Chapter 8
General discussion
The studies in this thesis aim to improve the clinical care pathway of adult cochlear implant (CI) users. The development, validation and clinical use of self-administered speech recognition tests were described in the first section of this thesis. The subsequent section described the prediction of speech recognition in quiet and in noise from fitting parameters and objective measures that are available to a clinician during a fitting session. The final section described the use of multimemory and automatically switching devices by CI users. The main findings of the studies are discussed in this final chapter. Furthermore, suggestions for future research and clinical implications are presented.

**Speech recognition assessment**

Currently, speech recognition tests are performed in the clinic in a sound-treated booth with calibrated equipment to create a controlled test environment. A clinician is needed to administer the tests and judge the responses given by the CI user. In the studies described in this thesis, we developed and evaluated the use of self-administered tests for CI users to assess their speech recognition at home. The home test setup comprises a tablet computer and an audio cable to directly present calibrated stimuli from the tablet computer to the CI sound processor. The tablet computer eliminates the need for a clinician to administer the tests, because the tests can be self-administered by the CI user and the correctness of the response is judged by an algorithm. The audio cable avoids the influence of loudspeaker quality, background noise and reverberation at the CI user’s home, thereby providing a controlled test environment and eliminating the need for a sound-treated booth like in the clinic. We have shown that the home tests are technically possible (chapter 2), that they are a valid alternative to tests in the clinic (chapter 3) and that CI users are generally positive about the possibility to perform self-administered speech recognition tests at home (chapter 3 and 4). Furthermore, we have shown that the home test setup can be used to assess other aspects of speech recognition as well, such as binaural speech recognition in noise of bimodal and bilateral CI users (chapter 5).

Several studies addressed the remote or self-assessment of speech recognition (Cullington et al., 2018; Cullington & Agyemang-Prempeh, 2017; Goehring et al., 2012; Hughes et al., 2012). Cullington and Agyemang-Prempeh (2017) used the remote speech recognition tests in combination with a questionnaire to identify CI users who would require intervention in the clinic. In a subsequent study, the tests were incorporated in a remote care tool (Cullington et al., 2018). In line with the studies in this thesis, the authors concluded that the majority of CI users are able and willing to assess their speech recognition at home, and that the frequent assessment of speech recognition can identify CI users who require intervention in the clinic. Goehring et al. (2012) and Hughes et al. (2012) compared speech recognition assessed at a remote location with a videoconference setup with regular testing in
a soundbooth and found poorer speech recognition scores at the remote sites. Background noise and reverberation were the most important factors that had a negative influence on speech recognition at the remote setting. The use of an audio cable diminishes the possible negative effects identified in the studies by Hughes et al. (2012) and Goehring et al. (2012), which is of paramount importance to prevent variation in scores as a result of the test environment. However, the functionality of the microphones cannot be assessed when using an audio cable, which is a disadvantage. Speech recognition assessed with an audio cable might therefore not fully represent speech recognition in daily life, but it might give a better indication of the potential speech recognition abilities of CI users than speech recognition assessed with a loudspeaker.

The speech recognition in noise scores obtained with an audio cable were better than speech recognition in noise scores obtained with a loudspeaker (chapter 3). In addition, several CI users obtained speech recognition in noise scores with an audio cable that were similar to speech recognition in noise scores of normal-hearing listeners (see Figure 2 in chapter 3 and Figure 1 in chapter 4). These findings are encouraging, but also suggest that sound processing is different for stimuli presented via the microphones (i.e., when a loudspeaker is used) or audio cable. We conducted some additional pilot testing to find explanations for this difference. As a first step, we explored the sound processor settings of the experienced CI users (who participated in the study presented in chapter 3) to find a possible link between settings and speech recognition in noise scores. However, due to the limited number of participants and the wide variety in sound processor settings (i.e., microphone directionality and noise reduction algorithms), no clear reason for the observed difference in speech recognition in noise scores could be identified. Subsequently, a pilot study was performed with 12 adult CI users in which the SNR-NR noise reduction algorithm was consecutively switched on and off. The tests were performed with continuous and discontinuous noise and with an audio cable. The results showed that speech recognition in noise was better for tests with continuous noise than for tests with discontinuous noise, which was in contrast to the results presented in chapter 2. Possibly, this is because the SNR-NR algorithm is more effective for higher SNRs, thus for CI users with poorer SRTs (Dawson, Mauger, and Hersbach, 2011). The study presented in chapter 2 included experienced CI users with relatively good (i.e., more negative) SRTs. Thus, the SNR-NR algorithm might have had no effect on the speech recognition in noise scores in these CI users.

The study with newly-implanted CI users (chapter 4) allowed us to further investigate the difference in speech recognition in noise scores obtained with a loudspeaker (clinic testing) or audio cable (home testing). The comparison revealed even a larger mean difference than in the study with experienced CI users (3.2 dB versus 1.6 dB previously). The tests in the clinic in this study, however, were conducted with a different type of masking noise
(i.e., discontinuous) than the masking noise used in the self-administered tests (i.e., continuous) from chapter 2. It was concluded that the scores obtained with the self-administered tests (i.e., audio cable and continuous noise) cannot be directly compared to scores obtained in the clinic (i.e., loudspeaker and discontinuous noise). If scores are to be compared, a reference measurement in the clinic with the home test setup is required. Based on these findings, we expect that the differences in speech recognition in noise scores are caused by a complex interaction between speech recognition scores, processor settings, noise reduction algorithms, silences in the masking noise and stimuli presentation mode. It has been demonstrated that some of the advanced sound processing features incorporated in modern CI devices (e.g., noise reduction and adaptive algorithms) improve speech recognition (see Wolfe et al. (2015) for an overview). However, it is unknown to what extent these advanced sound processor settings influence speech recognition scores when obtained with an audio cable.

It is likely that many factors make some unique contribution to the difference in speech recognition in noise scores assessed with the loudspeaker and those assessed with the audio cable. The acoustics of the sound booth may have a slight negative effect, and larger differences could arise between individuals due to head movements and differences in head diffraction. Further studies are required to investigate the causes of the differences in speech recognition in noise scores between the clinic and home tests.

**Further research**

Although the current self-administered test setup provides several advantages over the setup of the tests in the clinic, several aspects need to be dealt with before the tests are a viable alternative for tests in the clinic. First, the usability of the setup has to be improved to increase the number of CI users who will be able to use the technology required. The current setup of the self-administered tests is not suitable for all CI users, which was reflected by 2 out of 10 newly-implanted CI users who did not feel confident in using the technology required (chapter 4). Thus, it remains important to identify those CI users who are not able to use the technology required and provide them with care as usual. Whilst experienced CI users did not report any problems (chapter 3), one of the major complaints concerning the usability of the home tests in newly-implanted was the difficulty in connecting the audio cable to the sound processor and tablet computer. It is well known that newly-implanted CI users are less confident in handling their CI and are therefore somewhat reluctant in using accessories such as the audio cable. The usability of the home tests is expected to improve, if stimuli can be presented without the need of the audio cable that has to be connected. One of the recent developments that could lead to an improvement is the direct streaming of stimuli which is incorporated in the newest CI sound processor of Cochlear™.
Digital streaming could have an additional advantage if stimuli could be presented binaurally to bilateral CIs or a CI and contralateral hearing aid to assess binaural speech recognition of bilateral and bimodal CI users.

Second, to implement the self-administered tests in clinical care of CI users, the tests should be made available to users of other CI brands as well. Currently, the self-administered tests are limited to users of specific Cochlear™ sound processors, because of the need for an accessory socket to connect the audio cable. Likewise, the self-administered tests only allow binaural speech recognition assessment of bimodal CI users with contralateral hearing aids that have direct audio input. Furthermore, the tests have been developed for use on a Windows tablet computer. The accessibility of the tests can be improved further if the tests are made available for other platforms as well, such as laptops or mobile phones.

Third and final, further research is necessary to identify the causes of the difference in speech recognition in noise when assessed with an audio cable or loudspeaker. The first step would be to investigate possible differences in the signal that is presented to the internal receiver if stimuli are presented via an audio cable or loudspeaker. Subsequently, the influence of different sound processor settings, such as microphone directionality or noise reduction algorithms, or individual differences, such as head movements, should be systematically investigated. Possibly, this could lead to improvements in the signal processing and will thereby hopefully result in improvements in speech recognition performance of CI users.

**Future perspectives**

More frequent assessments of speech recognition that is possible with the home tests will provide clinicians with a far more detailed insight in both the current performance as well as the progression in speech recognition than currently available. This insight enables early identification of CI users for whom speech recognition performance deteriorates or does not improve as expected. For these CI users, auditory training can be intensified or appointments can be scheduled to fit the sound processor. This insight could also be used to reduce the number of visits and associated time spent in the clinic for those CI users for whom speech recognition is satisfactory and who therefore do not need to bring extra visits to the clinic. Thus, the information gathered with the home tests can be used to schedule visits based on the clinical need and patient’s requirements, as opposed to the current fixed schedule (i.e., 10 visits for a total of 20 hours within the first year after implantation). Individualized scheduling will most likely result in a significant reduction in the number of visits to the clinic, thereby lowering the demand per CI user on CI centres, whilst the information available to clinicians is more detailed than before.
The self-administered tests do have more potential than solely a reduction in the number of visits. For instance, clinicians can provide CI users with multiple sound processor settings. Subsequently, CI users can perform speech recognition tests with the different settings to find out which settings provide optimal speech recognition. The self-administered tests can also be used to assess speech recognition more often than the current annual assessment in the clinic. For instance if the CI users or their friends and family have doubts about their own speech recognition performance or do want to track their own performance over time. This might also be of use for clinicians, because the current annual assessment of speech recognition in the clinic only provides snapshots of performance.

From a CI user perspective, the self-administered tests allow CI users to assess their speech recognition, from the comfort of their home, more frequently and independently of visits to the clinic. The home tests provide insight in their progression in speech recognition, which has not been available to CI users so far and might motivate them to improve their speech recognition further. If appointments are scheduled based on their individual’s needs, the possible reduction in the number of visits could lead to a significant reduction in time spent away from work or family. Not only because they spent less time in clinic, but also in time spent travelling to their CI centre. This might not be as big of a problem for CI users in The Netherlands, however, when considering other countries such as Australia, where clinics might be located hours away from the CI users’ home, this can have a significant impact on the CI user’s life.

The interest in the use of telehealth technologies within the hearing healthcare field is growing (Pagliaong et al., 2018). Recently, Bush et al. (2016) identified 12 studies that present on the remote delivery of CI care, including intraoperative testing (Shapiro et al., 2008) and programming (Botros, Banna, and Maruthurkkara, 2013; Eikelboom et al., 2014; McElveen et al., 2010; Ramos et al., 2009; Wesarg et al., 2010). Although the interest in the use of these technologies is growing, they are only applied to a limited extent worldwide and are currently not part of care as usual for CI users in the Netherlands. Further research is needed to increase the penetration and efficacy of telehealth technologies in clinical practice. Telehealth applications, such as the MyHearingApp (chapter 4) in which the self-administered tests were incorporated, have the potential to facilitate self-care of CI users and thereby increase their involvement in their care. If parts of the CI care can be relocated to the CI user’s home, this can further decrease the demand per CI user placed on the CI centre. The functionalities currently implemented in the MyHearingApp (Philips et al., 2018) could be combined with other aspects of CI care, such as exercises for auditory training, remote fitting, and assessments of device and electrode functioning (e.g., impedances and audiometry).
Considerations for clinical practice

The development of the self-administered speech recognition tests provided several useful insights to be considered for current clinical practice. The first consideration is related to the masking noise used in speech recognition in noise testing. The standard clinic tests to assess speech recognition in noise use discontinuous noise, with quiet periods between stimuli. Modern CIs contain advanced sound processing features (i.e., noise reduction and adaptive algorithms), that are relatively slow-acting; with time constants in the order of seconds. The quiet periods between stimuli in the discontinuous noise prevent these features to become fully active, thereby possibly affecting speech recognition in noise scores. Therefore, the effect of another type of masking noise (i.e., continuous noise) for speech in noise testing was investigated in this thesis. Here, the noise is presented continuously throughout the test. Although we expected to find better speech recognition in noise scores with continuous noise, no significant differences in speech recognition between continuous and discontinuous noise were found for both normal-hearing individuals and CI users (chapter 2). In a different group of CI users (chapter 4), however, we found a mean difference of 3.2 dB between clinic tests with a loudspeaker and discontinuous noise and the self-administered tests with an audio cable and continuous noise in a group of newly-implanted CI users. This suggests that discontinuous noise does influence speech recognition in noise scores, because the difference is larger than the difference between tests with a loudspeaker and audio cable reported before (1.6 dB in experienced CI users). However, the tests in experienced users were conducted with continuous noise, and, as previously mentioned in this chapter, it is currently unknown what the exact underlying cause of the difference in speech recognition in noise scores assessed with the loudspeaker and audio cable is.

The second consideration is related to the word lists (NVA lists) used for the assessment of speech recognition in quiet with monosyllable words. The speech recognition in quiet tests use lists of 12 words. In total, there are 45 lists available, but only 15 lists contain unique words. The remaining lists contain the same words as the first 15 lists, but in a different order. The results of chapter 3 revealed that there are large differences in scores obtained with different word lists, and therefore suggest that the lists are not equally intelligible for CI users. Based on these results, the lists used for the speech recognition in quiet tests in newly-implanted CI users (chapter 4) were chosen automatically and at random. In clinical practice however, word lists are chosen by the clinician. If, by incidence, speech recognition is assessed with less intelligible lists of words, this might result in lower scores. This would suggest a deterioration in speech recognition in quiet, while it might actually be caused by the differences in word lists. It is therefore recommended to only use lists with equal intelligibility, or to normalize the lists for speech recognition assessment in CI users.
Fitting of the sound processor

The fitting and fine-tuning of the CI sound processor is important to achieve optimal speech recognition performance for CI users. Several important parameters that predict speech recognition in quiet and in noise were identified (chapter 6). The findings of the prediction models led to the following clinical recommendations for CI users with late onset of severe hearing impairment (i.e., onset after the age of seven years): (1) assess sound-field aided thresholds and adjust T levels if the mean aided thresholds are higher than the target of 25 dB SPL, (2) set T levels at threshold and increase C levels to ensure a large dynamic range, preferably as large as 40-60 CL, and (3) be aware of impedance profiles across the array with high variation. For CI users with early onset of severe hearing impairment (i.e., onset before the age of seven years) higher T levels were associated with worse speech recognition in quiet and in noise. However, it is not recommended to lower T levels in this group of CI users, because the higher T levels are most likely related to the duration of deafness (i.e., less surviving ganglion cells along the cochlea) in this group of CI users. The predictors of speech recognition in quiet and in noise were largely similar. Thus adjusting fitting parameters to optimize speech recognition in quiet will most likely also result in an improvement of, or will at least not be at the expense of, speech recognition in noise.

Further research

The generalizability of the results to other populations of CI users is limited. For instance, CI users with prelingual onset of hearing impairment or deviating MAP parameters were excluded. Vaerenberg et al. (2014) have shown that fitting practices across different CI centres vary widely. Therefore, the results of the current study (chapter 6) are not only limited to the CI population studied in this thesis, but may also be different for CI users fitted in other CI centres. Therefore, it is recommended to investigate the importance of the identified predictors in CI users of other CI centres, as well as CI users outside the homogeneous group that was studied in this thesis. Two suggestions for setting up such a study are: (1) the prediction model described in this thesis can be externally validated in a dataset with other CI populations or CI users from other CI centres, or (2) the procedure to build the prediction models as described in this thesis can be used to identify predictors of speech recognition in CI users that were excluded from the current study or CI users from other CI centres.

In addition to the generalizability of the results, it is important to assess the clinical relevance of the findings of this thesis. The predictors that were identified can be used to select a group of CI users in which an improvement in speech recognition could be expected when certain fitting parameters are changed. The group has to be selected based on their fitting parameters, specifically if these parameters deviate from the fitting parameters identified through the prediction model. Subsequently, a cross-over study design (e.g., A-B-A) can be
used to assess speech recognition with the old fitting (i.e., A), and new fitting (i.e., B) based on the prediction model. Such a study is needed to prove that the predictors that were identified can be used to improve speech recognition of individual CI users.

**Future perspectives**

Vaerenberg et al. (2014) identified many different fitting practices across CI centres. In addition to the difference in fitting practices across CI centres, there are no fitting rules available to clinicians, comparable to the ones used in hearing aid fitting (e.g., NAL and DSL prescription rules). The identification of important predictors of speech recognition may guide audiologists in their fitting practices and improve the performance of CI users. However, the combination of the differences in fitting practices and the lack of targets make it difficult, or even impossible, to compare outcome measures and to judge which settings yield the best results. Defining targets and outcome measures might be a next step to optimize fitting practices and improve outcomes. The Fitting to Outcomes eXpert (FOX) system (Govaerts et al., 2010; Vaerenberg et al., 2014; Vaerenberg et al., 2011) is an example of a software application that suggests adjustments to the fitting, based on target outcomes. In that case, target outcomes can be set by a clinician and, if targets are not met, changes to the fitting can be suggested. Systems like FOX may provide effective tools to set targets and optimize fittings, which can help clinicians to improve outcomes.

**The use of manually and automatically switching programs**

It is well known that speech recognition remains a challenge for CI users in many of the daily encountered listening situations. Therefore, CI users are often fitted with manual and/or automatic selection programs for various listening situations. A review of the literature (chapter 7) revealed that there is remarkably little evidence available on the use and appreciation of these features in users of hearing aids, whilst no studies were identified that included CI users. The review indicated that some hearing impaired individuals use the possibilities of manual switching hearing devices, and that an automatic switching device might be a good solution for those who are not able or willing to manually switch between programs for various listening environments. For others, satisfying results can be obtained with an automatically switching program in combination with manual programs. Through the scoping review (chapter 7), several characteristics of CI users who would potentially benefit of multitemory devices could be identified: (1) users must indicate a clear need for better hearing in various, often encountered, listening environments, (2) users must understand the use of a multitemory device and be able to use either a switch button or remote control to change settings (3) users must be able to assess the listening environment and change settings accordingly, and (4) users must be aware of the different programs.
The findings of the scoping review were used to design an experimental study to investigate the use of manually and automatically switching programs for various listening environments by 15 adult CI users. A cross-over study design was used in which Cochlear™ CI users alternatively used two manual programs or one automatic program for three weeks. Datalog information is stored on the sound processor. This datalog information contains information about the listening environments classified by the automatic program, and the use of the manual programs. This information was used to investigate whether CI users select the appropriate program in specific listening environments. In addition to the datalog information, the experiences with and preferences for either manual or automatic program selection were evaluated.

The automatic program incorporated in modern Cochlear™ sound processors classifies six listening situations (i.e., music, wind, speech, speech in noise, noise and quiet) and alters the microphone directionality (i.e., omnidirectional, fixed or adaptive directional) based on the identified listening environment. For the experimental study, the manual programs were based on the selections of the automatic program. However, only two programs were included. One program was included for quiet listening environments with the omnidirectional microphone (i.e., listening environments classified as music, speech, and quiet). The second program was included for noisy listening environments with the directional microphone (i.e., listening environments classified as wind, speech in noise, and noise).

An extensive counselling session was performed at the beginning of the three week study period in which the participants used the manual programs. In this counselling session, attention was paid to several of the characteristics identified through the scoping review (see above). First, the characteristics of the different programs were explained. Subsequently, the participants were exposed to a variety of listening situations to train them in assessing the situation and select the most appropriate program. The listening situations were presented in a room where the participant was surrounded by eight loudspeakers. Examples of the simulated listening situations are: having a conversation with someone in a quiet listening environment (i.e., target speaker presented at 0°) and having a conversation with someone in a busy restaurant (i.e., target speaker presented at 0° and four interfering speakers presented at 45°, 135°, 225°, and 315°). Finally, a listening situation was presented to the participant to let them experience the difference between the speech in quiet (omnidirectional) and speech in noise (directional) programs. Thus, at the end of this session, participants were (1) expected to understand the use of the manual programs and to be able to switch between them, (2) able to assess quiet and noisy listening environments and choose the appropriate program, and (3) aware of the difference between the two programs.
Chapter 8

An important aspect for the use of manual programs for various listening environments is that the programs provide benefit in different listening environments. Therefore, speech recognition in noise was assessed to examine the benefit of the adaptive directional microphone over the omnidirectional microphone in a listening environment with spatially separated speech and noise. As expected, all participants except for two, performed better with the adaptive microphone directionality than with the standard microphone directionality (mean SRT -6.2 dB SNR versus -4.0 dB SNR, respectively. See Figure 1).

The datalog information of the participants showed that they left their CI in the default setting (program 1) for 61% of the time when they had two manual programs available (left panel of Figure 2). This is in line with previous studies that have shown that hearing device users tend to leave their devices in the default setting (Banerjee, 2011; Cord et al., 2002; Searchfield et al., 2018; Van den Heuvel, Goverts, and Kapteyn, 1997). The omni- and directional programs were randomly assigned to either program 1 or program 2. Thus, half of the participants had the program for quiet environments in program 1, whilst the other half had the program for noisy environments in program 1. The datalog information shows that the program for quiet environments is used 60% of the time (middle panel Figure 2).

Thus, despite the counselling session, participants mainly used program 1. Several reasons were mentioned by the participants. The first and foremost mentioned reason was that programs were not sufficiently different, which was also identified as an important factor in the scoping review (Chapter 7). Some participants mentioned that there was a noticeable difference between the programs directly after switching, but that the difference was less noticeable after some time. Another frequently mentioned reason was that participants reported that they did not find themselves in varying listening environments on a regular basis. They reported that they spent most of their time in quiet listening environments and refrain from noisy situations because of their hearing impairment. The datalog information revealed that participants indeed spent most of their time in quiet environments (70.7%), compared to noisy environments (29.3%) (right panel Figure 2).

At the end of the study, 10 out of 15 participants preferred the automatic program selection. The main reasons that were reported were mostly related to the ease of use, because the CI assesses the listening situation and changes the settings accordingly, without CI users having to worry about selecting the appropriate program and constantly being reminded of their impairment. The remaining five participants preferred the manual selection of programs. These participants reported to prefer to be in control of their settings, because they felt that the automatic switching program did not always choose the appropriate settings.
Figure 1. Speech recognition in noise with standard (i.e., omnidirectional) microphone directionality (circles) and BEAM (i.e., directional) microphone directionality (triangles).

In conclusion, as already substantiated by the results from the scoping review, the questionnaires used in the current study showed that an automatic program, either in combination with manual programs, might be a good solution for the majority of CI users. The manual programs are valued by CI users who want to have control over their own device. Further investigation of the data will be performed to investigate whether CI users are able to select the most appropriate program for specific listening situations. This investigation is of paramount importance for the final recommendations about the use of manual programs.

Further research
The listening goals of CI users in the listening environments encountered are not taken into account in the selection of settings by the automatic classifier. This was also illustrated by several participants of the experimental study, who reported to have difficulties with having a conversation while an airplane flew over. In that case, the automatic classifier registered the noise coming from the airplane and subsequently changed to the directional microphone which impaired intelligibility of the speech in that specific listening situation. Further research is necessary to optimize the classification of the automatic program. Until then, a combination between the automatic program and customized manual programs seems valuable for CI users who want to have control over their device and encounter listening environments that are not properly classified by the automatic program. However, as mentioned above, further investigation of the data is required before the final recommendations on the use of automatic versus manual switching programs can be made.
In our study, the volume and sensitivity control were disabled to prevent CI users from creating additional differences between the two manual programs. Thus, the settings evaluated in the experimental study (i.e., only two programs, and fixed volume and sensitivity and sound processing features) only represent a subset of the possibilities of modern CIs. Future research could evaluate the use of the advanced sound processing features, for instance to create additional differences between programs for various listening environments. Furthermore, the volume and sensitivity control could be enabled for some CI users, because they might benefit from volume or sensitivity changes only and do not necessarily need multiple programs. However, research in this thesis has shown that volume and sensitivity changes can influence speech recognition outcomes negatively (chapter 6). Therefore, the impact of adjustments to the volume and/or sensitivity should be emphasized to the CI user.

Several aspects identified to be important in the scoping review could not be addressed in the experimental study and therefore require further study. First, the experimental study comprised two periods of three weeks each, to evaluate the automatic and manual programs. Although all participants were experienced CI users, they might need time to acclimatize to new settings. Also, CI users might be aware of the different programs in the context of the study, but might forget what the different programs are for once the study is finished. Therefore, it is recommended to evaluate the long-term use of the automatic and manual programs. This was well illustrated by one of the participants who used four programs prior to the study, but left her CI in one of them when she forgot what the different programs were for.

Second and final, it is well known that laboratory settings do not optimally reflect daily life situations. For instance, the difference between the two manual programs might be very clear in the controlled environment of a sound-treated booth, but might not be so obvious when listening in daily life. Furthermore, the counselling session was done in a room with eight loudspeakers, in which daily life situations were simulated. Examples of these simul-
ed situations were having a conversation with one person in a quiet environment, or talking to someone in a busy restaurant. Although it is very difficult to create listening environments in a laboratory setting that are truly representative of daily life environments, they might help CI users to get familiarized with different listening environments (i.e., quiet and noisy listening environments) that are represented by the manual programs. Alternatively, recordings of daily life situations can be used.

**Future perspectives**

It is suggested to provide CI users with an automatic program, unless they indicate a clear need for manual programs to accommodate for specific listening environments. Then, either a combination of automatic and manual programs or only manual programs can be provided. However, CI users should be clearly instructed on the settings they are provided with, even if it only concerns the automatic program. CI users should be counselled on the use of the programs in various listening environments and should be familiarized with the difference between the programs. A counselling session can be done within 10 minutes, and is considered important for the use and appreciation of the different programs. Therefore it should be implemented in current care. Finally, the use of multiple programs should be regularly evaluated, to prevent CI users from forgetting what the different programs are for.
Chapter 8

General conclusions

The rehabilitation after cochlear implantation is lifelong and includes the assessment of outcome measures and the fitting or fine-tuning of the sound processor. Our findings indicate that self-administration of speech recognition tests at home is a viable alternative to administration of tests in the clinic. With this improvement, CI centres can identify and spent their resources on those CI users who require intervention in the clinic, and reduce the number of visits for CI users who do not have a clinical need. Although the current self-administered test setup provides several advantages over the setup of the tests in the clinic, further research and development is needed prior to implementation in clinical care of CI users. The usability and availability have to be improved to increase the number of CI users who will be able to use the self-administered tests, and further investigation is required to investigate the differences in speech recognition in noise scores between clinic and home tests.

The mean aided thresholds, mean electrical dynamic range, mean T levels, and measures to express the impedance profile across the electrode array were identified as predictors of speech recognition in quiet and in noise. The identification of these predictors of speech recognition in quiet and in noise can be used by clinicians and CI centres to improve their fitting practices and subsequently improve the performance of CI users. Future research should assess the clinical relevance of predictors identified in this study.

The automatic program, or a combination of manual and automatic program selection, will provide satisfactory results for the majority of CI users. It is therefore suggested to provide CI users with an automatic program, unless they indicate a clear need for manual programs to accommodate for specific listening environments. Further research is required for the final recommendations on the use of automatic versus manual switching programs.