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Vanderbilt Audiology Journal Club: Vestibular Update - The Inion Potential

Gary Jacobson, PhD
Richard Roberts, PhD
Daniel Romero, PhD

Gary Jacobson, PhD

Gary Jacobson, PhD, is a Professor in the Department of Hearing and Speech Sciences at Vanderbilt University and the Director of the Division of Audiology for the Vanderbilt Bill Wilkerson Center for Otolaryngology and Communication Sciences. He is the author or co-author of over 100 peer-reviewed publications and the co-editor of three textbooks covering vestibular sciences. He is the past editor of the American Journal of Audiology and current Editor in Chief of the Journal of the American Academy of Audiology. He is the recipient of both the Honors of the Association from ASHA, and the Jerger Career Award for Research in Audiology from the American Academy of Audiology.

Richard Roberts, PhD

Richard A. Roberts is Associate Professor and Vice Chair of Clinical Operations for the Department of Hearing and Speech Sciences at Vanderbilt Bill Wilkerson Center. His primary research interests include various topics related to assessment and management of vestibular dysfunction. Dr. Roberts has served on the Board of Directors of the Alabama Academy of Audiology, the American Academy of Audiology, and as a Trustee of the American Academy of Audiology Foundation. He was recently recognized by the American Academy of Audiology with the Clinical Excellence in Audiology award.

Daniel Romero, PhD

Daniel J. Romero is a Postdoctoral Vestibular Fellow and licensed audiologist in the Department of Hearing and Speech Sciences at Vanderbilt University Medical Center. He earned his Au.D. from Northern Illinois University and Ph.D. with an emphasis in vestibular science from James Madison University. Daniel has co-authored six publications and given over 15 presentations at nationally recognized conferences such the American Balance Society and AAA conference. He currently serves as advisor on the Student Academy of Audiology Advisory Committee for the American Academy of Audiology and ad hoc reviewer for multiple peer-reviewed scientific journals. He also co-hosts a vestibular-focused podcast called a dose of dizzy.

Disclosures

- **Presenter Disclosure:** Financial: Gary Jacobson is employed by Vanderbilt University and is Co-Director of the Division of Vestibular Sciences at the Vanderbilt Bill Wilkerson Center at Vanderbilt University Medical Center. He is co-editor of the textbooks "Handbook of Balance Function Testing" and "Balance Function Assessment and Management. AudiologyOnline has made a donation to Vanderbilt Universities student educational program in appreciation of the presenters donating their time to the Vanderbilt Audiology Journal Club. Non-financial: Gary Jacobson has no relevant non-financial relationships to disclose. Financial: Richard Roberts is employed by Vanderbilt University. AudiologyOnline has made a donation to Vanderbilt Universities student educational program in appreciation of the presenters donating their time to the Vanderbilt Audiology Journal Club. Non-financial: Richard Roberts has no relevant non-financial relationships to disclose. Financial: Daniel Romero is employed by Vanderbilt University. AudiologyOnline has made a donation to Vanderbilt Universities student educational program in appreciation of the presenters donating their time to the Vanderbilt Audiology Journal Club. Non-financial: Daniel Romero has no relevant non-financial relationships to disclose.
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Learning Outcomes

After this course, participants will be able to

- Name sonomotor responses that can be recorded from the head and neck in response to auditory and non-auditory stimuli.
- Describe how successful investigators have been on average recording the inion potential.
- Discuss the effects of gaze direction and head position supporting the likelihood of a vestibular cerebellar evoked potential.
- Describe basic stimulus and recording parameters for the vestibular cerebellar evoked potential.

The averaged inion response evoked by acoustic stimulation: It's relation to the saccule

Townsend GL and Cody DTH

1971. Laryngoscope 80: 121-131.

A brief history

- The story began in late 1960’s and early 1970’s.
- The only auditory evoked responses that were being used clinically were for auditory threshold estimation. These were responses with latencies negative at ~100 msec and positive at ~165 msec)
- These responses were sensitive to subject state which limited their usefulness
- At the same time there was intense interest in what were termed “fast” responses (i.e. short latency evoked responses in the 0-50 ms latency period) including the MLR
- The hope was to use these responses to obtain “semi-objective” audiometric measures that were not as dependent on subject “state” as were the long latency responses
- The ABR that really changed the world would not appear until ~ 1971 (Jewett and Williston, 1971)
- Technology was holding back the investigators
  - The digitization rates were too slow to accurately depict the electrical events that occurred in the <10ms range

A brief history

- There were at least 4 evoked responses that occurred in the 0-50 ms time period. 3 of them were sound-evoked muscle responses, referred to as “sonomotor” responses. Like sensory auditory evoked potentials they could be evoked with transient signals like clicks and tone bursts. The 4th response appeared to be the MLR.
- The 3 sonomotor responses included: a response recorded from the masseter muscle called the acoustic jaw reflex, a response recorded from the post-auricular muscle called the post auricular muscle response, and lastly, a response recorded from the occipital protuberance called the inion response or inion potential (Cody et al. 1969, Tabor et al. 1969, Townsend and Cody 1971 and Yoshie and Okudaira 1969.
- Later in the mid 1990’s and mid 2000’s we would witness the discovery of the cVEMP and oVEMP.

A brief history

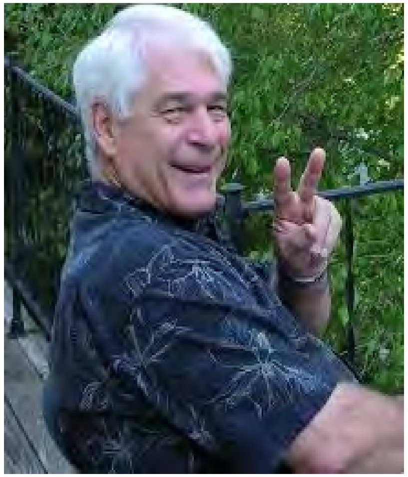
- Although the best stimuli for eliciting these evoked potentials were unfiltered clicks or low and midfrequency acoustical transients, what differed between the responses was where the non-inverting, or active electrode, was placed. That variable determined which of these short latency responses would be extracted from the electrical noise.
- I am going to focus on the inion response that was identified in the late 1960s and then disappeared into obscurity until a few years ago. In particular I will describe what we knew at that time about the anatomic and physiological origins of what may be a cerebellar evoked potential

Inion Response/Potential

- Cody and Bickford (1969) described the inion response and that it was recorded best from the occipital protuberance.
- Tabor and colleagues suggested that the response was myogenic in origin. They suggested the response could be used to assess vestibular function (Tabor et al. 1969)
- In this regard, the investigators such as Gibson in 1974 found that the presence or amplitude of the inion response correlated poorly with the result of caloric testing (Gibson, 1974). That suggested to the investigators that the response either was vestibular but generated by the otolith system, or, the response was not part of the vestibular system at all.
- The authors assembled illustrative case reports that they hoped would help determine the auditory neuroanatomic origins of the inion potential.

Tabor JR, Best L, Metz MJ 1969 Vestibular testing by evoked response. International Audiology 8: 2-3, 398-409.

- Stimulus was a click of 100 dB (no ref point provided)
- Response is 200 ms in duration



Michael J. Metz, Ph.D.

Mike Metz got me interested in becoming an audiologist. Taught at CSU-Fullerton

LeVar Best, Ph.D.

Statement of the problem

- Thru the 1960s no one studied the inion response in pathological conditions
- Purpose of the study was to “identify the end-organ receptor for the averaged inion response evoked by acoustic stimuli.”

What methods were used in the original papers to record the inion potentials?

Methods

Cody and Bickford (1968) et al.

- **Stimulus frequency**: 1000 Hz (other authors used a 750 Hz tone burst or unfiltered click stimulus)
- **Stimulus intensity**: 110 dB ISO
- **Ear**: right
- **Stimulus rate**: **2/sec (2 Hz)**
- **Total samples**: 150 per tracing
- **Active (non-inverting) electrode**: inion
- **Reference (inverting) electrode**: nose
- **Ground**: Forehead
- **Note**: Neither filter bandpass nor digitization rates (among other parameters) were provided

Methods

Townsend and Cody (1971)

- Subjects were seated in chair in a sound-treated room
- Traction was applied to head in a forward direction with a pully and a head strap.
- Objective was to create 3 lbs of traction and to increase the level of tonic EMG activity

Methods (Recording)

- Signal averaged: Mnemotron were the first summating computers used to improve signal to noise ratio (shortly thereafter averaging computers were invented)
- Traces: printed out on an X-Y plotter
- Representative responses are on the next slide

Results

- There were two primary waveforms referred to as “A” and “B”. Peak latency of the early inion response (Wave A) are shown below. Values from Cody and Bickford

Peak Latency	
Right	14.1 ms
Left	14.0 ms

Results

- The first negative peak was referred to as “A-wave” and it occurred in normals at 10-15 ms post stimulus onset
- The second negative peak referred to as the “B-wave” occurred 25-31 ms post stimulus onset
- Occasionally there was a “C-wave” and a “D-wave”
- The pattern varied from subject to subject
- The stimulus intensity had to be well above the subject’s threshold for the response to be appear
- Flexing the neck increased the amplitude of the response

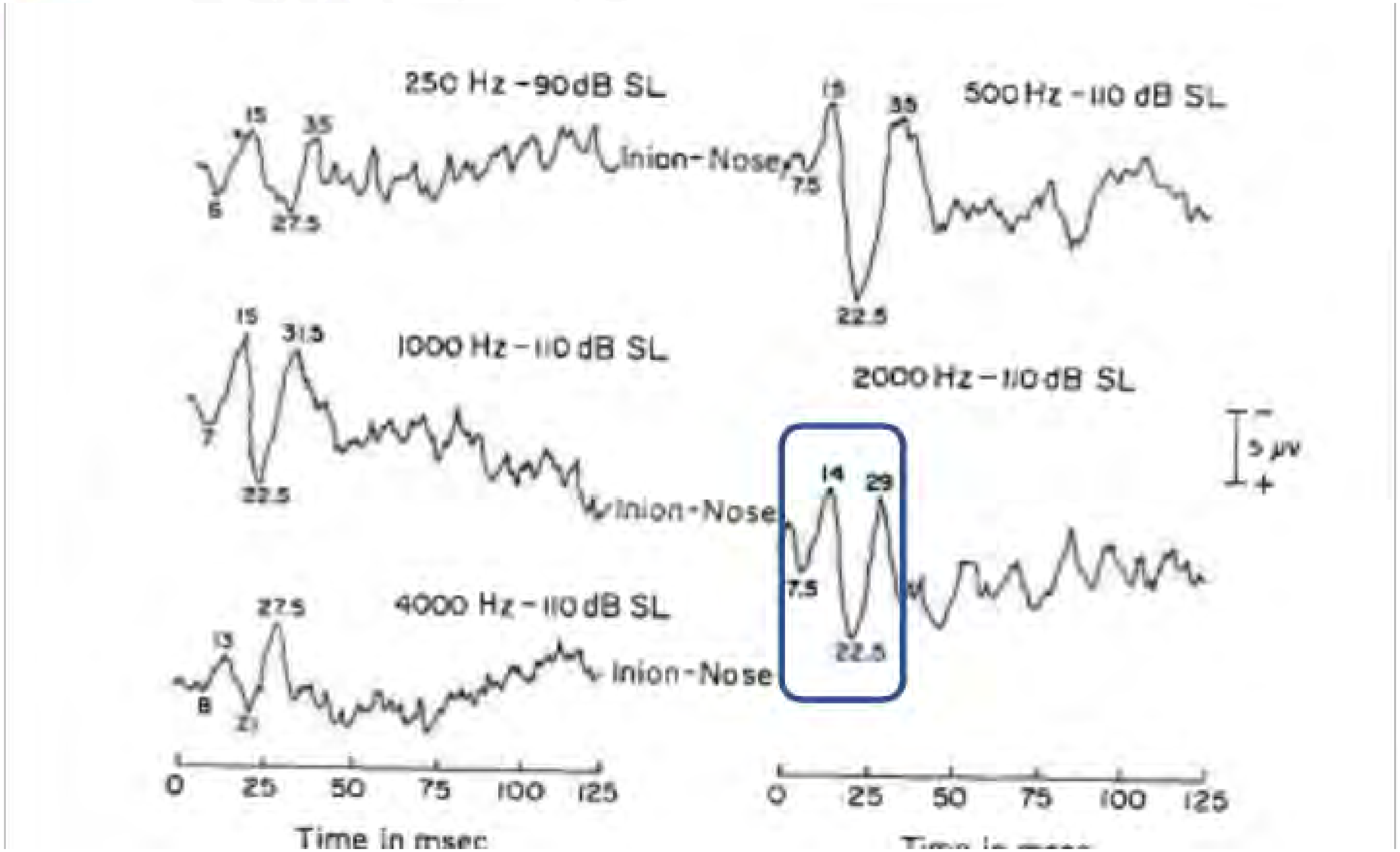


Figure 1: The effect of stimulus frequency on the inion potential for a single subject (Townsend, GL and Cody,DT, 1971, Ann Otol Rhinol Laryngol 80: 121-131). Positive is plotted as a downward deflection. The figure shows that the best frequency to record the inion potential is ~500 Hz – ~1000 Hz. Reproduced with the permission of the publisher.

Recordability of the inion response/versus stimulus frequency

Stimulus frequency	Response present (%)
500	86
1000	97
2000	69
4000	52

Figure 2: The subject was a 59 yo man with normal hearing and bilaterally absent caloric responses and absent post-rotary nystagmus. Caloric responses were absent due to streptomycin therapy. Inion responses were present bilaterally. Effect of streptomycin was to destroy the sensory epithelium of the semicircular canals. 90% of the hair cells were destroyed. Sensory cells of the utricle and saccule were unharmed. Suggests that inion response originates from utricle or saccule. From Townsend and Cody 1969 with permission of publisher.

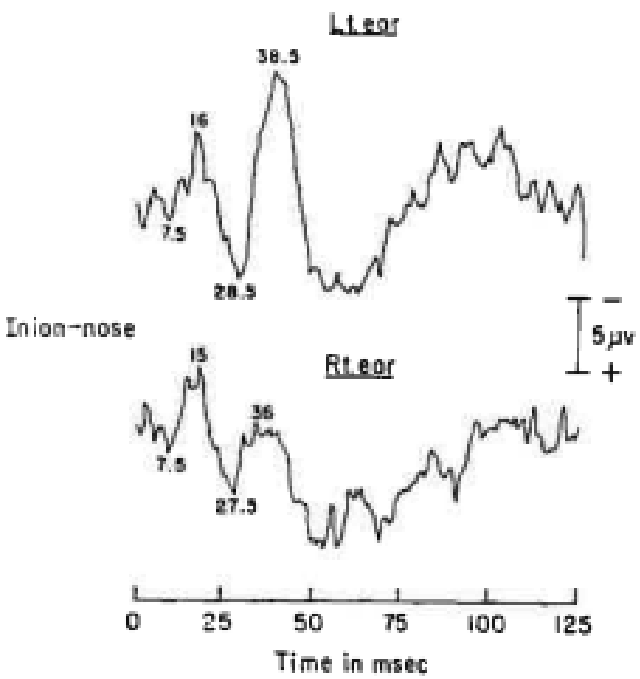
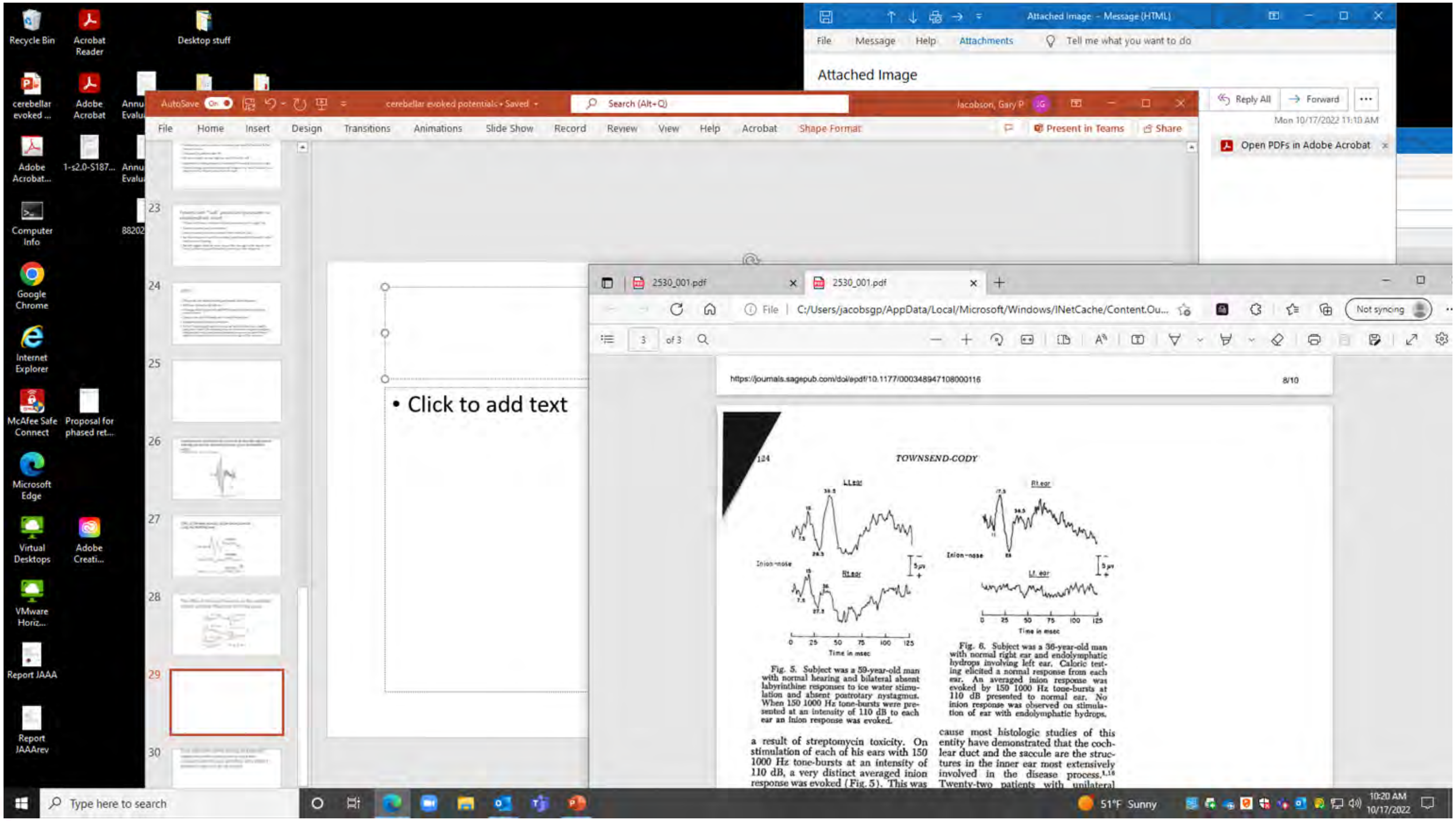


Figure 3: The subject was a 36 year old man with a normal right ear and endolymphatic hydrops involving the left ear. Caloric testing elicited a normal response from each ear. An averaged inion response was evoked by 150, 1000 Hz tone bursts at 110 dB presented to the normal ear. No inion response was observed on stimulation of the ear with endolymphatic hydrops. The response shows a normal caloric test bilaterally however the inion response was absent in ear with endolymphatic hydrops. From Townsend and Cody 1969 with permission of publisher.



Summary: Case reports that were designed to help determine what the Inion Response is and what it is not.

- Vestibular neuritis and vestibular nerve section abolishes the response (inion response is vestibular)
- Inion response can be recorded with acoustic stimulus from deaf subjects (inion response is vestibular)
- Administration of curare almost completely abolishes the response (myogenic in origin) – Cody et al. Response is myogenic or sonomotor
- Could record the response in a patient with no semicircular canal function due to streptomycin toxicity – Inion response probably saccular or utricular in origin (Townsend and Cody)
- Could not record the response from patient with EH and a tack procedure but normal caloric response – Suggests utricle or saccule as the source and the saccule primarily for EH (Townsend and Cody)

References

- Cody DT, Bickford RG, 1969. Averaged evoked myogenic responses in normal man. 1969. Laryngoscope. 79: 400-416.
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- Tabor JR, Best LG, Metz MJ. 1969. Vestibular testing by evoked response. International Audiology 8: 398-409.
- Townsend, GL, Cody DT, 1971. The averaged inion response evoked by acoustic stimulation: its relation to the saccule. Ann Otol Rhinol Laryngol 80: 121-131.
- Yoshie N, Okudaira T. 1969. Myogenic evoked potential responses to clicks in man. Acto oto-laryngological Suppl 252: 89-103.

The inion response revisited: Evidence for a possible cerebellar contribution to vestibular-evoked potentials produced by air-conducted sound stimulation

Todd, Govender, & Colebatch (2017) *Journal of Neurophysiology 117(3)*:1000-1013

Vanderbilt Journal Club

Richard A. Roberts, Ph.D.

Purpose:

Investigate several vestibular evoked responses to determine "potential" for a ***cerebellar*** contribution.

- Established that cVEMP amplitude increases with sternocleidomastoid (SCM) muscle contraction
- Established that oVEMP amplitude increases with upward gaze
  - Presumably an effect of background extraocular muscle (inferior oblique) contraction
  - Does upward gaze get muscle closer to surface electrode which increases amplitude or could it be something else?

- Gaze modifies translational (otolith organ) VOR gain (Angelaki, 2004)
- Is there central modulation of otolith-ocular reflex (oVEMP) by a cerebellar influence?
- Release of **cerebellar inhibition** of extraocular muscles (EOM) would allow EOM increase in contraction and that could create larger oVEMP amplitude.

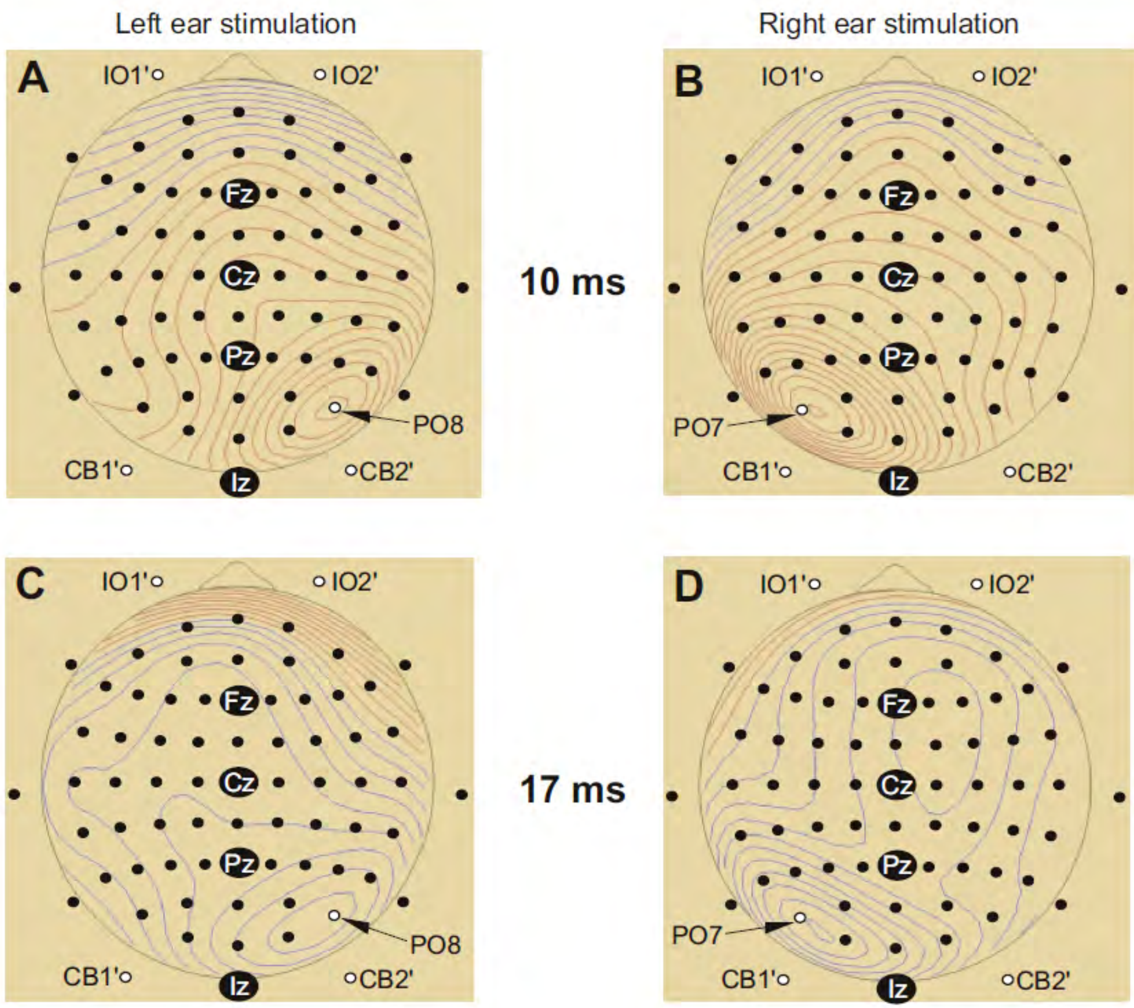
Assumptions

- Assuming oVEMP release of cerebellar inhibition, vestibular-related **sensory** potentials should be modulated by eye position.
  - Adds support for cerebellar contribution
- Vestibular **myogenic** potentials would be modulated by **head position**.
  - neck muscle effects like with cVEMP

Methods

- Subjects
  - n = 11, 7 women, age 23 – 53 years
  - Denied vestibular or hearing impairment
  - Confirmed presence of cVEMP
- Acoustic Stimuli
  - 2 ms, 500 Hz tone pips, 130-133 dB Peak SPL

Methods


Left ear stimulation
Right ear stimulation
A
B
C
D
IO1'
IO2'
Fz
Cz
Pz
Iz
CB1'
CB2'
PO8
PO7
10 ms
17 ms

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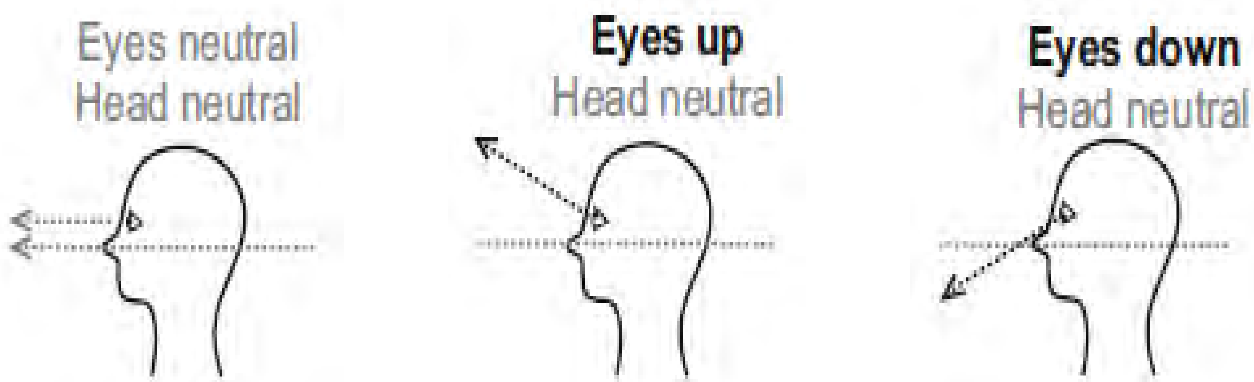
Splenius Muscles

Methods

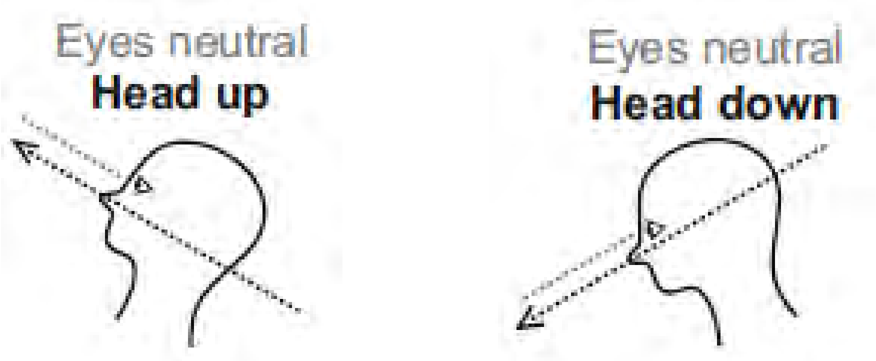
- Three eye gaze positions with head neutral
  - Neutral (0 deg horizontal)
  - Eyes up (+20 deg)
  - Eyes down (-20 deg)



- **Eye position change with head position neutral should modulate <u>sensory</u> responses**

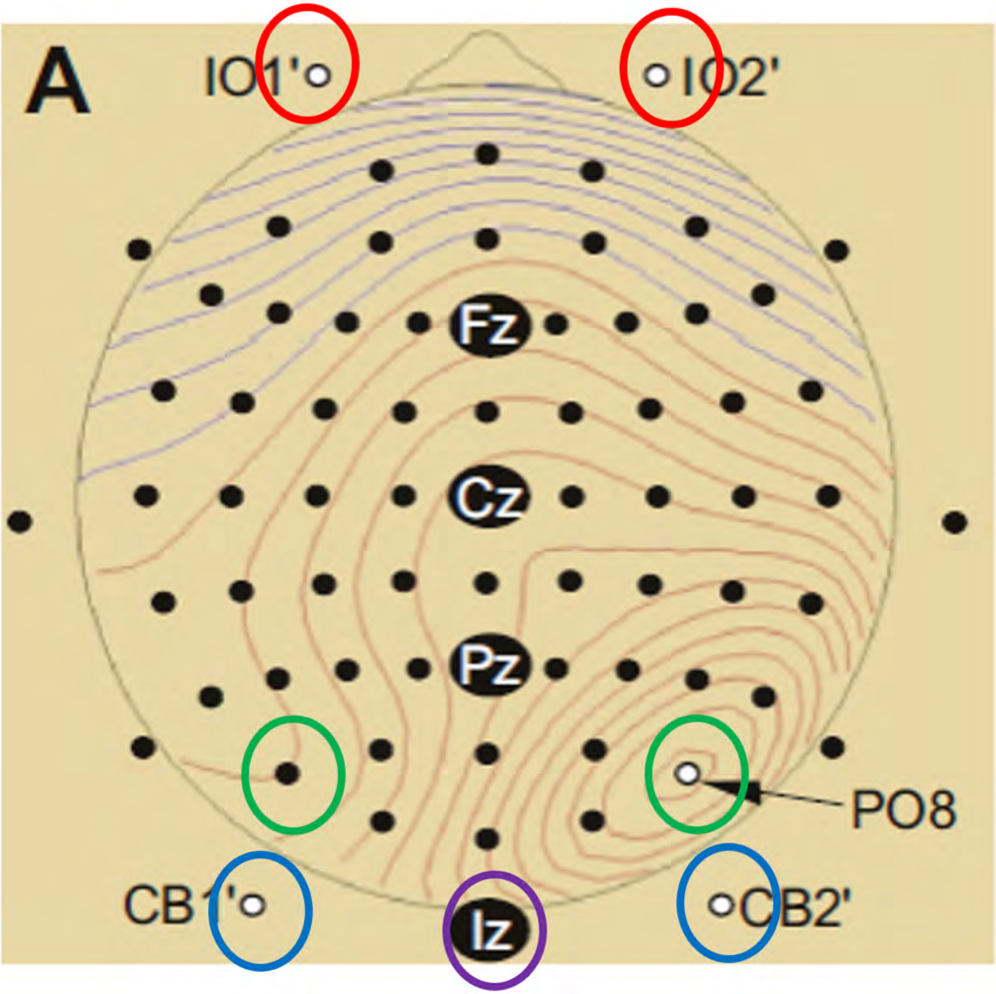
Methods

- Two head positions with eye gaze neutral
  - Head up (+20 deg)
  - Head down (-20 deg)



  - **Head position, eyes neutral should modulate <u>myogenic</u> responses**
- Left ear and Right ear stimulation 3x2 = 6, 2x2 = 4, So 10 recordings

= inferior obliques; oVEMP

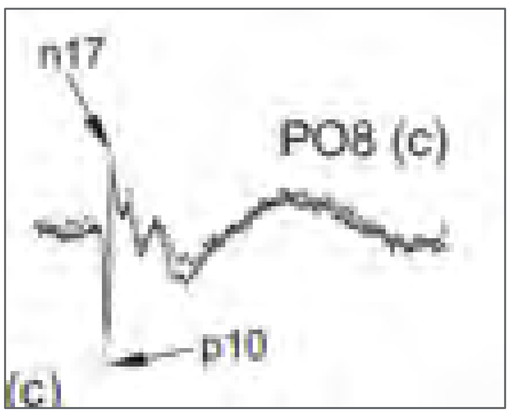


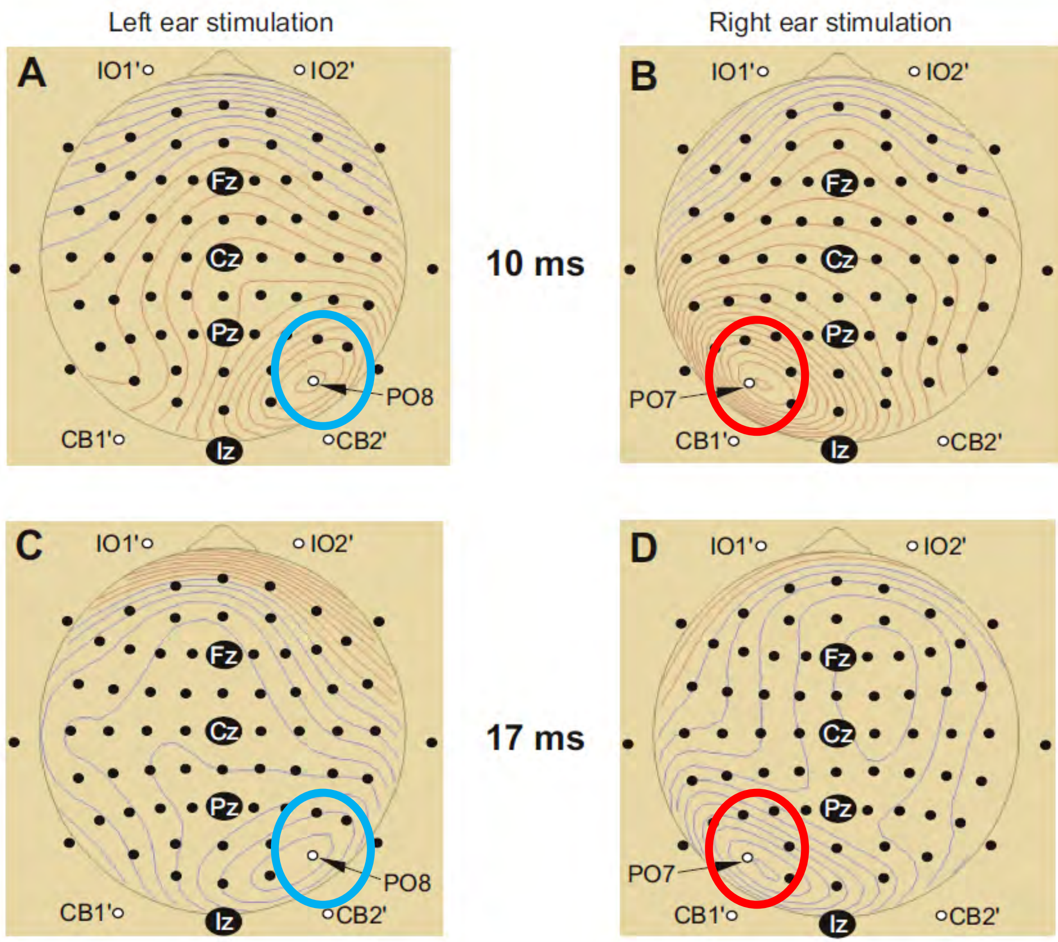
= parietal occipital area; Anterior cerebellum

= splenius muscles; cVEMP

= inion; inion response

Results - Grand Means of average evoked EEG – Head and Eyes Neutral





Waveforms ipsilateral to stimulated ear

Waveforms contralateral to stimulated ear

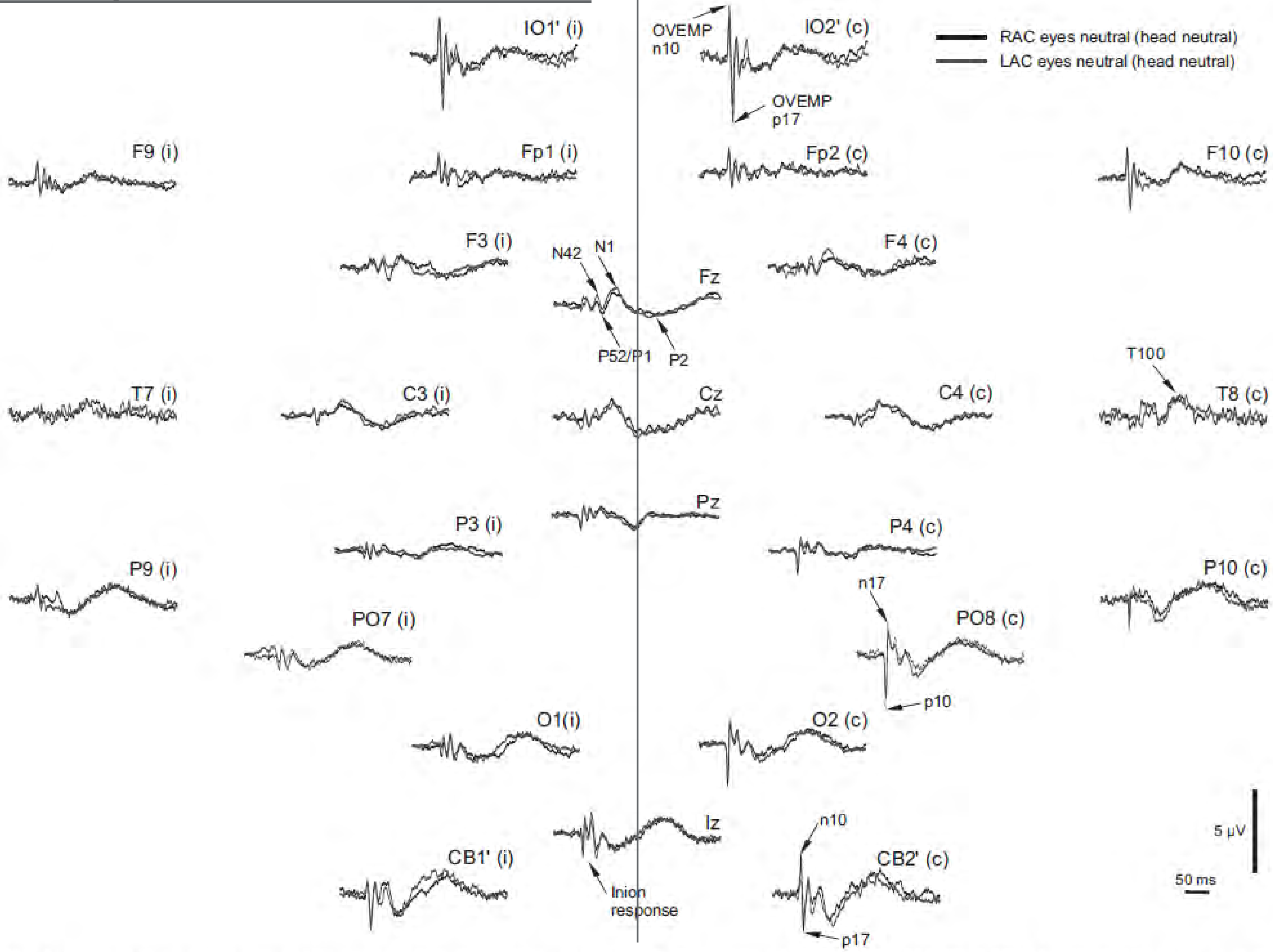
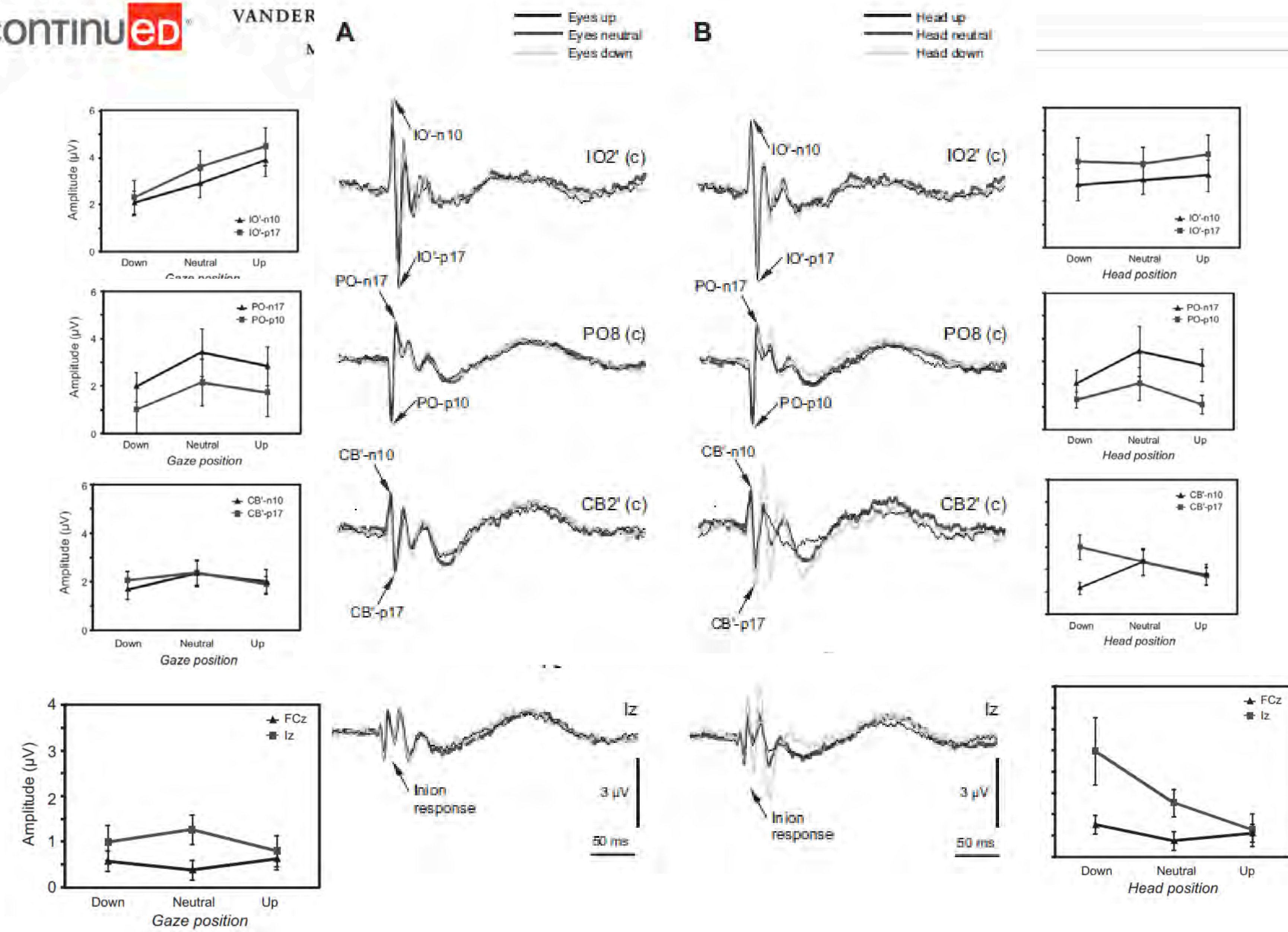


Fig. 2. Array of grand means of evoked potentials elicited by AC sound at +6 to 9 dB regarding 1 V peak (130–133 dB pk SPL) for left (LAC; gray)- vs. right (RAC; black)-ear stimulation in neutral gaze. The right-ear grand mean has been reflected over the midline so that in the figure, the *left/right* side of the array represents responses ipsilateral (i)/contralateral (c) to the side of stimulation. Epoch is −50 to +300 ms.

VANDER



A
Eyes up
Eyes neutral
Eyes down
B
Head up
Head neutral
Head down
Amplitude (µV)
IO'-n10
IO'-p17
Down
Neutral
Up
IO'-n10
IO2' (c)
IO'-p17
PO-n17
PO-p10
Gaze position
PO8 (c)
PO-p10
CB'-n10
CB'-p17
CB2' (c)
Iz
Inion response
3 µV
50 ms
FCz
Iz
Head position

Initial Results Summary

- Large magnitude activity over contra parietal occipital area (anterior cerebellum)
- Overall larger waveform responses contra to stimulus ear for all recording electrode sites
- IO (oVEMP) response has large gaze effect (cerebellar release of inhibition; **SENSORY**); no effect of head position)
- ***CB (cVEMP-like) response has no gaze effect but head position effect; MYOGENIC); especially 17 ms; modulates like inion response, both likely have large cervical muscle influence)***
- ***PO (cerebellar?) has largest p10 response in neutral gaze and neutral head position suggesting greatest cerebellar inhibition***
- Overall, may have more gaze effects for 10 ms waves and more head position effects for 17 ms waves

Results - Brain Electrical Source Analysis (BESA)

- Software used to analyze EEG data to help identify generator source areas
  - Accounts for radial thickness and conductivity of head, scalp, bone, and CSF
- Algorithm of modeling with iterative dipoles to arrive at the "best fit" which should identify the source of the energy
- For example, the oVEMP response is measured off the inferior oblique so there would be an expectation of a source at the infraorbital electrodes.

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Table 3. *Ocular regional sources plus additional dipole models*

Model	X, Y, Z	Antero-Postero Location	RV	Possible Origin
Pair + 1 DP	±17, 64, −28	Ant	4.8%	Bilateral EOMs
	35, −72, −46	Post		Contra cerebellum, inf. semi-lun. l.
Pair + 2 DP	±25, 73, −26	Ant	3.5%	Bilateral EOMs
	34, −72, −46	Post		Contra cerebellum, inf. semi-lun. l.
	−16, −45, −56			Ipsi cerebellum, inf. semi-lun. l., tonsil
Pair + 3 DP	**±26, 70, −31**	**Ant**	**2.1%**	**Bilateral EOMs**
	35, −75, −49	**Post**		**Contra cerebellum, inf. semi-lun. l./cervical muscles**
	−27, −57, −34			**Ipsi cerebellum, tonsil**
	−35, −86, −49			**Ipsi cervical muscles**
Pair + 3 DP 2	±26, 70, −31	Ant	2.2%	Bilateral EOMs
	40, −79, −51	Post		Contra cerebellum, inf. semi-lun. l./cervical muscles
	−16, −54, −16			Ipsi cerebellum, culmen, declive, dentate
	−32, −86, −50			Ipsi cervical muscles
Pair + 4 DP	±26, 70, −32	Ant	2.2%	Bilateral EOMs
	36, −72, −48	Post		Contra cerebellum, inf. semi-lun. l.
	15, 79, −23			Contra cervical muscles
	−18, −87, −57			Ipsi cervical muscles
	−38, −52, −27			Ipsi cerebellum, culmen, tonsil, tuber
Pair + 4 DP 2	±26, 71, −31	Ant	2.2%	Bilateral EOMs
	55, −58, −35	Post		Contra cerebellum, tonsil, inf. semi-lun. l.
	35, −78, −55			Contra cervical muscles
	−22, −86, −57			Ipsi cervical muscles
	−27, −56, −28			Ipsi cerebellum, culmen, tonsil

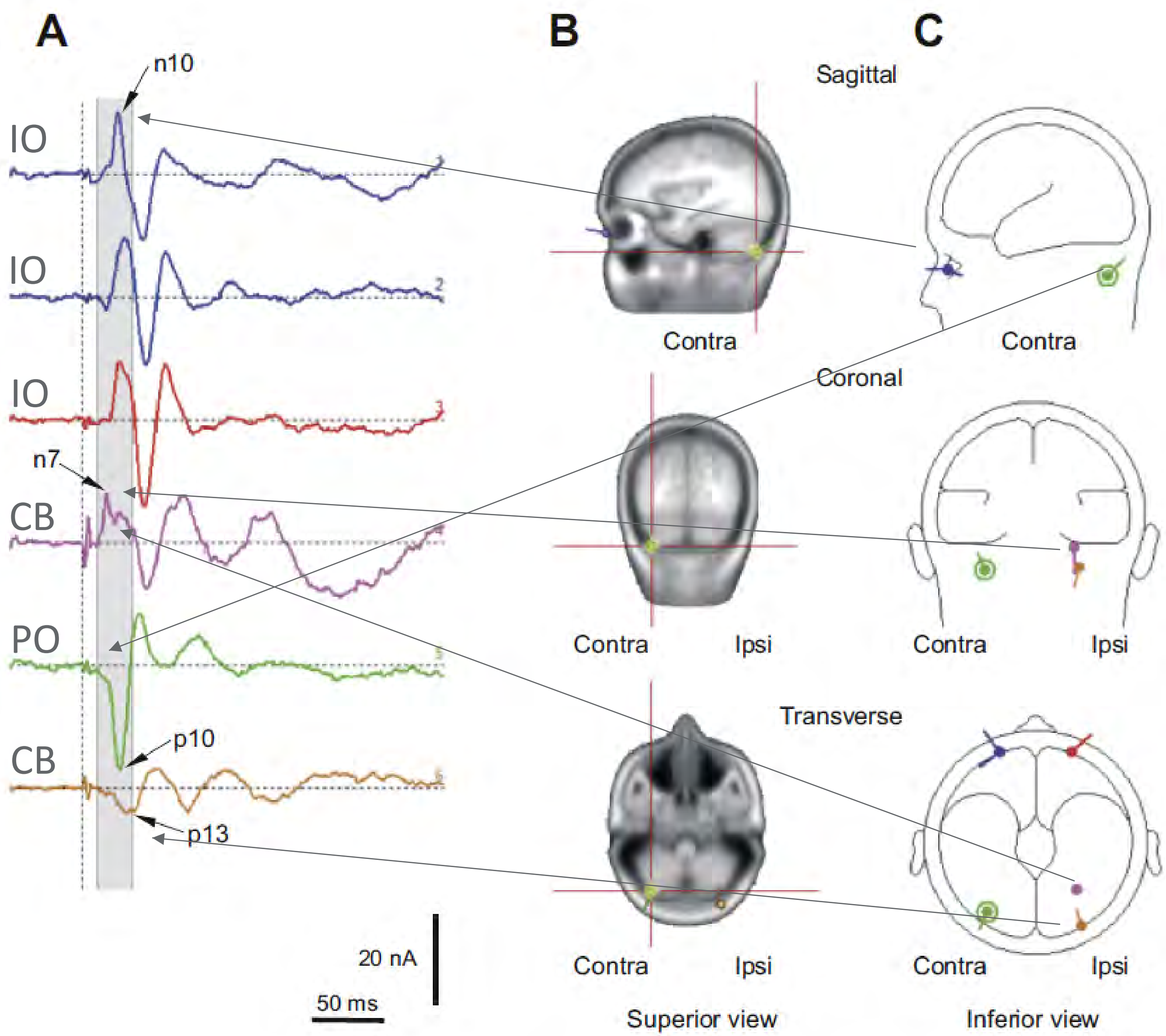
Results obtained using 2 anterior regional ocular sources and then adding dipole sources. Suffix 2, additional solution. X, Y, and Z, stereotactic coordinates (Talairach and Tournoux 1988). RV, residual variance; DP, dipoles; Post, postero; Ant, antero; inf. semi-lun. l., inferior semi-lunar lobule. Boldface indicates the solution illustrated in Fig. 8.

Contra
EOM
source

Ipsi
cerebellar
source

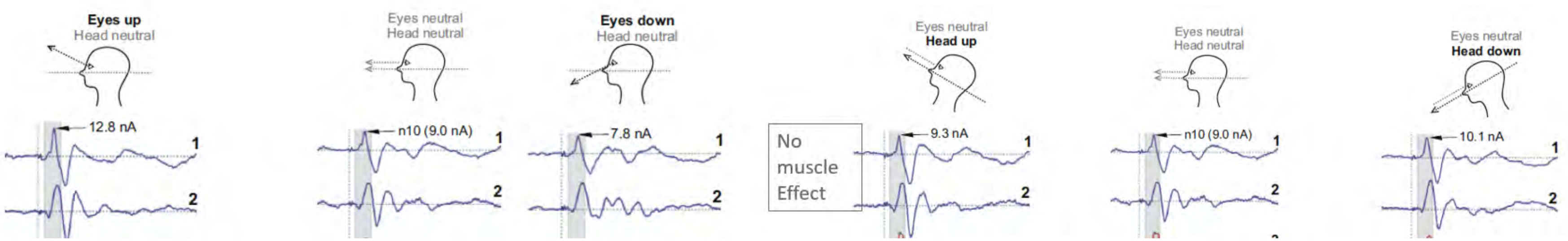
Contra
cerebellar
source

Ipsi
cervical
source



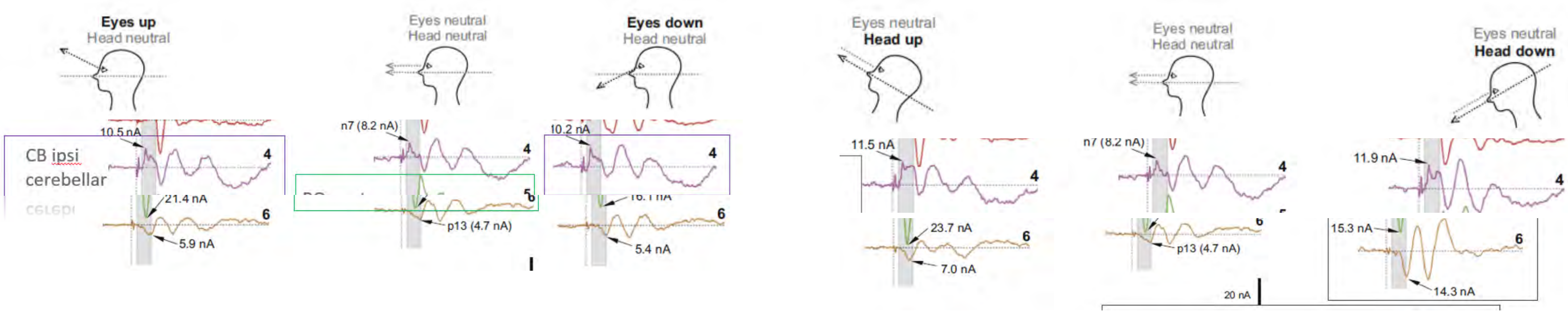
Infraocular Electrodes

- n10 – p17 is oVEMP
- Largest generator contribution from contralateral inferior oblique
- Modulated by **gaze** but not head position
- Todd et al.
  - Suggests decrease of cerebellar inhibition on EOM needed which decreases PO cerebellar response in gaze up.



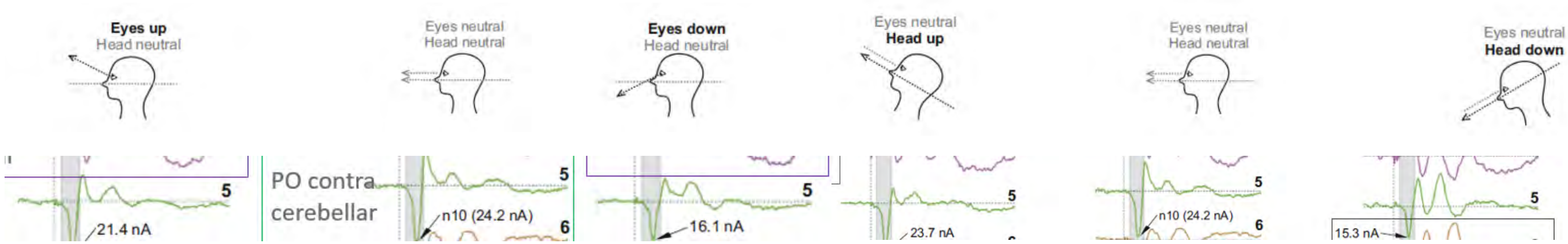
CB Electrodes

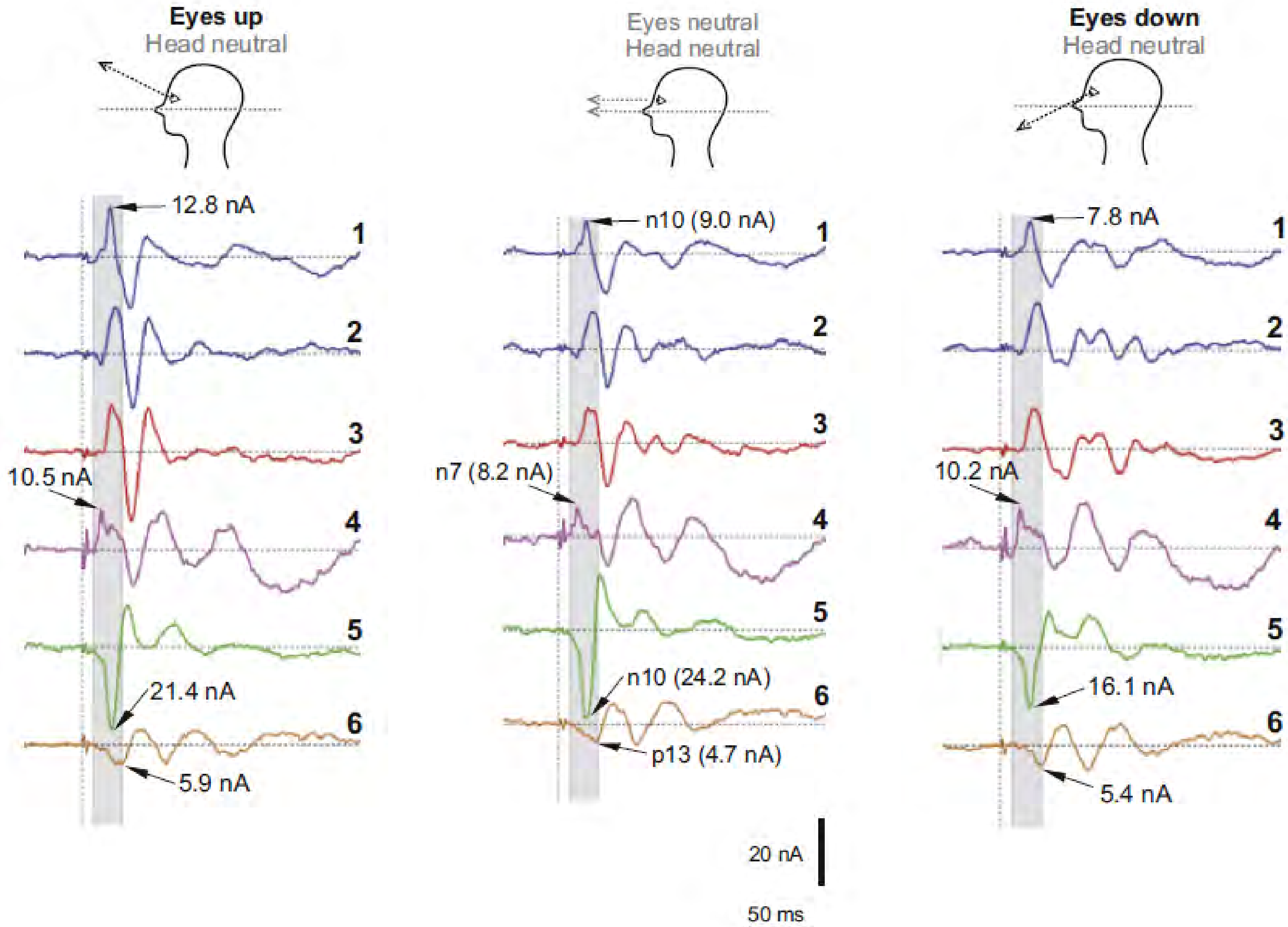
- n7 – p17; Position is over splenius muscles of neck
- Largest generator contribution to n7 from <u>ipsilateral cerebellum</u>; largest generator contribution to p17 from <u>ipsilateral cervical muscles</u>
- Gaze effects on n7 inverse to PO p10; largest o17 in Head Down like inion.
- Suggests CB site is **mixed** p7 sensory, but n17 myogenic – could be similar mixed for inion response?

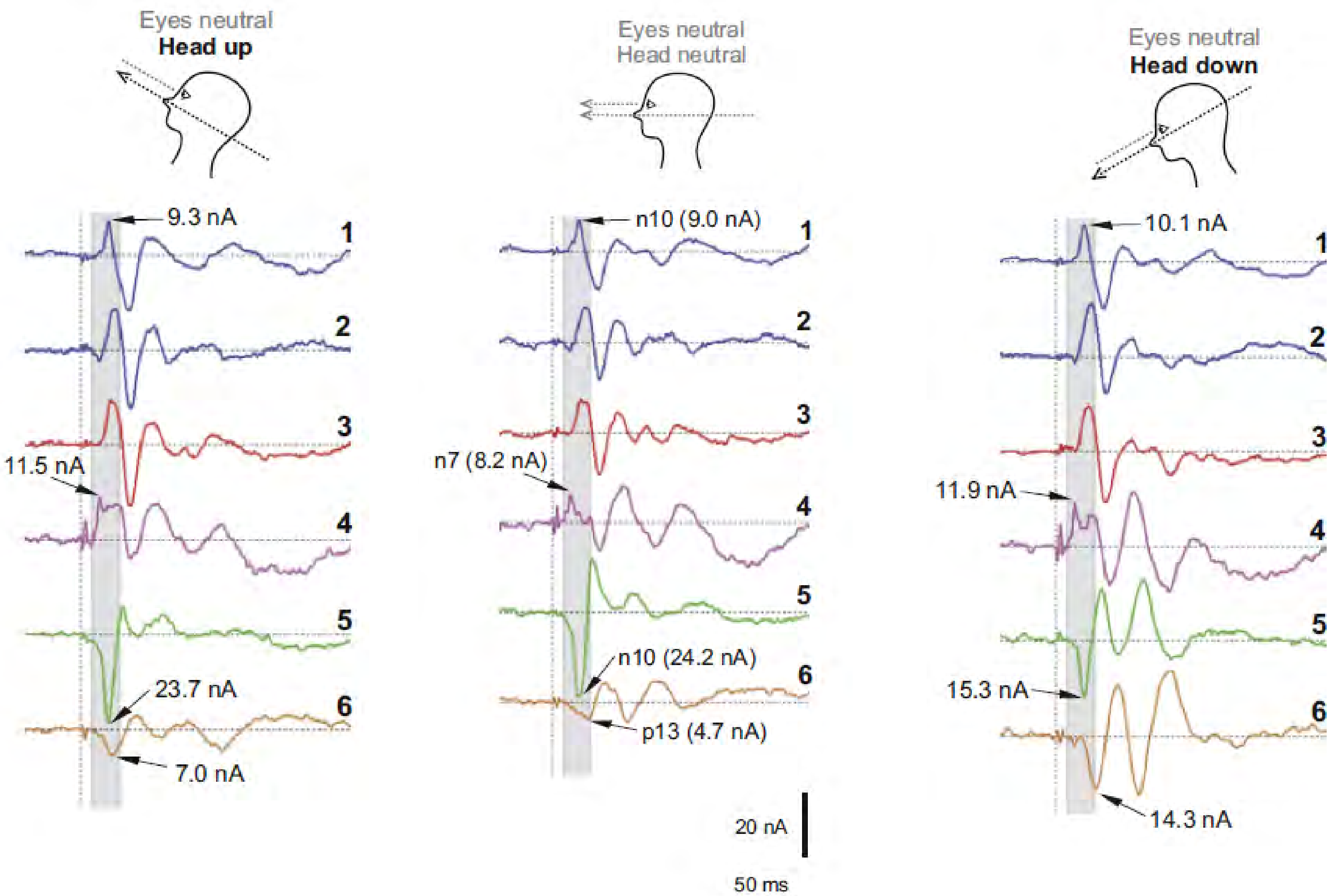


Posterior Occipital Electrodes

- p10 – n17; Opposite polarity from oVEMP (IO leads)
- Position is over occipital lobes, above anterior lobe of cerebellum with largest generator contribution from contralateral cerebellar hemisphere
- Largest p10 and n17 amplitude with neutral gaze and neutral head position.
- If cerebellar then <u>more inhibition on EOM for neutral gaze</u>; potential for similar inhibitory effect on neck muscles, especially n17




Eyes up
Head neutral
Eyes neutral
Head neutral
Eyes down
Head neutral
12.8 nA
n10 (9.0 nA)
7.8 nA
1
2
3
4
5
6
10.5 nA
n7 (8.2 nA)
10.2 nA
21.4 nA
n10 (24.2 nA)
16.1 nA
5.9 nA
p13 (4.7 nA)
5.4 nA
20 nA
50 ms


Eyes neutral
Head up
9.3 nA
11.5 nA
23.7 nA
7.0 nA
1
2
3
4
5
6
Eyes neutral
Head neutral
n10 (9.0 nA)
n7 (8.2 nA)
n10 (24.2 nA)
p13 (4.7 nA)
Eyes neutral
Head down
10.1 nA
11.9 nA
15.3 nA
14.3 nA
20 nA
50 ms

Take Home Points

- Vestibular cerebellum potentials recordable from posterior occipital electrodes with primary positive wave at 10 ms
  - Largest amplitude from contralateral recording site over anterior cerebellum
  - Largest amplitude in neutral gaze and head position; associated with greatest cerebellar inhibition
- Smaller cerebellar potential recorded from splenius muscle with negative wave at 7 ms
  - Ipsilateral cerebellar generator
  - Smallest amplitude in neutral gaze and head position; excitatory?
  - Could be true for earlier inion response as well though later (17 ms) is most certainly myogenic
- More work needed to confirm

Recordability of the vestibular cerebellar evoked potential (VsCEP)

Daniel J. Romero, Richard A. Roberts, Jessica J. Feller, and Gary P. Jacobson

Department of Hearing and Speech Sciences, Division of Vestibular Sciences, Vanderbilt University Medical Center, Nashville, TN

Vanderbilt Journal Club

Daniel J Romero, AuD, PhD

Background

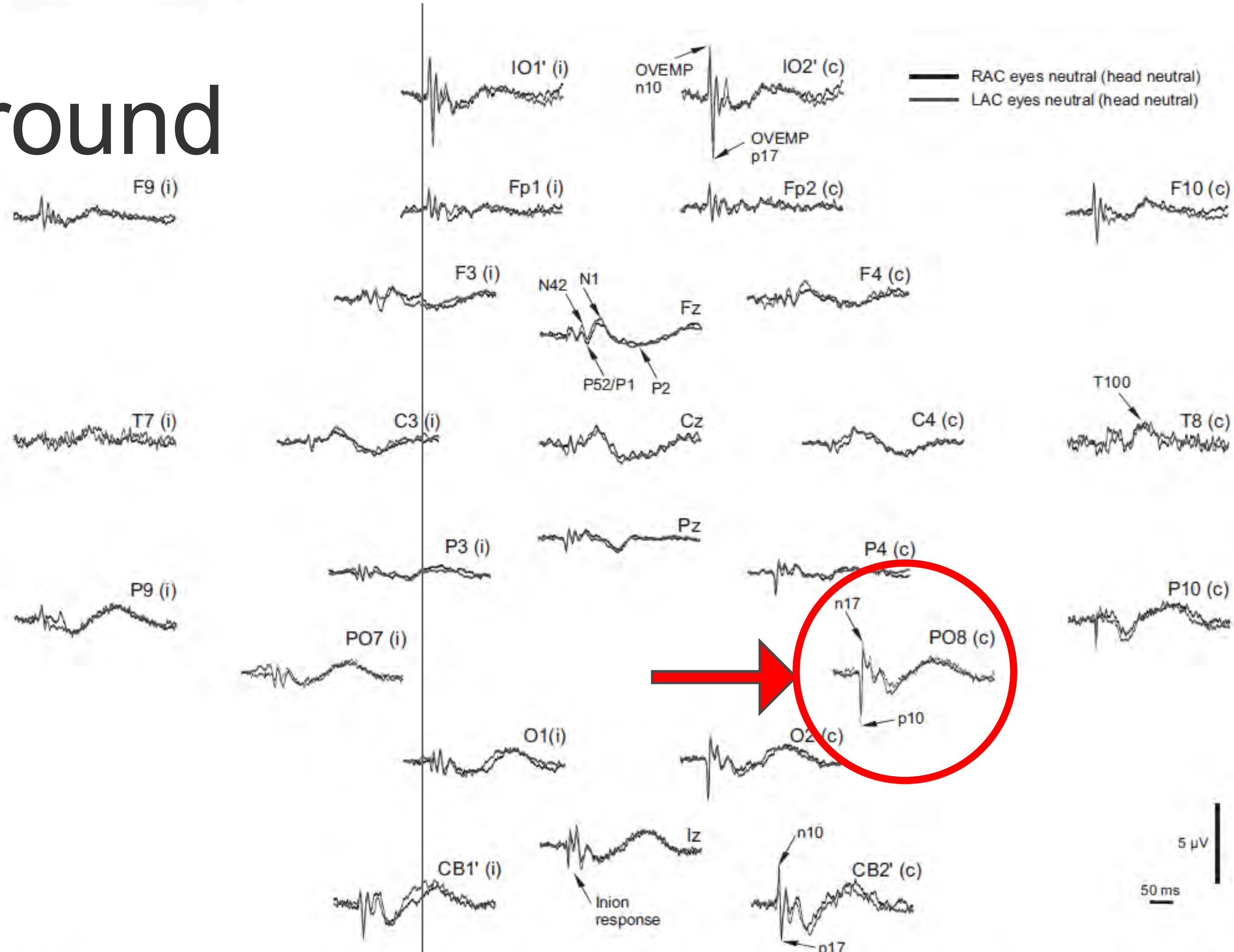
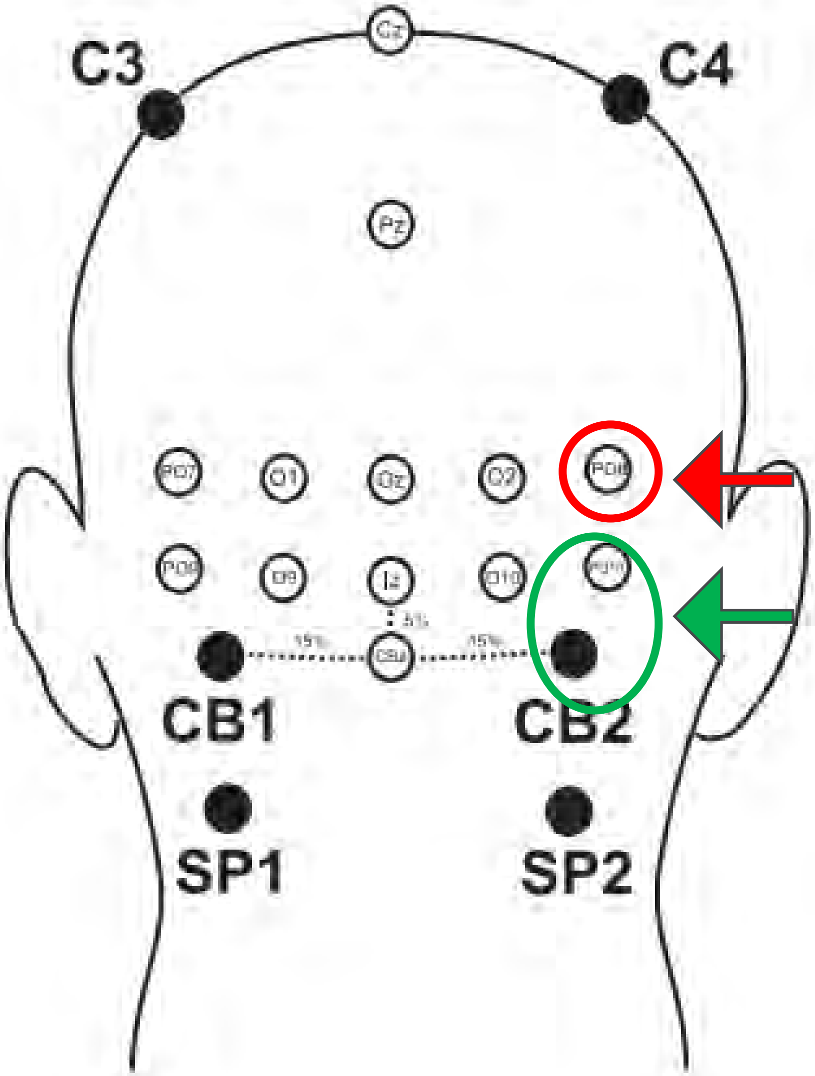


Fig. 2. Array of grand means of evoked potentials elicited by AC sound at +6 to 9 dB regarding 1 V peak (130–133 dB pk SPL) for left (LAC; gray)- vs. right (RAC; black)-ear stimulation in neutral gaze. The right-ear grand mean has been reflected over the midline so that in the figure, the *left/right* side of the array represents responses ipsilateral (i)/contralateral (c) to the side of stimulation. Epoch is −50 to +300 ms.

Todd et al., 2017



Todd et al., 2018

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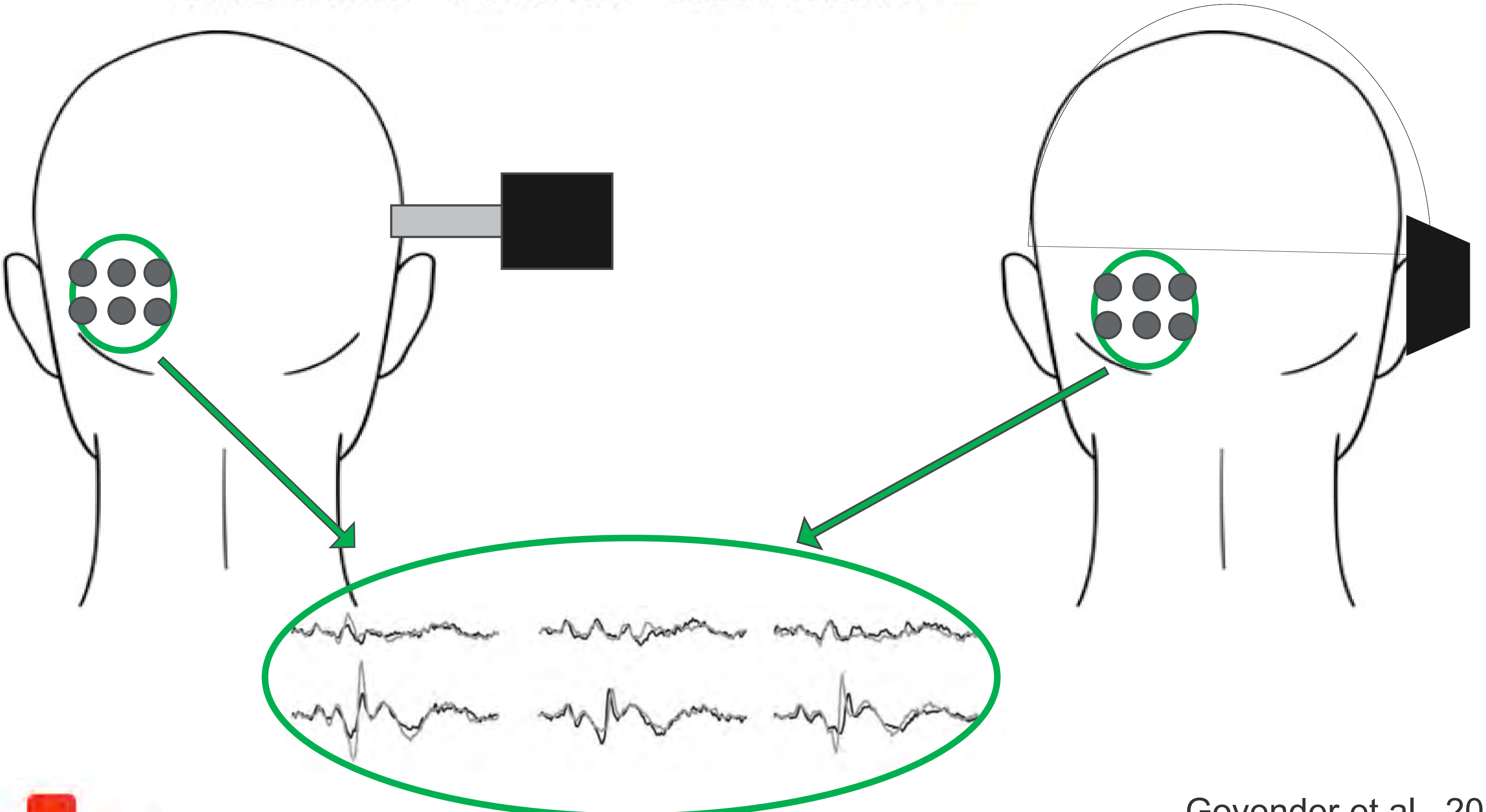
Mapping the vestibular cerebellar evoked potential (VsCEP) following air- and bone-conducted vestibular stimulation

Sendhil Govender[1] · Neil P. M. Todd[3] · James G. Colebatch[1,2]



Govender et al., 2020

The purpose of our study

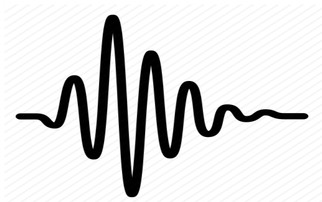
- Replicate several components of previous investigations
  - Where on the scalp is the VsCEP best recorded?
    - Defined as the largest <u>peak-to-peak amplitude</u> and highest <u>response rate</u>
  - Which reference location (nose vs. earlobe) yields the largest VsCEP response?

Participants

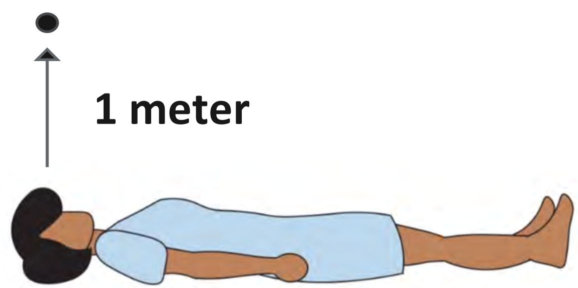
- 6 participants (Mean age = 26.5; SD = 2.1)
- 5 Females
- All participants reported no known history of hearing, balance, or known neurological conditions

Methods

125 dB pSPL



Supine



Ear

Right

Left

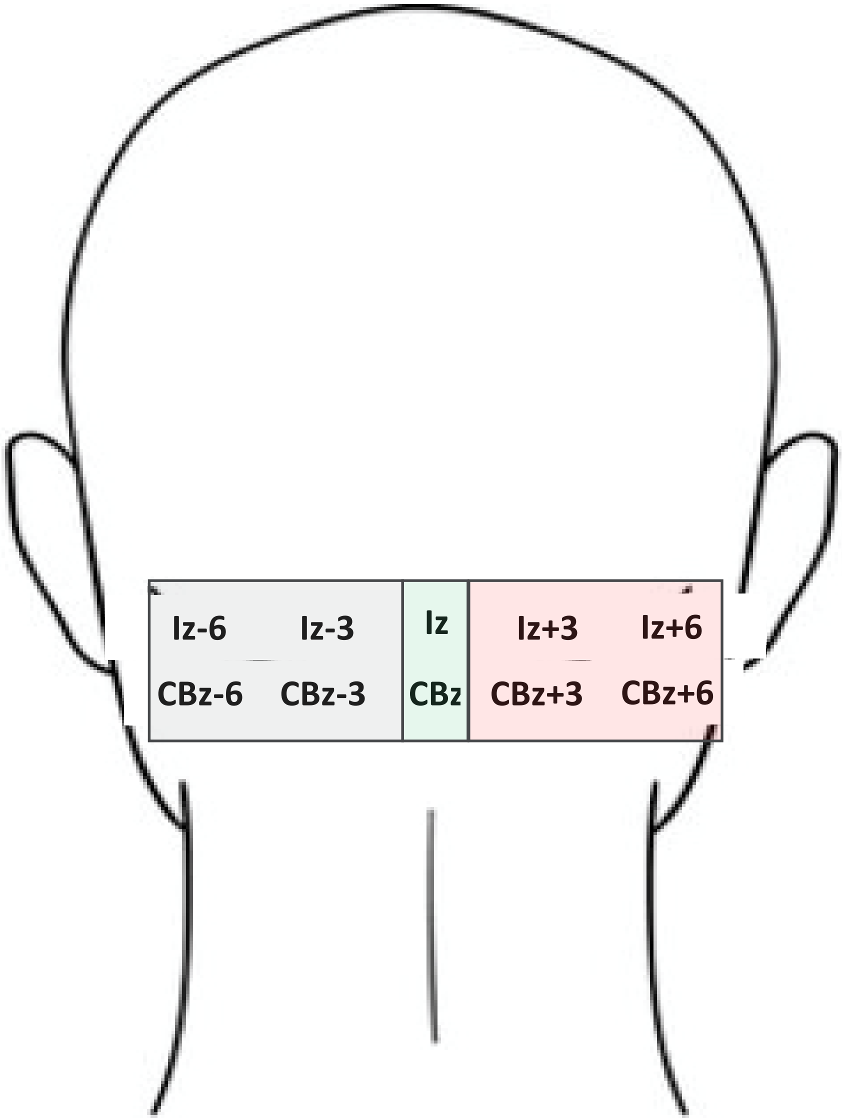
Reference

1. Contralateral earlobe (CA)
2. Tip of the nose (N)

- Air conduction using ER3A Insert earphones
- Transient blackman-gated tone bursts at 500 Hz (2-0-2 msec)

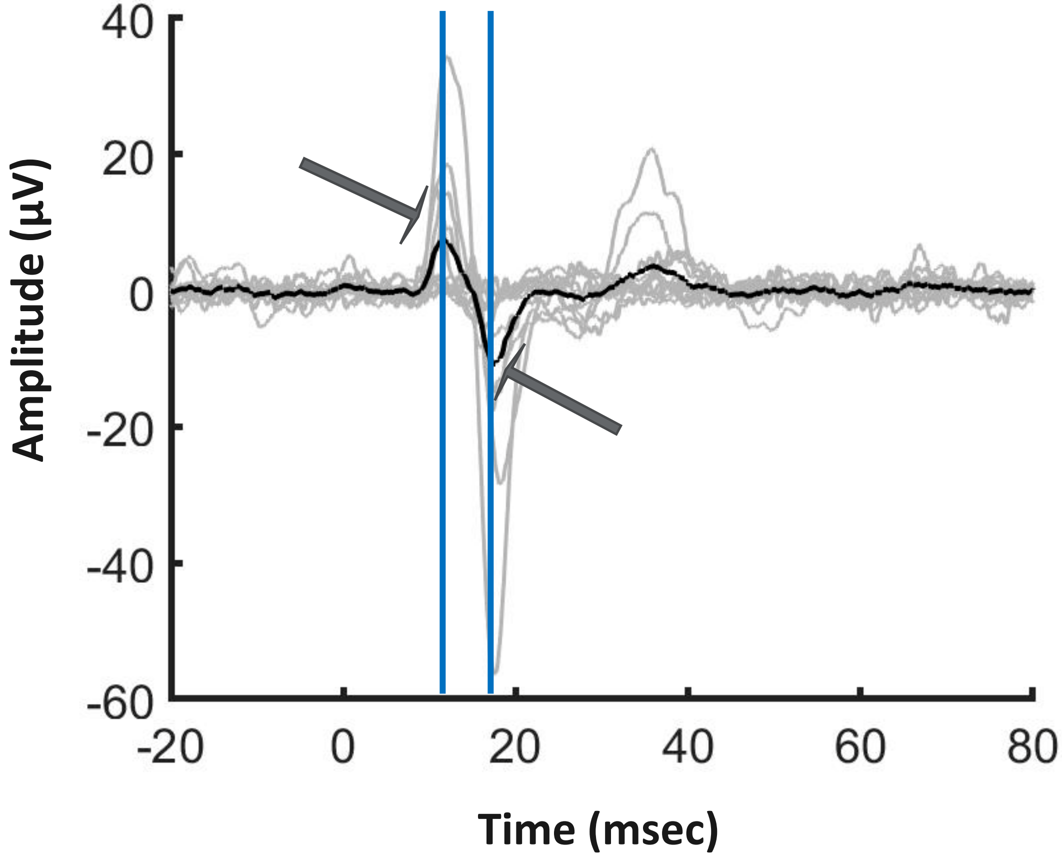
Methods

- Scalp (active) electrodes were positioned at the cerebellar midline (Iz and CBz) and bilaterally 3 and 6 cm lateral to midline
- Ground electrode on the forehead
- Reference electrode was placed at CA and N positions contralateral to the stimulated ear

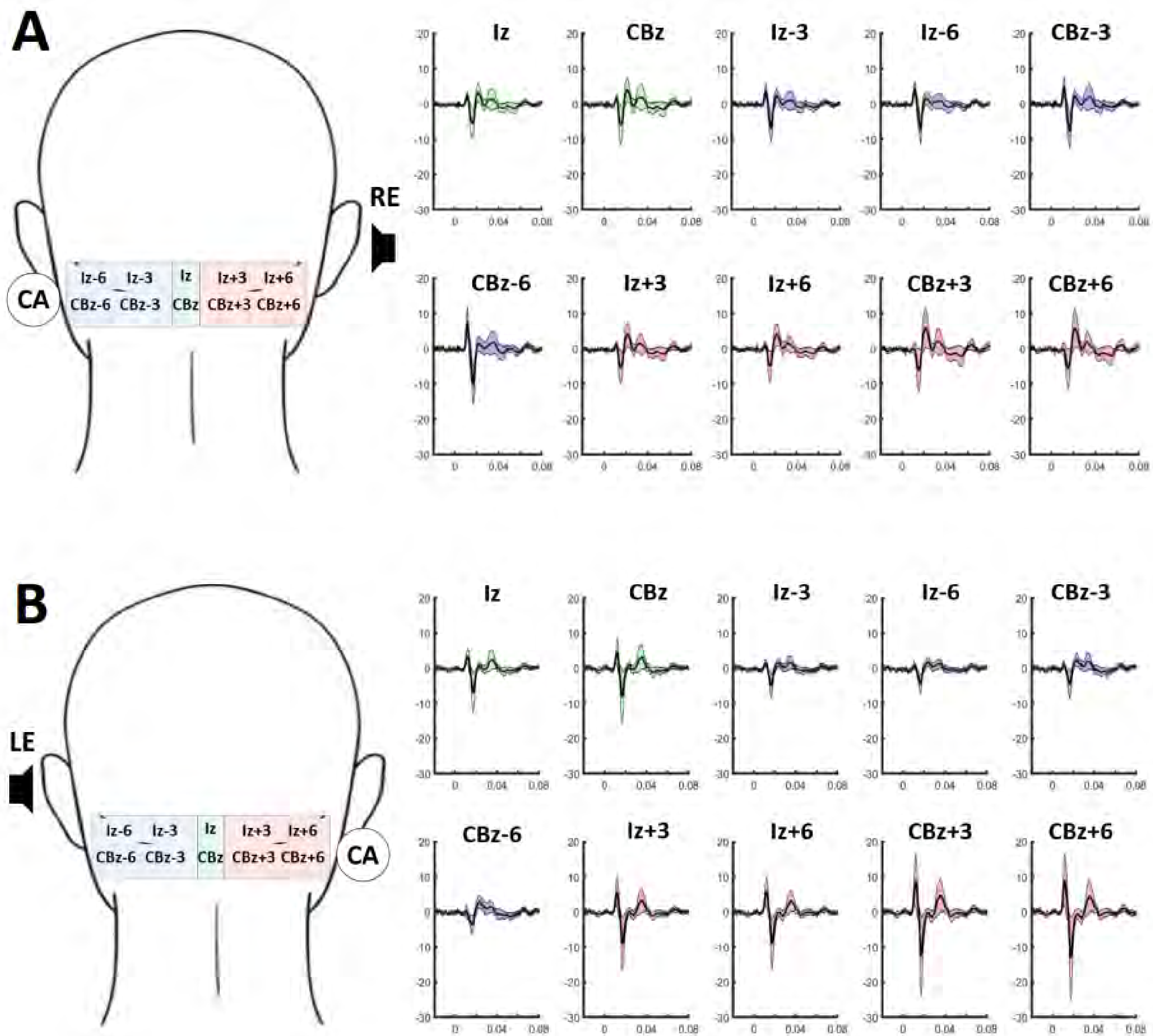


- Responses were considered present if both a positive and negative peak could be identified above the noise floor.
- Waveforms marked p1 and n1 latencies and p1n1 peak-to-peak amplitudes.

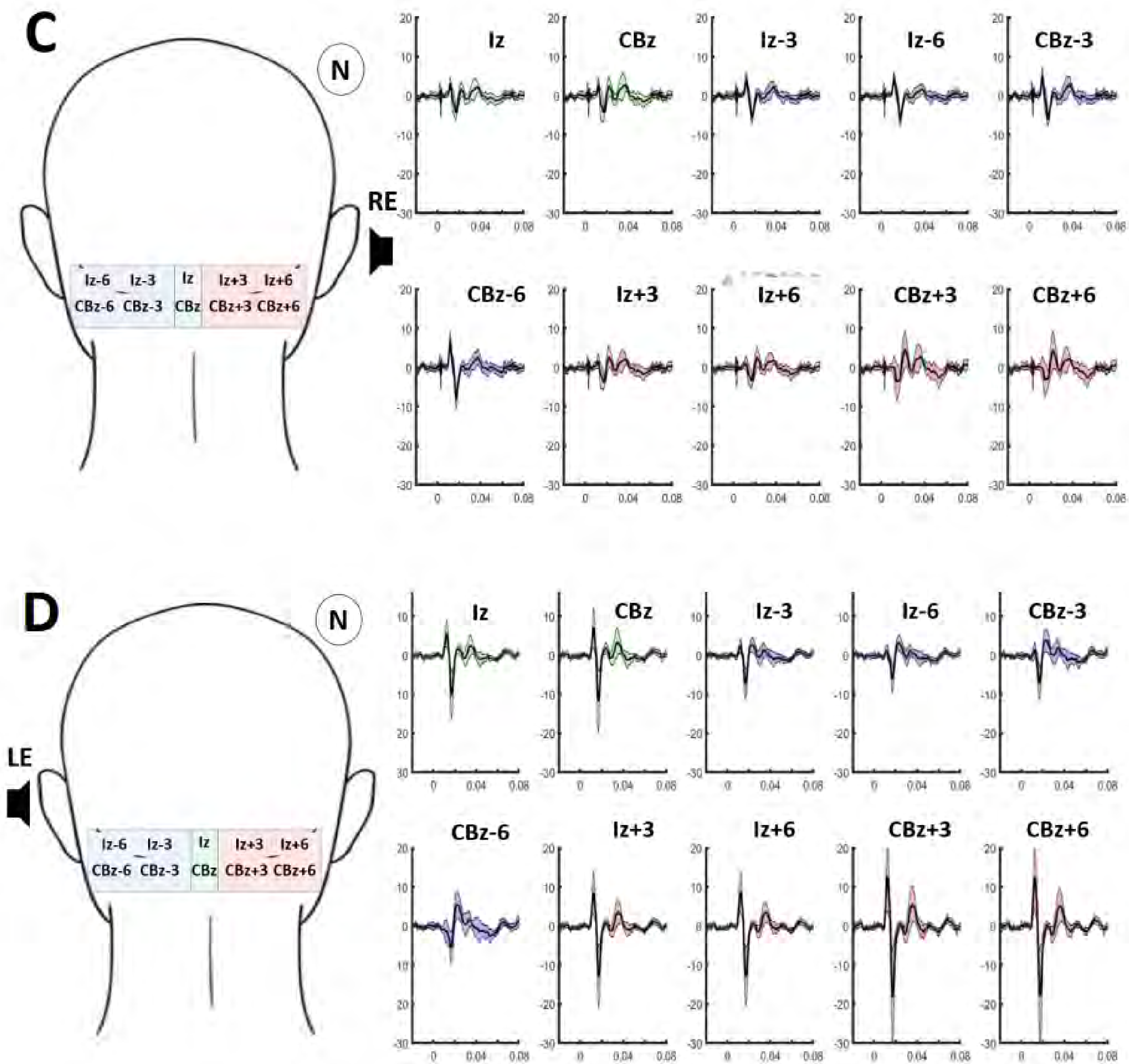
Results



Results


A
RE
CA
Iz-6 Iz-3 Iz Iz+3 Iz+6
CBz-6 CBz-3 CBz CBz+3 CBz+6
Iz
CBz
Iz-3
Iz-6
CBz-3
CBz-6
Iz+3
Iz+6
CBz+3
CBz+6
B
LE
CA
Iz-6 Iz-3 Iz Iz+3 Iz+6
CBz-6 CBz-3 CBz CBz+3 CBz+6
Iz
CBz
Iz-3
Iz-6
CBz-3
CBz-6
Iz+3
Iz+6
CBz+3
CBz+6

Results

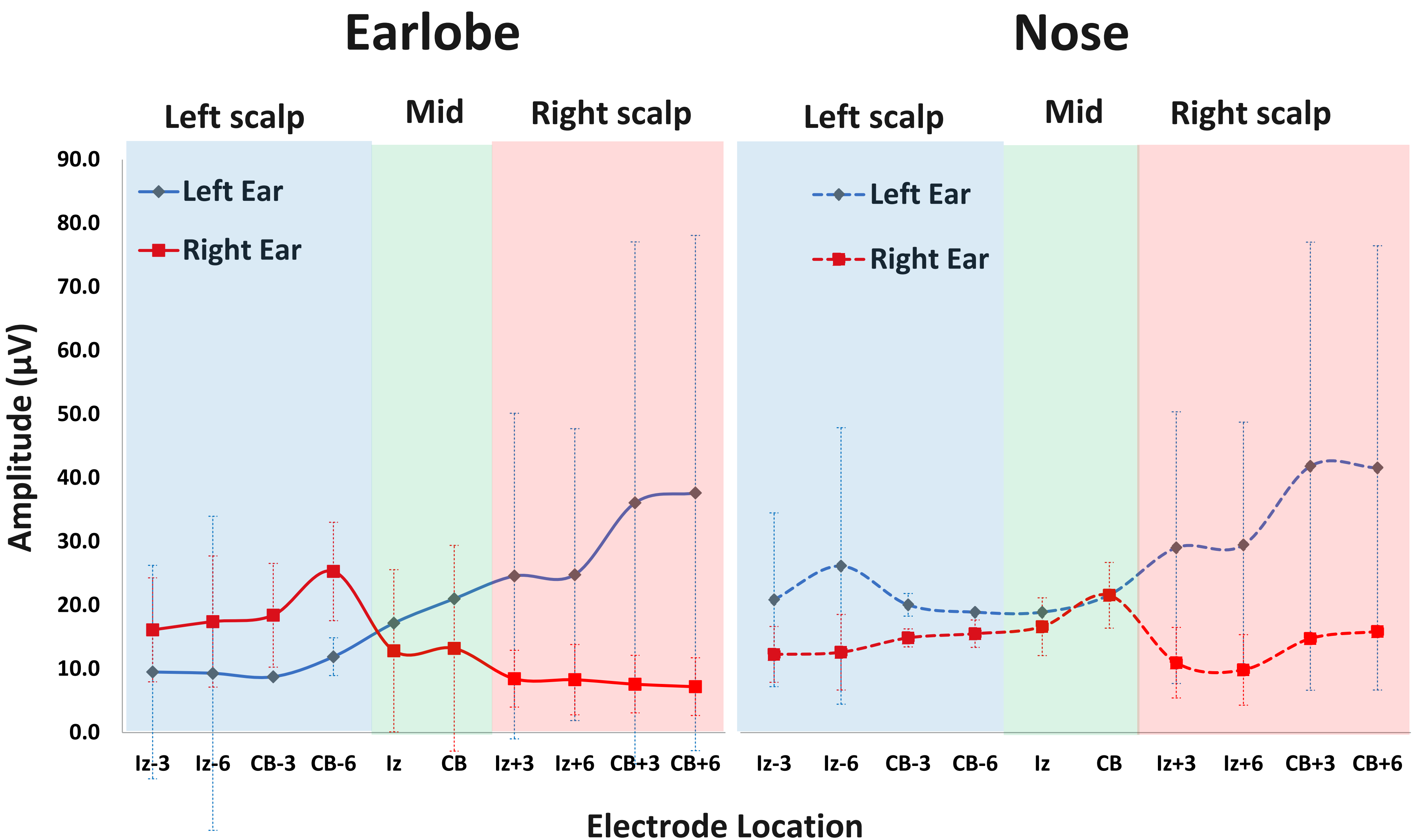

C
N
RE
Iz-6 Iz-3 Iz Iz+3 Iz+6
CBz-6 CBz-3 CBz CBz+3 CBz+6
Iz
CBz
Iz-3
Iz-6
CBz-3
CBz-6
Iz+3
Iz+6
CBz+3
CBz+6
D
N
LE
Iz-6 Iz-3 Iz Iz+3 Iz+6
CBz-6 CBz-3 CBz CBz+3 CBz+6
Iz
CBz
Iz-3
Iz-6
CBz-3
CBz-6
Iz+3
Iz+6
CBz+3
CBz+6

Left ear stimulated

	n	Site	P1 Latency (ms)	N1 Latency (ms)	P1-N1 (μV)
Earlobe Reference					
	4	Iz	11.4 (1.0)	16.8 (0.4)	17.2 (16.8)
	4	CBz	11.3 (0.7)	16.5 (0.6)	21.0 (24.7)
	2	Iz-3	11.4 (0.7)	17.2 (1.3)	9.5 (0.1)
	2	Iz-6	11.0 (0.4)	16.9 (2.1)	9.3 (3.0)
	2	CBz-3	11.1 (0.6)	16.8 (0.7)	8.8 (0.2)
	1	CBz-6	10.9 (-)	15.6 (-)	11.2 (-)
	4	Iz+3	11.1 (0.9)	17.0 (0.5)	24.6 (25.6)
	4	Iz+6	11.5 (0.8)	16.9 (0.5)	24.8 (22.9)
	4	CBz+3	11.5 (0.8)	16.9 (0.4)	36.1 (41.0)
	4	CBz+6	11.4 (0.6)	17.2 (0.5)	37.6 (40.5)
Nose Reference					
	4	Iz	12.2 (0.3)	17.1 (0.6)	20.8 (13.6)
	4	CBz	12.1 (0.2)	17.2 (0.6)	26.0 (21.6)
	2	Iz-3	12.2 (0.1)	16.8 (0.4)	20.0 (1.8)
	1	Iz-6	11.3 (-)	16.6 (-)	18.8 (-)
	1	CBz-3	12.3 (-)	17.0 (-)	18.2 (-)
	1	CBz-6	12.2 (-)	16.6 (-)	21.5 (-)
	4	Iz+3	12.1 (0.2)	17.1 (0.6)	28.9 (21.3)
	4	Iz+6	12.1 (0.3)	17.3 (0.7)	29.3 (19.2)
	4	CBz+3	12.2 (0.3)	17.3 (0.7)	41.7 (35.0)
	4	CBz+6	12.2 (0.3)	17.4 (0.8)	41.4 (34.7)

Right ear stimulated

	n	Site	P1 Latency (ms)	N1 Latency (ms)	P1-N1 (μV)
Earlobe Reference					
	4	Iz	11.7 (0.9)	16.0 (1.2)	12.9 (8.2)
	4	CBz	11.8 (1.0)	15.9 (1.4)	13.2 (10.3)
	4	Iz-3	11.8 (1.0)	16.2 (1.5)	16.1 (8.1)
	4	Iz-6	11.8 (1.1)	16.3 (1.5)	17.4 (7.7)
	4	CBz-3	12.0 (0.9)	16.2 (1.2)	18.4 (12.7)
	4	CBz-6	11.9 (0.8)	16.5 (1.2)	25.3 (16.2)
	2	Iz+3	11.3 (0.6)	15.5 (1.5)	8.5 (4.5)
	2	Iz+6	11.3 (0.6)	15.6 (1.6)	8.3 (5.5)
	2	CBz+3	11.3 (0.6)	15.5 (1.4)	7.6 (4.5)
	2	CBz+6	11.4 (0.7)	15.3 (1.9)	7.2 (4.5)
Nose Reference					
	4	Iz	12.1 (0.5)	16.9 (1.4)	12.2 (4.4)
	4	CBz	12.0 (0.5)	16.8 (1.3)	12.6 (5.9)
	4	Iz-3	12.0 (0.5)	17.3 (0.8)	14.8 (1.4)
	4	Iz-6	11.8 (0.1)	17.3 (0.8)	15.5 (2.1)
	4	CBz-3	12.1 (0.4)	17.0 (0.9)	16.6 (4.5)
	4	CBz-6	11.8 (0.2)	17.3 (0.7)	21.5 (5.1)
	2	Iz+3	12.3 (0.6)	17.4 (0.9)	10.9 (5.5)
	2	Iz+6	12.3 (0.6)	17.3 (1.0)	9.8 (5.5)
	1	CBz+3	11.9 (-)	17.4 (-)	14.7 (-)
	1	CBz+6	11.9 (-)	17.6 (-)	15.8 (-)



Earlobe
Nose
Left scalp
Mid
Right scalp
Left scalp
Mid
Right scalp
Left Ear
Right Ear
Left Ear
Right Ear
Amplitude (µV)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Iz-3
Iz-6
CB-3
CB-6
Iz
CB
Iz+3
Iz+6
CB+3
CB+6
Iz-3
Iz-6
CB-3
CB-6
Iz
CB
Iz+3
Iz+6
CB+3
CB+6
Electrode Location

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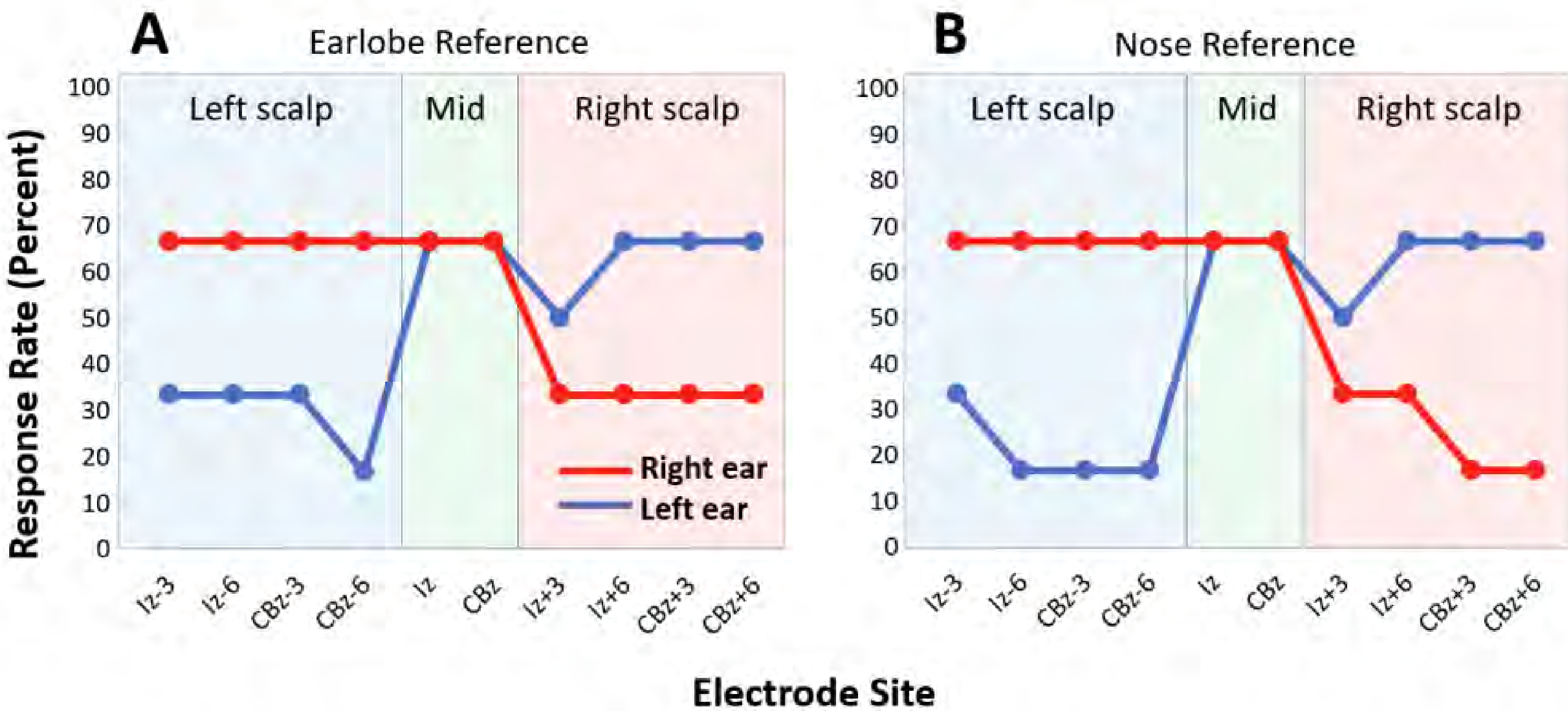
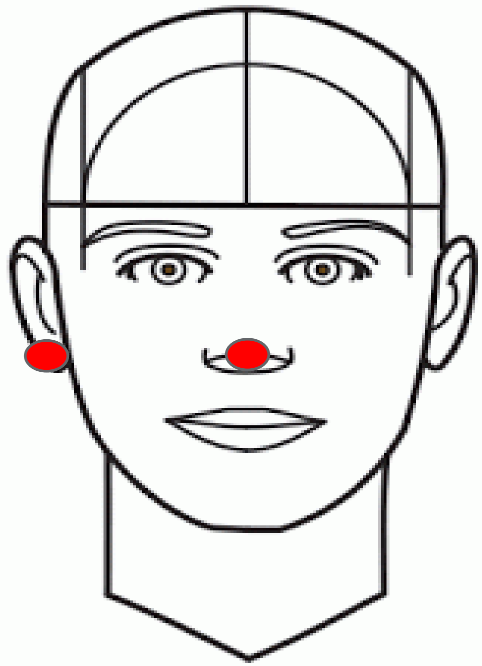
Results



Main Findings

- Best responses recorded at midline and contralateral to the ear being stimulated
- No significant difference between contralateral earlobe and nose reference sites
- 66% response rate (4/6)
  - What could be contributing to less than 100% response rate?
    - Myogenic contamination?
    - Not a true physiologic stimulus?
    - Not enough vection?
    - Skull thickness?
    - Combination?



Possible study limitations

- Single stimulus (acoustic only)
- Smaller N may be contributing to variability in responses
- Fixed one inch target

Future directions

- Explore variables contributing to less than desirable response rate
- Investigate clinical utility of VsCEP in the assessment of dizzy patients

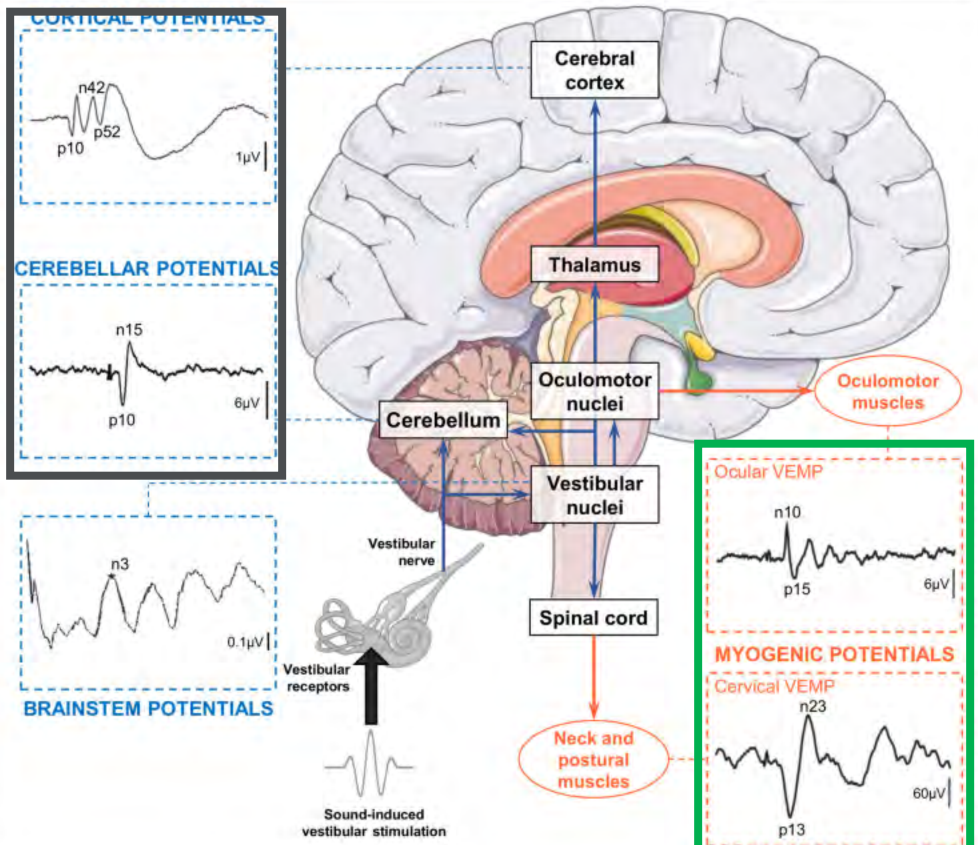


FIGURE 1 | Electrical potentials evoked by sound-induced vestibular stimulation can be recorded along the pathways from the otolithic receptors to the central nervous system and muscles. Vestibular-evoked myogenic potentials (VEMPs) are recorded over extraocular, neck, and postural muscles. Cervical VEMPs reflect an inhibitory reflex and are recorded with electrodes over the sternocleidomastoid muscle ipsilateral to the stimulation. Ocular VEMPs reflect an excitatory reflex and are recorded with electrodes placed over the inferior oblique muscle contralateral to the stimulation. Both traces are adapted from (39). Vestibular-evoked cerebral potentials (VestEPs) are recorded from electrodes placed on the scalp or neck. Brainstem potentials are characterized by an n3 component observed under electrode P3 [this example recorded in a healthy participant is adapted from (40)]. Cerebellar potentials: Grand mean evoked potentials showing probable cerebellar components p10 and n15 observed under electrode P08 [illustration adapted from cf. Govender et al. (41) with permissions from Springer Nature]. Cortical potentials: Grand mean evoked potentials showing components p10, n42 and p52 observed under electrode FCz [illustration adapted from (42)]. Brain illustration from Servier Medical Art (smart.servier.com).

Nakul et al., 2021

Thank you!