Original research paper

# Evaluation of the 'Fitting to Outcomes eXpert' (FOX®) with established cochlear implant users

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**Objectives:** To evaluate the possible impact of 'Fitting to Outcomes eXpert (FOX®)' on cochlear implant (CI) fitting in a clinic with extensive experience of fitting a range of CI systems, as a way to assess whether a software tool such as FOX is able to complement standard clinical procedures.
**Methods:** Ten adult post-lingually deafened and unilateral long-term users of the Advanced Bionics™ CI system (Clarion CII or HiRes 90K™) underwent speech perception assessment with their current clinical program. One cycle 'iteration' of FOX optimization was performed and the program adjusted accordingly. After a month of using both clinical and FOX programs, a second iteration of FOX optimization was performed. Following this, the assessments were repeated without further acclimatization.
**Results:** FOX prescribed programming modifications in all subjects. Soundfield-aided thresholds were significantly lower for FOX than the clinical program. Group speech scores in noise were not significantly different between the two programs but three individual subjects had improved speech scores with the FOX MAP, two had worse speech scores, and five were the same.
**Conclusion:** FOX provided a standardized approach to fitting based on outcome measures rather than comfort alone. The results indicated that for this group of well-fitted patients, FOX improved outcomes in some individuals. There were significant changes, both better and worse, in individual speech perception scores but median scores remained unchanged. Soundfield-aided thresholds were significantly improved for the FOX group.

**Keywords:** Cochlear implants, Fitting, Speech perception, Device programing, Outcomes

## Introduction

Cochlear implant (CI) systems include an external processor which receives microphone input and converts this signal into an ongoing stream of coded commands which are transmitted to the internal implant in order to provide appropriate stimulation. The overall pattern of stimulation within a CI for a given microphone signal is defined by the 'coding strategy' stored within the processor. For any specific coding strategy, there are many individual parameters that may be manipulated using the programming software, all of which affect fine details of the input–output characteristics of the system and which can be adjusted to optimize the auditory percept in individual users. Once the 'fitting' process is completed, the CI recipient will have had an individual program or MAP created for them.

The most important initial adjustment is the setting of the lower and upper output limits for each electrode/channel (Baudhuin *et al.*, 2012; Holden *et al.*, 2011; Plant *et al.*, 2005; Sainz *et al.*, 2003). As electrode location and neural survival is different among users and also among electrodes in individual users, these limits (threshold of detection, T-level and upper tolerance level, M-level) must be set for each electrode so that the incoming acoustic signal results in electrical stimulation that is within an audible yet comfortable range. These limits are the first parameters to be individually set and are identified in adults by delivering short bursts of current pulses to individual electrodes at different levels while the CI user indicates the loudness percept produced, typically using a visual–analogue scale.

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During the initial phase of programming, T- and M-levels can fluctuate and are adjusted frequently, but stabilize in adults after approximately 1 month of use (Walravens *et al.*, 2006). After this early period, further modification of other parameters may take place in order to optimize performance. Adjustment of the input dynamic range (IDR), rate of stimulation, and coding strategy resulted in better performance in some individuals (Holden *et al.*, 2011; Plant *et al.*, 2007; Skinner *et al.*, 2002; Spahr *et al.*, 2007). However, recommendations for parameter modifications are still provided by the device manufacturers and no standardized system is used across centres (Quality Standards for Adult Cochlear Implantation, Craddock, 2006). There are many other parameters provided within the device programming software which may be adjusted e.g. channel bandpass filter boundaries, gains and compression functions. However, there is a lack of published evidence to guide audiologists in how to optimally set them and more often than not, they are not adjusted but left on the manufacturers defaults. Thus, processor adjustment tends to be based on a combination of audibility and comfort, subjectively assessed by the user.

The present study investigated aspects of an alternative fitting approach using the 'Fitting to Outcomes eXpert' (FOX), which is a software fitting tool developed by the Antwerp Eargroup (Govaerts *et al.*, 2010). FOX provides an approach which optimizes and validates program parameter settings based on a set of outcome measures, rather than comfort alone. It provides a systematic method of fitting, thereby avoiding local variations and idiosyncrasies in clinical methodology. FOX analyses processor programs using a deterministic logic (a process flow based on a predictable rule set) and suggests modifications, using the full range of parameter settings available in the fitting software, based on a set of hard targets which asses the auditory system at a psychoacoustic level and can be compared to normal values. The preprogrammed rules for which MAP parameters to change to improve a particular outcome measure are currently derived from the programming experience at the Eargroup (the EG0910 advice, Govaerts *et al.*, 2010). The outcome measures used in FOX are then repeated and used to determine whether a parameter change has been effective in improving the results. The audiologist has the option to either accept or reject the advice given.

A key feature of FOX is the use of a set of preset programs ('automaps') which have been developed specifically for the initial period of adjustment, when outcome measures are not available. A series of 10 automaps are created, which provide an incremental increase in output levels to accommodate the increase in loudness tolerance that typically occurs in the first few weeks following initial activation (Walravens *et al.*, 2006). The user initially moves up through this series independently at home, according to comfort requirements, but after 1–2-week outcome measures are introduced and FOX is used to identify modifications aimed at optimizing these. Vaerenberg *et al.* (2011) demonstrated that, in a series of eight new users of the Advanced Bionics HiRes 90K system programmed with the FOX system, by the 1 month follow-up session all recipients were on at least the fifth intensity auto MAP. At the final session, 3 months post switch on, 50% of MAPs were defined by FOX as being optimal and FOX had suggested and implemented 10 parameter changes across the eight subjects. There were four requests for MAP changes, based on the loudness scaling outcomes measures, still outstanding at the 3-month interval. The use of FOX allowed a large number of parameter combinations to be adjusted in a short time, to ensure the MAPs were optimized.

The present study aimed to evaluate the possible impact of FOX on existing users in a clinic with extensive experience of fitting a range of CI systems as a way to assess whether a software tool such as FOX is able to complement standard clinical procedures.

The approach used was to select a group of established CI users with stable programs and then to run two iterations of FOX in order to record which parameter modifications (if any) were recommended and whether any such modifications resulted in improvements in speech perception.

## Method

### *Subjects*

Demographic details are summarized in Table 1. Ten post-lingually deafened adults, unilaterally implanted with the Advanced Bionics CI system (Clarion CII or HiRes 90K), were recruited into the study. They all used the Auria™ or Harmony™ behind-the-ear processors and either the HiRes or HiRes 120 coding strategies (Büchner *et al.*, 2011). Duration of deafness pre-implantation was a median of 5.5 years (range 0–37.7 years) and at the time of the study their median age was 59.5 years (range 28.9–80.2 years) and median duration of CI use was 2 years (range 0.4–9.7 years). All subjects had a full insertion of the electrode array, had at least 14 functional electrodes (out of a possible maximum of 16) and were native German speakers. The study was conducted according to the guidelines of the International Research Code of Ethics (PAHO) and was approved by the Freiburg Ethics Commission International (FECI), FECI code: 09/2939.

### *Baseline assessments*

Participants attended an initial baseline session in which speech perception with their existing clinical

**Table 1 Demographic details of the study participants. Processor types: H: Harmony™; A: Auria™**

| Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Age (years) | 43.1 | 43.7 | 50.3 | 64.7 | 66.7 | 80.2 | 67.9 | 66.7 | 55.5 | 28.9 |
| Hearing loss duration (years) | 37.7 | 23.1 | 11.0 | 0 | 0 | 31.0 | 0 | 10.4 | 0 | 0.8 |
| CI use (years) | 2.1 | 0.4 | 2.3 | 1.2 | 2.8 | 0.6 | 7.2 | 1.4 | 2.4 | 9.7 |
| Implant type | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | HiRes 90K | CII |
| Processor | H | H | H | H | H | H | A | H | H | H |
| Coding strategy | HiRes 120 | HiRes | HiRes | HiRes 120 | HiRes | HiRes | HiRes | HiRes 120 | HiRes | HiRes |

program was first assessed. Speech recognition was measured using the German Hochmair-Schult-Moser (HSM) Sentence Test (Hochmair *et al.*, 1998), consisting of 30 lists of 20 everyday sentences. The speech signal was presented at 65 dB Sound Pressure Level (SPL) and with speech-shaped and modulated Comite Consultative International Telegraphique et Telephonique noise at a signal–noise ratio (SNR) of 10 dB. The sentence test with adaptive randomized roving levels (STARR test) (Boyle *et al.*, 2013, Haumann *et al.*, 2010) was also used, which presents sentences at randomized levels of 50, 65, and 75 dB SPL, in adaptive level speech-shaped noise, in order to define the SNR associated with a 50% score. Practice lists were given before each speech test was conducted.

FOX speech perception and psychoacoustic measures were performed in a fitting room through the auditory speech sounds evaluation software (A§E) and calibrated as described in Govaerts *et al.* (2006). Sounds were produced via the internal sound card of the laptop, connected to a Samson, Media One 4a (active studio monitor) loudspeaker. Soundfield-aided thresholds and sentence testing in noise were conducted in a sound booth through a Homoth Audio 4000 audiometer. The loudspeaker was located 1 m from the subject and at 0° azimuth. Two lists of HSM sentences were presented at an SNR of 10 dB. Responses were made verbally by the subject and the experimenter recorded the number of words correctly repeated, using tight scoring. If any subject scored less than 20% on the first list, then two further lists were presented with an SNR of +15 dB. The STARR test involved the presentation of 30 HSM sentences, during which the noise level was adjusted adaptively in order to identify the SNR that produces a 50% score. This was performed twice.

### *Program optimization by FOX*

Following the baseline speech recognition assessment, a single 'iteration' or 'cycle' of FOX was performed. A single iteration involved the measurement of the FOX test battery, consisting of speech perception and psychoacoustic test measures, followed by an analysis by FOX of the appropriateness of the processor program in use. The FOX-Eargroup Advice specific outcome measures are described fully by Govaerts *et al.* (2010), but brief details are as follows:

1. Soundfield-aided thresholds were performed using warble tones presented at 250, 500, 1000, 2000, 4000, and 8000 Hz, using standard clinical audiometric methods.
2. A§E phoneme discrimination was measured at 70 dB SPL, using a sub set of 7 of the available 20 phoneme contrasts.
3. A§E loudness scaling was performed using one-third octave narrow band noises, centred at 250, 1000, and 4000 Hz. A 1876 ms stimulus was presented twice at each level and scored on a visual–analogue scale ranging from 0 (inaudible) to 6 (too loud). Levels were randomly presented at 5 dB increments between 30 and 80 dB HL. A 'loudness index' was derived at each intensity level, based on the root mean square deviation of the scores from the average score in normally hearing listeners. The scores were pooled for four different levels (30–35–40, 45–50–55, 60–65–70, and 75–80–85 dB HL). A negative value indicates an abnormal loudness scaling with more percepts judged quieter than the average in hearing listeners.
4. Speech audiometry using Freiburger monosyllabic words, consisting of meaningful CVC words with no carrier phrase, with phoneme scoring and two lists of 10 words per condition, at 40, 55, 70, and 85 dB SPL tested in a random order.

In this study, FOX was implemented directly from the Advanced Bionics Soundwave™ fitting software, this enabled FOX to read the current program values, make any required modifications and directly read in the results from the A§E test modules. For the present study, soundfield-aided thresholds were entered manually into FOX, but the other test results (phoneme discrimination, loudness scaling and speech audiometry) were read in directly from the A§E software. Any program parameter modifications suggested by FOX were presented to the audiologist. If accepted, they were then implemented automatically by FOX in order to produce a new program which could then be tested or downloaded to the subject's processor.

Depending on the analysis of the test results, FOX may have pending outcome requests, which is a request to repeat one or other of the outcome measures following a program modification, for verification purposes. Pending outcome requests were made for 8 out of 10 subjects. In four subjects, the additional outcomes measures were performed at the baseline session, whereas in the other four subjects they were performed as part of the second FOX cycle at the follow-up session (see below). In the two remaining subjects the program modifications following initial FOX cycle at each session were the smallest among the 10 participants. It was found that a second cycle of FOX would have prolonged the testing session and increased subjects' fatigue without further significant gain in performance and it was decided not to run a second FOX iteration. The program changes made by FOX are listed in Table 2. The majority of changes were made during the first iteration of FOX. All baseline Harmony™ programs were initially changed from a 60 dB IDR to an 80 dB IDR and from sensitivity 0 to sensitivity −10, before FOX was implemented. As a default pre-setting, these modifications are always requested by FOX for the Harmony™ speech processor (Govaerts *et al.*, 2010). For the single Auria™ processor user (S07), the initial 55 dB IDR and 0 dB sensitivity settings were not modified.

At the end of the baseline session each subject was sent home with their original processor program together with the new program generated by FOX. They were encouraged to use both programs evenly, in a variety of listening situations, in order to assess their relative merits over a 1 month period.

### *Follow-up session*

Approximately 1 month after the baseline session, the subjects returned to the clinic for the follow-up session. Their overall relative preference and experiences with the two programs was discussed. The FOX test battery was repeated and a second FOX iteration was performed, resulting in a few minor modifications in some cases. Following this, HSM sentences in noise and the STARR test were then repeated at the end of the session, with the new FOX program.

At the end of the session subjects were given the choice of whether to take away either or both of the programs (original clinical program and/or the program optimized by FOX).

### *Statistical analysis*

As a primary measure the median of the speech perception results for the HSM sentence test and STARR test obtained at baseline and the final study session after 1 month were compared. The four measures included in the FOX test battery were also compared. Wilcoxon paired test for dependent samples was performed to assess whether median scores were significantly different.

## Results

### *Programming changes recommended/implemented by FOX*

At least some modifications were recommended in all subjects and several patterns could be observed from careful comparison of the original clinical programs and those finally produced after the two FOX iterations.

1. M-levels were modified in 8 of the 10 subjects. In six cases there was an overall increase, with a decrease in two cases, but these changes were mostly small. In only two cases, M-level changes were greater than 10% of the dynamic range. There was no obvious tendency for changes to be recommended at any particular region along the array.
2. T-levels were modified in all cases. Routine clinical practice is to set T-levels to 10% of the M-levels in all recipients. FOX recommended relatively small increases to T-levels of up to a maximum of 40–50 charge units in nine of the subjects, and a reduction in just a single subject, who initially had T-levels set above 10% of M-levels.
3. Gains were extensively modified, with changes in nine subjects. There was a general increase in gains in eight of these and a reduction in only one case. There was no obvious tendency for changes to be recommended at a particular region along the electrode array, although in most cases gains were increased for the majority of the electrodes.
4. Electrodes were de-activated in four subjects. In three cases these were electrodes between 1 and 4, at the basal end of the array and in one case (S02), three electrodes were de-activated in the central–apical region. The underlying basis for FOX to deactivate electrodes is a combination of several factors, of which high audiometric thresholds and a narrow dynamic range on the associated electrodes are the most important (Govaerts *et al.*, 2010).

### *FOX speech perception and psychoacoustic test results*

The baseline results for the clinical program and the most recent results for the FOX program, taken from the follow-up session, were compared for the four measures in the FOX test battery (Fig. 1). Median values are provided for each subject with box plots showing the group median on the right-hand end of each graph. Soundfield-aided thresholds were averaged across all frequencies (250, 500, 1000, 2000, 4000, and 8000 Hz). Loudness scaling scores for each subject were averaged over each level and each test frequency (250, 1000, and 4000 Hz). Speech audiometry scores were also averaged across all intensities (40, 55, 70, and 85 dB SPL), therefore this does not represent

**Table 2 Program modifications for each subject as suggested and implemented by FOX**

| | M-level modifications | T-level modifications | Gain modifications | Electrode modifications | Preference program |
|---|---|---|---|---|---|
| S01 | Increase on the middle electrodes by approx. 5% | Increase of all electrodes by 10–15% | Increased globally by 4 dB up to 6 dB on the basal electrodes | No | FOX |
| S02 | Increase on four apical and six basal electrodes by approx. 15% | Increase on four apical and eight basal electrodes by approx. 50% | Increase on the apical and middle electrodes by 4 dB | Three middle electrodes deactivated | Both |
| S03 | No changes | Increase of the 12 apical electrodes by approx. 50% | Increase of the 12 apical electrodes by 4 dB | Four basal electrodes deactivated | Both |
| S04 | Increase on the ten basal electrodes by approx. 10% | Increase of all electrodes by approx. 100% | Increase on the five apical electrodes by 4 dB, six middle by 2 dB, and decrease of the three most basal by 0.5 dB | One most basal electrode deactivated | Clinical |
| S05 | Decrease of the five most basal electrodes by approx. 5% | Increase on 11 apical electrodes by approx. 20% and five basal electrodes by approx. 80% | Increase ranging from 6 dB on the most apical to 3 dB on the most basal electrodes | None | Both |
| S06 | Increase of all electrodes by approx. 15% | Global increase of approx. 150% | Global increase on all electrodes by 4 dB | None | Clinical |
| S07 | Increase on the middle and decrease on apical and basal electrodes by approx. 5% | Increase on two apical, three middle and three basal electrodes by approx. 100% | Increase on five apical channels by 2 dB and decrease on three basal channels by 2 dB | Two most basal electrodes deactivated | Clinical |
| S08 | Map smoothed; average increase of all channels by approx. 10% | Global increase of all electrodes by approx. 120% | Increase on eight middle and decrease on four basal electrodes by 2 dB | None | FOX |
| S09 | Decrease of nine basal and increase of three apical electrodes by approx. 10% | Increase on five apical and four basal electrodes by approx. 80% | Decrease on five apical and five basal electrodes ranging from 1.8 to 6 dB | None | FOX |
| S10 | No changes | Increase on four basal and two apical electrodes by approx. 80% | No changes | None | FOX |

the highest score obtained as most subjects score close to zero at 40 dB, but provides a composite score that reflects the ability of the subject to understand speech over a wide range of input levels. Poor detection, resulting in low scores at low intensities, or reduced scores at high intensities ('rollover'), would reduce the overall score for this measure.

Soundfield-aided thresholds (Fig. 1A) showed that median thresholds were more than 5 dB lower for the FOX program in 7 of the 10 subjects, with a significant difference in overall medians of 12 dB between the clinical program (43 dB HL) and the FOX program (31 dB HL) ($Z = 2.40$, $p = 0.02$). Phoneme discrimination scores in five subjects were the same before and after FOX (Fig. 1B), with all subjects getting at least five out of the seven phoneme pairs correct. For four subjects FOX improved their phoneme score by at least one pair and for one subject (S06), FOX reduced their phoneme score by one pair. There was no significant difference between the groups. Speech audiometry scores (Fig. 1D) showed a trend for higher scores for the FOX program, however group median scores of 43% for the clinical program and 55% for the FOX program, were not significantly different. There was no difference between the median loudness deviations for the FOX and clinical groups.

### *Speech perception in noise results*

The individual scores recorded for HSM sentences in noise are shown in Fig. 2. The median scores for the Clinical and FOX programs were 53.3 and 53.1% respectively, and were not statistically different on a Wilcoxon matched pairs test ($Z = 0.25$, $p = 0.79$). The individual scores recorded for the STARR test are shown in Fig. 3. In Boyle *et al.* (2013) the critical difference in test scores for one individual is given as 2.2 dB or greater. Using this criterion, five subjects scored the same with both programs, two subjects were worse with the FOX program (S08 and S02) and three subjects were better (S01, S09, and S10) with the FOX program. The median SNR for the Clinical and FOX programs were 6.45 and 8.45 dB, respectively, and were also not statistically different on a Wilcoxon matched pairs test ($Z = 0.15$, $p = 0.87$).

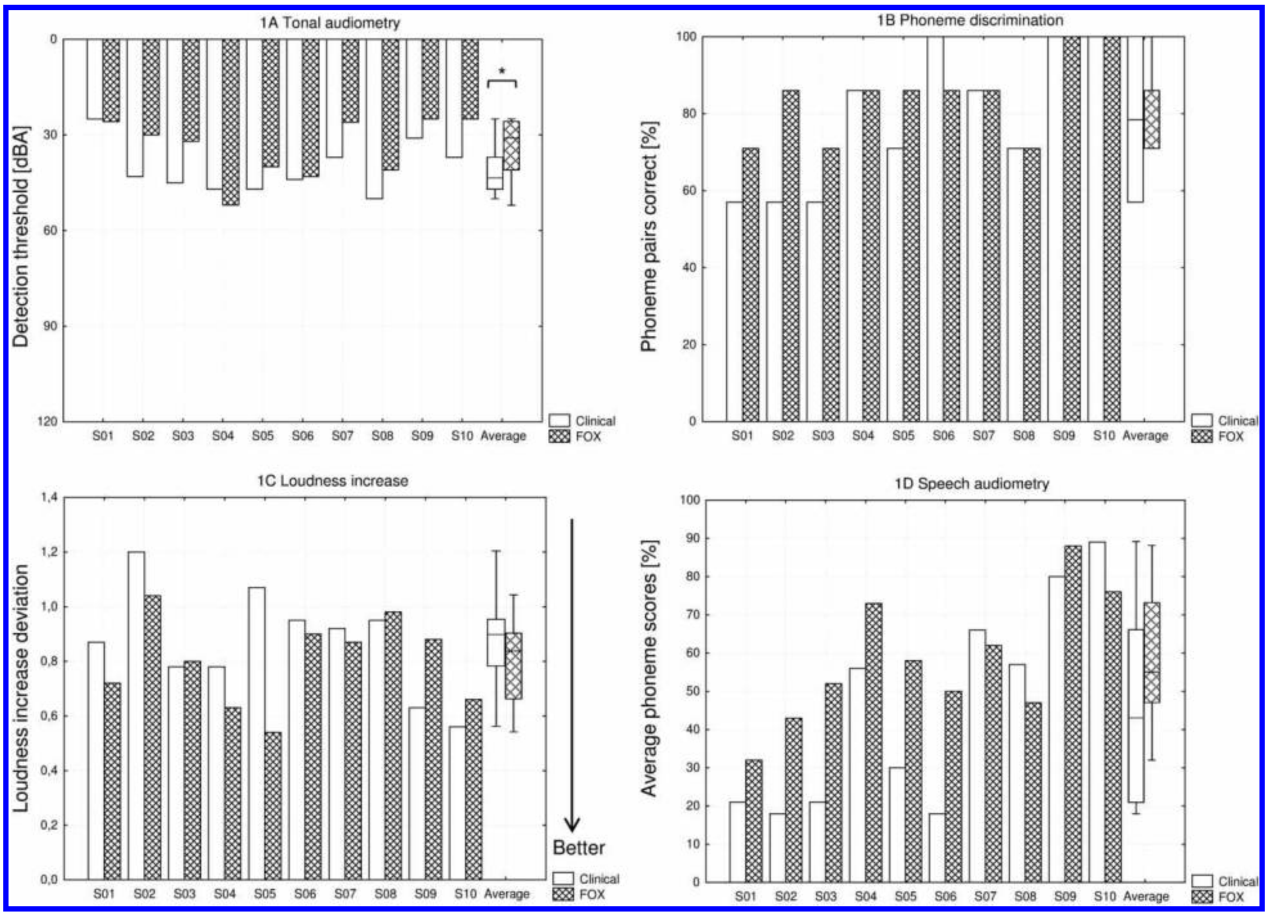


**Figure 1** Scores are shown for the clinical and FOX generated programs for each of the four FOX outcome measures. (A) Shows detection thresholds averaged across 250, 500, 1000, 2000, 4000, and 8000 Hz. (B) Shows the percentage of phoneme pairs correct. (C) Shows the loudness index pooled across all four levels. (D) Shows the percentage of phonemes correct from the Freiburger monosyllabic word test. Bars show results for individual subject results with the box plots showing the median, upper, and lower quartiles for the group for each measure. Lower loudness increase scores indicate lower average deviations from the normative data (normal hearing). Significant differences at $P < 0.05$ are indicated with a starred bracket.

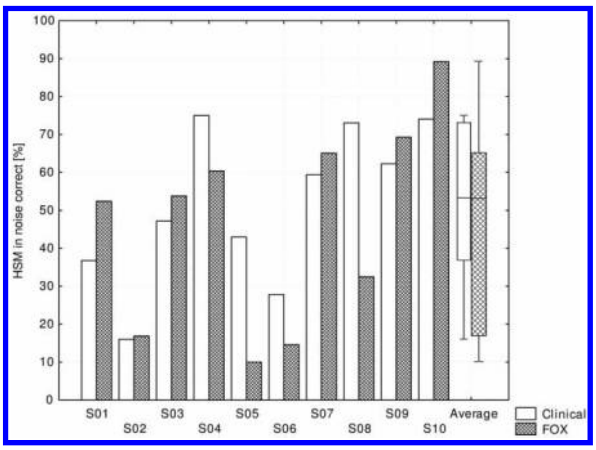


**Figure 2** Speech perception in noise scores are shown for the clinical and FOX generated programs. Bars show individual per cent correct scores for HSM sentences averaged across two lists in either +10 or +15 dB of noise, depending on the performance of the subject. The box plots show the median, upper, and lower quartiles for the group. Error bars indicate the minimum and maximum values recorded.

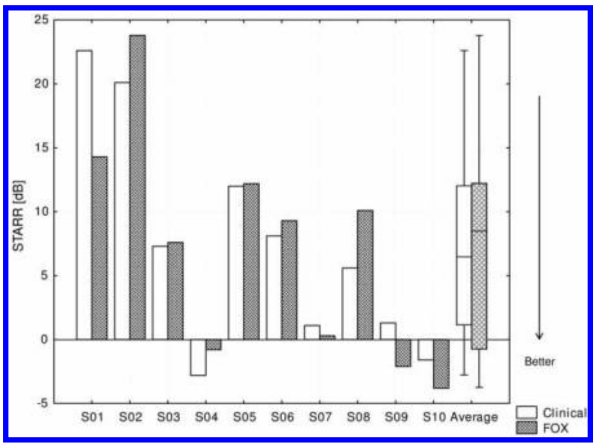


**Figure 3** Scores show the SNR, averaged across two repetitions, required to produce 50% correct on the STARR test for the clinical and FOX programs. Lower scores indicate better results. Bars show the individual scores with a critical difference between results of 2.2 dB indicating a clinically significant result. The box plots show the median, upper, and lower quartiles for the group. Error bars indicate the minimum and maximum values recorded.

### *Subjective overall preferences*

Four subjects expressed a preference for the FOX program (S01, S08, S09, and S10), three for the clinical program (S04, S06, and S07) and three had no preference (S02, S03, and S05). Of the four subjects who expressed a preference for FOX three (S01, S09, and S10) performed better with the FOX program but one (S08) performed worse.

## Discussion

FOX would normally be used from the early stages of device programming and the way it was implemented in the present study should be viewed as atypical (Vaerenberg *et al.*, 2011). The principal aim of this study, however, was to assess its impact on programming and associated outcomes in a group of CI users who were considered to have well-adjusted processors and in whom MAP T- and M-levels were stable. In this situation large improvements would not be anticipated as a result of implementing FOX, but it might be very informative to observe what programming changes, if any, are recommended, and if they result in any measurable changes in speech perception.

The study used a repeated measures design, where each subject acted as their own control. Baseline measures were taken with the clinical MAP at the beginning of the test period and then repeated at the end with the FOX MAP. During this time it is not inconceivable that improvements in speech perception may have taken place, irrespective of the treatment under investigation i.e. the FOX programming system (Lazard *et al.*, 2012). Therefore, any significant improvements in speech testing in noise, occurring over the test phase, could be attributed to learning.

Fig. 1A–D shows the changes in the FOX outcome measures before and after FOX implementation. Improvement in soundfield-aided thresholds was the only measure which showed an overall statistically significant improvement. Median thresholds were lower in 7 of the 10 subjects. Routine speech perception assessments (HSM sentences in noise and STARR) did not suggest any overall change in speech perception performance in noise following implementation of FOX (Figs. 2 and 3). However, individual scores for the STARR test indicated a significant improvement for three subjects and a significant decrement for two subjects and no change in scores for the remaining five subjects.

It was observed that in this group of subjects, FOX did recommend programming modifications for all subjects; although in many cases these changes were relatively minor. All subjects had their T-levels increased and for the majority, 8 out of 10, increased gains and M-levels as well. Nine out of the 10 MAPs also had the IDR increased, prior to the first FOX iteration. These MAP changes, particularly to the IDR and T-levels, are reflected in the significant increase in the soundfield-aided thresholds of 12 dB observed for the FOX programs. Other adjustments made were the deactivation of several electrodes in four of the subjects. In all cases, these electrodes showed the highest initial M-levels and subjects had typically high audiometric thresholds at frequencies associated with these electrodes. For subject 2 these electrodes were located in the middle of the array and while the scores for phoneme recognition went up by two pairs and speech recognition within the FOX test battery seemed to be improved, speech perception in noise with the STARR test was significantly worse with the FOX MAP. This subject is also notable as having less than 6 months of CI use and whilet T- and M-levels may be stable (Walravens *et al.*, 2006), speech perception results are continuing to improve (Lazard *et al.*, 2012).

The FOX changes were made over two sessions, with the majority being made after the first iteration and only a few minor changes after the second. For this reason 1 month's acclimatization was only given for the first iteration of FOX. If any MAP changes were made in the second FOX session, these were tested acutely and this would disadvantage FOX. Nonetheless, three subjects performed better with the FOX program on the adaptive STARR test and only two subjects performed worse, S08 and S02. Subject 2 has been discussed in the previous paragraph, but subject 8 also had a large reduction of 40% in HSM sentence score with the FOX MAP. The main modification to this subject's MAP was a global increase in T-levels by 102%, however this only represents a small change in charge units. However, soundfield thresholds for this subject show an average increase of 9 dB between the clinical and FOX MAPs and at the final session they reported FOX as being their preferred MAP.

As mentioned earlier, clinics that regularly use FOX are likely to use it from the early stages of device fitting following the 'switch-on session'. This usually begins with use of the 'automap' feature, which provides an opportunity for the user to become habituated to the electrical signal as the electrical dynamic range increases over the first week or so (Vaerenberg *et al.*, 2011). Following this initial stage, the FOX outcome measures are introduced, initially to focus on threshold detection and spectral composition. This stage is based on the soundfield-aided thresholds and phoneme discrimination and occurs typically in the first month. The next stage would focus on mapping of acoustic input over the frequency range as measured by the loudness increase measure, and the last step is to ensure that the user shows robust speech perception scores at different presentation levels as measured by speech audiometry.

The present study implemented a process that was very much shortened by comparison, although was still time consuming to complete, an aspect of FOX explored in a future study. The phoneme discrimination test used in this study comprised only seven basic phoneme contrasts which were found to be more appropriate for avoiding extensive testing sessions and potential patients' fatigue effects. In a clinical FOX session, a list of 20 phoneme contrasts is typically measured. The associated lower spectral accuracy of this implementation may have led to less precise advice and program changes made by the FOX-Eargroup Advice.

## Conclusion

FOX provides a standardized approach to fitting based on outcome measures rather than comfort, and is perhaps particularly useful in clinics without extensive specialist experience. The results indicated that for this group of well-fitted patients, FOX improved outcomes in some individuals: there were significant changes, both better and worse, in individual speech perception scores but median scores remained unchanged. Soundfield-aided thresholds were significantly improved for the FOX program in 7 of the 10 subjects, with a significant improvement in overall group medians for the FOX group when compared to the clinical group.

## Disclaimer statements

### Contributors

All authors were actively involved in either planning, development, execution, monitoring, analysing and in the reviewing stage of this research.

### Funding

None.

### Conflicts of interest

FOX has been developed by the members of the Eargroup who have commercial rights and interests on this product.

### Ethics approval

This study was reviewed and approved by the 'Freiburger Ethik-Kommission'.

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