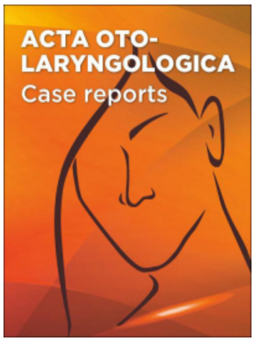

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Auditory brainstem implant pitch discrimination and auditory outcome

Karin Hallin and Helge Rask-Andersen

Department of Surgical Sciences, Otorhinolaryngology, Uppsala University, Uppsala, Sweden

ABSTRACT

We present a pitch discrimination test performed by five experienced adult auditory brainstem implant (ABI) users with neurofibromatosis type 2 (NF2). The ability to discriminate frequency/pitch from different channels on the implant may be an important factor in improving speech performance. The pitch discrimination ability was evaluated by using a triangle test compared to adjacent contacts and the speech perception was measured by the Swedish three-digit test. The test was easy to perform, and all patients were able to answer reliably, even though it cannot be ruled out that patients used attributes other than pitch to differentiate between sounds. Due to the limited number of patients and small variation in results, no conclusive correlations could be made regarding pitch discrimination and auditory outcome. There was a tendency for poorer ability to discriminate pitch (discrimination of tonotopically adjacent electrodes) at testing to result in poorer speech results.

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KEYWORDS
ABI; auditory brainstem implant; NF2; neurofibromatosis type 2; pitch discrimination

Introduction

William House and William Hitselberger were the first to implant an auditory brainstem implant (ABI) in a patient in 1979 [1]. The implants have since developed from single ball-type electrodes to multi-channel devices. Most patients implanted with an ABI are adults being deaf from neurofibromatosis type 2 (NF2). In recent years, the indications for surgery have been widened and nowadays also non-tumour patients and children may benefit from ABIs. Even though the functional outcome from ABIs usually does not match outcomes from cochlear implants (CIs), the ABI can give patients access to environmental sounds, improved lip-reading ability, and aid them in controlling their speech volume. Most implanted patients use their implant and depend on it, even though their hearing is limited. A small group of patients receive open set speech perception from the ABI [2–6]. The reason for the large inter-individual variances in hearing outcome is unclear. Some studies suggest that tumour size, deafness duration, pre-surgery gamma knife treatment, and number of active channels influence the outcome whilst others show no such correlations. The ability to receive pitch variances between ABI contacts is alleged to be crucial to discriminate and catch speech sounds but it has not been thoroughly investigated [7–9]. Behr et al. [10] found a weak correlation between improved speech recognition when a larger number of distinct channels was found. They noted that NF2 ABI patients who scored more than 60% correct on a standard sentence test material had significantly more distinct pitches on their ABIs than those who scored less than 60% correct. They also found that a minimum of four distinct pitch channels were needed to score at least 30% correct on the sentence test.

The present study focuses on ABI-patients' ability to perceive pitch differences between tonotopically adjacent contacts on the ABI array, and correlations were made with hearing outcome. The patients were implanted at the University Hospital of Uppsala, Sweden between 2003 and 2018. This study was approved by the Uppsala Ethical Review Board (7/11-2013, Dnr: 2012/388).

Materials and methods

All patients included in this study were adult patients with NF2 and implanted with an ABI in Uppsala. The implants used were from Cochlear (Lane Cove, Australia). In the pitch discrimination test, the patients listened to two tonotopically adjacent contacts on the implant at C-level. One of the channels

CONTACT Karin Hallin karin.t.hallin@akademiska.se Department of Surgical Sciences, Otorhinolaryngology, Uppsala University, Uppsala, Sweden

was played twice and the other once, i.e. a triangle test [11]. The patient was to tell which of the three sounds that differed from the other two. They were informed that they should focus on pitch and not loudness, and that the loudness could vary. Patient instructions can be read in detail in Appendix 1. Every active contact-pair-sequence was presented once until all adjacent active channels on the implant had been compared. Testing was repeated three times so that every contact-pair was played three times. The order in which the adjacent contacts were presented, and the order within every contact-pair-sequence, were randomly altered between rounds. The randomised presentation order was achieved using R©. An example of a complete test with 13 active channels is shown in Appendix 2. Correct answers on two out of three rounds for a contact-pair were considered a positive response. The contacts on the implant were placed in the subjective correct tonotopical order by the patients using a method earlier described by Siegbahn et al. [8] before the test, as a part of the regularly fitting sessions. Speech perception was tested by the closed set three-digit-test in sound field at a sound level chosen by the patient using hearing from the implanted ear only. The three-digits-test consists of 20 series of three digits between 1 and 17 and the patient must answer correctly on all three digits in each series to get a positive response.

Twenty-seven adult patients have been implanted in Uppsala, 20 were not able to participate in the testing due to: death $n = 9$, non-user $n = 9$, recently activated implant less than one year $n = 1$, severity of NF2 decease and incapability to travel to the hospital $n = 1$. Seven adults were asked to participate, and five patients were willing to contribute to the study. All patients in this study were earlier described by Siegbahn et al. [8] and Lundin et al. [3].

Results

Number of active channels, percentage of channel-pairs able to discriminate, frequency range for channels not able to discriminate, channels not able to discriminate, device (implant and processer type), years of active use, results from three-digit test and comments are displayed in Table 1. Channels not able to discriminate show what channels cannot be distinguished from each other, for example 7–8 in that column means that the patient cannot distinguish channel 7 from channel 8. Percentage of channel-pairs able to discriminate in relation to results from three-digit test is shown in Figure 1.

Discussion

Our study aims to provide the ABI patient with improved stimulation maps to perceive different pitches. If the map contains several tonotopically adjacent contacts that the patient cannot discriminate, they may be deactivated as described by Kuchta et al. [12]. This needs further assessments in order to clarify if, and how, such modifications can enhance patient's speech perception. According to Kuchta et al. [12], a minimum of three channels programmed in appropriate tonotopic order seems to be required for satisfactory speech recognition. No further improvement was noticed in those patients with five or more active channels. The patients were tested shortly after the first fitting, which may influence the results due to the years of time it takes to learn to hear with an ABI. Vickers et al. [13], on the other hand, found in their study of 13 CI users that deactivation of channels that did not provide distinct pitch information gave no significant benefit. However, the complex tonotopic organisation of the cochlear nucleus compared to the cochlea could make these devices incomparable [14]. McKay et al. [15] found in their study of five adult ABI users that none of the subjects benefitted from a map with a reduced electrode number even if it was well-ordered in place pitch. They concluded that although poor spectral processing may contribute to poor speech understanding, it is not likely to be the sole contributor.

It is the channel order chosen by the patient that is considered the correct tonotopical order and this may be a challenge. Channels that are tonotopically placed next to each other (by the patient) are compared. It means that the more accurately the patient's channels are ordered, the more difficult is the task to discriminate between different channel pairs. The other way around, the more inaccurate the channel order is, the easier is the task. We chose to use the channel order used in the patient's most recent and used map. The instruction to the patient was that the volume of sounds would vary, and the patient should listen solely for the sound frequency. However, it is possible that the patient used other cues than frequency to discriminate the three sounds. This may represent a weakness of the triangle test; namely that the test only shows that the samples (sounds in this study) sounded different but does not significantly define in what way they differed [11]. Tested patients were more successful at the pitch discrimination task than we expected, and one cannot rule out that they used other clues than frequency to discriminate the sounds. As the test was a forced choice test, patients had to

Table 1. Number of active channels, channel-pairs able to discriminate, frequency range for channels not able to discriminate, channels not able to discriminate, device, years of active use, results from three-digit test and comments.

Patient no.	No. of channels	Channel-pairs able to discriminate (%)	Frequency range for channels not able to discriminate	Channels not able to discriminate	Device: implant/processor	Years of active use	Three-digit-test (%)	Comment
1	19	94%	2463–3347 Hz	7–8	Nucleus 24 ABI/Cp910	18	75%	Uses ABI 14 h/day. Can manage conversations in daily life using lip-reading.
2	14	69%	313–813 Hz 2813–5188 Hz	8–11 16–21 21–22 22–16	Nucleus 24 ABI/Cp910	9	10%	Uses ABI 15 h/day. Feels unsecure without ABI. Never leaves the house without the ABI. Swedish is not the patient's native language.
3	11	90%	2063–3688 Hz	7–8	Nucleus 24 ABI/Cp910	16	60%	Uses ABI 16 h/day. Can with difficulty manage conversations in daily life using lip-reading. Uses writing interpreter at meetings at work.
4	13	92%	813–1313 Hz	2–6	Nucleus ABI541/Cp1000	3	55%	Uses ABI 13 h/day. The implant provides safety, and it is easier to communicate with the implant on.
5	15	79 %	188–813 Hz 4563–6563 Hz	3–6 4–7 12–13	Nucleus 24 ABI/Cp910	4	0%	Uses ABI 1.6 h/day. Gets very tired from using the device even though it helps controlling her own voice. Uses writing interpreter on many occasions when needed, cannot follow conversations with implant only.

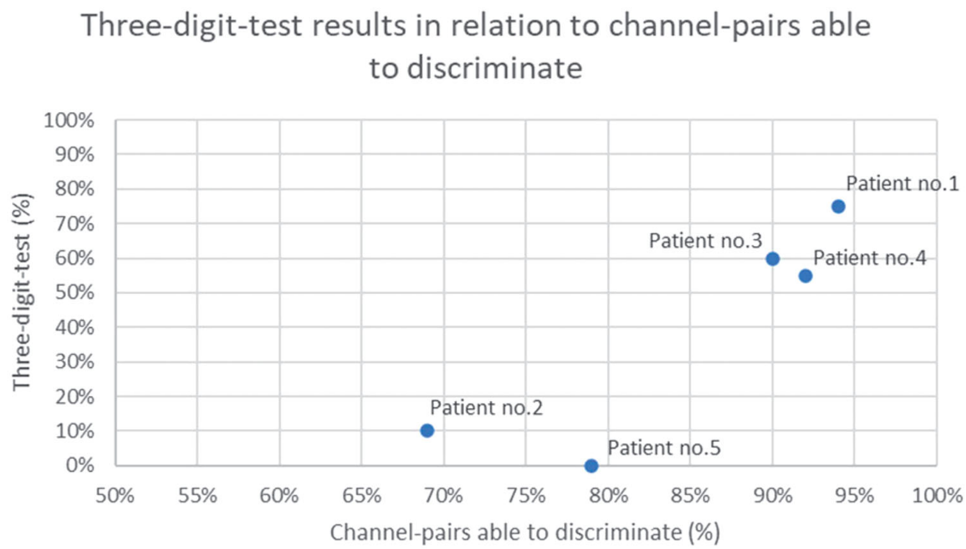

Figure 1. The three-digit-test results (%), on the *y*-axis, in relation to channel-pairs able to discriminate (%), on the *x*-axis. Patient no. is displayed for each data point for identification of the patient in Table 1.

choose one of the sounds even if they thought all sound were the same, also chance could have influenced the outcome.

One may assume that it is more important to discriminate between different pitches essential in human speech (2–5 kHz) to achieve good speech perception. In this study, the frequencies that were difficult to discriminate varied among patients but this should be further evaluated in a larger group of patients.

There was a tendency for poorer pitch discrimination (discrimination of tonotopically adjacent electrodes) to result in worse speech perception. However, this was difficult to conclude since the variation of the results was low. The patient with the poorest results on the pitch discrimination task (patient 2: 69% correct on pitch task and 10% correct on three-digit test) did not have Swedish as their native language, which may have influenced the result on the speech test. The patient who scored 0% on the three-digit-test (patient 5: 79% correct on pitch task and 0% correct on three-digit test) did not use the implant fulltime. The three other tested patients had similar high results on pitch discrimination (90–94%) and similar results on the three-digit test (55–75%).

Conclusions

Results from the present study present a simple method for testing pitch discrimination that is easy to perform and not too difficult or tiresome for the patient. Further analyses on a larger group of patients is, however, needed.

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The code written in R© to achieve the randomised test-order for the pitch discrimination task was created by engineer Jonas Ekeroot.

Informed consent

Informed written consent was given by the patients.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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ORCID

Karin Hallin http://orcid.org/0000-0001-5239-5858

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Appendix 1

Patient instructions

Three sounds will be played. Two of them will have the same frequency, and one will be brighter or duller than the other two that sound the same. You are to tell me which one of the three sounds differs from the other two. It can be the first, the second, or the third sound that differs. The volume of the sounds will vary. You are to listen for the frequency. If you cannot hear any difference among the three sounds, you have to make a guess. The test consists of X^* comparisons of three sounds as described above.

$^*X$ = number of active channels − 1

Appendix 2

This is an example of a test with 13 active channels. The channel order in this example (from the map) is: 17, 14, 11, 9, 12, 13, 8, 7, 6, 2, 10, 4, and 5. Each channel pair is played once in each round. The random test order in each round, between channel pairs and between rounds, is achieved using R©.

	Round 1			Round 2			Round 3		
	Sound 1	Sound 2	Sound 3	Sound 1	Sound 2	Sound 3	Sound 1	Sound 2	Sound 3
Channel	14	11	11	12	13	12	14	14	17
Channel	8	7	8	10	10	2	11	11	9
Channel	4	5	5	6	2	2	10	4	10
Channel	10	10	2	14	17	17	13	12	13
Channel	9	12	12	9	11	11	2	6	6
Channel	14	17	14	10	4	10	4	4	5
Channel	6	7	6	13	8	13	11	11	14
Channel	11	9	9	12	12	9	13	8	8
Channel	4	10	10	7	7	8	12	9	9
Channel	2	6	6	11	11	14	7	6	6
Channel	13	13	12	5	4	5	8	8	7
Channel	8	13	13	7	6	7	10	2	2