successful canalith repositioning can abolish attacks of vertigo, although not necessarily a persisting imbalance, which patients frequently describe as a temporary and momentary instability. This is most likely related to a remaining otolithic deficit.

Key Words: benign paroxysmal positioning vertigo; early vestibular evoked potentials; electro-otolithography; electrovestibulography; otolithic organ

Averaging as a form of signal processing is a well-established concept in otoneurology, but applying it to the vestibular organ is not easy. One reason is the difficulty of phase-locking individual and independent vestibular responses to frequent stimuli.

Vestibular evoked myogenic potentials are regarded as suitable in examining the otolithic organ, and vestibular brainstem potentials are suited to examining the semicircular canals [1–3]. However, these investigative procedures are not specific as responses from other sensory modalities, and responses from the contralateral ear are included in the response pattern.

Potentials from the vestibular nerve have been recorded after rotatory stimulation in animal experiments and, combined with electrical stimulation, attempts were made to develop a method for electrovestibulography [4,5]. This is not feasible in clinical practice. Linear acceleration impulses delivered to an animal's head were further attempts to study responses of the otolithic organ in particular [6]. These potentials also are non-specific and are not suitable for application in humans.

During the last two years, we have improved the processing of cochlear and vestibular signals and have gained experience with electrovestibulography [7,8]. Consequently, we had an interest in investigating whether the same recording principle could be extended to electro-otolithography.

METHOD AND SUBJECTS

Eighteen patients with diagnosed benign paroxysmal positioning vertigo (13 female and 5 male; average age, 63.7 ± 13.6 years) were investigated in this study. Their diagnoses were based on clinical examination, particularly on a positive result on a Dix-Hallpike maneuver. All patients underwent a standard audiological test battery consisting of pure-tone audiometry, speech audiometry, and tympanometry. Auditory brainstem

Reprint requests: Burkhard Franz, M.D., Tinnitus Research and Balance Clinic, 230 Mountain Highway, Wantirna 3152, Victoria, Australia. Phone: (03) 9800 5744; Fax: (03) 9887 5333; E-mail: burkhard@bigpond.net.au

responses were performed to exclude retrocochlear pathology. The otoneurological tests consisted of stress-electrocochleography and electro-otolithography (Biologic Navigator, Chicago, IL).

Electro-otolithography always followed extratympanic electrocochleography, with the electrode remaining in the tympanic recess. The response of the utriculus was obtained with ipsilateral and contralateral head tilt (roll). The response of the sacculus usually followed with the head in forward and backward tilt (pitch). Measurements in each roll and pitch were always preceded by an averaged baseline recording (nonstimulus position). Baseline recordings were performed with patients keeping their head in an upright, resting position.

Each head-tilt position was believed to change the static tonus in the otolith with hidden harmonics within the response, and this change was recorded. Each recording was conducted over a period of approximately 15 seconds. Recording was stopped as soon as the averaged signal became clear on the monitor. This usually occurred within 10–15 seconds' recording time and permitted adding approximately 115–345 sweeps.

Recording responses of the vestibular nerve were thus not phase-locked to the stimulus frequency but were phase-locked to the harmonic of an individual response frequency. The harmonic of the individual response frequency was determined empirically. The recording frequency was initially set at 7.1 Hz. This frequency was gradually increased in decimal steps until a clear difference between recording in resting position and recording in stimulus position was obtained. Often the best recording frequency was found at approximately 11.5 and 23.0 Hz.

The gain was set at 50,000, the high-pass filter at 1,500 Hz, and the low-pass filter at 3 Hz. The notch filter was engaged and artifact rejection enabled. The stimulator level was set at −35 dB; however, it was put aside, as it was not placed into the ear canal during recording.

Results from symptomatic patients were compared with those obtained from 12 patients who had no history of ear disorders (6 female and 6 male; average age, 37.9 ± 11.4 years) and who had not experienced vestibulocochlear symptoms during the last 12 months.

All symptomatic patients were treated with an Epley canalith repositioning maneuver [9] and were reviewed after 4–8 weeks. Five patients agreed to an otoneurological reassessment, which consisted of the Dix-Hallpike maneuver and repeat electro-otolithography. Statistical analysis was conducted with the Student's *t*-test.

RESULTS

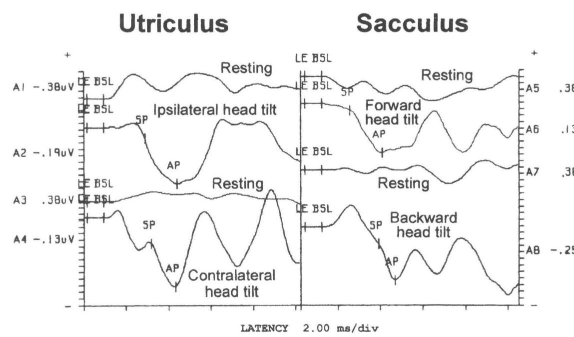
All symptomatic patients with diagnosed benign paroxysmal positioning vertigo demonstrated during the Dix-Hallpike maneuver a typical temporary upbeat and torsional nystagmus into the lower ear, suggesting canalolithiasis of the posterior semicircular canal. As expected, stress electrocochleography in symptomatic patients revealed that their baseline summating potential–action potential (SP/AP) ratio was just within normal limits (24.15 ± 10.48%) and that it showed a vestibular pattern of voltage changes during raised intracranial pressure [10].

Electro-otolithography recordings showed features that were reminiscent of electrocochleography results (Fig. 1). In normal subjects, the utriculus response with ipsilateral head tilt had an average SP/AP ratio of 17 ± 5.6%; with contralateral head tilt, it was 33.7 ± 12.9% with a coefficient of 0.56 ± 0.23. The sacculus response with forward head tilt had an average SP/AP ratio of 17.6 ± 6.9%; with backward head tilt, it was 33.9 ± 10.9% with a coefficient of 0.57 ± 0.27.

Electro-Otolithography

(Normal)

Patient D.C. **DOB** 22-09-62 **Date** 10-26-01



Latencies (ms)

	Utriculus SP	Utriculus AP		Sacculus SP	Sacculus AP
A2	2.08	3.60	A6	+1.48	3.00
A4	2.40	3.52	A8	+2.84	3.60

Interamplitudes (μV)

	Utriculus SP BSL	Utriculus AP BSL	Utriculus SP/AP		Sacculus SP BSL	Sacculus AP BSL	Sacculus SP/AP
A2	+0.30	+1.72	0.17	A6	+0.12	+1.04	0.11
A4	+0.41	+1.36	0.30	A8	+0.63	+2.20	0.29

Coefficient 0.57 | Coefficient 0.38

Figure 1. Electro-otolithography in a patient without vestibulocochlear symptoms. On the right side, response of the utriculus; on the left, response of the sacculus. Note the contrast of recorded responses in resting and stimulus positions. (*AP BSL* = action potential [in microvolts] measured from the baseline; *SP BSL* = summating potential [in microvolts] measured from the baseline.)

The SP/AP ratio with ipsilateral head tilt was significantly smaller than that with contralateral head tilt. Similarly, the SP/AP ratio with forward head tilt was significantly smaller than that with the backward head tilt. This led to the introduction of a coefficient. A coefficient of less than 1 was found to be normal, whereas a coefficient greater than 1 suggested abnormality. This became particularly apparent in patients with benign paroxysmal positioning vertigo, wherein the coefficient on the unaffected side remained below 1 and on the affected side always exceeded 1.

The response of a patient without vestibulocochlear symptoms is shown in Figure 1. On the left side of the diagram is the response of the utriculus, and on the right side is the response of the sacculus. Recordings in the resting position clearly contrast recordings in the stimulus position.

From our symptomatic subjects, eight revealed an abnormal utriculus response, four demonstrated an abnormal sacculus response, and six showed a combined abnormal utriculus-sacculus response.

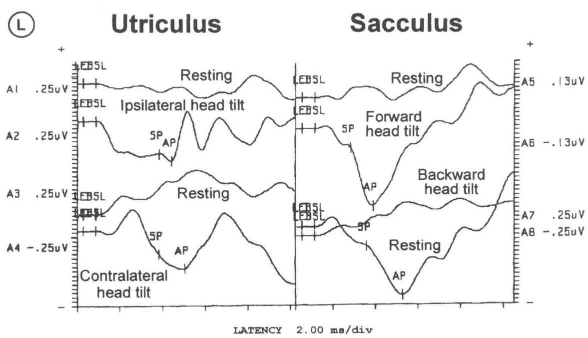
The Epley canalith repositioning maneuver was successful and resulted in abolition of attacks of vertigo. The repeat Dix-Hallpike maneuver result was clear in all patients on review 4–8 weeks after treatment. Two of five reassessed patients were asymptomatic after canalith repositioning, and electro-otolithography results returned to normal (Figs. 2 and 3). Three patients no longer had attacks of vertigo but continued to be symptomatic, experiencing temporary instability during quick head movements. In these patients, repeat electro-otolithography remained abnormal on the affected side (Figs. 4 and 5).

DISCUSSION

Averaging is a well-established concept in demonstrating biological signals, but applying it to the vestibular organ is difficult. One reason is the inability to phase-lock individual and independent vestibular responses to frequent stimuli. Rotatory chair examination allows signal processing, but interpretation can be difficult, as responses are not recorded from an independent and individual ear. Responses are contaminated by simultaneous contralateral stimulation.

Electro-Otolithography

Patient L.B. **DOB** 25-10-31 **Date** 25-09-01



Interamplitudes (μV)

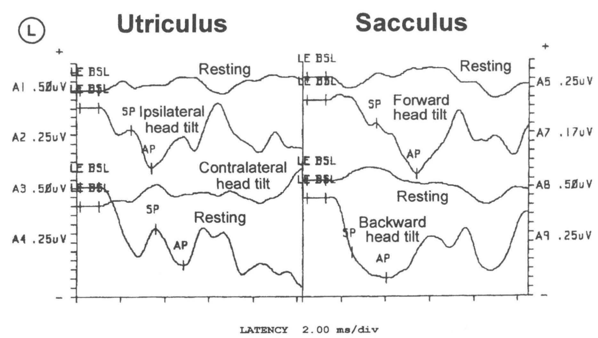
	Utriculus SP BSL	AP BSL	SP/AP		Sacculus SP BSL	AP BSL	SP/AP
A2	+1.89	+2.67	0.71	A6	+0.49	+2.39	0.21
A4	+1.29	+2.35	0.55	A8	+1.01	+4.05	0.25

Coefficient 1.3 Coefficient 0.84

Figure 2. Electro-otolithography of the left ear in a patient with benign paroxysmal positioning vertigo before canalith repositioning. The coefficient is raised, indicating an abnormal response of the utriculus. (*AP BSL* = action potential [in microvolts] measured from the baseline; *SP BSL* = summating potential [in microvolts] measured from the baseline.)

Electro-Otolithography
(Post Epley)

Patient L.B. **DOB** 25-10-31 **Date** 24-10-01



Interamplitudes (μV)

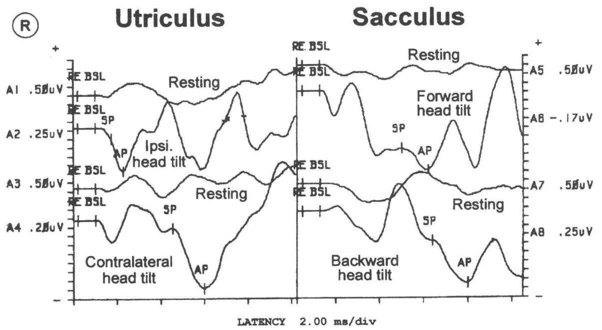
	Utriculus SP BSL	AP BSL	SP/AP		Sacculus SP BSL	AP BSL	SP/AP
A2	+0.66	+1.78	0.37	A6	+0.39	+1.47	0.26
A4	+1.12	+2.22	0.50	A8	+1.53	+2.25	0.68

Coefficient 0.74 Coefficient 0.38

Figure 3. Electro-otolithography of the left ear in the same patient as in Figure 2 after successful canalith repositioning. Both coefficients were normal and consistent with the patient's no longer having a balance problem. (*AP BSL* = action potential [in microvolts] measured from the baseline; *SP BSL* = summating potential [in microvolts] measured from the baseline.)

Electro-Otolithography

Patient N.C. **DOB** 14-02-40 **Date** 09-10-01



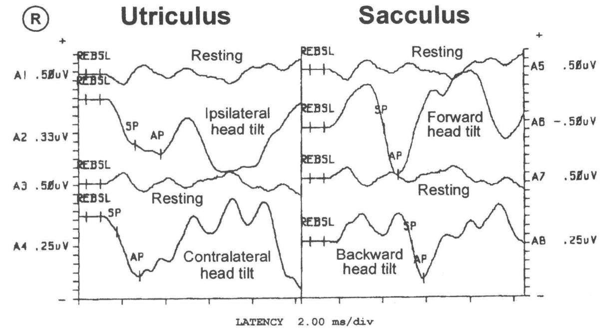
Interamplitudes (μV)

	Utriculus				Sacculus		
	SP BSL	AP BSL	SP/AP		SP BSL	AP BSL	SP/AP
A2	+0.33	+1.27	0.26	A6	+1.12	+1.52	0.73
A4	+0.20	+1.56	0.13	A8	+0.85	+2.04	0.41
	Coefficient 2.0				Coefficient 1.7		

Figure 4. Electro-otolithography of the right ear in a patient with benign paroxysmal positioning vertigo before canalith repositioning. The coefficients are raised, indicating an abnormal response of both the utriculus and the sacculus. (*AP BSL* = action potential [in microvolts] measured from the baseline; *SP BSL* = summating potential [in microvolts] measured from the baseline.)

Electro-Otolithography (Post Epley)

Patient N.C. **DOB** 14-02-40 **Date** 04-12-01



Interamplitudes (μV)

	Utriculus				Sacculus		
	SP BSL	AP BSL	SP/AP		SP BSL	AP BSL	SP/AP
A2	+1.77	+2.18	0.81	A6	+0.12	+2.74	0.04
A4	+0.38	+1.74	0.22	A8	+0.16	+1.09	0.15
	Coefficient 3.68				Coefficient 0.27		

Figure 5. Electro-otolithography of the right ear in same patient as in Figure 4 after successful canalith repositioning. Attacks of vertigo were abolished, but instability persisted. The response of the sacculus normalized, whereas the response of the utriculus remained abnormal, consistent with a remaining otolithic deficit. (*AP BSL* = action potential [in microvolts] measured from the baseline; *SP BSL* = summating potential [in microvolts] measured from the baseline.)

Electrocochleography has become widely accepted as a neurootological technique [11]. It is a very specific test, measuring voltages and latencies in various inner-ear conditions. Responses are obtained using clicks or tone bursts as a stimulus. This technique, phase-locked to the stimulus frequency, uses multiple stimuli. Minute responses are added over a certain period, allowing the background noise to cancel out and the signal to appear.

Introducing multiple stimuli into the individual vestibular organ is difficult; therefore, signal processing similar to that employed in electrocochleography is generally perceived as impossible. However, the response of the cochlea to a stimulus and the response of the vestibular organ to a stimulus are different. The response of the cochlea is fast, as is its decline, whereas the response of the vestibular organ is slow, as is its decline. This characteristic of the vestibular organ with its gradual decline of the response to a stimulus can be used advantageously for signal processing.

Signal processing after a single stimulus, however, requires a rhythmic response that declines gradually. Our experience with electrovestibulography confirms the presence of rhythmicity after a stimulus. This observation in humans is supported by a similar observation in animals, which shows regularly firing neurons in the otolithic organ [12].

Signal processing still requires the use of individual recording frequencies or harmonics thereof that are in phase with the individual frequency response of the vestibular organ. Signal processing thus is different. Rather than adding responses that are phase-locked to the stimulus frequency, such added responses are phase-locked to the recording frequency, but the recording frequency must harmonically match an individual response frequency. The latter can be determined empirically or alternatively through a process of frequency analysis and filtering.

Electro-otolithography recordings were reminiscent of electrocochleography showing clear SP and AP voltages (see Fig. 1). The response of the utriculus was obtained with ipsilateral and contralateral head tilt (roll). The response of the sacculus was obtained with forward and backward head tilt (pitch). These head tilts changed the static tonus in the otolithic organ, and this change was recorded.

Various head tilts, however, are likely to be contaminated by some response of the utriculus or sacculus, as the case may be. Nevertheless, side head tilt (roll) occurs mainly under the influence of the utriculus, which controls neck flexors, whereas forward and backward head tilts (pitch) take place mainly under the influence of the sacculus, which controls neck extensors [13–15].

The application of electro-otolithography has shown consistency with the clinical condition that was under investigation. In all patients with benign paroxysmal positioning vertigo, we found an abnormal otolithic response, as expected. Two reassessed patients responded to the canalith repositioning without any further symptoms of intermittent vertigo or instability. As expected, repeat electro-otolithography had normalized as well, confirming the clinical outcome. Either adaptation or, indeed, otoconia regeneration, a finding that has been observed in animals, might explain this improvement [16].

Three patients responded to the canalith repositioning, in that they no longer had attacks of vertigo; nonetheless, they continued to feel light-headed, particularly when moving quickly. Although they all felt much better, they were still not 100% stable. This is a typical observation in benign paroxysmal positioning vertigo. A successful repositioning maneuver can abolish attacks of vertigo but not necessarily a persisting imbalance, which affected patients frequently describe as a form of light-headedness and instability after quick head movements. This instability seems to be related to an otolithic deficit.

Comparing these results of electro-otolithography with previous experiences in electrovestibulography and stress electrocochleography [8,10], we observed that since the introduction of this new otoneurological test battery consisting of stress electrocochleography, electrovestibulography, and electro-otolithography, our understanding of inner-ear disorders is changing. Very rarely, we find a single unit within the inner ear responding independently. These findings here fit in well with the observation that the cochlea, the semicircular canals, and the otolithic organ are all part of a combined response to an insult inflicted on the inner ear, although individual responses and the combinations therein may vary.

CONCLUSION

Electro-otolithography is a new technique for investigating the otolithic organ. It shows reliable responses when applied to the clinical condition of benign paroxysmal positioning vertigo. It gives new insights into the understanding of inner-ear disorders. Successful canalith repositioning can abolish attacks of vertigo, but a persistent imbalance seems to be related to a remaining otolithic deficit.

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