Chapter 7

GENERAL DISCUSSION
This thesis aimed to obtain scientific insight into how hearing impairment may impact the lives of adults, and the determinants and consequences of a deterioration in speech recognition ability over time. In this final chapter, the main findings are presented first. Then methodological issues are discussed and recommendations for future research are given. The last section describes the clinical implications of the results. This chapter will end with a list of major conclusions.

**MAIN FINDINGS**

**Comorbidity and hearing**

Chapters 2 and 3 studied the issue of comorbidity, with impaired hearing ability being the index chronic condition. In Chapter 2 associations between hearing ability in noise, as measured by the online National Hearing Test (NHT; Smits et al., 2004; 2006), and a list of 27 self-reported chronic conditions were determined. Cross-sectional data of 890 hearing-impaired and 975 normally hearing adults aged 18 to 70 years were analyzed. Overall, the co-occurrence of chronic conditions was more common in adults with hearing impairment than in their normally hearing peers. Multinomial regression models revealed significant associations between poorer hearing ability and dizziness causing falling, types of arthritis different from osteoarthritis and rheumatic arthritis, and diabetes. The associations remained significant after adjustment for age and gender. Our results are in concordance with a similar study in older adults where 12 chronic conditions were examined (Crews & Campbell, 2004).

In Chapter 3, the issue of comorbidity was viewed from another perspective. Asking participants about which chronic conditions they currently encounter or had previously experienced in the last twelve months is one method of determining an individuals' health status (as applied in Chapter 2). Another option is asking participants to report their medication use. This is what we explored in the study presented in Chapter 3.

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Logistic regression models were built to investigate associations between hearing ability in noise and medication use, as grouped per organ or system that the medication acts on (e.g., alimentary tract and metabolism; blood and blood forming organs). Worse SNR (i.e., poorer hearing ability) was not found to be associated with medication use (yes/no) nor with polypharmacy, but the association with medication for diabetes seemed to remain, even after adjustment for confounding variables. This finding confirms and strengthens the conclusion regarding the co-occurrence of diabetes with hearing disability, as reported in Chapter 2. It also supports the conclusions of recent review studies and meta-analyses (Horikawa et al., 2013; Akinpelu et al., 2014). In contrast to the results from Chapter 2, no associations between hearing ability and medication for dizziness causing falls or arthritis were found in Chapter 3.

In theory, many pathways about the occurrence of two chronic conditions within the same individual can be modeled. In the nineties, Neale and Kendler simulated different statistical models of comorbidity (Neale & Kendler, 1995). They outlined some important factors leading to “false” comorbidity: by chance, by sample bias when sampling clinical patients, or by population stratification. When reviewing these possible biases, in the light of the current NL-SH results, it seems that the impact of these biases is relatively small. The NL-SH sample is a convenience sample rather than a clinical sample, reducing the impact of sample bias. Population stratification does not influence the findings, as the main goal of the NL-SH was to study the importance of hearing in daily life, rather than the study of some specific subgroups of participants with regard to diabetes and hearing. Our results supporting an association between hearing and diabetes can be explained by the reported histological changes in the inner ears of diabetic people. For instance, the thickening of the walls in the vessels of the basilar membrane and the stria vascularis has been reported in diabetic people (Fukushima et al., 2005; Fukushima et al., 2006; Austin et al., 2009). Other explanations for this finding are described in the paragraph “Comorbidity in hearing health care” below.

### Participation in work: differences between adults with and without impaired hearing ability

The cross-sectional associations between hearing ability and parameters of socioeconomic status, and between hearing ability and participation in different
categories of work were determined in Chapter 4. The concept of work was given a broad interpretation: both participation in paid and unpaid work (e.g., performing voluntary or household work) were examined in NL-SH participants as well as socioeconomic status, participation in education, and retirement age. Baseline data of 1888 participants aged 18 to 64 years were analyzed. It appeared that participants with poorer hearing ability in noise were less likely to be in the upper categories of educational level and income compared to their good hearing peers. Significant associations were found between poorer hearing ability and a lower likelihood of paid work, being a student, or taking early retirement. The participants with poorer hearing ability were more likely to look for work or to be unfit for work.

Over 60 percent of the adults with impaired hearing ability reported to have paid work. Although this percentage is somewhat lower than in the normal hearing ability group (68 percent), it demonstrates that the participation in paid work amongst people with hearing problems is high. Previous NL-SH results showed that adults with hearing impairment perform the same level of work productivity as their normally hearing peers if they receive social support from their managers and colleagues (Nachtegaal et al., 2012). The current results are in agreement with this finding, which underlines the importance of rehabilitation programs in audiology, specifically for adults in the workforce. Such a program is currently offered at the VU University Medical Center and is known as the Vocational Enablement Protocol in Audiology (Gussenhoven et al., 2012). Supporting people with hearing impairment to help them to successfully enter or re-enter the workforce is important, especially in challenging economic times when changing jobs is difficult.

**Deterioration in hearing ability over time, and its potential psychosocial consequences**

Chapter 4 describes the first follow-up results of the NL-SH study. Baseline and five-year follow-up data of 427 participants were analyzed to determine the change in hearing ability over time. A statistically significant deterioration in Speech-Reception Threshold in noise (SRTn) of 0.38 dB Signal-to-Noise Ratio over five years was determined in adults 18 to 70 years at baseline. Consequently, on average, adults over a large age span have increasing difficulties of speech recognition at less favorable Signal-to-Noise Ratios (SNRs) over these years. An acceleration in the decline in speech recognition was
observed in the age group of 50 to 59 years. Results from linear regression models, accounting for the phenomenon of regression towards the mean, showed that the mean deterioration over five years for the 50 to 59 years age group was 0.64 dB SNR larger than in the 18 to 39 years age group. Gender, educational level, initial level of speech recognition, and the number of chronic conditions were not found to be significantly associated with a decrease in speech recognition over five years.

These change in SRTn scores have to be interpreted in the light of the steepness of the speech recognition function of the NHT, which is approximately 20 percent per dB. Thus an average change of 0.64 dB in the age group of 50 to 59 years corresponds to almost 13 percent loss in speech recognition in the most difficult listening situations. It has been reported that a 5-dB shift in SRTn corresponds – on average – to an approximate 40-dB difference in pure-tone thresholds (Smits et al., 2004). This means that the change of 0.64 dB in SRTn would correspond to approximately 5-dB difference in pure-tone thresholds.

Deterioration in hearing may have an impact on adults’ psychosocial functioning over time. In Chapter 6 the longitudinal relationship between hearing ability in noise and psychosocial health outcomes was investigated. Loneliness, anxiety, depression, distress, and somatization were included as outcomes, and multiple regression analyses and sophisticated statistical models were applied. One of the main outcomes is that as averaged over time, poor hearing ability in noise was associated with emotional and social loneliness. In only some subgroups of participants (those that got married in the five-year study period and those who did not use hearing aids), also a decline in hearing was found to be associated with an increase in social loneliness. Although this result may be surprisingly at first glance, it may be that due to changes in social roles or the need to start new relationships the decline in hearing results in lower feelings of being socially embedded.

No significant longitudinal associations appeared between a change in hearing and a change in anxiety, depression, distress, or somatization. This is in agreement with results of the Longitudinal Aging Study Amsterdam (LASA) where longitudinal relationships were also reported between hearing ability and emotional and social loneliness, but not with depression and anxiety (Pronk et al., 2014).
One may suggest that the variation of hearing ability between participants (cross-sectional relationship) associates stronger with loneliness than the individual hearing deterioration over five years (longitudinal relationship). However, some caution is needed when interpreting these results as the measurement error was considered as relatively large and the systematic changes over time were relatively small in our study. It can also be that other factors, such as personal or environmental factors, may underlie these relationship with psychosocial health rather than a hearing decline. Examples of personal factors can be concepts related to vulnerability or resilience.

**METHODOLOGICAL CONSIDERATIONS FOR WEB-BASED STUDIES**

Web-based studies, such as the NL-SH study, have their advantages and disadvantages compared to other sampling methods. Advantages include the relatively low costs (due to direct storage of the answers in a database) and the ease of inviting a large group of participants via the Internet. In addition, participants from a variety of geographical distribution and socioeconomic background can participate online, as travel time and travel costs do not influence their ability for partaking (Gosling et al., 2004; Crump et al., 2013). However, Web-based studies yield some methodological considerations which will be discussed in more detail below.

**Representativeness of an Internet sample**

Representativeness of a study sample is always an issue for consideration in cohort studies. It refers to the generalizability of the research findings to the general population (Bhopal, 2002). The NL-SH is a convenience sample, which means that interested adults can subscribe themselves into the study. This leads to a somewhat selected sample in terms of gender distribution (more women participating) and educational level (larger proportion of higher educated people than in the general Dutch population). However, as the NL-SH is a large cohort with considerable variety among participants with regard to their demographic, socioeconomic and health status, it is possible to study differences between various groups of participants. To illustrate, in Chapter 4, we compared the work status of adults with and without hearing impairment. In all statistical regression models potential confounding factors were taken into account by adding the variables age and gender into the models. Following this procedure, it was feasible to reliably
estimate the association between a determinant (hearing ability) and the outcome (participation in paid work).

In prospective studies selective loss to follow-up may also lead to a lower representativeness of the results. As described in Chapter 5, we performed extensive statistical analyses to determine the loss to follow-up between baseline and the five-year follow-up measurement of the NL-SH study. Younger participants, those with better hearing ability, those with a lower educational level, and those being a single parent were more likely to drop out. The question arises what the specific reason for this loss to follow-up was. We therefore made some telephone inquiries in which the contacted participants gave various reasons, including having overlooked the post in their mailbox, no time to participate, or that they did not remember that they subscribed themselves online some years ago.

**Repeated measures of online speech-in-noise tests**

Unique parts of the NL-SH study are that speech recognition is measured repeatedly over time via the Internet, and that the NL-SH study sample consists of adults over a wide age range. Although more and more online applications including speech-in-noise tests are becoming available (e.g., Molander et al., 2013; Dawes et al., 2014) the NL-SH is the only longitudinal dataset to date. The advantages of such an Internet version of the NHT are that participants can perform the test at their own pace and in their own environment. However, it has to be kept in mind that obtaining results that are comparable over time, in terms of equipment and hearing aid technology used, may be better guaranteed in studies where the speech-in-noise test is performed under supervision (such as in the LASA study, Pronk et al., 2014).

NL-SH participants may choose themselves whether they use speakers or headphones to perform the test. It must be realized that speech reception thresholds measured over headphones are on average lower (i.e., better) than thresholds measured over a speaker (Smits et al., 2006), which may lead to some extra variation amongst the results. When analyzing outcomes of one measurement, this variation seems not to be a large problem (Nachtegaal et al., 2009), but when analyzing repeated measures of the speech-in-noise test there is a need for strict criteria. In Chapters 5 and 6, only SRTn scores of participants who performed the test twice unaided and with the same transducer (either
speaker of headphone) were included in the analyses to determine changes in SRTn over a period of five years, and the psychosocial consequences. As a result, not all available SRTn data of all participants of the two NL-SH measurement rounds could be analyzed. However, by applying these strict criteria, we were able to compare the results with other studies, such as the LASA study (Pronk et al., 2013; Pronk et al., 2014). It is recommended to take this point of comparability of NHT outcomes into consideration when planning new follow-up measurements in the NL-SH study.

RECOMMENDATIONS FOR FURTHER RESEARCH

Comorbidity in hearing health care

Comorbidity is a highly complex topic, both in terms of measuring the construct and in terms of investigating the underlying mechanisms leading to comorbidity. In the current thesis, in particular, the relationship between diabetes and poorer hearing ability emerged (Chapters 2 and 3) and therefore the comorbidity between these will be further discussed.

The findings represented in these studies underline the need to further address and explore this issue of comorbidity. Figure 1 describes some possible pathways between hearing disability and diabetes where risk factors for both diseases can be independent or dependent. It is also possible that a causal relationship exists between the two. To date, histological changes in the inner ears of patients with diabetes have been reported, but underlying risk factors and their relationships have not been studied in that detail. In addition, it may be that cardiovascular is a mediator in the relationship between diabetes and hearing disability. These pathways underlying the comorbidity between diabetes and hearing need further investigation in existing and future prospective epidemiological studies. Longitudinal data, such as those of the NL-SH study, are needed to examine cause and effect in the relationship. Not only pathways of comorbidity relating to the etiology of hearing problems need attention in research. Comorbidity is also relevant in hearing rehabilitation. For instance, the comorbidity between vision and hearing problems is quite common in adults aged 50 years and older (Vreeken et al. 2014). Also, when diabetes is a factor, the focus may be on vision, as a well-known complication of diabetes is retinopathy (WHO, 2014). Research has shown that patients with multisensory impairment have more difficulty in using hearing aid technologies.
like replacing batteries of their hearing aids (Wallhagen et al., 2001), and thus these issues should be taken in consideration in hearing research as they make health care and auditory rehabilitation more complex.

**Figure 1:** Theoretical models that may possibly underlie the relationship between diabetes and hearing impairment, based on comorbidity models as tested by Neale & Kendler (1996).
NL-SH third wave: further investigation of the process of hearing deterioration

This thesis has presented some of the five-year follow-up results of the NL-SH study. Although this is a reasonable time to follow-up, as this time period has been used in other studies as well (e.g., Karlsmose et al., 2000; Cruickshanks et al., 2003), it is still only a first step in monitoring adults hearing ability over their life span. From 2016 onwards, a further follow-up measurement of the NL-SH is planned, extending our database to a ten-year follow-up period. Analyses of these longitudinal data will provide extensive insight into the process of decline from normal hearing to hearing-impaired, over a longer period of time. In addition, its results will be useful in studying which factors can be identified as predictors for hearing aid uptake and use of assistive listening devices. Besides self-reported and objectively measured hearing ability (NHT scores), many other factors will be included such as personal, health-related, and work-related factors.

Longitudinal patterns of hearing status and loneliness

There is growing focus on the patient journey of people developing hearing problems, taking action, and the psychosocial consequences of hearing loss (Laplante-Levesque et al., 2010; Manchaiah et al., 2011). Longitudinal studies about changes in hearing and their consequences on psychosocial health parameters, such as described in Chapter 6, may provide insight in this field. An interesting development within applied epidemiological methods is the use of latent class models (Hoekstra, 2013). With this method, different patterns over time for separate groups of participants can be modeled. By inclusion of more than two measurement points per individual into the statistical analyses, more reliable estimations of longitudinal relationships can be determined. The extension of the NL-SH study will lead to an large amount of valuable data to model the relationship between development of hearing problems and loneliness over time. When the latent class model is applied, different extents of deterioration (steady decline versus faster deterioration), or the existence of additional comorbid conditions can be considered. These types of descriptive models will provide detailed and valuable insight for the prevention of psychosocial health problems in adults with hearing deterioration.
Possible new tests in the NL-SH study

Both auditory and cognitive capabilities influence speech understanding (Akeroyd, 2008; Houtgast & Festen, 2008; Besser et al., 2013; Moore et al., 2014). Within the last five years, research with the promising method of measuring pupil dilation as an indication for listening effort has provided fascinating results (Zekveld & Kramer, 2014). For instance, adults with hearing impairment have increased listening effort even in less difficult listening situations (Zekveld et al., 2011). Also results now clearly show, what was already anticipated, that cognitive load during speech processing increases with interfering speech present compared to fluctuating noise (Koelewijn et al., 2014).

New cognitive tests have been developed since 2006 when the NL-SH study was launched, and it is recommended to incorporate one or more cognitive tests related to hearing function in daily life into future research. As suggested in Chapter 5, it would be interesting to test cognitive abilities of the NL-SH participants and relate these abilities to the change in speech recognition over time. The relationship between cognition, hearing ability, and functioning in daily life are highly complex, and therefore need to be further explored. Epidemiological studies on hearing are suitable for this, as many variables (e.g., personal characteristics, health and hearing status) are measured over time, which provides unique opportunities to link these concepts if associated.

Innovations in Web-based longitudinal studies

In longitudinal studies it is important that the same questionnaires and tests are examined repeatedly to study individual change over time. In future measurement rounds this calls for a continuation of all previous tests. However, when new constructs in the questionnaire are added or when new tests are included, it may lead to a larger burden for the participants, as the time needed to complete the measurements will increase. Innovations in information and communication technology may be a partial solution. Currently, the psychometric qualities and validity of the Amsterdam Inventory for Auditory Disability and Handicap (AIADH; Kramer et al., 1995) is again under investigation in our department. By using large datasets, such as the baseline NL-SH data, and by applying sophisticated statistical models, it is determined whether the questionnaire items are optimally designed with regard to their validity and measurement characteristics. The ultimate goal is to improve the AIADH questionnaire.
by integrating software for Computational Adaptive Testing (CAT). This would mean that participants will only be presented with questions that apply to them. Currently, the NL-SH still contains some loops in its questionnaire, but in the near future it may be efficient to also consider evidence-based CAT in the design.

**IMPLICATIONS FOR CLINICAL PRACTICE**

**Hearing ability screening in adults from the age of 50 years onwards**

One of the main findings of this thesis is that speech recognition scores seem to deteriorate faster over a period of five years in adults aged 50 to 59 years (Chapter 4). This rather small numeric change represents a relevant and significant impact on individuals. Evidence from other cross-sectional studies (Plomp & Mimpen, 1979; Dawes et al., 2014) implies that around the age of 50 years, hearing will start to deteriorate. Our results showed no gender difference in speech reception thresholds, and this was recently confirmed in a large study in the United Kingdom where they found that speech-in-noise hearing declined exponentially with age for both sexes from about 50 years onwards (Moore et al., 2014).

In clinical practice, this result has important implications. It is known that, in general, adults start seeking help for their hearing problems around five to ten years after the onset of their hearing loss. Adult hearing screening has been proposed as a potential strategy to motivate adults to seek help earlier (Linssen, 2015). In the Netherlands, hearing screening in the adult population is not yet implemented, but it is likely that this may change in the near future as the evidence for the effectiveness of hearing screening is growing. Recently, it was concluded that internet screening with the NHT starting at the age 50, repeated at ages 55, 60, 65, and 70 was cost-effective, harmless, and highly accessible (Linssen, 2015). As hearing impairment is mostly invisible and affects people silently over the years, and because of the growing evidence about the cost-effectiveness of hearing screening programs in adults, implementation should be considered by policymakers.

**Some subgroups of patients with hearing impairment may need more attention**

Some relations between variables appeared to be for specific subgroups. With regard to socioeconomic status (Chapter 4), it was found that participants aged 50 to 64 years
with poorer hearing ability had a low level of income. Research show that income satisfaction related to hearing aid uptake (Garstecki & Erler, 1998), indicating that socioeconomic status may be a factor to consider in the clinical encounter. Due to governmental rules in Europe, the retirement age is shifting to 67 years (European Commission, 2010), meaning that adults with hearing impairment will be obliged to continue working for longer. Considering that hearing impaired people in the age group of 50 to 64 years need special attention, because it is likely that their hearing will further deteriorate, this is of great importance for the new guidelines. Hearing care professionals should consider the needs of adults with hearing impairment participating in paid employment. Successful hearing aid prescription or any other recommended hearing assistive technology should not be viewed as the end point for hearing rehabilitation, but as the start of successful integration of a person with their hearing impairment for participation in society.

**Broadening perspectives on patients**

The co-occurrence of chronic conditions within one individual is becoming more and more prevalent (National Institute for Public Health and the Environment [RIVM], 2014). Besides the definition of comorbidity by Feinstein (1970) as applied in the current thesis, other terminology has been mentioned in today's literature to describe the comorbidity status, the impact of comorbidity or all influencing attributes to a patient’s well being. Examples of these are *multimorbidity*, *morbidity burden*, or *patient complexity* (Valderas et al., 2009). Each of this constructs has its own application, both from a patient and from a professional perspective. To illustrate, a patient with hearing impairment, diabetes, and hypertension is considered by a general practitioner as having *multimorbidity* (multiple chronic conditions; not focusing on one particular condition as index disease). While for an audiologist, this patient is considered as hearing-impaired with some comorbidity. With regard to *morbidity burden*, not only the presence of a chronic condition is taken in consideration, but also the total burden of types of illness having an impact on an individual’s physiologic reserve. An even more detailed conceptualization is the construct of *patient complexity*. This construct acknowledges non-health related individual attributes, such as socioeconomic, cultural, environment, and patient behavior characteristics (Safford et al., 2007; Nardi et al., 2007). Research has shown that from a patient’s perspective, different chronic
conditions may lead to different impacts on their well-being and participation in society (Fortin et al., 2004). Altogether this suggests that professionals, both researchers and hearing health care professionals such as audiologists and otolaryngologists, should look at a patient from a broad perspective. This means that not only people’s hearing status has to be taken into account, but also other personal factors, environmental factors, and health status related factors. This recommendation follows the main message of the *International Classification of Disability, Functioning and Health* (ICF) theoretical model (WHO, 2001).

This argument about the importance of comorbidity in health care does not only hold for hearing health care professionals, but also for specialists who are involved in the care for people with diabetes. As mentioned previously, our current results about a relationship between diabetes and hearing impairment are in concordance with recently published review studies and meta-analyses on this topic (Horikawa et al., 2013; Akinpelu et al., 2014). However, in diabetes care, these scientific findings seem neglected as part of treatment protocols in every day practice. To illustrate, the impact of diabetes on hearing function is not mentioned at all in the recently updated “Fact sheet on Diabetes” (WHO, 2014). Hearing loss is thus not yet included specifically as a complication of diabetes.

Recently, a project working group, as commissioned by a worldwide distribute of hearing solutions and hearing aids, published a consensus paper about hearing and diabetes (Helzner et al., 2014). Although more knowledge is needed to clarify the underlying mechanism and for instance, the potential impact of the disease on hearing aid fitting, these kinds of publications may raise awareness about hearing problems in diabetic people. Ultimately, it may lead to hearing problems being associated with diabetes more often, and therefore will become a standard determination in diabetes care. As the number of people with diabetes is expected to grow worldwide, and given the mounting evidence about the relationship between diabetes and hearing, it indicates that inclusion and consideration of this comorbidity is of great importance.

**CONCLUSIONS**

The overall topic of the current thesis is the identification of factors affecting the impact of hearing impairment on different aspects of social life in adults. The study population
consisted of adults aged 18 to 70 years at the start of the study. Baseline and five-year follow-up results of the Web-based NL-SH study were reported. In Chapters 2, 3, and 4 cross-sectional NL-SH data were used to investigate comorbidity and participation in work. Chapters 5 and 6 describe the results of longitudinal analyses about changes on speech recognition over time, and the possible psychosocial consequences. The main conclusions of this thesis are:

- Diabetes relates to impaired hearing ability: associations were found between poor speech recognition ability in noise and ① self-reported diabetes, and ② self-reported diabetes medication.
- Adults with poor speech recognition ability in noise aged 18 to 64 years have a relatively poorer socioeconomic status than their normally hearing peers as indicated by paid work, educational level, and income.
- On average, for the total group of adults aged 18 to 70 years, a decline in speech recognition ability was found (mean change: 0.4 dB SNR) over five years.
- Our findings confirm previous cross-sectional results that at age 50 speech recognition ability start to deteriorate.
- Poor hearing ability is associated with increased levels of emotional and social loneliness averaged over a period of five year.
- A deterioration in hearing ability is in some subgroups of participants (participants who became married and those who did not use hearing aids at both measurements) related to increased feelings of social loneliness.
- No significant longitudinal associations appear between hearing ability over time and feelings of depression, anxiety, distress, and somatization.
- Subgroup effects emerge in some relationships with impaired hearing ability. This means that the effect is different for some specific groups of participants. For instance, in older adults the relationship between hearing impairment and low income is stronger than in younger adults. These kind of effects deserve further investigation.
- Continuation of the NL-SH study and other longitudinal epidemiological studies in hearing is indispensable to study the changes in hearing ability over the life span, and its subsequent consequences for functioning in daily life.
REFERENCES


