Cochlear Implants International
An Interdisciplinary Journal

ISSN: 1467-0100 (Print) 1754-7628 (Online) Journal homepage: https://www.tandfonline.com/loi/ycii20

From manual to artificial intelligence fitting: Two cochlear implant case studies

Justine Wathour, Paul J. Govaerts & Naïma Deggouj

To cite this article: Justine Wathour, Paul J. Govaerts & Naïma Deggouj (2019): From manual to artificial intelligence fitting: Two cochlear implant case studies, Cochlear Implants International, DOI: 10.1080/14670100.2019.1667574

To link to this article: https://doi.org/10.1080/14670100.2019.1667574

Published online: 17 Sep 2019.

Case report

From manual to artificial intelligence fitting: Two cochlear implant case studies

Justine Wathour [1], Paul J. Govaerts [2], Naïma Deggouj[1]

[1]Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, Brussels, 1200, Belgium, [2]Eargroup, Antwerpen-Deurne, Belgium

Objective: To assess whether CI programming by means of a software application using artificial intelligence (AI), FOX®, may improve cochlear implant (CI) performance.
Patients: Two adult CI recipients who had mixed auditory results with their manual fitting were selected for an AI-assisted fitting. Even after 17 months CI experience and 19 manual fitting sessions, the first subject hadn't developed open set word recognition. The second subject, after 9 months of manual fitting, had developed good open set word recognition, but his scores remained poor at soft and loud presentation levels.
Main outcome measure(s): Cochlear implant fitting parameters, pure tone thresholds, bisyllabic word recognition, phonemic discrimination scores and loudness scaling curves.
Results: For subject 1, a first approach trying to optimize the home maps by means of AI-proposed adaptations was not successful whereas a second approach based on the use of Automaps (an AI approach based on universal, i.e. population based group statistics) during 3 months allowed the development of open set word recognition. For subject 2, the word recognition scores improved at soft and loud intensities with the AI suggestions. The AI-suggested modifications seem to be atypical.
Conclusions: The two case studies illustrate that adults implanted with manual CI fitting may experience an improvement in their auditory results with AI-assisted fitting.

Keywords: Cochlear implant, Artificial intelligence, T & C levels, Auditory outcomes

Introduction

A cochlear implant (CI) is a device that restores audition in patients with severe to profound bilateral sensorineural deafness (Cullington *et al.*, 2016; Orzan *et al.*, 2016).

The fitting of CI processors is a real challenge and aims to achieve good access to speech sound information as well as good speech understanding without the use of visual cues. To date, no widely established 'Good Practice' exists, and this leads to substantial variability, both in the fitting methods and the electrical maps that are given to CI recipients (Battmer *et al.*, 2014; Vaerenberg *et al.*, 2014). There is no 'standard operating procedure' for device fitting, the process of CI mapping is variable.

One option to improve and systematize CI fitting could be the introduction of decision support software applications, such as 'Fitting to Outcome eXpert® (FOX®)' (Bermejo *et al.*, 2013; Govaerts *et al.*, 2010; Vaerenberg *et al.*, 2011). Initially, FOX® used deterministic logic, i.e. rule sets to determine how to modify a map based on measured outcomes. A second generation of FOX® (FOX® 2G) has been developed using artificial intelligence (AI) that uses probabilistic logic and self-learning capacities (Meeuws *et al.*, 2017). AI is a relatively new science with many theoretical applications such as rational decision-making to optimize the results in complex systems, for example, navigation systems (Li *et al.*, 2017).

FOX® is a decision support application. It provides recommendations and it remains up to the expert to either accept them or not.

The outcomes used by FOX® for map optimization, in free field with the CI in use, are aided thresholds at 250, 500, 1000, 2000, 4000 and 6000 Hz (warble tones), speech audiometry in quiet (mono or bisyllabic recorded words) at 40, 55, 70 and 85 dB SPL, spectral discrimination scores using an odd ball test in which 20 spectral contrasts are presented and the listener is expected to discriminate them (Govaerts *et al.*, 2006), and loudness growth curves with narrow band noises centred at 250, 1000 and

Correspondence to: Justine Wathour, Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, Brussels 1200, Belgium. Email: justine.wathour@uclouvain.be

DOI 10.1080/14670100.2019.1667574

4000 Hz and a six point visual analogue scale for loudness scoring (A§E® test battery; Meeuws *et al.*, 2017).

The manual fitting of CIs in adults is traditionally based on seeking the thresholds (T) and comfortable/most comfortable (C/M) electrical levels for each or some electrodes (Maria and Maria, 2016; Rader *et al.*, 2018).

A balancing procedure may also be performed to control the perceived loudness on all the tested electrodes. The classical method described above of fitting CI is believed to provide the best comfort while avoiding over-stimulation (Wolfe and Schafer, 2015). But the procedure is time consuming and complex. Indeed, except for T & C levels, only very few CI parameters are modified. It is clear that the full fitting capacities are underused (Vaerenberg *et al.*, 2014).

This approach differs from AI-assisted fitting by means of FOX®. Here, during the first activation or the 'switch-on', a list of 10 computer-generated maps (Automaps) is proposed with incremental T and C/M levels. The CI recipient starts with the lowest Automap and is instructed to change progressively to the next Automap, hence to higher T & C levels, allowing a progressive experience and tolerance. The highest Automap that is reached without causing lasting discomfort serves as the starting point for the next fine-tuning based on the measured outcomes.

In experienced CI patients who have received typical manual fitting so far, FOX®-assisted fitting can be accomplished with 2 approaches.

In the first approach, the home map is reset to an Automap that then serves as a starting point for fine-tuning. Automaps are typically used for the switch-on procedure. It is a series of ten maps with increasing T and C levels based on a statistical analysis of population based data (Govaerts *et al.*, 2010).

For this, FOX® offers a short version of the 10 Automaps, starting with the map corresponding best to the home map of the CI recipient, plus all higher Automaps. The CI recipient is switched to the lower map of this series and is instructed to try out one or two maps higher, and pick the most comfortable of these Automaps for audiological testing and optimization. Hereafter, this way is called 'reset to Automaps'.

In the second approach, the CI recipient keeps his/her home map, which then serves as the starting point for audiological testing and optimization. Hereafter, this will be referred to as 'proceed with home map'.

The audiologist is free to choose either of both these two fitting options.

This paper describes our experience with AI-assisted fitting in the optimization of hearing outcomes in 2 manually fitted CI recipients: one with poor functional results despite many manual fitting sessions and one satisfied subject to evaluate whether AI can further improve its auditory results, mainly for speech audiometry.

Case study 1

A 75-year-old woman was implanted in the left ear for progressive bilateral profound hearing loss of unknown origin. The subject had not worn hearing aids though she did try them for a short period. Her principal communication mode was based on lipreading and writing. Preoperative assessment showed excellent articulation (Speech Intelligibility Rating scale = 5) (Yücel *et al.*, 2015) and no signs of depression according to the HAD scale ('Hospital Anxiety and Depression' scale) (Ingvar *et al.*, 2002). The subject was implanted with a Nucleus CI512 cochlear implant (Cochlear Ltd, Australia) with full insertion of the electrode array, and she received a CP910 speech processor.

During the first 17 months after implantation, the patient underwent 19 manual fitting sessions with 2 experienced audiologists, in which many adjustments were done on electrical T & C levels, pulse width, stimulation rate (audiologist started at 900 pps and after 6 months decreased at 250 pps because this patient didn't have any auditory perception maybe due to her long duration of deafness), T-SPL, C-SPL, and electrode deactivation. Hearing training was provided by a speech therapist on a regular basis. At the end of this period, the audiometric hearing thresholds were approximately 45 dB HL (Fig. 1A); nevertheless, the subject did not develop any recognition of bisyllabic words presented at 65–85 dB SPL (Fig. 1B).

The 'Manual map' parameters are summarized in Table 1. Figure 2 displays the electrical T & C levels of the 17 electrodes (the 5 most basal electrodes had been disabled because of intolerance).

It was decided to evaluate whether either of both AI assisted fitting approaches could improve these disappointing results.

Our first approach was to use the 'proceed with home map' procedure. For this, we performed the phoneme discrimination (Fig. 1C) and loudness scaling tests (Fig. 1D) with the 'Manual map' that was the home map. FOX® analyzed this home map as well as the outcome and proposed a 'New map'. Some parameters were changed: electrical T & C levels; T-SPL (25–23 dB); and Q-value (20–18 dB) (Table 1 and Fig. 2B). After 2 months take home experience, the audiological performance was measured with this 'New map', and it did not improve (Fig. 3A–D).

Therefore, it was decided to try the 'reset to Automaps' approach. FOX® proposed an incremental series starting at Automap level 3. The CI recipient tolerated Automap level 3, and increased it to Automap level 4. The 'reset to Automaps' procedure led to many parameter modifications: electrical T & C

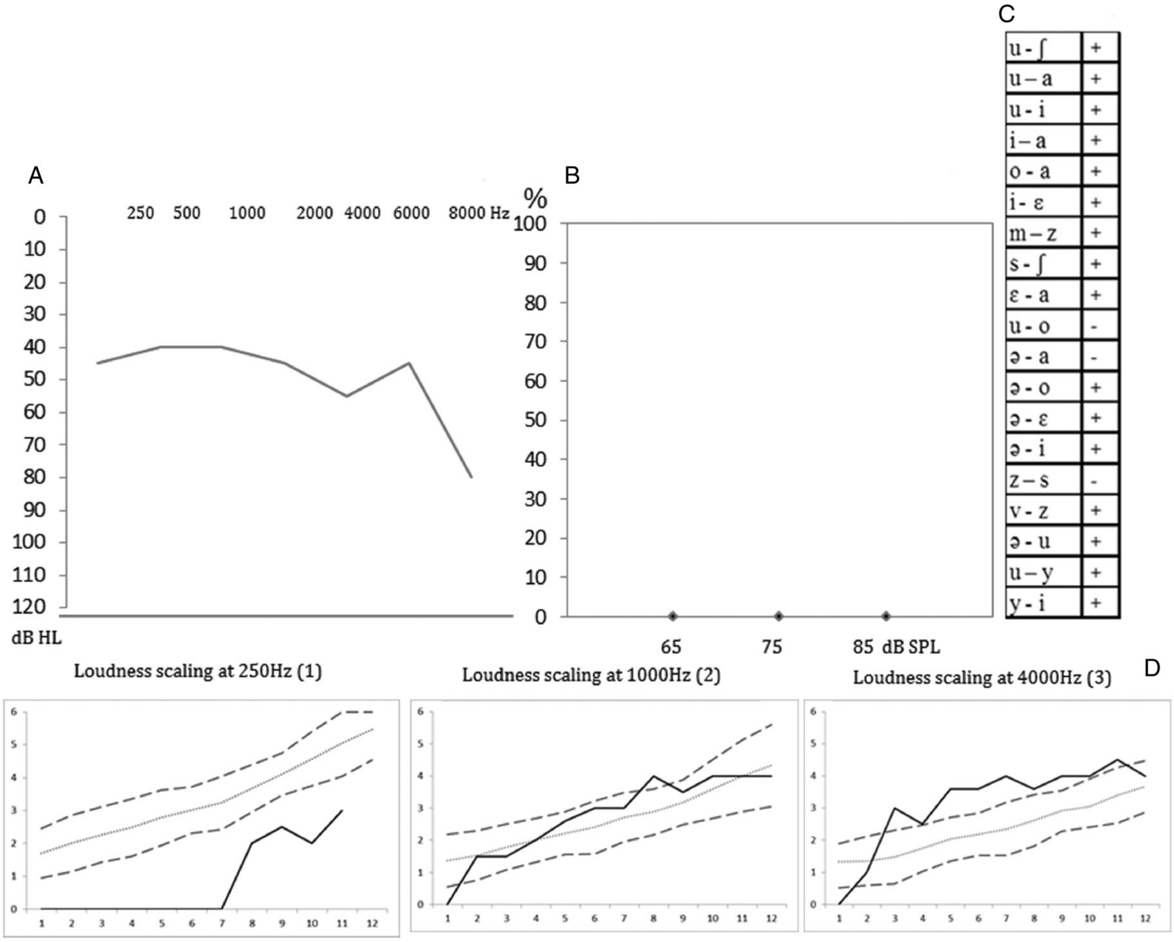


Figure 1 **Case 1, auditory results of 'Manual map': (A) Pure tone audiogram (dB HL), (B) speech audiogram % of correct repetition of bisyllabic words presented in quiet at 65, 75 and 85 dB SPL (C) phoneme discrimination (wrong (–) – correct (+)) & (D) loudness scaling curves at 250 Hz (1) – 1000 Hz (2) – 4000 Hz (3), Mean (.........), ±2 standard deviation (- - -) for normal hearing population and patient result (——).**

levels; stimulation rate (250–900 pps); number of maxima (8–11); T-SPL (25–20 dB); and C-SPL (65–70 dB) (Table 1 and Fig. 2C). The subject instantaneously reported better hearing of the high frequencies, and this result was confirmed with tone audiometry (Fig. 4A). Furthermore, speech audiometry scores progressively improved (Fig. 4B).

Table 1 Map parameters – 'Manual map'; 'New map'; 'Automap level 4'

Map parameters	'Manual map'	'New map'	'Automap level 4'
Strategy	ACE	ACE	ACE
Stimulation mode	MP1 + 2	MP1 + 2	MP1 + 2
Sensitivity	12	12	14
Volume	6	6	10
Electrodes	17	17	17
Pulse width	25	25	25
Stimulation rate	250	250	900
Maxima	8	8	11
T-SPL	25	23	20
C-SPL	65	65	70
Loudness growth (Q-value)	20	18	20

Clinical implications and discussion

This case was a CI recipient with disappointing results after 17 months of manual fitting. She had never developed word recognition, despite good cognitive abilities.

After the 'proceed with home map' procedure, in which FOX® starts from the home map and modifies it, FOX® increased the electrical levels in the 'New map', decreased T-SPL from 25 to 23 dB, decreased Q-value from 20 to 18 dB and increased C levels for the apical electrodes around electrode 10 without truly changing the electrical dynamic range (the interval between T & C levels). The 'New map' did not result in better outcomes. In contrast, the 'reset to Automaps' procedure, in which FOX® starts from scratch with its own Automaps, did improve the results. This procedure yielded 'Automap level 4' as a recommendation; this map gives more electrical charge than 'New map'. This approach resulted in better speech audiometry scores.

One of the differences between the two procedures is that, for safety reasons, the 'proceed with home map' procedure does not allow overly large map changes in

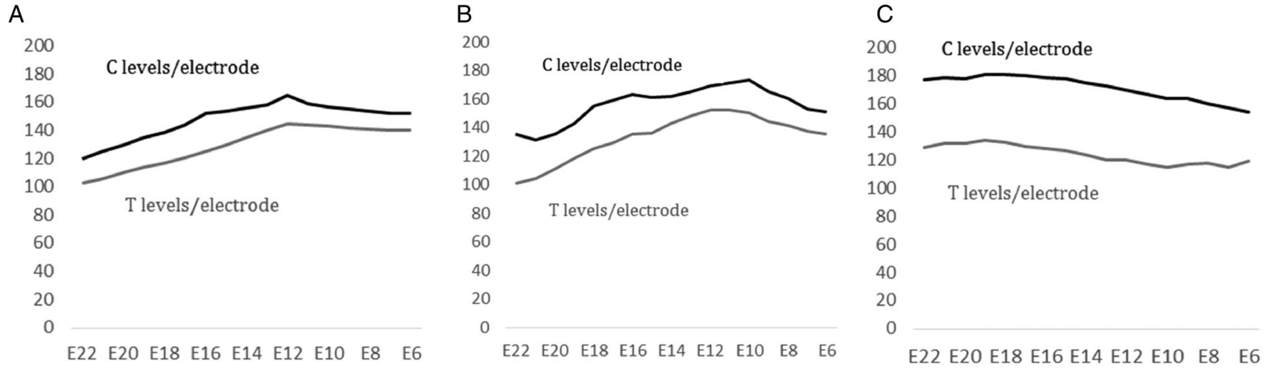
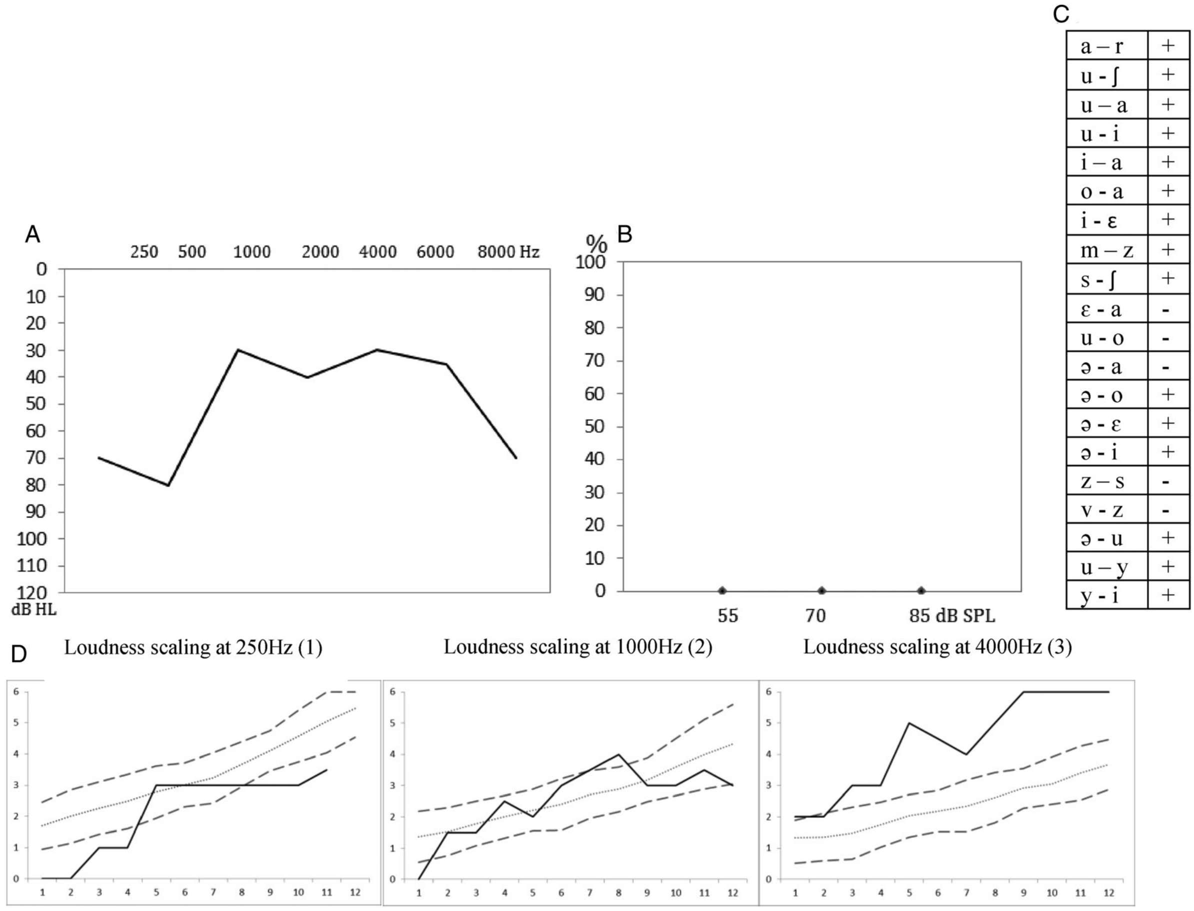


Figure 2 Maps of Case 1, showing (A) the home map; (B) the optimized home map after the 'proceed with home map' approach and (C) the optimized Automap after the 'reset to Automaps' approach. The map graph shows the T and C levels for the electrode array.

one iteration, meaning that the optimal map may not lay within the search space of FOX®. In the 'reset to Automap' procedure, such constraints do not apply. It must also be specified that this AI-assisted fitting has an impact on what is expected from the patient. This procedure modifies the cognitive approach of the electrical stimulation. In the manual approach, the cognitive resources are oriented to comfort and acceptability, where the more comfortable levels are sought (Vaerenberg *et al.,* 2014). In the AI-assisted approach, the cognitive resources are focused on the 'best' functional results produced by some electrical parameters proposed by the software. The cognition is more oriented toward the functional result than toward the electrical stimulation to reach it. In this particular case, higher current levels had been vigorously rejected by the CI recipient during the manual approach. With the Automap, the patient initially



a – r	+
u - ʃ	+
u – a	+
u - i	+
i – a	+
o - a	+
i - ɛ	+
m – z	+
s - ʃ	+
ɛ - a	-
u - o	-
ə - a	-
ə - o	+
ə - ɛ	+
ə - i	+
z – s	-
v - z	-
ə - u	+
u – y	+
y - i	+

Figure 3 Case 1, auditory results of 'New map': (A) Pure tone audiogram (dB HL) (B) speech audiogram % of correct repetition of bisyllabic words presented in quiet at 55, 70 and 85 dB SPL (C) phoneme discrimination (wrong (–) – correct (+)) & (D) loudness scaling curves at 250 Hz (1) – 1000 Hz (2) – 4000 Hz (3), Mean (………), ±2 standard deviation (- - -) for normal hearing population and patient result (——).

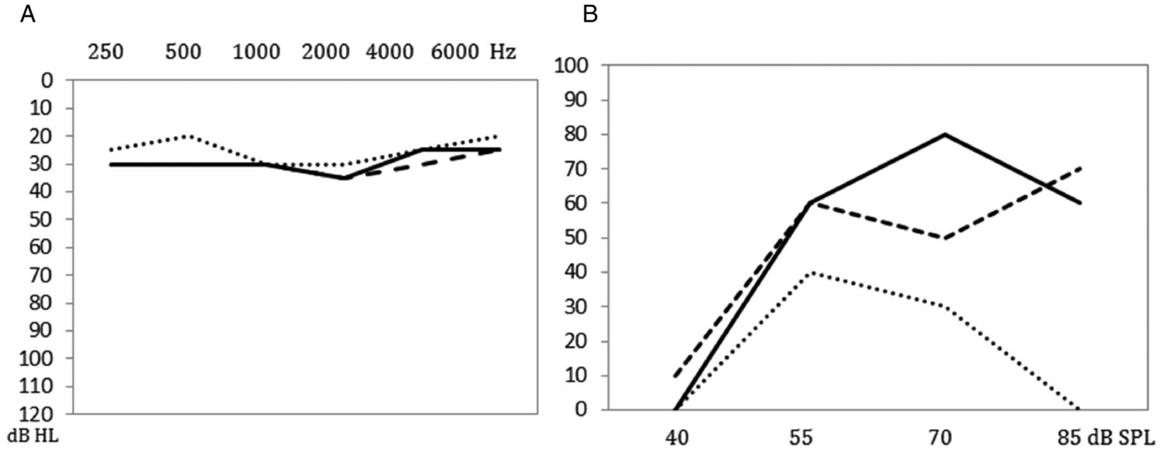


Figure 4 Case 1, auditory results of 'Automap level 4': (A) Pure tone audiogram (dB HL) and (B) speech audiogram % of correct repetition of bisyllabic words presented in quiet at 40, 55, 70 and 85 dB SPL at 3 different test intervals +3 (·········), +6 (- - -), +10 (——) months post 'CI switching on'.

also reacted negatively; however, after explanations and encouragement, she managed to tolerate the new and louder map that provided better functional results.

This case shows that the supposed superiority of comfort driven fitting parameters to a recipient is debatable.

Case study 2

A 72-year-old man with bilateral profound hearing loss associated with a COCH gene mutation (Pawlak-Osiñska *et al.*, 2018) was implanted in the right ear. His communication was mainly based on writing and poor lipreading. The patient had not been wearing hearing aids for a year because they no longer provided functional benefit. The preoperative assessment showed good articulation (Speech Intelligibility Rating scale = 5) and no signs of depression (HAD scale). The subject was implanted with an AB HR90 K/Hifocus ms (Advanced Bionics, California) with full insertion of the electrode array, and he received a Naïda Q90 speech processor.

The first 'Manual map' fitting took place one month post-CI surgery using 16 electrodes, the Hires optima strategy, an 18 µs pulse width, a channel rate of 3712 pps, 120 spectral bands, an IDR of 60 dB, a clear voice fixed at a medium voice and a sensitivity of 0 dB. Figure 5 displays the T & M levels of the 16 electrodes.

After 9 months, the audiologic evaluation showed good pure tone thresholds (Fig. 6A), good speech audiometric scores at 55 and 70 dB SPL, with lower scores at soft (40 dB SPL) and loud (85 dB SPL) presentation levels (Fig. 6B) and low loudness scarving curve at 250 Hz (Fig. 6C). The 'proceed with home map' procedure was attempted to see whether this would have any impact. FOX® proposed a 'New map' where only T & M levels were modified (Fig. 5B). T levels increased from 4 to 25 CU in apical electrodes 2–6, which coded for 455–906 Hz; these levels decreased from 6 to 16 CU in electrodes 7–14, which coded for 1076–3590 Hz. All M levels increased from 4 to 28 CU, except for those of basal electrode 15. With this 'New map', the patient showed an improvement in understanding both soft and loud speech (Fig. 6B) and a higher scaling curve at 250 Hz (Fig. 6D).

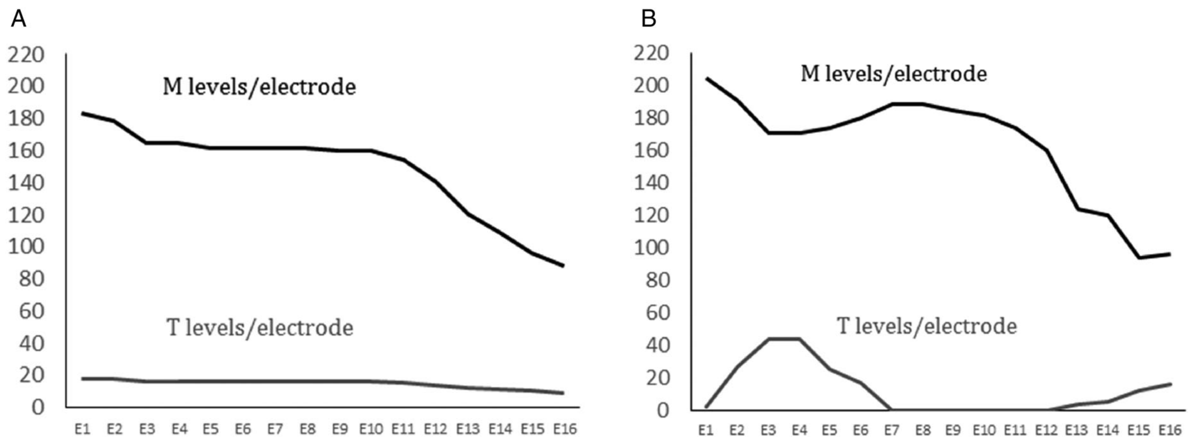


Figure 5 Maps of Case 2, showing (A) the home map and (B) the optimized home map after the 'proceed with home map' approach. The map graph shows the T and M levels for the electrode array.

Clinical implications and discussion

This case was a good performer with his 'manual home map'. Speech understanding at soft and loud intensities was inferior to the scores at 55 and 70 dB SPL; however, this result was never considered problematic. FOX® analyzed the map and measured outcome and proposed a map with modified T and M levels. This approach improved the understanding of soft and loud speech.

Advanced Bionics (AB) promotes fitting strategies with no specific evaluation of the T levels (Wolfe and Schafer, 2015). The T levels are set automatically at 10% of the M levels for AB. One can question whether this approach is optimal. The negative impact of too high or too low levels have been discussed in the literature. Too high T levels are reported to produce the perception of background noise (Busby and Arora, 2016), and too low T levels produce decreased detection of quiet sounds (Busby and Arora, 2016). However, access to soft sound is important because it improves the ability to understand soft voices and the outcomes used by FOX® for map optimization comprehend difficult everyday listening situations (Holden *et al.*, 2011). The evaluation of real T levels provides better functional results and better detection of phonemes and frequency modulated tones than fitting them at 10% of the M levels in AB cochlear implanted children (Baudhuin *et al.*, 2012). On the other hand, Spahr and Dorman (2005) didn't find an effect of setting T levels based on behavioural assessment as compared to setting them at 10% of MCL levels in MedEl Tempo+ CI users. No significant difference was observed in terms of speech recognition and the audibility of soft sounds.

In our case, the improvement observed in soft speech intelligibility can be explained by the combined effect of increased T levels and the dynamic field being

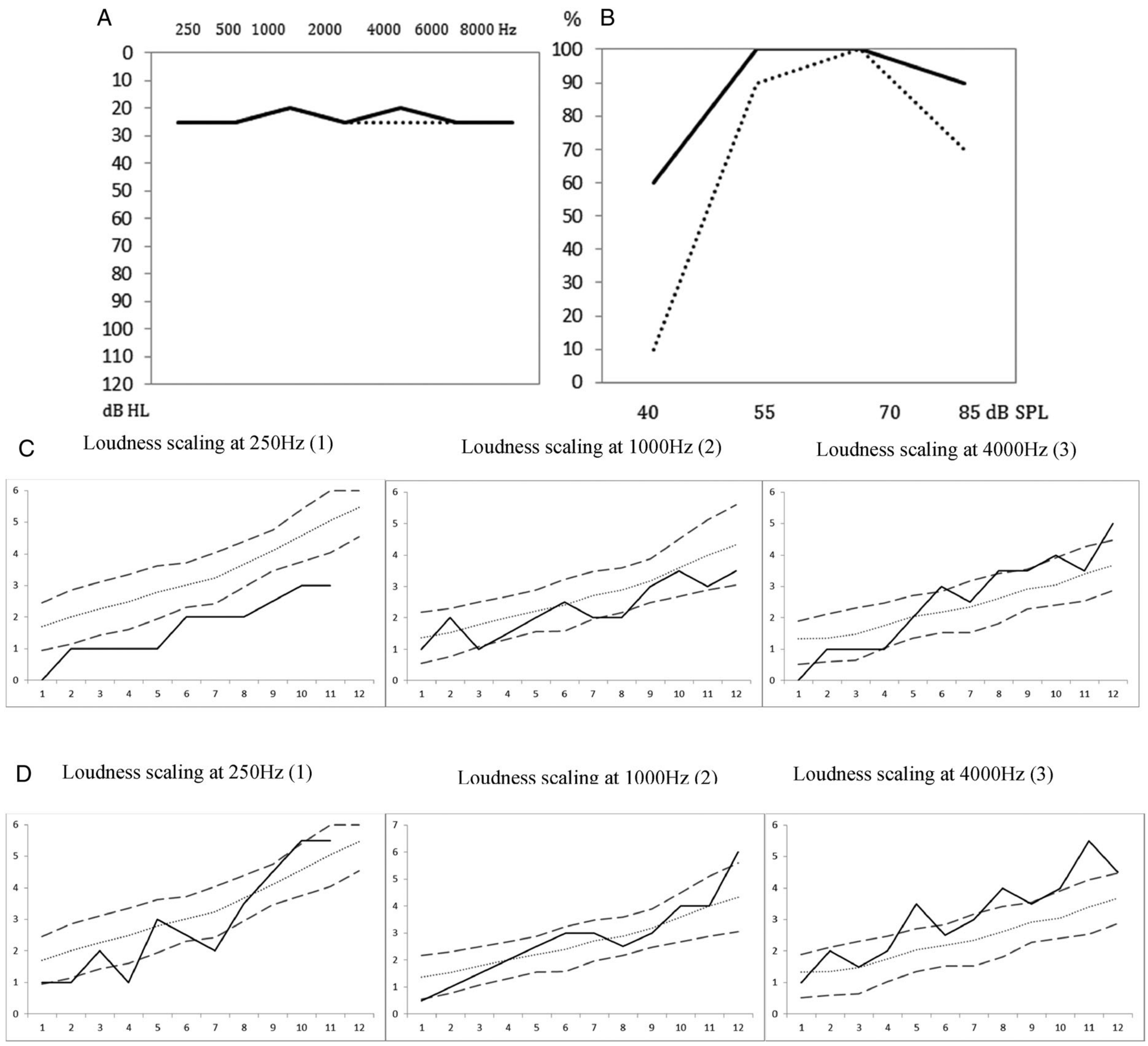


Figure 6 Case 2, auditory results, 'Manual map' (………) and 'New map' (——): (A) pure tone audiogram (dB HL) and (B) speech audiogram % of correct repetition of bisyllabic words presented in quiet at 40, 55, 70 and 85 dB SPL. 'Manual map' (C) & 'New map' (D) loudness scaling curves at 250 Hz (1) – 1000 Hz (2) – 4000 Hz (3), Mean (………), ±2 standard deviation (- - -) for normal hearing population and patient result (——).

more compressed for the 455–906 Hz sounds. Indeed, the decreased T levels and increased M levels for the other electrodes are expected to decrease the detection of very soft sounds.

FOX® proposed an increase in the behaviourally measured M levels, aiming to improve speech intelligibility specifically at louder intensities.

This case shows that the proposed T & M levels don't correspond to the behaviourally set levels. The levels proposed by FOX® would probably not be proposed by experienced audiologists in manual fitting. The constraints imposed by manufacturers must not always be respected.

Conclusion

These two case studies report on our first experience with outcome driven, computer assisted fitting by means of FOX®. They illustrate that adult CI recipients with manually programmed devices may experience an improvement in their auditory results with this new AI-assisted fitting.

Up to now, it was generally accepted that CI fitting must be based on the subject-specific electrical thresholds. It may be possible to obtain better functional results by focusing on outcome rather than on comfort. AI-assisted fitting offers a new insight in our attitude towards the programming of CIs.

Disclaimer statements

Contributors None.

Funding None.

Conflicts of interest Authors JW and ND report no conflict of interest relevant to this article. Author PG owns intellectual property rights in FOX® and has royalty benefits related to this product.

Ethics approval This study was approved by the local ethical review board (hospital St-Luc – B403201734403).
Clinical Trials Registry NCT03700268.

ORCID

J. Wathour http://orcid.org/0000-0002-2048-8053
P. J. Govaerts http://orcid.org/0000-0002-9519-9002

References

Battmer, R.D., Borel, S., Brendel, M., Buchner, A., Cooper, H., Fielden, C., *et al.* 2014. Assessment of "fitting to outcomes expert" FOX™ with new cochlear implant users in a multicentre study. *Cochlear Implants International*, 16(2): 100–109.

Baudhuin, J., Cadieux, J., Firszt, J.B., Reeder, R.M., Maxson, J.L. 2012. Optimization of programming parameters in children with the advanced bionics cochlear implant. *Journal of the American Academy of Audiology*, 23(5): 302–312.

Bermejo, I., Diez, F.J., Govaerts, P.J., Vaerenberg, B. 2013. A probabilistic graphical model for tuning cochlear implants. In: Peek, N., Marin Morales, R., Peleg, M., (eds.) *Artificial intelligence in medicine*. Berlin: Springer-Verlag, p. 150–155.

Busby, P.A., Arora, K. 2016. Effects of threshold adjustment on speech perception in nucleus cochlear implant recipients. *Ear and Hearing*, 37(3): 303–311.

Cullington, H., Kitterick, P., DeBold, L., Weal, M., Clarke, N., Newberry, E., *et al.* 2016. Personalised long-term follow-up of cochlear implant patients using remote care, compared with those on the standard care pathway: study protocol for a feasibility randomised controlled trial. *BMJ Open*, 6(5): e011342. doi:10.1136/bmjopen-2016-011342

Govaerts, P.J., Daemers, K., Yperman, M., De Beukelaer, C., De Saegher, G., De Ceulaer, G. 2006. Auditory speech sounds evaluation (A§E): a new test to assess detection, discrimination and identification in hearing impairment. *Cochlear Implants International*, 7(2): 92–106.

Govaerts, P.J., Vaerenberg, B., De Ceulaer, G., Daemers, K., Schwauwers, K. 2010. Development of a software tool using deterministic logic for the optimization of cochlear implant processor programming. *Otology and Neurotology*, 31(6): 908–918.

Holden, L.K., Reeder, R.M., Firszt, J.B., Finley, C.C. 2011. Optimizing the perception of soft speech and speech in noise with the advanced bionics cochlear implant system. *International Journal of Audiology*, 50(4): 255–269.

Ingvar, B., Alv, A.D., Tone, T.H., Dag, N. 2002. The validity of the hospital anxiety and depression scale: an updated literature review. *Journal of Psychosomatic Research*, 52(2): 69–77.

Li, T., Chang, X., Wu, Z., Li, J., Shao, G., Deng, X., *et al.* 2017. Autonomous collision-free navigation of microvehicles in complex and dynamically changing environments. *American Chemical Society Nano*, 11(9): 9268–9275.

Maria, C.S., Maria, P.L.S. 2016. Variables that effect psychophysical parameters and duration to stability in cochlear implant mapping. *Otolaryngology: Open Access*, 6(2): 226. doi:10.4172/2161-119X.1000226

Meeuws, M., Pascoal, D., Bermejo, I., Artaso, M., De Ceulaer, G., Govaerts, P.J. 2017. Computer-assisted CI fitting: is the learning capacity of the intelligent agent FOX® beneficial for speech understanding? *Cochlear Implants International*, 18(4): 198–206.

Orzan, E., Muzzi, E., Marchi, R., Falzone, C., Battelino, S., Ciciriello, E. 2016. Achieving early functional auditory access in paediatric cochlear implantation. *Acta Otorhinolaryngologica Italica*, 36: 45–50.

Pawlak-Osińska, K., Linkowska, K., Grzybowski, T. 2018. Genes important for otoneurological diagnostic purposes - current status and future prospects. *Acta Otorhinolaryngologica Italia*, 38(3): 242–250.

Rader, T., Doms, P., Adel, Y., Weissgerber, T., Strieth, S., Baumann, U. 2018. A method for determining precise electrical hearing thresholds in cochlear implant users. *International Journal of Audiology*, 57(7): 502–509. doi:10.1080/14992027.2017.1412519

Spahr, A.J., Dorman, M.F. 2005. Effects of minimum stimulation settings for the Med El Tempo+ speech processor on speech understanding. *Ear and Hearing*, 26(4): 2S–6S.

Vaerenberg, B., Govaerts, P.J., De Ceulaer, G., Daemers, K., Schwauwers, K. 2011. Experiences of the use of FOX, an intelligent agent, for programming cochlear implant sound processors in new users. *International Journal of Audiology*, 50: 50–58.

Vaerenberg, B., Smits, C., De Ceulaer, G., Zir, E., Harman, S., Jaspers, N., *et al.* 2014. Cochlear implant programming: a global survey on the state of the art. *The Scientific Journal World*, 2014: 501738. doi:10.1155/2014/501738

Wolfe, J., Schafer, E. 2015. *Programming cochlear implants – second edition*. San Diego, CA: Plural Publishing.

Yücel, E., Aslan, F., Özkan, H.B., Sennaroğlu, L. 2015. Recent rehabilitation experience with pediatric ABI users. *The Journal of International Advanced Otology*, 11(2): 110–113.