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Cochlear implant telemedicine: Remote fitting based on psychoacoustic self-tests and artificial intelligence

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Objective: This study aims to assess the feasibility of autonomous cochlear implant (CI) fitting by adult CI recipients based on psychoacoustic self-testing and artificial intelligence (AI).
Design: A feasibility study was performed on six adult CI recipients implanted with a Nucleus device. Two weeks after processor activation in the clinic, a 'self-fitting' session was organized in a supervised simulated home environment. The CI recipient performed pure tone audiometry and spectral discrimination tests as self-tests. The AI application FOX analysed the results and recommended a new map. The participants filled out a questionnaire and were tested again after 2 months of take-home experience.
Results: Four out of six patients performed the self-tests without any help from the audiologist and four were fitted by FOX without any manual intervention. All patients were comfortable with the concept of self-testing and automated fitting. Patients acknowledged that at this stage the remote supervision of an audiologist remains essential.
Conclusions: The study showed that audiological self-assessment and remote CI fitting with AI under the supervision of an audiologist is feasible, at least in a number of CI recipients. Currently, there are still some technical and regulatory challenges to be addressed before this can become routine practice.

Keywords: Telemedicine, Remote fitting, Artificial Intelligence, Cochlear implant fitting, Self-test, Audiometry

Introduction

Cochlear implantation is a widely accepted treatment for people with severe to profound hearing loss. Despite this, less than 15% of potential cochlear implant (CI) candidates have been implanted globally, most of them living in high-income countries (De Raeve and van Hardeveld, 2014; Fagan and Tarabichi, 2018). Therefore, a need exists for CIs in developing countries. However, audiological services in developing countries are often very limited (Fagan and Tarabichi, 2009; Swanepoel et al. 2010; World Health Organization 2019). Even in highly developed countries, people living in rural areas and isolated communities do not always have easy access to hearing health care with well-trained professionals. Telemedicine provides a possible answer to these problems. Telemedicine can be defined as 'the delivery of healthcare services and information via high-tech telecommunications technologies' (Wootton et al. 2009). From a healthcare provider's perspective, automation processes accompanied by telehealth applications can provide more streamlined and efficient medical procedures and thus create the possibility of treating more patients in a given timespan than with conventional methods (Swanepoel et al. 2010; Wootton et al. 2009).

The applications of telemedicine for remotely fitting CI recipients have been discussed in several publications (Franck et al. 2006; Ramos et al. 2009; Wesarg et al. 2010). These studies applied fitting procedures based on objective measurements such as electrically evoked compound action potential (ECAP) measurements or based on the behavioural response and comfort of the patient. In these reports, an audiologist was still required to test the CI recipient, analyse the results, create new maps, and write them into the processor. Hence, the benefits of this type of telemedicine are merely for the CI recipient, who acquires better and quicker access to healthcare services. The CI audiologist, however, does not spend less time in this type of fitting process.

A further level of telemedicine could comprise autonomous fitting or 'self-fitting'. With no or

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minimal intervention by the CI audiologist, professional resources would be reduced substantially. For this to be possible, it is necessary that the patient can self-assess his or her psychoacoustic performance and that a computer system can take over the intellectual act of interpreting the results and proposing map changes. Both prerequisites are becoming achievable with modern technology.

We have previously reported on a computer-assisted fitting strategy that is driven by measurable audiological targets rather than patient subjective responses or objective measurements (Govaerts et al. 2010). The artificial intelligence (AI) software application FOX (Fitting to Outcomes eXpert, Otoconsult NV, Antwerp, Belgium) and its performance have been described in several papers (Battmer et al. 2015; Büchner et al. 2014; Govaerts et al. 2010; Meeuws et al. 2017; Vaerenberg et al. 2011; Vaerenberg et al. 2014; Waltzman and Kelsall 2020; Wathour et al. 2016). The current (second) generation of FOX (FOX 2G) analyses the map and the psychoacoustic test results obtained with it. Then, it calculates the predicted outcome of millions of alternative maps by means of probabilistic networks and proposes the map with the best predicted outcome for the patient (Meeuws et al. 2017). To date, the audiologist still needs to judge this recommended map and decide whether to write it to the processor.

The psychoacoustic targets used in the AI-based approach are defined as test results on pure tone audiometry, spectral discrimination (Govaerts et al. 2006), loudness scaling, and speech audiometry. These tests can be administered by the software application Audiqueen (Otoconsult NV, Antwerp, Belgium) and the first three of them are available as self-tests. The patient then performs the tests on a computer screen without any help or instruction of an audiologist. To address the possible limitations of home-testing regarding audio quality, calibration of the stimuli, and the occurrence of possible background noise due to the absence of a soundproof room (Bexelius et al. 2008; Choi et al. 2007) a software link (Coala Link, Otoconsult NV, Antwerp, Belgium) was developed for Nucleus CP900 and CP1000 processors (Cochlear Ltd., Sydney, Australia). This link delivers test sounds directly from the computer soundcard to the CI sound processor with an auxiliary cable or through a Bluetooth connection without the need for a free-field speaker or soundproof test environment. Calibration can be ensured using a feedback system that records the intensity of the incoming stimuli.

With these technological developments available, the possibility of setting up a home fitting session is becoming reality. Therefore, we decided to set up a proof of concept evaluation of a ‘self-fitting’ session in a supervised simulated home environment. The goal of this study is to assess the feasibility of such autonomous CI fitting based on psychoacoustic self-testing and AI. For safety reasons, this was performed under the supervision of an audiologist to assist the patient where necessary and to authorize the maps proposed by the AI engine FOX due to the current regulatory status of the computer-assisted fitting strategy.

Material and methods

Subjects

Six consecutive adult post-lingual subjects with a remote home base near Hasselt, Belgium (see below) were recruited for this study and underwent a ‘self-fitting’ session with their CP1000 sound processor (Cochlear Ltd., Sydney, Australia) two weeks after switch-on. Switch-on was done by means of FOX auto maps, as described elsewhere (Govaerts et al. 2010). No other selection criteria were used, and no candidates refused to take part in the study. The study protocol was approved by the Institutional Review Board (B243201732762). All participants had been implanted with a Cochlear device and had undergone their switch-on session in our centre. Written informed consent was obtained during the switch-on session, and the subjects received a brief introduction of how the self-fitting session would look.

Test environment setup

For ethical and study monitoring reasons, the self-fitting session was organized in a hospital near the patients’ home base (Jessa Hospital, Hasselt, Belgium). This local environment consisted of a laptop with the following software applications:

- **Audiqueen**: Audiological data manager and psychoacoustical testing software (Otoconsult NV, Antwerp Belgium). Audiqueen can deliver test sounds for several psychoacoustic tests to the soundcard of the computer.
- **Custom Sound 5.0:** Fitting software (Cochlear Ltd, Sydney, Australia) for Cochlear sound processors.
- **FOX 2G**: AI application (Otoconsult NV, Antwerp, Belgium) to analyse psychoacoustic test results and propose map changes to improve the outcome. The FOX application interfaces seamlessly with Audiqueen and Custom Sound.

In addition, the local unit was equipped with the following hardware components:

- Cochlear programming pod (Cochlear Ltd., Sydney, Australia),
- Cochlear wireless mini microphone 2+ (Cochlear Ltd., Sydney, Australia),
- USB external stereo soundcard (Sabrent Ltd., Los Angeles, United States).

Test sounds were delivered wirelessly (Bluetooth) to the processor through the mini microphone that was connected to the soundcard with an auxiliary cable (Fig. 1). Initially, the processor was connected with a wireless programming pod. Due to technical issues with the wireless pod for the first two participants, it was decided to proceed with the study using wired pod. An audiologist at the local hospital assisted with the hardware setup. The audiologist did not interfere with the testing and fitting process.

Since this was a proof of concept, the entire procedure was monitored by audiologists from our CI centre using internet communication with Zoom software, webcams, and computer microphones. For two patients, written communication was used with a chat function (see further details in the results section).

Eargroup fitting procedure outline

The second fitting session, which was two weeks after the switch-on session, was chosen for the simulated home fitting. The reason is that all psychoacoustical tests that are typically performed during this fitting session at the Eargroup are available in self-test form.

During switch-on, we routinely give a series of preset programmes, called 'automaps'. The patients are asked to build up loudness tolerance by gradually switching to a higher automap within their comfort zone (Vaerenberg et al. 2014). The second fitting session (in this study, it was replaced by the 'self-fitting' session) is organized two weeks after to evaluate the auditory performance at the detection and discrimination level with the most recent home map. For this evaluation, audiometry and phoneme discrimination tests were performed. Depending on the results, FOX may drop electrodes and change electrical parameters, such as threshold and comfort levels. The patient then returns home with this new map. Three months after the switch-on session, the patient returns for the third fitting session where, among other tests, speech recognition is assessed for the first time.

Self-test procedure

The Audiqueen software package contains self-tests for tonal audiometry, phoneme discrimination, and loudness growth (Fig. 2). The self-tests are conceived to mimic a clinical test procedure. After an automatic calibration procedure of a few seconds, the patient is first acquainted with the test sounds and the test procedure and then executes the test using a touchscreen. Easy messages guide the test person through the test procedure. In case of inconsistent results, the software provides more training before continuing. During the autonomous fitting, hearing threshold and spectral discrimination capabilities are evaluated with the following self-tests discussed in the next section.

Audiometry self-test

A screenshot of the audiometry self-test is given in the upper left panel of Fig. 2. When a stimulus is played during the self-test, the subject can choose between two buttons: *sound* and *silence*. The specific sequence of provided intensities for the test stimuli and the eventual threshold estimation are determined by the *threshold estimation by managed algorithm* (TEMA; Vaerenberg et al. 2013a). This algorithm contains internal controls to determine whether the listener is understanding the task (e.g. using one response option only) and whether he or she is answering consistently without guessing. The audiometry self-test has been clinically validated against the manual counterpart on 90 subjects, consisting of 30 normal hearing persons, 30 patients with hearing loss, and 30 CI recipients and is publicly available on the Otoconsult NV website (https://otoconsult.com/references/).

Phoneme discrimination

A§E phoneme discrimination was performed using 20 speech sound contrasts presented at 70 dB HL in an oddity paradigm (for test details, see Govaerts et al. 2006). A result of yes or no was recorded for the discrimination of each contrast. The patient is asked to push a button on the touchscreen each time the odd stimulus is presented. When unsuccessful, the patient can receive an additional automated training session to acquaint the patient better with the contrast.

Course of the simulated self-fitting session

After the hardware setup with the assistance of the local audiologist, the participants autonomously performed a pure tone audiometry and phoneme discrimination test with 20 contrasts. Then, FOX analysed the map and test results and calculated whether another map yielded a better predicted outcome. In such cases, this new map was judged remotely by the Eargroup audiologist who would write it to the sound processor. This latter manual step was done for safety reasons because the current regulatory status of FOX is that of a decision-support system that does not write autonomously to the processor. After the fitting session, the participants filled in a questionnaire concerning several topics, such as the following:

- the general feel and comfort of the patient during the remote fitting;
- the need for supervision by the audiologist and/or local representative;
- the overall experience of performing the self-tests, regarding the ease, speed, and intuitiveness of the test.

Approximately three months after switch-on, the subjects came back for the third fitting session, where, for the first time, speech audiometry, and

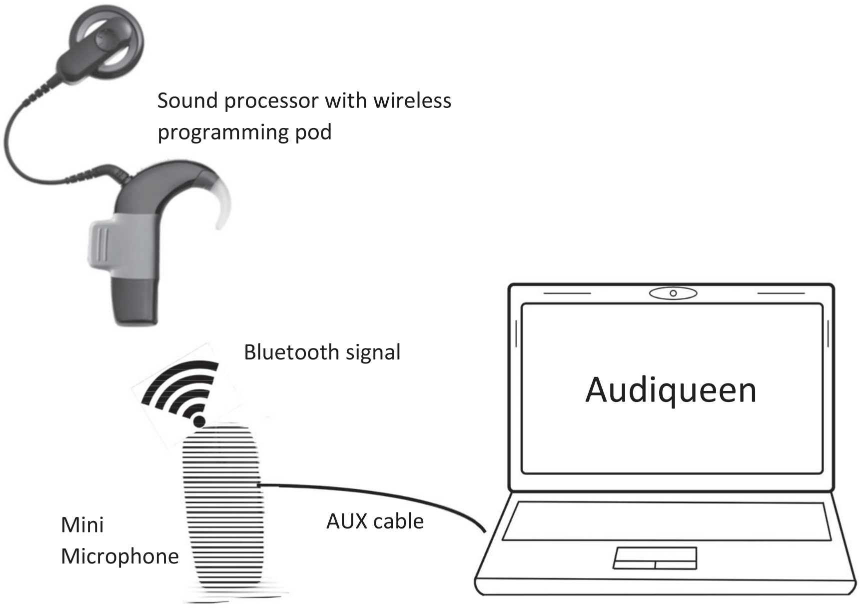

Figure 1 Schematic drawing of the Coala Link setup.

loudness growth were tested. For the speech audiometry test, a list of 24 consonant–vowel-consonant (CVC) words was presented at intensities of 40, 55, 70, and 85 dB SPL, and the phoneme scores were recorded. This session was again conducted in the CI centre, as usual.

Results

The demographic details of the six participants are given in Table 1.

Communication with the patient

Participants S1, S2, and S3 had no problems communicating with the audiologist because of their sufficient contralateral hearing or ability to lipread or because they had a partner with them to assist. With participants S4 and S6, oral communication was not possible because of insufficient hearing, and live written communication was established with the ZOOM chat function. Meanwhile, the patient could speak aloud to the audiologist. Participant S5 would have been able to communicate orally, but due to internet connection problems, the audiologists had to revert to written chat and counselling. The written chat option was perceived as comfortable in all three situations.

Quality of self-test

Four of the six patients had no problems with any of the self-tests (see all test results below). Participant S2 was initially confused with the audiometry self-test instructions in which he interpreted the buttons 'sound' and 'silence' as 'loud' or 'silent,' which resulted in an erroneous test procedure. After discontinuing the test to receive additional instructions by the audiologists, the procedure went well. The phoneme discrimination self-test also went well for this patient. Patient S4 had some difficulties with the phoneme discrimination self-test. In this test, the user clicks on the 'next contrast' button after having executed a previous contrast. Patient S4 had not really understood this part of the task, and the audiologist repeatedly had to click this button instead of the patient to proceed with the test. Both S2 and S4 are the oldest study participants, both aged 72 years.

Test results

The initial aided results for audiometry and spectral discrimination are given in Table 2.

Fitting

Table 3 summarizes the results of the fitting sessions, including electrode inactivation and electrical parameters changed by FOX. Fig. S1 (Supplemental Digital Content 2 (figure 3).docx) shows the home maps before and after the fitting session.

Four out of six subjects received a fitting session according to our standard procedure without special intervention by the audiologists. Subject S2 needed an intervention during fitting because of a non-auditory sensation. The participant complained about irritation in the throat when the implant was stimulated, especially while using his own voice. Therefore, the pulse width of the proposed FOX map was manually raised from 37 to 50 and the Threshold (T) and Comfort (C) levels were lowered accordingly with 18 clinical units, and that seemed to considerably reduce the patient's complaints. Patient S6 entered the self-fitting session reporting a high-pitched hiss and clicking sounds that she had experienced during the two weeks after the previous (i.e. switch-on) session. The self-fitting session was nevertheless conducted and was uneventful. One week later, however, the subject

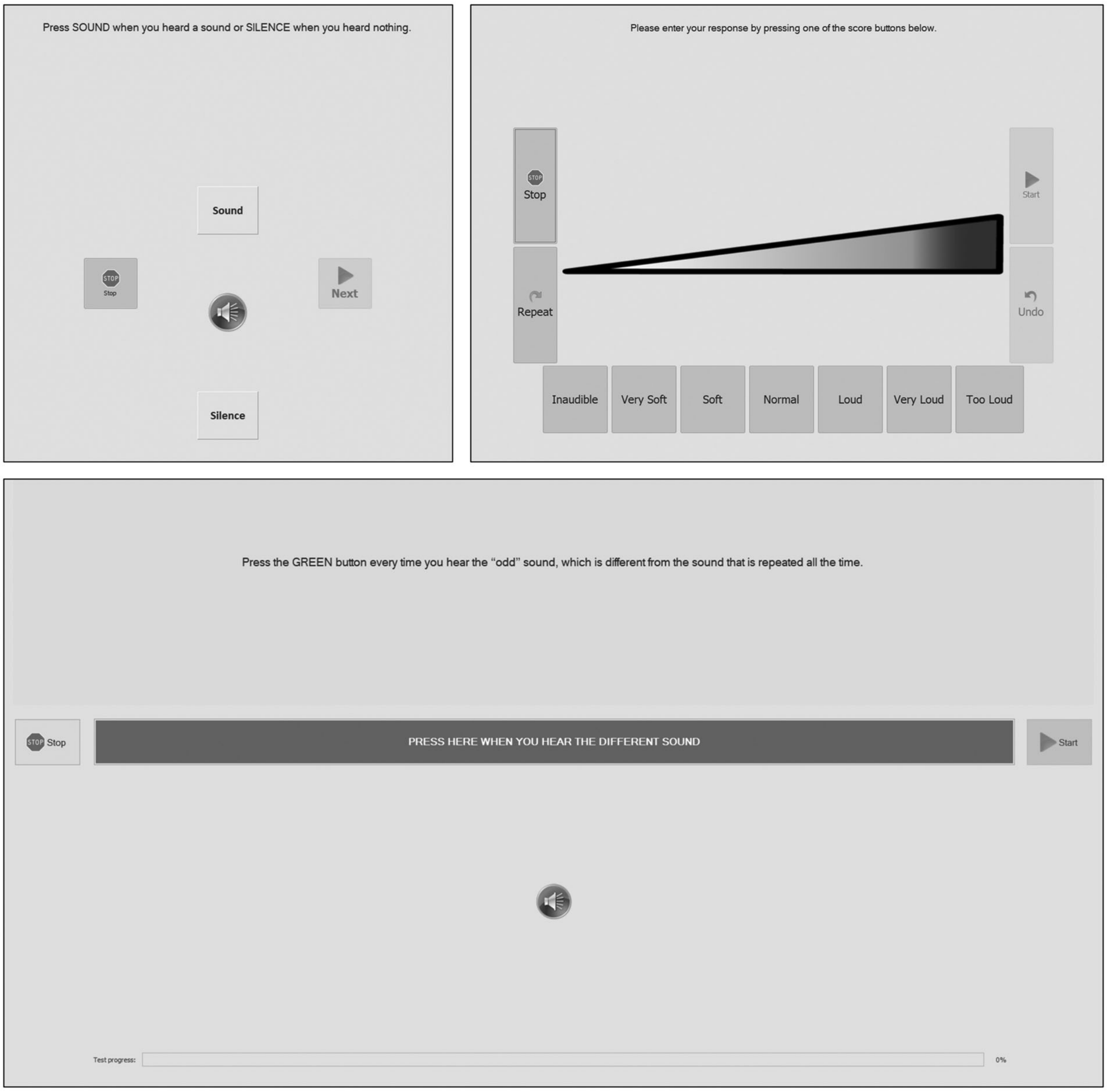

Figure 2 Screenshots of the self-test modules of Audiqueen. Upper left panel: Tonal audiometry, Upper right panel: Loudness scaling. Lower panel: Phoneme discrimination. The test subject receives detailed instructions before and during a test and can record his or her responses by clicking on the buttons through a touchscreen or with a computer mouse.

returned to the clinic because she did not tolerate the sound. Upon evaluation, her processor appeared to be malfunctioning and replacement with a new processor resolved the problem.

Questionnaire

The questionnaire and answers are depicted in Table S1 (Supplemental Digital Content 1 (table 4).docx). Despite two patients needing intervention from an audiologist during the self-tests, the instructions on the screen were perceived as clear and intuitive by most participants, and they generally felt comfortable performing these tests on their own (Questions 1-9). Five out of six participants had as much confidence in this kind of testing as in manual testing by an audiologist (Question 6). Although there were occasional connection problems, the patients generally experienced the fitting procedure as smooth (Question 10). During the fitting, five out of six patients found live contact with a CI audiologist from the CI centre essential (Question 12), and three out of six patients found the presence of a local audiologist essential

Table 1 Demographic details of the study participants

Subject number	Gender	Age at self-fitting	Mode of deafnessonset
S1	F	50	Progressive
S2	M	72	Progressive
S3	M	39	Progressive
S4	M	72	Progressive
S5	F	41	Progressive
S6	F	63	Progressive

Table 2 Initial psychoacoustic test results during the remote fitting

	S1	S2	S3	S4	S5	S6
Frequency [Hz]			*Audiometry thresholds [dB HL]*			
250	25	27	27	17	22	17
500	32	25	37	25	22	20
1000	37	25	32	27	22	17
2000	22	27	32	27	27	25
4000	17	30	60	27	22	45
6000	20	57	82	20	30	57
			*Phoneme discrimination results**			
# contrasts discriminated	19/20	19/20	19/20	13/20	20/20	18/20
Failed contrast	/ɛ/-/a/	/v/-/z/	/u/-/o/	/u/-/i/ /ɛ/-/a/ /u/-/o/ /ə/-/a/ /ə/-/o/ /ə/-/ɛ/ /y/-/i/		/u/-/y/ /y/-/i/

* The result shows the number of spectral contrasts that were successfully discriminated per total number of administered contrasts.

(Question 13). Despite this latter result, five out of six people would not hesitate to do these self-tests at home with the remote supervision of a CI audiologist (Question 18). In general, five out of six participants found the session as a whole practical and easy (Question 16).

Follow-up fitting session

During the third fitting session in the CI centre three months after switch-on, all subjects were assessed with a speech audiometry test, loudness scaling test, and for the sake of the study, a retest of the phoneme discrimination and audiometry tests with their home map. In subject S3, who received a manual map with a pulse width of 50 µs due to presumed non-auditory stimulation, the audiologist switched back to the original map with a pulse width of 37 µs. The non-auditory stimulation issue did not reappear, and the patient continued with the testing phase with the original FOX map.

The relevant test results for each participant can be found in Table 4. After performing the psychoacoustic tests, FOX again proposed a new map for all subjects, and speech audiometry was retested with this map. From the five patients who performed speech audiometry, four showed instantaneous improvement in speech perception phoneme scores with an average phoneme score improvement of 6%. The home maps before and after the fitting session are depicted in Fig. S2 (Supplemental Digital Content 3 (figure 4).docx).

Discussion

In this proof of concept, six adult post-lingual CI recipients were selected for the simulation of a self-fitting session in a controlled and supervised simulated home environment. The results illustrate that, compared to fitting in the CI centre, remote fitting using this setup does not introduce additional hazards for the patient. There is no reason to believe that possible hazards such as the observed non-auditory sensation would occur more than in regular fitting sessions. For this reason, the described procedures could be the first step in developing an autonomous self-fitting system. In this study, all steps were still carefully monitored and supervised by trained audiologists.

Table 3 Summary of the remote fitting session of each participant

	Number of Electrodes dropped	Global parameters changed*	Electrode-dependent parameters changed	Human intervention** during 'self-fitting' session
S1	None	No	Yes	No
S2	3	No	No	No
S3	3	Yes	Yes	Pulse width raised due to non-auditory stimulation
S4	None	Yes	Yes	No
S5	None	No	No	No
S6	3	Yes	Yes	No (but returned prematurely to CI centre after this fitting session because of processor malfunctioning, see text)

* Global parameters considered by FOX are T-SPL and C-SPL, pulse width and loudness growth. They are different from electrode-dependent parameters, which are T-level, C-level, gain and enabled/disabled.
** Human intervention refers to manually changing the fitting parameters.

Table 4 Outcomes of pure tone audiometry and speech audiometry during the third fitting session

		S1	S2	S3	S4	S5	S6
Frequency [Hz]				*Audiometry thresholds [dB HL]*			
250		25	25	20	N.A.	20	25
500		25	25	25	N.A.	20	25
1000		30	30	30	N.A.	20	20
2000		25	25	25	N.A.	25	30
4000		15	15	20	N.A.	15	30
6000		10	10	25	N.A.	30	25
				Loudness Scaling [loudness score]*			
250 Hz	35 dBHL	1,0	1,2	1,7	1,5	2,0	1,0
	50 dBHL	2,2	2,2	2,8	1,8	3,2	1,7
	65 dBHL	3,0	2,8	3,0	2,2	3,7	2,0
	80 dBHL	2,8	2,5	2,8	2,7	3,3	2,5
1000 Hz	35 dBHL	1,0	1,7	1,2	1,3	1,5	1,2
	50 dBHL	2,2	2,7	2,2	2,3	2,7	1,7
	65 dBHL	3,3	3,5	3,0	3,0	3,5	2,5
	80 dBHL	4,0	4,0	3,0	3,0	4,3	2,7
4000 Hz	35 dBHL	2,0	1,8	1,8	2,2	2,0	1,0
	50 dBHL	2,7	3,2	3,0	2,8	3,5	2,3
	65 dBHL	3,8	4,2	3,0	2,8	4,8	2,8
	80 dBHL	4,0	6,0	3,0	3,0	6,0	3,0
Intensity [dB SPL]				*Speech audiometry [phoneme score %]*			
40 dB	*Pre*	38	67	57	N.A.	56	18
	Post	69	68	63	N.A.	57	43
55 dB	*Pre*	64	60	64	N.A.	81	75
	Post	76	65	60	N.A.	78	69
70 dB	*Pre*	69	50	53	N.A.	72	82
	Post	74	60	51	N.A.	81	86
85 dB	*Pre*	56	49	56	N.A.	75	63
	Post	76	46	47	N.A.	76	74
Average	*Pre*	57	56	57	N.A.	71	59
	Post	74	60	55	N.A.	73	68
				Phoneme Discrimination contrasts correct after third fitting			
		19/20	20/20	20/20	19/20	20/20	20/20

* Loudness scores: 0 = inaudible; 1 = very soft; 2 = soft; 3 = normal; 4 = loud; 5 = very loud; 6 = too loud.
N.A.: In subject S4, audiometry was not performed during this session because of time, and speech audiometry was not performed because the patient was not yet able to perform open set CVC speech testing.

A number of technical flaws were encountered, such as problems with the wireless pod or with the WI-FI internet connection. At the time of the study, the wireless pod proved to be unreliable. After two participants, it was decided to proceed with the wired pod for the study. These are considered temporary problems that will be resolved by improved technology. It can be expected that the wireless pod will become much more reliable in the future.

The self-tests incorporated in Audiqueen were perceived as comfortable by all participants, who felt confident with this kind of testing. The instructions to the patients are of crucial importance, especially for elderly patients who may be less familiar with technology. For two out of six patients, the self-test execution was challenging. Optimizing the instructions, design, and interface of the self-testing modules may be considered, but even then, some subjects may remain incapable of performing a fully autonomous session.

In the future, it would be favourable if some prior screening could be performed to identify patients who would be eligible for such autonomous fitting sessions. Moreover, eligible patients could be trained or empowered on all aspects of the autonomous fitting session, such as handling the equipment and performing the self-tests.

In general, the participants felt at ease with the remote fitting experience. The availability of a supervising audiologist was felt necessary by the majority of them; however, the proximity of this supervision was not regarded as mandatory. Most participants would not hesitate to do testing and fitting at home. Both oral or written (chat) communication were judged successful and comfortable. It must be mentioned that, for the current study, self-fitting was organized in the early phase after switch-on, when patients still have doubts and questions and are uncertain regarding the new experience of CI hearing. In this stage, people typically need some counselling and reassurance. Should self-testing and self-fitting be organized in a later phase, the need for a supervising audiologist may become less important.

It must be noted that the assurance of the patient to perform a self-fitting at home, which was reflected in the questionnaire, could be influenced by the presence of the audiologist. However, it is not expected that fitting sessions two weeks after switch-on would be done routinely in a fully remote fashion in the future. This session was chosen only because a reliable speech audiometry self-test is not yet available, and the second fitting session typically does not require speech performance yet. It can be expected that established users with experience in handling their CI equipment will be even more comfortable to do this fully autonomously at home. On a regular basis, we see fitting sessions with long-term users in our clinic that have become so straightforward that they could easily be performed in a remote fashion, provided that the technology allows this.

In addition to the test battery described in the previous section, outcome testing for fitting purposes typically requires speech perception tests as well, especially in a later stage. Unfortunately, a self-test for monosyllable CVC word tests is not obvious. A few alternatives exist for automated speech audiometry testing, such as digit triplet tests (Cullington and Aidi, 2017; Smits et al. 2004) or open-set speech tests, where the patient needs to type the answers on a screen (Francart et al. 2009). The disadvantages of the above examples are that they are language-dependent and when a test is created in a new language, validation and normalization are required, which can be very time-consuming and resource intensive. Moreover, the latter type of testing requires written language competence, which makes the test less suitable for younger children and functionally illiterate adults. Other alternatives are based on automatic speech recognition, where the answer of the patient is recorded and then compared to the original wave file (Ooster et al. 2018; Vaerenberg et al. 2013b; Venail et al. 2016). The disadvantage of these methods is that they rely heavily on both microphone and recording quality. Hence, while efficient in controlled environments, they are less suitable for home-testing with, for instance, a smartphone.

Considering that the above technical impediments can be resolved, a scenario with CI recipients using a smartphone to perform audiological tests and writing an AI optimised map to their processor becomes realistic. It is unlikely that this will rule out the need for audiologists. Their role will remain crucial to decide which psychoacoustic tests are required to be run, to invite/instruct the CI recipients remotely, to monitor and evaluate the test session, and to judge the new map and accept it or overrule it.

For all this to become possible, there are still several technicalities to overcome. For instance, coupling the processor with the mini microphone and the wireless programming pod should become more user-friendly. The testing and fitting software would have to be modified for home use and should be available as smartphone apps. The fitting application FOX should evolve to a (semi-)autonomous decision-support system to enable it to write optimized maps directly to the processor. After years of experience and optimization in the clinic, our audiologists already consider FOX to be a reliable decision-support application. However, it still requires an expert audiologist to judge each map change as recommended by FOX and to either accept or overrule it. In this study for example, FOX improved the speech audiometry results instantaneously in four out of five patients without any intervention by the audiologist. While this improvement on such a small sample size may not be convincing, it must be noted that the capabilities of FOX to ameliorate speech performance were already established in a previous paper (Meeuws et al. 2017).

On the other hand, the expert audiologist needed to intervene with one participant who suffered from a non-auditory sensation. The current version of FOX cannot handle such an event. Another participant had a malfunctioning processor that was not detected during the remote fitting. Malfunctioning hardware will need special attention in telemedicine because it may not be as easily detected as it is in face-to-face interactions.

The use of psychoacoustical self-tests in audiology and fitting CI users from a distance has already been extensively discussed in the literature. To our knowledge, this is the first time that AI-based automated CI programming combined with psychoacoustical self-tests has been successfully performed. Although manual guidance from audiologists was still needed, due to the status of the equipment and AI engine, this could be the first step towards a fully autonomous home fitting.

Conclusion

This proof of concept study demonstrated that audiological self-assessment and remote CI fitting with AI under the supervision of an audiologist is feasible, at least for a number of CI recipients. The remote fitting was perceived as comfortable by both patients and audiologists. Currently, there are still a few challenges to be addressed, such as technological simplification and reliability, smoothening the instructional guidance, counselling the test subjects, and selecting which subjects are capable of executing testing and fitting autonomously. Especially in the early phase after switch-on, remote assistance by an expert audiologist remains essential and it will require some technical and regulatory adaptations before such a fitting can become a routine clinical practice.

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Supplemental data

Supplemental data for this article can be accessed 10.1080/14670100.2020.1757840.

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