



Universiteit
Leiden
The Netherlands

A closer look at stimulation thresholds and spread of excitation in cochlear implants: recording aspects and clinical implications

Biesheuvel, J.D.

Citation

Biesheuvel, J. D. (2023, February 1). *A closer look at stimulation thresholds and spread of excitation in cochlear implants: recording aspects and clinical implications*. Retrieved from <https://hdl.handle.net/1887/3514327>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3514327>

Note: To cite this publication please use the final published version (if applicable).

CHAPTER



Bibliography



- Abbas, P.J., Brown, C.J., Shallop, J.K., et al. (1999). Summary of results using the nucleus CI24M implant to record the electrically evoked compound action potential. *Ear Hear.*, 20, 45–59.
- Abbas, P.J., Hughes, M.L., Brown, C.J., et al. (2004). Channel interaction in cochlear implant users evaluated using the electrically evoked compound action potential. *Audiol. Neurotol.*, 9, 203–213.
- Agresti, A. (2002). *Categorical Data Analysis*, Hoboken, NJ, USA: John Wiley & Sons, Inc.
- Akhoun, I., Bestel, J., Pracht, P., et al. (2015). Automated classification of electrically-evoked compound action potentials. In *2015 7th International IEEE/EMBS Conference on Neural Engineering (NER)*. (pp. 687–690). IEEE.
- Akin, I., Kuran, G., Saka, C., et al. (2006). Preliminary results on correlation between neural response imaging and “most comfortable levels” in cochlear implantation. *J. Laryngol. Otol.*, 120, 261–5.
- Akin, I., Mutlu, M., Kuran, G., et al. (2008). One-year results of the banded neural response imaging study. *Otol. Neurotol.*, 29, 635–8.
- Alvarez, I., de la Torre, A., Sainz, M., et al. (2010). Using evoked compound action potentials to assess activation of electrodes and predict C-levels in the Tempo+ cochlear implant speech processor. *Ear Hear.*, 31, 134–45.
- Arnoldner, C., Kaider, A., Hamzavi, J. (2006). The role of intensity upon pitch perception in cochlear implant recipients. *Laryngoscope*, 116, 1760–5.
- Arora, K., Dowell, R., Dawson, P. (2012). Cochlear Implant Stimulation Rates and Speech Perception. *Mod. speech Recognit. approaches with case Stud.*, 215–254.
- Baudhuin, J.L., Hughes, M.L., Goehring, J.L. (2016). A Comparison of Alternating Polarity and Forward Masking Artifact-Reduction Methods to Resolve the Electrically Evoked Compound Action Potential. *Ear Hear.*, 1–9.
- Beek, F.B. van der, Braire, J.J., Frijns, J.H.M. (2015). Population-Based Prediction of Fitting Levels for Individual Cochlear Implant Recipients. *Audiol. Neurotol.*, 20, 1–16.
- van der Beek, F.B., Braire, J.J., Frijns, J.H.M. (2012). Effects of parameter manipulations on spread of excitation measured with electrically-evoked compound action potentials. *Int. J. Audiol.*, 51, 465–74.
- Bes, C.J., Chutham, S., Serdijn, W.A. (2010). An Additive Instantaneously Companding Readout System for Cochlear Implants. *2010 Biomed. Circuits Syst. Conf.*, 126–29.
- Bierer, J. a., Litvak, L. (2016). Reducing Channel Interaction Through Cochlear Implant Programming May Improve Speech Perception: Current Focusing and Channel Deactivation. *Trends Hear.*, 20, 1–12.
- Bierer, J.A. (2007). Threshold and channel interaction in cochlear implant users: evaluation of the tripolar electrode configuration. *J. Acoust. Soc. Am.*, 121, 1642–1653.

- Bierer, J.A., Bierer, S.M., Kreft, H. a., et al. (2015). A Fast Method for Measuring Psychophysical Thresholds Across the Cochlear Implant Array. *Trends Hear.*, 19, 1–12.
- Biesheuvel, J.D., Briaire, J.J., Frijns, J.H.M. (2016). A Novel Algorithm to Derive Spread of Excitation Based on Deconvolution. *Ear Hear.*, 37, 572–81.
- Biesheuvel, J.D., Briaire, J.J., Frijns, J.H.M. (2017). The Precision of eCAP Thresholds Derived From Amplitude Growth Functions. *Ear Hear.*, 39, 701–711.
- Biesheuvel, J.D., Briaire, J.J., de Jong, M.A.M., et al. (2019a). Channel discrimination along all contacts of the cochlear implant electrode array and its relation to speech perception. *Int. J. Audiol.*, 58, 262–268.
- Biesheuvel, J.D., Briaire, J.J., Kalkman, R.K., et al. (2021). The effect of stimulus level on the spread of excitation in cochlear implants. *Hear. Res.*, Submitted.
- Biesheuvel, J.D., Goffi-Gomez, M.V.S., James, C.J., et al. (2019b). Applying the deconvolution method in Nucleus Cls to better characterize spread of excitation. *Congr. Eur. Fed. Audiol. Soc.*, Lisbon, Portugal.
- Bonham, B.H., Litvak, L.M. (2008). Current focusing and steering: Modeling, physiology, and psychophysics. *Hear. Res.*, 242, 141–53.
- Borenstein, M. (2009). Effect Sizes for Continuous Data. In H. . Cooper, L. V. Hedges, & J. C. Valentine, eds. *The Handbook of Research Synthesis and Meta-analysis*. (pp. 221–235). New York: Russell Sage Foundation.
- Bosman, A.J., Smoorenburg, G.F. (1995). Intelligibility of Dutch CVC syllables and sentences for listeners with normal hearing and with three types of hearing impairment. *Audiology*, 34, 260–84.
- Botros, A., van Dijk, B., Killian, M. (2007). AutoNR: an automated system that measures ECAP thresholds with the Nucleus Freedom cochlear implant via machine intelligence. *Artif. Intell. Med.*, 40, 15–28.
- Botros, A., Psarros, C. (2010). Neural response telemetry reconsidered: I. The relevance of ECAP threshold profiles and scaled profiles to cochlear implant fitting. *Ear Hear.*, 31, 367–79.
- Bourneque, J.L., Hughes, M.L., Baudhuin, J.L., et al. (2014). Effect of ECAP-based choice of stimulation rate on speech-perception performance. *Ear Hear.*, 34, 437–46.
- Briaire, J., Biesheuvel, D., Frijns, J. (2014). Deconvolution of the spread of excitation curves measured in cochlear implants. *Int. Conf. Object. Meas. Audit. Implant.*, Toronto, Canada.
- Briaire, J.J., Frijns, J.H. (2000a). Field patterns in a 3D tapered spiral model of the electrically stimulated cochlea. *Hear. Res.*, 148, 18–30.
- Briaire, J.J., Frijns, J.H.M. (2000b). 3D mesh generation to solve the electrical volume conduction problem in the implanted inner ear. *Simul. Pract. Theory*, 8, 57–73.

- Briaire, J.J., Frijns, J.H.M. (2005). Unraveling the electrically evoked compound action potential. *Hear. Res.*, 205, 143–56.
- Brown, C.J., Abbas, P.J., Borland, J., et al. (1996). Electrically evoked whole nerve action potentials in Ineraid cochlear implant users: responses to different stimulating electrode configurations and comparison to psychophysical responses. *J. Speech Hear. Res.*, 39, 453–67.
- Brown, C.J., Abbas, P.J., Gantz, B.J. (1998). Preliminary experience with neural response telemetry in the nucleus CI24M cochlear implant. *Am. J. Otol.*, 19, 320–7.
- Brown, C.J., Hughes, M.L., Luk, B., et al. (2000). The relationship between EAP and EABR thresholds and levels used to program the nucleus 24 speech processor: data from adults. *Ear Hear.*, 21, 151–63.
- Busby, P. a, Battmer, R.D., Pesch, J. (2008). Electrophysiological spread of excitation and pitch perception for dual and single electrodes using the Nucleus Freedom cochlear implant. *Ear Hear.*, 29, 853–864.
- Cafarelli Dees, D., Dillier, N., Lai, W.K., et al. (2005). Normative findings of electrically evoked compound action potential measurements using the neural response telemetry of the nucleus CI24M cochlear implant system. *Audiol. Neurotol.*, 10, 105–116.
- Caner, G., Olgun, L., Gütürkün, G., et al. (2007). Optimizing fitting in children using objective measures such as neural response imaging and electrically evoked stapedius reflex threshold. *Otol. Neurotol.*, 28, 637–40.
- Carlyon, R.P., Lynch, C., Deeks, J.M. (2010). Effect of stimulus level and place of stimulation on temporal pitch perception by cochlear implant users. *J. Acoust. Soc. Am.*, 127, 2997–3008.
- Charasse, B., Chanal, J.M., Berger-Vachon, C., et al. (2004). Influence of stimulus frequency on NRT recordings. *Int. J. Audiol.*, 43, 236–44.
- Cohen, L.T. (2009). Practical model description of peripheral neural excitation in cochlear implant recipients: 2. Spread of the effective stimulation field (ESF), from ECAP and FEA. *Hear. Res.*, 247, 100–111.
- Cohen, L.T., Richardson, L.M., Saunders, E., et al. (2003). Spatial spread of neural excitation in cochlear implant recipients: Comparison of improved ECAP method and psychophysical forward masking. *Hear. Res.*, 179, 72–87.
- Cohen, L.T., Saunders, E., Richardson, L.M. (2004). Spatial spread of neural excitation: comparison of compound action potential and forward-masking data in cochlear implant recipients. *Int. J. Audiol.*, 43, 346–55.
- Collins, L.M., Zwolan, T. a, Wakefield, G.H. (1997). Comparison of electrode discrimination, pitch ranking, and pitch scaling data in postlingually deafened adult cochlear implant subjects. *J. Acoust. Soc. Am.*, 101, 440–55.

- Cosentino, S., Gaudrain, E., Deeks, J., et al. (2015). Multistage nonlinear optimization to recover neural activation patterns from evoked compound action potentials of cochlear implant users. *IEEE Trans. Biomed. Eng.*, 7, 1–1.
- Cosentino, S., Vries, L. De, Schepeler, R., et al. (2016). Dual-stage algorithm to identify channels with poor electrode-to-neuron interface in cochlear implant users. In *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. (pp. 834–838). IEEE.
- Cosetti, M.K., Shapiro, W.H., Green, J.E., et al. (2010). Intraoperative neural response telemetry as a predictor of performance. *Otol. Neurotol.*, 31, 1095–9.
- Cullington, H. (2000). Preliminary neural response telemetry results. *Br. J. Audiol.*, 34, 131–40.
- D'Elia, A., Bartoli, R., Giagnotti, F., et al. (2012). The Role of Hearing Preservation on Electrical Thresholds and Speech Performances in Cochlear Implantation. *Otol. Neurotol.*, 33, 343–347.
- Debruyne, J.A., Francart, T., Janssen, A.M.L., et al. (2017). Fitting prelingually deafened adult cochlear implant users based on electrode discrimination performance. *Int. J. Audiol.*, 56, 174–185.
- DerSimonian, R., Laird, N. (1986). Meta-analysis in clinical trials. *Control. Clin. Trials*, 7, 177–88.
- Donaldson, G.S., Kreft, H. a, Litvak, L. (2005). Place-pitch discrimination of single- versus dual-electrode stimuli by cochlear implant users (L). *J. Acoust. Soc. Am.*, 118, 623–6.
- Dumville, J.C., Torgerson, D.J., Hewitt, C.E. (2006). Research methods - Reporting attrition in randomised controlled trials. *BMJ Br. Med. J.*, 332, 969.
- Firszt, J.B., Koch, D.B., Downing, M., et al. (2007). Current steering creates additional pitch percepts in adult cochlear implant recipients. *Otol. Neurotol.*, 28, 629–36.
- Franck, K.H. (2002). A model of a nucleus 24 cochlear implant fitting protocol based on the electrically evoked whole nerve action potential. *Ear Hear.*, 23, 67S-71S.
- Franck, K.H., Norton, S.J. (2001). Estimation of psychophysical levels using the electrically evoked compound action potential measured with the neural response telemetry capabilities of Cochlear Corporation's CI24M device. *Ear Hear.*, 22, 289–99.
- Friesen, L.M., Shannon, R. V., Baskent, D., et al. (2001). Speech recognition in noise as a function of the number of spectral channels: comparison of acoustic hearing and cochlear implants. *J. Acoust. Soc. Am.*, 110, 1150–63.
- Frijns, J.H., Briaire, J.J., Grote, J.J. (2001). The importance of human cochlear anatomy for the results of modiolus-hugging multichannel cochlear implants. *Otol. Neurotol.*, 22, 340–349.

- Frijns, J.H.M., Briaire, J.J., de Laat, J.A.P.M., et al. (2002). Initial evaluation of the Clarion CII cochlear implant: speech perception and neural response imaging. *Ear Hear.*, 23, 184–197.
- Frijns, J.H.M., Briaire, J.J., Schoonhoven, R. (2000). Integrated use of volume conduction and neural models to simulate the response to cochlear implants. *Simul. Pract. Theory*, 8, 75–97.
- Frijns, J.H.M., Kalkman, R.K., Vanpoucke, F.J., et al. (2009). Simultaneous and non-simultaneous dual electrode stimulation in cochlear implants: evidence for two neural response modalities. *Acta Otolaryngol.*, 129, 433–9.
- Frijns, J.H.M., Klop, W.M.C., Bonnet, R.M., et al. (2003). Optimizing the number of electrodes with high-rate stimulation of the clarion CII cochlear implant. *Acta Otolaryngol.*, 123, 138–42.
- Frijns, J.H.M., De Snoo, S.L., Schoonhoven, R. (1995). Potential distributions and neural excitation patterns in a rotationally symmetric model of the electrically stimulated cochlea. *Hear. Res.*, 87, 170–186.
- Garcia, C., Goehring, T., Cosentino, S., et al. (2021). The Panoramic ECAP Method: Estimating Patient-Specific Patterns of Current Spread and Neural Health in Cochlear Implant Users. *J. Assoc. Res. Otolaryngol.*, 22, 567–589.
- Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochem. Medica*, 25, 141–151.
- Glassman, E.K., Hughes, M.L. (2013). Determining electrically evoked compound action potential thresholds: a comparison of computer versus human analysis methods. *Ear Hear.*, 34, 96–109.
- Goehring, J.L., Neff, D.L., Baudhuin, J.L., et al. (2014). Pitch ranking, electrode discrimination, and physiological spread of excitation using current steering in cochlear implants. *J. Acoust. Soc. Am.*, 136, 3159.
- Gordon, K. a, Papsin, B.C., Harrison, R. V (2004a). Toward a battery of behavioral and objective measures to achieve optimal cochlear implant stimulation levels in children. *Ear Hear.*, 25, 447–63.
- Gordon, K., Papsin, B.C., Harrison, R. V (2004b). Programming cochlear implant stimulation levels in infants and children with a combination of objective measures. *Int. J. Audiol.*, 43 Suppl 1, S28-32.
- Guedes, M.C., Weber, R., Gomez, M.V.S.G., et al. (2007). Influence of evoked compound action potential on speech perception in cochlear implant users. *Braz. J. Otorhinolaryngol.*, 73, 439–45.
- Han, D.-M., Chen, X.-Q., Zhao, X.-T., et al. (2005). Comparisons between neural response imaging thresholds, electrically evoked auditory reflex thresholds and most

- comfortable loudness levels in CII bionic ear users with HiResolution sound processing strategies. *Acta Otolaryngol.*, 125, 732–5.
- He, S., Teagle, H.F.B., Buchman, C.A. (2017). The Electrically Evoked Compound Action Potential: From Laboratory to Clinic. *Front. Neurosci.*, 11, 339.
- Hedges, L., Olkin, I. (1985). Meta-analysis from a small sample. In *Statistical methods for meta-analysis*. (p. 32). Orlando: Academic Press.
- Holstad, B. a, Sonneveldt, V.G., Fears, B.T., et al. (2009). Relation of electrically evoked compound action potential thresholds to behavioral T- and C-levels in children with cochlear implants. *Ear Hear.*, 30, 115–27.
- Hughes, M.L. (2013). *Objective Measures in Cochlear Implants*, San Diego: Plural Publishing.
- Hughes, M.L., Abbas, P.J. (2006a). Electrophysiologic channel interaction, electrode pitch ranking, and behavioral threshold in straight versus perimodiolar cochlear implant electrode arrays. *J. Acoust. Soc. Am.*, 119, 1538–1547.
- Hughes, M.L., Abbas, P.J. (2006b). The relation between electrophysiologic channel interaction and electrode pitch ranking in cochlear implant recipients. *J Acoust Soc Am*, 119, 1527–1537.
- Hughes, M.L., Baudhuin, J.L., Goehring, J.L. (2014). The relation between auditory-nerve temporal responses and perceptual rate integration in cochlear implants. *Hear. Res.*, 316, 44–56.
- Hughes, M.L., Brown, C.J., Abbas, P.J., et al. (2000). Comparison of EAP thresholds with MAP levels in the nucleus 24 cochlear implant: data from children. *Ear Hear.*, 21, 164–74.
- Hughes, M.L., Goehring, J.L., Baudhuin, J.L. (2016). Effects of Stimulus Polarity and Artifact Reduction Method on the Electrically Evoked Compound Action Potential. *Ear Hear.*, 1.
- Hughes, M.L., Stille, L.J. (2010). Effect of stimulus and recording parameters on spatial spread of excitation and masking patterns obtained with the electrically evoked compound action potential in cochlear implants. *Ear Hear.*, 31, 679–692.
- Hughes, M.L., Stille, L.J., Baudhuin, J.L., et al. (2013). ECAP spread of excitation with virtual channels and physical electrodes. *Hear. Res.*, 306C, 93–103.
- Hughes, M.L., Vander Werff, K.R., Brown, C.J., et al. (2001). A longitudinal study of electrode impedance, the electrically evoked compound action potential, and behavioral measures in nucleus 24 cochlear implant users. *Ear Hear.*, 22, 471–486.
- Jeon, E.K., Brown, C.J., Etler, C.P., et al. (2010). Comparison of electrically evoked compound action potential thresholds and loudness estimates for the stimuli used to program the Advanced Bionics cochlear implant. *J. Am. Acad. Audiol.*, 21, 16–27.

- Jones, G.L., Won, J.H., Drennan, W.R., et al. (2013). Relationship between channel interaction and spectral-ripple discrimination in cochlear implant users. *J. Acoust. Soc. Am.*, 133, 425–33.
- Julious, S.A., Mullee, M.A. (1994). Confounding and Simpson's paradox. *BMJ*, 309, 1480–1.
- Kalkman, R.K., Briaire, J.J., Dekker, D.M.T., et al. (2014). Place pitch versus electrode location in a realistic computational model of the implanted human cochlea. *Hear. Res.*, 315, 10–24.
- Kalkman, R.K., Briaire, J.J., Dekker, D.M.T., et al. (2022). The relation between polarity sensitivity and neural degeneration in a computational model of cochlear implant stimulation. *Hear. Res.*, 415, 108413.
- Kalkman, R.K., Briaire, J.J., Frijns, J.H.M. (2015). Current focussing in cochlear implants: an analysis of neural recruitment in a computational model. *Hear. Res.*, 322, 89–98.
- Kalkman, R.K., Briaire, J.J., Frijns, J.H.M., et al. (2016). Stimulation strategies and electrode design in computational models of the electrically stimulated cochlea: An overview of existing literature. *Netw. Comput. Neural Syst.*, 6536, 0–28.
- Kaplan-Neeman, R., Henkin, Y., Yakir, Z., et al. (2004). NRT-based versus behavioral-based MAP: a comparison of parameters and speech perception in young children. *J. Basic Clin. Physiol. Pharmacol.*, 15, 57–69.
- Kenway, B., Tam, Y.C., Vanat, Z., et al. (2015). Pitch Discrimination: An Independent Factor in Cochlear Implant Performance Outcomes. *Otol. Neurotol.*, 36, 1472–9.
- King, J.E., Polak, M., Hodges, A. V., et al. (2006). Use of neural response telemetry measures to objectively set the comfort levels in the Nucleus 24 cochlear implant. *J. Am. Acad. Audiol.*, 17, 413–31;
- Kiss, J.G., Tóth, F., Nagy, A.L., et al. (2003). Neural response telemetry in cochlear implant users. *Int. Tinnitus J.*, 9, 59–60.
- Klop, W.M.C., Frijns, J.H.M., Soede, W., et al. (2009). An objective method to measure electrode independence in cochlear implant patients with a dual-masker forward masking technique. *Hear. Res.*, 253, 3–14.
- Klop, W.M.C., Hartlooper, A., Briaire, J.J., et al. (2004). A new method for dealing with the stimulus artefact in electrically evoked compound action potential measurements. *Acta Otolaryngol.*, 124, 137–43.
- Koch, D.B., Downing, M., Osberger, M.J., et al. (2007). Using current steering to increase spectral resolution in CII and HiRes 90K users. *Ear Hear.*, 28, 38S-41S.
- Lai, W.K., Dillier, N. (2007). Comparing neural response telemetry amplitude growth functions with loudness growth functions: preliminary results. *Ear Hear.*, 28, 42S-45S.
- Lai, W.K., Dillier, N., Weber, B.P., et al. (2009). TNRT profiles with the nucleus research platform 8 system. *Int. J. Audiol.*, 48, 645–54.

- Laneau, J., Wouters, J., Moonen, M. (2004). Relative contributions of temporal and place pitch cues to fundamental frequency discrimination in cochlear implantees. *J. Acoust. Soc. Am.*, 116, 3606–19.
- Lawand, N.S. (2015). *Micromachining technologies for future cochlear implants*. Delft University.
- Lawless, H.T. (2010). A simple alternative analysis for threshold data determined by ascending forced-choice methods of limits. *J. Sens. Stud.*, 25, 332–346.
- Long, C.J., Holden, T. a., McClelland, G.H., et al. (2014). Examining the electro-neural interface of cochlear implant users using psychophysics, CT scans, and speech understanding. *J. Assoc. Res. Otolaryngol.*, 15, 293–304.
- Lorens, A., Walkowiak, A., Piotrowska, A., et al. (2004). ESRT and MCL correlations in experienced paediatric cochlear implant users. *Cochlear Implants Int.*, 5, 28–37.
- McDermott, H.J., McKay, C.M. (2005). Pitch ranking with nonsimultaneous dual-electrode electrical stimulation of the cochlea. *J. Acoust. Soc. Am.*, 96, 155–162.
- McKay, C.M., Fewster, L., Dawson, P. (2005). A different approach to using neural response telemetry for automated cochlear implant processor programming. *Ear Hear.*, 26, 38S-44S.
- McKay, C.M., McDermott, H.J., Carlyon, R.P. (2000). Place and temporal cues in pitch perception: are they truly independent? *Acoust. Res. Lett. Online*, 1, 25–30.
- McKay, C.M., O'Brien, A., James, C.J. (1999). Effect of current level on electrode discrimination in electrical stimulation. *Hear. Res.*, 136, 159–64.
- McKay, C.M.C.M., Chandan, K., Akhoun, I., et al. (2013). Can ECAP Measures Be Used for Totally Objective Programming of Cochlear Implants? *J. Assoc. Res. Otolaryngol.*, 14, 879–90.
- Mens, L.H.M. (2007). Advances in cochlear implant telemetry: evoked neural responses, electrical field imaging, and technical integrity. *Trends Amplif.*, 11, 143–59.
- de Miguel, Á.R., Argudo, A.A., Borkoski Barreiro, S.A., et al. (2018). Imaging evaluation of electrode placement and effect on electrode discrimination on different cochlear implant electrode arrays. *Eur. Arch. Oto-Rhino-Laryngology*, 0, 0.
- Miller, C.A., Abbas, P.J., Brown, C.J. (2000). An Improved Method of Reducing Stimulus Artifact in the Electrically Evoked Whole-Nerve Potential. *Ear Hear.*, 21, 280–290.
- Miller, C.A., Brown, C.J., Abbas, P.J., et al. (2008). The clinical application of potentials evoked from the peripheral auditory system. *Hear. Res.*, 242, 184–197.
- Mittal, R., Panwar, S.S. (2009). Correlation between intra-operative high rate neural response telemetry measurements and behaviourally obtained threshold and comfort levels in patients using Nucleus 24 cochlear implants. *Cochlear Implants Int.*, 10, 103–11.

- Morita, T., Naito, Y., Hirai, T., et al. (2003). The relationship between the intraoperative ECAP threshold and postoperative behavioral levels: the difference between postlingually deafened adults and prelingually deafened pediatric cochlear implant users. *Eur. Arch. Otorhinolaryngol.*, 260, 67–72.
- Muhaimeed, H. Al, Anazy, F. Al, Hamed, O., et al. (2010). Correlation between NRT measurement level and behavioral levels in pediatrics cochlear implant patients. *Int. J. Pediatr. Otorhinolaryngol.*, 74, 356–60.
- Di Nardo, W., Ippolito, S., Quaranta, N., et al. (2003). Correlation between NRT measurement and behavioural levels in patients with the Nucleus 24 cochlear implant. *Acta Otorhinolaryngol. Ital.*, 23, 352–5.
- Nelson, D.A., Van Tasell, D.J., Schroder, A.C., et al. (1995). Electrode ranking of “place pitch” and speech recognition in electrical hearing. *J. Acoust. Soc. Am.*, 98, 1987–99.
- O'Brien, G., DiNino, M., Biesheuvel, J.D., et al. (2016). Comparing auditory perceptual thresholds in pediatric and adult cochlear implant populations. *J. Acoust. Soc. Am.*, 140, 3157–3157.
- Pedley, K., Psarros, C., Gardner-Berry, K., et al. (2007). Evaluation of NRT and behavioral measures for MAPping elderly cochlear implant users. *Int. J. Audiol.*, 46, 254–62.
- Petersen, B., Gjedde, A., Wallentin, M., et al. (2013). Cortical plasticity after cochlear implantation. *Neural Plast.*, 2013, 318521.
- Pfingst, B.E., Xu, L. (2004). Across-site variation in detection thresholds and maximum comfortable loudness levels for cochlear implants. *J. Assoc. Res. Otolaryngol.*, 5, 11–24.
- Pfingst, B.E., Xu, L., Thompson, C.S. (2004). Across-site threshold variation in cochlear implants: relation to speech recognition. *Audiol. Neurotol.*, 9, 341–52.
- Plant, K., Law, M.-A., Whitford, L., et al. (2005). Evaluation of streamlined programming procedures for the Nucleus cochlear implant with the Contour electrode array. *Ear Hear.*, 26, 651–68.
- Polak, M., Hodges, A. V., King, J.E., et al. (2006). Objective methods in postlingually and prelingually deafened adults for programming cochlear implants: ESR and NRT. *Cochlear Implants Int.*, 7, 125–41.
- Potts, L.G., Skinner, M.W., Gotter, B.D., et al. (2007). Relation between neural response telemetry thresholds, T- and C-levels, and loudness judgments in 12 adult nucleus 24 cochlear implant recipients. *Ear Hear.*, 28, 495–511.
- Raghunandhan, S., Ravikumar, A., Kameswaran, M., et al. (2014). A clinical study of electrophysiological correlates of behavioural comfort levels in cochlear implantees. *Cochlear Implants Int.*, 15, 145–60.

- Ramekers, D., Versnel, H., Strahl, S.B., et al. (2014). Auditory-nerve responses to varied interphase gap and phase duration of the electric pulse stimulus as predictors for neuronal degeneration. *J. Assoc. Res. Otolaryngol.*, 15, 187–202.
- Rosenfeld, R.M. (2010). How to review journal manuscripts. *Otolaryngol. Head. Neck Surg.*, 142, 472–86.
- Scheperle, R.A., Abbas, P.J. (2015). Relationships Among Peripheral and Central Electrophysiological Measures of Spatial and Spectral Selectivity and Speech Perception in Cochlear Implant Users. *Ear Hear.*, 36, 441–53.
- Schwarz, J.R., Reid, G., Bostock, H. (1995). Action potentials and membrane currents in the human node of Ranvier. *Pflugers Arch.*, 430, 283–92.
- Seyle, K., Brown, C.J. (2002). Speech perception using maps based on neural response telemetry measures. *Ear Hear.*, 23, 72S-79S.
- Shannon, R. V. (1983). Multichannel electrical stimulation of the auditory nerve in man. I. Basic psychophysics. *Hear. Res.*, 11, 157–89.
- Shannon, R. V., Fu, Q.-J., Galvin, J. (2004). The number of spectral channels required for speech recognition depends on the difficulty of the listening situation. *Acta Otolaryngol. Suppl.*, 124, 50–4.
- Smit, J.E., Hanekom, T., Hanekom, J.J. (2009). Estimation of stimulus attenuation in cochlear implants. *J. Neurosci. Methods*, 180, 363–373.
- Smoorenburg, G.F., Willeboer, C., van Dijk, J.E. (2002). Speech perception in nucleus CI24M cochlear implant users with processor settings based on electrically evoked compound action potential thresholds. *Audiol. Neurotol.*, 7, 335–47.
- Snel-Bongers, J., Briare, J.J., Vanpoucke, F.J., et al. (2012). Spread of excitation and channel interaction in single- and dual-electrode cochlear implant stimulation. *Ear Hear.*, 33, 367–76.
- Snel-Bongers, J., Briare, J.J., Veen, E.H. van der, et al. (2013). Threshold levels of dual electrode stimulation in cochlear implants. *J. Assoc. Res. Otolaryngol.*, 14, 781–90.
- Snel-Bongers, J., Netten, A.P., Boermans, P.-P.B.M., et al. (2018). Evidence-Based Inclusion Criteria for Cochlear Implantation in Patients With Postlingual Deafness. *Ear Hear.*, 39, 1008–1014.
- Spivak, L., Auerbach, C., Vambutas, A., et al. (2011). Electrical compound action potentials recorded with automated neural response telemetry: threshold changes as a function of time and electrode position. *Ear Hear.*, 32, 104–13.
- Stevens, S.S. (1935). The Relation of Pitch to Intensity. *J. Acoust. Soc. Am.*, 6, 150–154.
- Stronks, H.C., Biesheuvel, J.D., de Vos, J.J., et al. (2019). Test/Retest Variability of the eCAP Threshold in Advanced Bionics Cochlear Implant Users. *Ear Hear.*, 40, 1457–1466.

- Sun, Y.-S., Wu, C.-M., Liu, T.-C. (2004). Mandarin speech perception in nucleus CI 24 implantees using MAPs based on neural response telemetry. *ORL. J. Otorhinolaryngol. Relat. Spec.*, 66, 255–61.
- Tang, Q., Benítez, R., Zeng, F. (2011). Spatial channel interactions in cochlear implants. *J. Neural Eng.*, 8.
- Terhardt, E. (1979). Calculating virtual pitch. *Hear. Res.*, 1, 155–82.
- Thai-Van, H., Chanal, J.M., Coudert, C., et al. (2001). Relationship between NRT measurements and behavioral levels in children with the Nucleus 24 cochlear implant may change over time: preliminary report. *Int. J. Pediatr. Otorhinolaryngol.*, 58, 153–62.
- Thai-Van, H., Truy, E., Charasse, B., et al. (2004). Modeling the relationship between psychophysical perception and electrically evoked compound action potential threshold in young cochlear implant recipients: clinical implications for implant fitting. *Clin. Neurophysiol.*, 115, 2811–24.
- Townshend, B., Cotter, N., Van Compernolle, D., et al. (1987). Pitch perception by cochlear implant subjects. *J. Acoust. Soc. Am.*, 82, 106–15.
- Undurraga, J.A., Carlyon, R.P., Wouters, J., et al. (2012). Evaluating the Noise in Electrically Evoked Compound Action Potential Measurements in Cochlear Implants. *IEEE Trans. Biomed. Eng.*, 59, 1912–1923.
- Vaerenberg, B., Smits, C., DeCeulaer, G., et al. (2014). Cochlear Implant Programming: A Global Survey on the State of the Art. *Sci. World J.*, 2014.
- Vanpoucke, F.J., Zarowski, A.J., Peeters, S. a. (2004). Identification of the impedance model of an implanted cochlear prosthesis from intracochlear potential measurements. *IEEE Trans. Biomed. Eng.*, 51, 2174–2183.
- de Vos, J.J., Biesheuvel, J.D., Briare, J.J., et al. (2017). Use of Electrically Evoked Compound Action Potentials for Cochlear Implant Fitting: A Systematic Review. *Ear Hear.*, 39, 401–411.
- Walkowiak, A., Lorens, A., Polak, M., et al. (2011). Evoked stapedius reflex and compound action potential thresholds versus most comfortable loudness level: assessment of their relation for charge-based fitting strategies in implant users. *ORL. J. Otorhinolaryngol. Relat. Spec.*, 73, 189–95.
- Wesarg, T., Battmer, R.-D., Garrido, L.C., et al. (2010). Effect of changing pulse rate on profile parameters of perceptual thresholds and loudness comfort levels and relation to ECAP thresholds in recipients of the Nucleus CI24RE device. *Int. J. Audiol.*, 49, 775–87.
- Wichmann, F. a., Hill, N.J. (2001a). The psychometric function: I. Fitting, sampling, and goodness of fit. *Percept. Psychophys.*, 63, 1293–1313.
- Wichmann, F.A., Hill, N.J. (2001b). The psychometric function: II. Bootstrap-based confidence intervals and sampling. *Percept. Psychophys.*, 63, 1314–1329.

- Willeboer, C., Smoorenburg, G.F. (2006). Comparing cochlear implant users' speech performance with processor fittings based on conventionally determined T and C levels or on compound action potential thresholds and live-voice speech in a prospective balanced crossover study. *Ear Hear.*, 27, 789–98.
- Wolfe, J., Kasulis, H. (2008). Relationships among objective measures and speech perception in adult users of the HiResolution Bionic Ear. *Cochlear Implants Int.*, 9, 70–81.
- Wolfe, J., Schafer, E.C. (2014). *Programming Cochlear Implants* Second Edi., Plural Publishing.
- Zeng, F.-G. (2004). Trends in cochlear implants. *Trends Amplif.*, 8, 1–34.
- Zeng, F.G. (2002). Temporal pitch in electric hearing. *Hear. Res.*, 174, 101–6.
- Zhang, F., Benson, C., Murphy, D., et al. (2013). Neural adaptation and behavioral measures of temporal processing and speech perception in cochlear implant recipients. *PLoS One*, 8, e84631.

Appendices



A.1. Abbreviations

3AFC	three alternative forced choice
AB	Advanced Bionics
AGF	amplitude growth function
AP	alternating polarity
ART	auditory response telemetry
BEDCS	bionic ear data collection system
BM	basilar membrane
CI	cochlear implant
CU	clinical unit
CVC	consonant vowel consonant
eCAP	electrically evoked compound action potential
EDP	excitation density profile
FM	forward masking
ICD	inter channel distance
JND	just noticeable difference
LE	linear extrapolation
LV	last visible
M	masker
MAL	maximum acceptable loudness
MCL	most comfortable loudness
MP	masker-probe
mSOE	measured spread of excitation
NRA	neural response amplifier
NRI	neural response imaging
NRT	neural response telemetry
P	probe
PRISMA	preferred reporting items for systematic reviews and meta-analyses
pSOE	predicted spread of excitation
RMSE	root mean square error
RSPOM	research studies platform objective measures
sEDP	simulated excitation density profile
SFAP	single fiber action potential
SFM	spatial forward masking
SNR	signal to noise ratio
SOE	spread of excitation
TCI	threshold confidence interval

A.2. List of publications

1. The effect of stimulus level on the excitation patterns of individual stimuli in cochlear implants, J.D. Biesheuvel, J.J. Briaire, R.K. Kalkman, J.H.M. Frijns, Hearing Research, 2022, 420:108490
2. Full array channel discrimination in cochlear implants: validation and clinical application, C.A.A. Windmeijer, J.D. Biesheuvel, J.J. Briaire, P.P.B.M. Boermans, J.H.M. Frijns, International Journal of Audiology, 2022, Jul 23:1-10
3. Unravelling the temporal properties of human eCAPs through an iterative deconvolution model, Y. Dong, J.J. Briaire, J.D. Biesheuvel, H.C. Stronks, J.H.M. Frijns, Hearing Research, 2020, 395:108037
4. Effectiveness of phantom stimulation in shifting the pitch percept in cochlear implant users, M.A.M. de Jong, J.J. Briaire, J.D. Biesheuvel, J. Snel-Bongers, S. Böhringer, G.R.F.M. Timp, J.H.M. Frijns, Ear and Hearing, 2020, 41(5):1258-1269
5. Test/retest variability of the eCAP threshold in advanced bionics cochlear implant users, H.C. Stronks, J.D. Biesheuvel, J.J. de Vos, P.S. Boot, J.J. Briaire, J.H.M. Frijns, Ear and Hearing, 2019, 40(6):1457-1466
6. Channel discrimination along all contacts of the cochlear implant electrode array and its relation to speech perception, J.D. Biesheuvel, J.J. Briaire, M.A.M. de Jong, S. Boehringer, J.H.M. Frijns, International Journal of Audiology, 2019, 58(5):262-268
7. The precision of eCAP thresholds derived from amplitude growth functions, J.D. Biesheuvel, J.J. Briaire, J.H.M. Frijns, Ear and Hearing, 2018, 39(4):701-711
8. Use of electrically evoked compound action potentials for cochlear implant fitting: a systematic review, J.J. de Vos, J.D. Biesheuvel, J.J. Briaire, P.S. Boot, M.J. van Gendt, O.M. Dekkers, M. Fiocco, J.H. M. Frijns, Ear and Hearing, 2018, 39(3):401-411
9. A novel algorithm to derive spread of excitation based on deconvolution, J.D. Biesheuvel, J.J. Briaire, J.H.M. Frijns, Ear and Hearing, 2016, 37(5):572-581
10. Initial systolic time interval (ISTI) as a predictor of intradialytic hypotension (IDH), J.D. Biesheuvel, M.G. Vervloet, R.M. Verdaasdonk, J.H. Meijer, Journal of Physics: Conference Series, 2013, 434

A.3. Curriculum vitae

Personalia

Name: Jan Dirk Biesheuvel
Born: 13-05-1990, Lienden

Education

2017-2021	Klinisch fysicus - audioloog in opleiding	LUMC, Leiden
2013-2017	PhD student	LUMC, Leiden
2011-2013	Master Medical Natural Sciences	Vrije Universiteit, Amsterdam
2008-2011	Bachelor Medische Natuurwetenschappen	Vrije Universiteit, Amsterdam
2002-2008	Voorbereidend Wetenschappelijk Onderwijs	Van Lodenstein College, Amersfoort

Work experience

2021-now	Klinisch fysicus - audioloog	LUMC, Leiden
2017-2021	Klinisch fysicus - audioloog in opleiding	LUMC, Leiden
2013-2017	PhD student	LUMC, Leiden