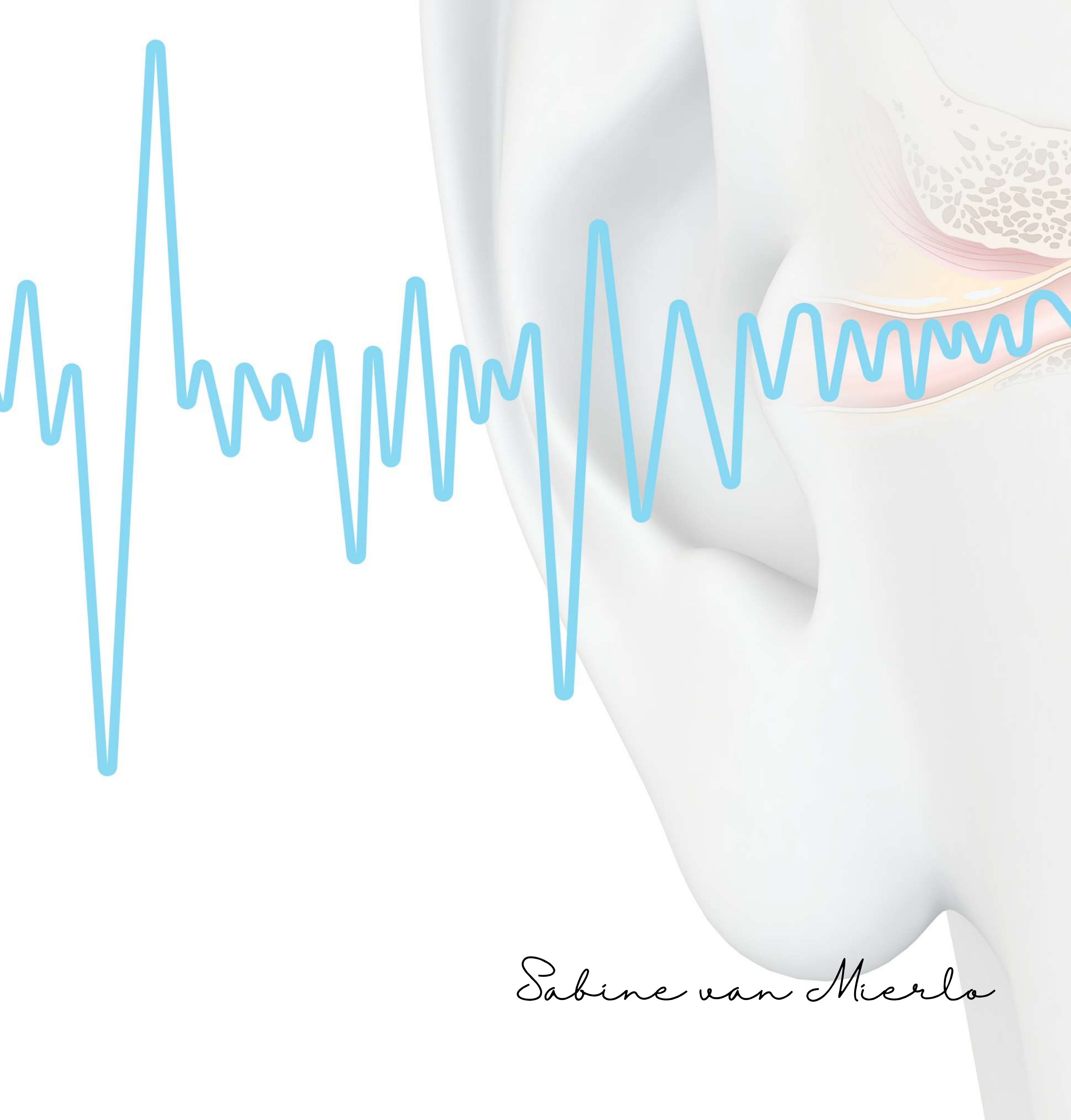
# HEARING SCREENING AT THE MEMORY CLINIC FOR PATIENTS WITH SUSPECTED DEMENTIA



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# A Hearing Screening at the Memory Clinic for Patients with Suspected Dementia

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# Abstract

**Introduction**: Although hearing impairment is recognized as a significant modifiable risk factor for dementia, no standardized methods or guidelines exist for hearing screening in cognitively impaired patients. The objectives of this study are to establish a suitable hearing assessment method at the memory clinic, compare the prevalence of hearing loss with a general population, and examine the relationship between hearing loss and the neuropsychological outcomes.

**Methods**: Participants included adult volunteers without hearing loss and cognitive impairment, patients from the audiology department with hearing loss but without cognitive impairment, and patients visiting the memory clinic for cognitive evaluation. Hearing screenings were included in the consultation hours of the memory clinic and were conducted using a word recognition test in free field and PTA serving as validation. The prevalence of hearing loss in the memory clinic population was compared to that of a general population of the same age. Neuropsychological test results were compared between patients with and without hearing loss. Healthy subjects underwent free field word recognition tests at the memory clinic and in soundproof cabins to evaluate the influence of ambient sound. Patients from the audiology department were administered the free field word discrimination test at the memory clinic in order to investigate the influence of the cognitive component on the results of the hearing screening.

**Results**: Hearing loss was found in approximately half of the patients from the memory clinic. The results indicate a similar distribution of hearing loss prevalence between the memory clinic population and the general population. No statistically significant differences were found in neuropsychological test results between patients with and without hearing loss. Ambient sound at the memory clinic influenced the hearing screening results, but the cognitive component did not significantly impact the test outcomes. Strong correlations were observed between free field word recognition tests and PTA, as well as in test-retest results.

**Discussion**: Hearing loss is highly prevalent in the memory clinic population. The word recognition test in free field is an applicable, reliable, and efficient method for hearing screening at the memory clinic. Implementing a hearing screening at the memory clinic could enhance the neuropsychological examination process and enable early detection of hearing problems in patients unaware of their hearing impairment. Referrals to audiologists or ENT doctors and the use of hearing aids may potentially slow cognitive decline and reduce social isolation, loneliness, and depression. However, further research with a larger test population is necessary to validate these findings and investigate the impact of hearing loss treatment on cognitive function and the progression of cognitive decline.

# Contents

# 1 Introduction

An estimated number of 55 million people world wide were affected by dementia in 2021. Despite intensive research regarding the underlying mechanisms of the disease, this population is expected to rise to approximately 152 million people by 2050, mainly due to the aging of society [1]. Currently, no disease modifying treatment is available and clinical drug trials of the last decade have had a failure rate of 99.6% [2]. However, the understanding of cognitive decline in patients with dementia is rapidly expanding with a growing insight in the causes of the clinical syndrome. Next to that, the focus of researchers is shifting moreover towards the risk factors that influence the progress to dementia. Especially the prodromal stages of dementia, including mild cognitive impairment (MCI), are considered as a window in which it may be possible to intervene and delay progression to dementia when tackling the risk factors [2].

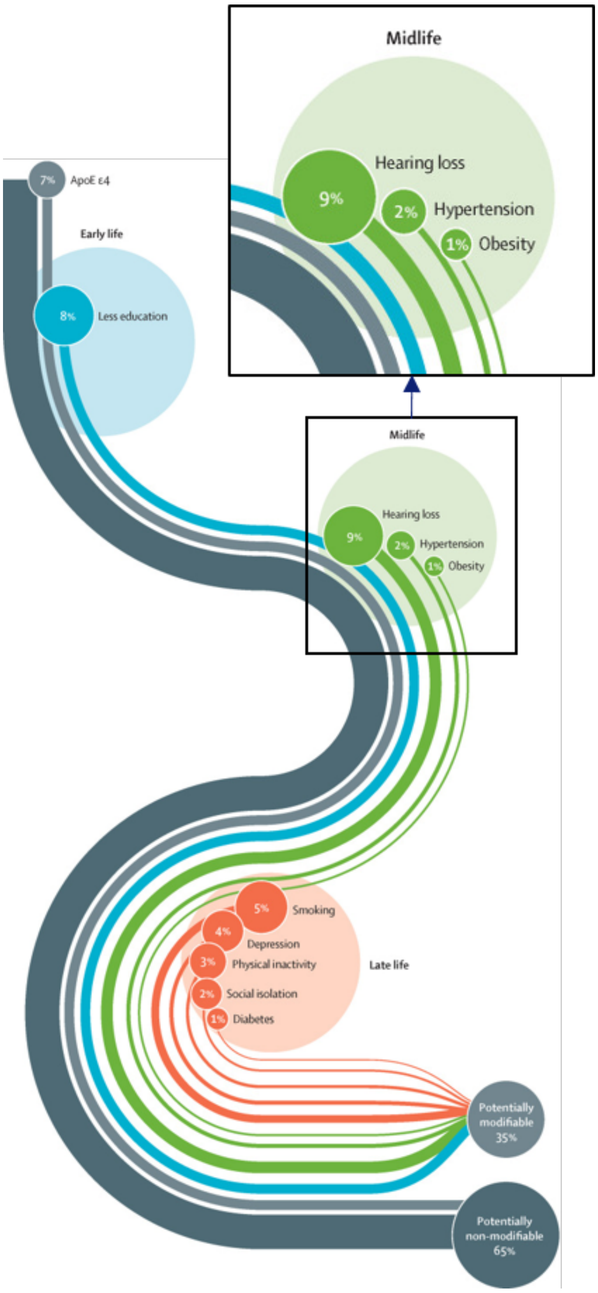


Figure 1: A life-course model for contribution of modifiable risk factors to dementia[3]

In 1979, hearing loss was already identified as one of the possible risk factors of reversible dementia [4]. In the years following, research on the association between cognitive decline and hearing impairment has continued to be elaborated and currently there are many studies delivering the evidence of hearing loss as the strongest modifiable mid-life risk factor for developing dementia [3, 5, 6, 7] as shown in figure 1. Among the studies investigating the relationship between hearing impairment and cognitive decline, a great heterogeneity in study methodology can be found. The large variety in hearing- and cognitive assessment methods and the parameters defining hearing loss and cognitive impairment, make it difficult to define the exact prevalence of hearing loss among cognitively impaired populations. Literature however does consistently show a higher prevalence of hearing loss in cognitively impaired populations compared to populations without cognitive impairment. Subsequently, populations with a cognitive impairment contain higher age levels [8].

According to epidemiological data, hearing loss is highly prevalent among the older adult population and strongly increases with age [7, 9] (figure 2). Resulting therefrom, due to the high average age of cognitively impaired populations, hearing loss logically occurs more often in populations with cognitive impairment. However, the connection between hearing loss and cognitive decline is believed to be more complex than that. The exact underlying mechanisms that link hearing impairment and cognitive decline remains unknown, but multiple hypotheses based on current knowledge have been revealed by researchers. One of these possible mechanistic pathways is the common cause or common pathology hypothesis, describing a common pathology affecting the cochlea and ascending auditory pathway and the cortex leading to both hearing loss and dementia [10, 11]. An option is, for example, a non-causal mechanism in which a third variable could lead to both cognitive decline and hearing loss, for example genetic risk factors for Alzheimer's disease (AD) [12, 13]. Another possible mechanism is the cognitive load hypothesis, suggesting that people with hearing impairment use greater cognitive resources for listening, making these resources unavailable for other aspects of higher cognition as they are already occupied during listening [10, 11, 14]. Additionally the cascade hypothesis has been described, implying that an auditory deprivation creates an impoverished environment, which is in its turn leading to the decreased stimulation of cognitive processing. Lastly, a function-pathology interaction could link hearing loss to cognitive impairment. This theory describes the interaction between brain activity related to the processing of sound and dementia pathology, focusing on auditory processing mechanisms in the medial temporal lobe (MTL) that may be specifically linked to the pathology of dementia in the same brain region [11]. Future research has to establish the truth about one or a combination of the hypotheses.

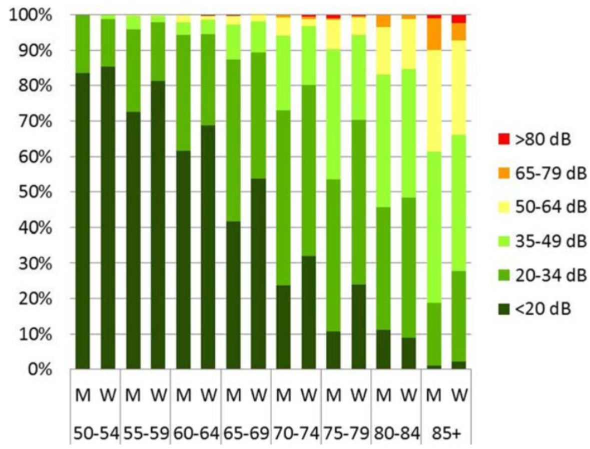


Figure 2: Distribution of hearing loss of an unscreened general population of older adults, classified according to the criteria of Global Burden of Disease 2010. Average loss at 0.5, 1, 2 and 4 kHz in the better ear, with men (M) and women (W) depicted separately [7]

Despite all evidence pointing towards hearing impairment as the most important modifiable risk factor for developing dementia (in case of a causal mechanism), no standardized method or guidelines exist to apply a hearing screening on cognitively impaired patients or as part of the neurocognitive assessment routine investigating patients with suspicion of dementia[15]. Without any hearing screening in memory clinics, it remains unclear how many patients diagnosed with cognitive impairment also present with hearing impairment. Hence, the effect of the diagnosis of hearing impairment and the treatment of hearing loss in cognitively impaired patients remains unknown. Next to that, hearing impairment could negatively influence the results of

the neuropsychlogical examination and distort the insight of the cognitive function of patients suffering from hearing loss. However, referring every patient that is visiting the memory clinic for audiological assessment is inefficient and might unnecessarily increase the working load for the audiologists. A brief and sensitive screening for hearing loss at the memory clinic should be carefully considered.
Traditionally, pure-tone audiometry (PTA) is used clinically to measure hearing thresholds in adults. The specialized clinical settings and advanced training of the audiologists usually lead to reliable test-retest hearing assessment results for patients with mild levels of dementia [16]. Nonetheless, the consulting rooms of memory clinics are not as appropriate to administer PTA and the healthcare professionals require extensive training. Next to that, the effectiveness for determining hearing thresholds with PTA for adults with dementia in a more progressed stage is questionable, as PTA requires a behavioural response [17]. As last, the neuropsychological assessment at the memory clinic is an extensive, demanding and time taking procedure. An additional hearing test to the existing neuropsychological tests should be quick and easy to perform.
The purpose of this study is to set up and administer a suitable hearing assessment method at the memory clinic of the Erasmus Medical Centre in order to to investigate the prevalence of hearing loss in the population of the memory clinic. Next to that, this study investigates how hearing loss interacts with the results of the neuropsychological tests.

## 2 Background information

At the memory clinic of the Erasmus Medical Centre (Erasmus MC) in Rotterdam, patients having cognitive problems and who are suspected to have dementia, are examined in order to determine a diagnosis and to deliver the best suitable care. "Dementia is any disorder where significant decline from one's previous level of cognition causes interference in occupational, domestic, or social functioning" (Gale et al., (2018) [18]). The evaluation and diagnoses of dementia requires an extensive research. The neurological examination should assess multiple domains of the mental function, including memory, language, visuospatial abilities, processing speed, executive function, basic attention and social cognition. The examination of patients visiting the memory clinic at the Erasmus MC with the suspicion of dementia consist of an anamnesis and an extensive neuropsychological test battery investigating these domains of the mental function. In advance of the neuropsychological tests, the patient is usually asked whether he or she has any hearing problems, but no objective measures are taken to retrieve the patient's hearing function.
The most common hearing tests for adults visiting the department of Ear, Nose and Throuat (ENT) due to hearing problems are PTA and word discrimination tests. Both hearing assessments can be performed with the use of headphones or in free field with speakers. The PTA is an objective, behavioural test which relies on the patient responses to pure tone stimuli of different frequencies. The patients hearing threshold of the pure tones on 250, 500, 1000, 2000, 4000 and 8000 Hz are being retrieved. The objective of the PTA is to determine the presence of hearing loss and in addition its degree and nature. The word discrimination test provides information on the discriminatory ability of the patients hearing and the effect of hearing loss. The patients are presented lists of words and asked to repeat them. The first list of words is presented on a clearly audible hearing level, followed by lists presented in descending steps of 10 dB. For every sound level, the percentage of correct repeated phonemes is calculated (the phoneme score) and from these scores a speech audiogram containing the discrimination curve, is retrieved. The sound level on which 50% of the phonemes is understood correctly, is called the speech reception threshold (SRT).
Figure 3 shows the reference curve of a normal hearing person (A) and curves of different kind of hearing losses. A pilot study concerning a hearing screening at the memory clinic which included nine patients was already performed at the memory clinic of the Erasmus MC. Both a PTA and word discrimination test with

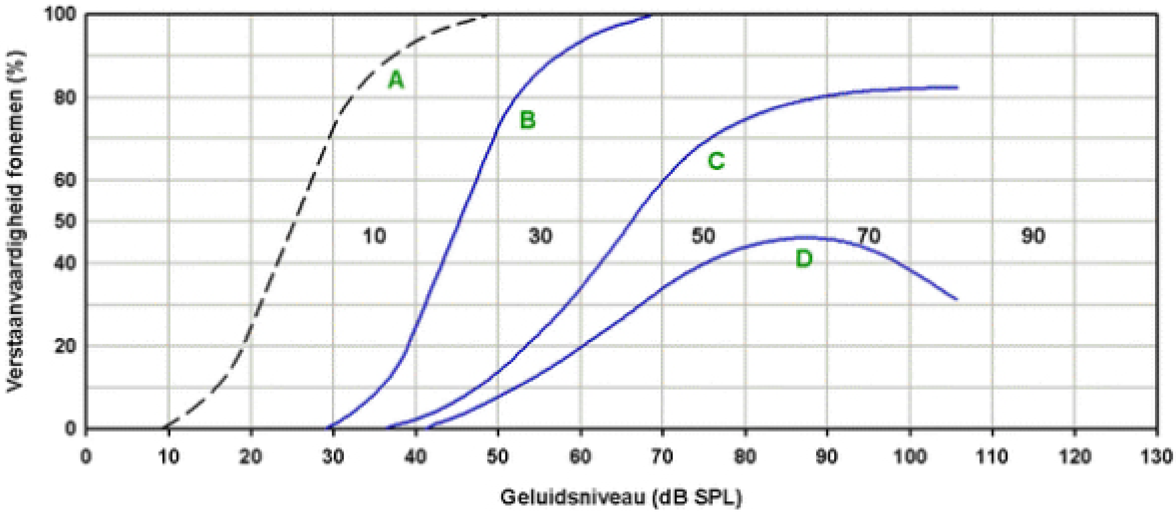


Figure 3: The phoneme scores as a function of the sound levels on which the word lists are presented for different kind of hearing losses: reference curve (A), conductive hearing loss (B), perceptive hearing loss (C) and perceptive hearing loss with regression (D) [19]

headphones was performed using a mobile audiometer in the consulting rooms of the memory clinic. These tests were chosen because of the strong relationship between the hearing loss according to the PTA and the hearing loss according to the shift of the discrimination curve compared to the reference curve of the word discrimination test [20]. The findings in this study implicate that the word discrimination test with headphones is an easy, quick and feasible hearing screening method to generally assess the hearing function of patients visiting the memory clinic. Three patients were identified to have hearing loss and were referred for further audiological research. Two of these patients were already aware of their hearing problems. Nonetheless, this pilot study contained a very small set of subjects and it remained questionable whether a word discrimination test with headphones is the most suitable method. Next to that, some of the included patients were suffering from cognitive complaints due to another underlying reason than dementia. Also, no analysis on the relation between the hearing function and the results of the neuropsychological tests were performed. Whether the hearing screening at the memory clinic is of added value for the patients and for the research on the relation between cognitive function and hearing loss, has yet to be determined.

# 3 Materials and Methods

This study was conducted at the memory clinic and the department of ENT at the Erasmus MC in Rotterdam. A hearing screening was temporarily included as as part of the regular care of the consultation hours at the memory clinic for patients with a suspicion of dementia.

## 3.1 *Study population*

Participants were 1) adult volunteers without hearing loss and cognitive impairment, 2) adult volunteers with hearing loss and without cognitive impairment visiting the audiology department for their appointment and 3) patients visiting the memory clinic for the investigation of their cognitive complaints. Patients visiting the memory clinic for other purposes were not included as these patients have a high probability of different comorbidities influencing the hearing function and could therefore distort the investigation into the relation between hearing loss and dementia. Patients with hearing aids visiting the memory clinic were included in the study as a specific subgroup of the study population.

## 3.2 *Study design*

This was a cross sectional observational study of patients attending appointments at the memory clinic of the Erasmus MC. Patients from the memory clinic signed informed consent for the use of their medical data (MEC no.: MEC-2016-069). Hearing assessments were conducted in two different consulting rooms of the memory clinic containing a comparable setting. Before the hearing screening was administered to patients, it was conducted on healthy adult volunteers in these consulting rooms in order to diligently decide over the most suitable setup for a hearing screening for patients visiting the memory clinic and to retrieve reference values. The healthy subjects additionally underwent the hearing screening procedure in a soundproof audiometric cabin with the same measurement setup as used in the consulting rooms, in order to investigate the influence of ambient sounds at the memory clinic on the results of hearing tests.

Once the best suitable measurement setup was established, the patients visiting the memory clinic for the investigation of dementia were administered the hearing assessment as part of their standard clinical care. One investigator was trained to administer the hearing screening. The hearing screening was performed between the anamnesis and the Neuropsychological examination. Additionally, the patients were asked whether they had hearing problems and if they were using hearing aids. The results of the hearing screening of each patient were reported to the attending physician. After the last included patient was subjected to the hearing test, the attending physicians received a questionnaire about the hearing screening at the memory clinic. The questionnaire consisted of a scale survey containing five questions with response options ranging from totally agree to totally disagree (Appendix A).

During the same period of the measurements on patients from the memory clinic, patients visiting the audiology department for a hearing assessment appointment were invited to participate in the research. This patient group was administered the same hearing screening in the same setup as administered to the patients from the memory clinic in order to investigate how the test is performed by persons with hearing loss but without any cognitive complaints.

## 3.3 *Hearing screening set up*

### 3.3.1 *Choice of test*

Requirements for a hearing test at the memory clinic were as following:

- Short duration ($\leq$ 10 minutes), as the neuropsychological examination already is an intensive and exensive procedure
- Easy to perform: patients should not be afflicted by the difficulty of the test and attending physicans should be able to perform the test independently after a short training.
- Deliver reliable information on the hearing function

Initially, the free field word discrimination test was thought to be the test of preference, since this test was expected to deliver the best reflection of the hearing function of the patients in daily life and due its strong correlation with the results from the PTA [20]. Additionally, the word discrimination test in free field is easy and quick to perform and the patients do not have to be troubled with the use of headphones. Another advantage of a hearing screening in the free field is the possibility to investigate the effect of the use of hearing aids. Speech in noise tests were ought to be less eligible for this research as these tests also appeal to a person's ability of processing and differentiating sound. This could increase the chance of the cognitive component to distort the results of the hearing assessment. The second best expected option for the hearing assessment is the binaural speech discrimination test with headphones. The disadvantages of the use of headphones are a decrease in the accessibility of the screening for both the patient and the investigator and it reduces the comparability of the hearing in daily life. Next to that, the headphones can cause collapse of the external auditory meatus, especially in the elderly, due to weakened tissues. On the other hand, the use of headphones reduces the effect of ambient sounds. Based on the first hearing tests on the healthy volunteers, it was decided to continue the research with the word discrimination test in the free field.

### 3.3.2 *Free field word discrimination test*

The measurement setup consisted of a mobile audiometer, the Decos Audiology Workstation, connected to headphones and a Yamaha MSP5 Studio speaker. The mobile audiometer could be positioned in one of the consulting rooms when needed. The sound of the speaker was calibrated in one of the consulting rooms with the use of a Brüel & Kjær type 2250 sound meter. The speaker was positioned on the edge of a medical trolley with some distance from any walls or closets to reduce the effects of reflections. A prepolarized free-field 1/2" microphone type 4189 was attached to the Brüel & Kjær sound meter and was held at a distance of 1 meter and a 0°-angle from the speaker. A gauge noise containing a 1kHz octave band was played by the Decos Audiology Workstation. A sound correction of 16.8 dB was applied in order to achieve a sound level of 70 dB detected by the Brüel & Kjær sound meter. This correction was saved and applied on the output of the Decos Audiology Working which was connected to the speaker (output 4).
A free field word discrimination test in Dutch was administered to each participant in one of consulting rooms at the memory clinic. During the hearing assessments, the speaker was positioned in exactly the same way as during the calibration. The subjects were positioned such that their heads were at a distance of 1 meter and a 0°angle from the speaker. An illustration of the measurement set up and the setting of one the consulting rooms is shown in figure 4. A map of both consulting rooms including the measurement setup are illustrated in Appendix B.

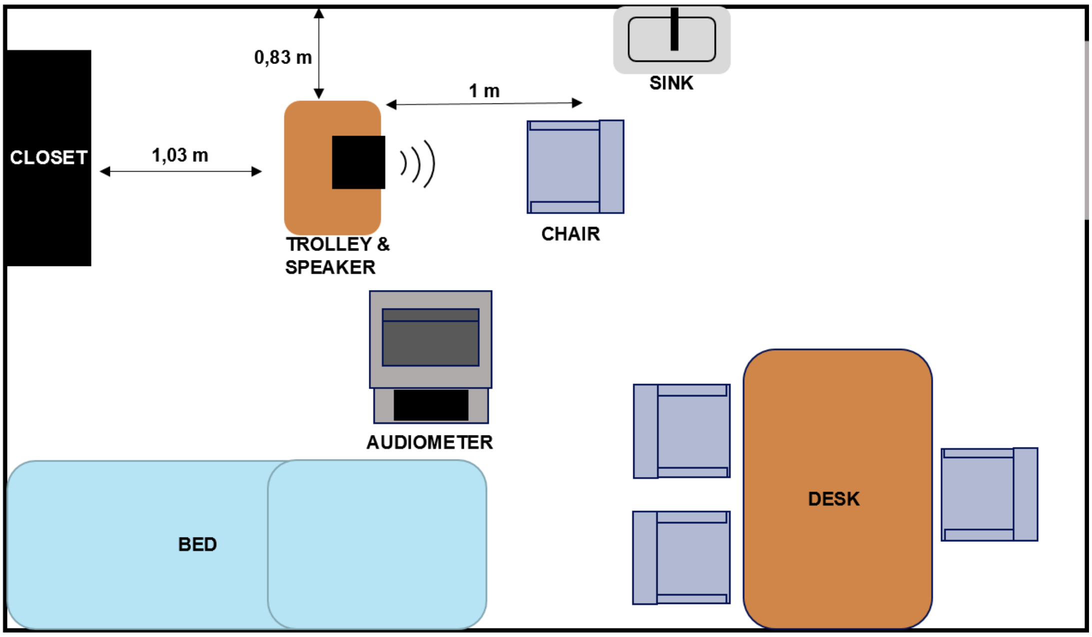


Figure 4: Top view of the consulting room with the measurement setup of the audiometer

The word discrimination tests were conducted with the Bosman's NVA-lists (Nederlandse Vereniging voor Audiologie) [21] consisting of low redundant Consonant-Vowel-Consonant-words (CVC-words) recorded by a non-dialect speaking and normal articulating woman in an anechoic room [22]. Each list contained 12 words; one word for practice and 11 test words. The test procedure started with the administration of one list on 55 dB Sound Pressure Level (SPL). According to the Erasmus MC protocol for speech audiometry, a word discrimination test should start on a level of 45 dB higher than the average air conduction loss at 500, 1000 en 2000 Hz (the Fletcher index) [23].

For a normal hearing 18-year old, this would mean a start list at 45 dB. However, the population of this study was estimated to be between 50 and 85 years old. From results of the Rotterdam Study (ERGO), an ongoing population-based prospective cohort study to investigate the health of aging people, the average air conduction loss at 500, 1000, 2000 en 4000 Hz for this age group is between the 10 and 40 dB (figure 5). Meeting the requirements of the protocol, it would be logical to start the word discrimination test with a list at 85 dB when administered to a 85 years old. However, the maximum accepted sound level of a free field hearing test is 75 dB due to safety measures. Next to that, the hearing screening at the memory clinic should be as short as possible and starting at higher sound levels would prolong the duration of the test. The average hearing threshold of a general population matching with the age of our study population does not exceed 50 dB. A start list at 55 dB is therefore expected to be sufficient to be able to make a reliable statement about the patient's hearing function.

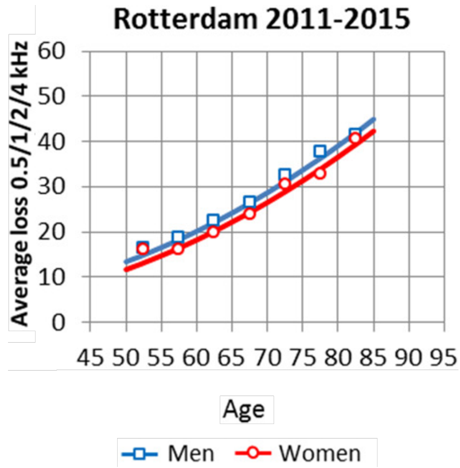


Figure 5: Average hearing loss (0.5 - 4 kHz) in the right ear in the Rotterdam Study [9]

The subjects were asked to repeat every presented word of the word discrimination test, while the investigator was keeping track of the percentage of phonemes that were correctly repeated by the subject according to the Erasmus MC protocol [23]. The consecutive lists were administered on sound levels decreasing with steps of 10 dB until the phoneme score dropped below 50% and the test was finished. Based on the scores at the different sound levels, a discrimination curve was created for each of the subjects.

### 3.3.3 *Ambient sound levels at the memory clinic*

The Brüel & Kjær type 2250 sound meter was used to measure the ambient noise levels present in both the consulting rooms of the memory clinic. The LAeq, LAFmax and LAFmin broadband values and the LAeq audio frequency spectrum values were measured over a time period of two minutes for each room. During the measurements of the ambient noise levels, one investigator was present in the room acting quietly. The microphone of the sound level meter was positioned in the middle of the rooms. The LAeq is the equivalent sound level corresponding to the average received sound energy over the period of time measured (eq) and is weighted in such a way that the high and low frequencies are reduced in order to represent what humans hear (A). This is the most commonly used weighing for the measurements of environmental noise in hospitals [24]. The time weighting "F" reacts quickly to sudden changes in sound levels and the "max" and "min" simply describe the maximum and minimum value measured over the period of time.

## 3.4 *Hearing screening procedures*

### 3.4.1 *Healthy volunteers*

Healthy subjects performed a speech recognition test as described before in one of the consulting rooms of the memory clinic. The word discrimination test in free field with the mobile audiometer was repeated in a soundproof audiometric cabin for the investigation of the influence of ambient noise in the consulting room. Additionally, a PTA with the mobile audiometer was performed in order to ensure the volunteers have a normal hearing function. Headphones with sufficient interaural attenuation (between 45 and 85 dB) were used and the PTA was performed on the frequencies of 250, 500, 1000, 2000, 4000 and 8000 Hz according to the Erasmus MC protocol [25].

### 3.4.2 *Memory Clinic Patients*

Patients from the memory clinic were administered the free field word discrimination test in one of the consulting rooms with the same measurement setup as used for the healthy subjects, but with a couple of adjustments to the procedure. On the sound levels of 55 dB and 45 dB, two lists were administered to each patient to retrieve information on the test-retest reliability. Patients wearing hearing aids performed the speech recognition test twice, first without hearing aids and subsequently while wearing their hearing aids set to their settings used in daily life. Again, for both the patients with and without hearing aids, the lists succeeding the start list were administered on sound levels decreasing with steps of 10 dB until a phoneme score below 50% was achieved. During the anamnesis of the consulting hour, the attending physician had decided whether the patient was able to be imposed with an additional hearing test. Patients who were judged capable to do so, were also administered PTA with the mobile audiometer and headphones. Patients wearing hearing aids were not subjected to the PTA as they already performed the word discrimination test twice. The pure tone thresholds on 250, 500, 1000, 2000 en 4000 and 8000 Hz were retrieved according to the Erasmus MC protocol. Bone conductivity and masking was not applied in any of the hearing tests in order to limit the duration of the test.

### 3.4.3 *Audiology Patients*

Patients from the audiology department who were diagnosed with hearing problems, had no cognitive problems or complaints and who gave consent to participate in the research, were administered the hearing screening test at the memory clinic consecutive to their audiology appointments. The form of consent signed by the participants can be found in Appendix C. The free field word discrimination test was performed by the patients from the audiology department without wearing their hearing aids and followed the same protocol as applied to the patients from the memory clinic.

## 3.5 *Data analysis*

### 3.5.1 *Healthy volunteers*

The age, gender and discrimination curves of the hearing tests from the healthy subjects were extracted. The discrimination curves resulting from the hearing test at the memory clinic were compared to the discrimination curves resulting from the test in a soundproof audiometric cabin. For each subject, the difference in the SRT and the difference in the phoneme scores of every measured sound level was calculated. Next, the overall average differences of all subjects in the SRT and the phoneme scores on each sound level between the two test locations were retrieved. The results were compared using a paired samples t-test if the data was normally distributed, or through a Wilcoxon Signed-Rank test in case the assumption of normality was not met. Finally, an average discrimination curve from all the measurements in the consulting rooms of the memory clinic and an average discrimination curve from all the measurements in the audiometric cabin were created.

### 3.5.2 *Memory Clinic Patients - Prevalence of Hearing Loss*

The average hearing loss on 500, 1000, 2000 en 4000 Hz in the better ear was calculated for each patient who completed the PTA. Based on this average hearing loss, the patients were categorized by the severity of hearing loss according to the "2010 GBD Hearing Loss Expert Group" [26] (Table 1).

Table 1: Categorisation of hearing loss

| Hearing impairment category | HL PTA (dB)[1] |
|---|---|
| Normal hearing | -10 - 19.9 |
| Mild hearing loss | 20 - 34.9 |
| Moderate to severe hearing loss | 35.0+ |

[1] Average hearing loss on 500, 1000, 2000 en 4000 Hz in the better ear

Subsequently, the hearing function of each patient was defined based on the scores from the free field word discrimination test. A discrimination curve was fitted through the retrieved scores and the SRT was derived from the this curve. The shift of the 50%-score compared to the reference curve should be in agreement with the average loss at 500, 1000 and 2000 Hz of the PTA [23]. However, in this research it is desirable to draw a conclusion about the hearing function of the patients at the memory clinic based on the free field word discrimination test only. Based on the categorisation of hearing loss from the 2010 GBD Hearing Loss Expert Group and the experience from the earlier pilot study, the patients were divided in different categories as following:

- Category 0: a shift of $\leq$ 15 dB of the 50% score
- Category 1: a shift of 15-20 dB of the 50% score
- Category 2: a shift of $\geq$ 20 dB of the 50% score
- Category 3: a score of $\leq$ 50% at 55 dB

Patients assigned to category 0 were expected to have a sufficient hearing ability to function normally in daily life. Patients assigned to category 1 were expected to have very mild hearing loss which is of limited influence on daily life. For these patients, it would be useful to visit an audiologist or ENT doctor in 5 years or earlier in case of hearing complaints. Patients assigned to category 2 and 3 will most likely experience hearing loss which also has a noticeable impact on their daily life. These patients would certainly benefit from a visit to an audiologist or ENT doctor.
The results from the hearing assessments were used to determine the prevalence and severity of hearing loss of the patients at the memory clinic. The prevalence of hearing loss in patients visiting the memory clinic was compared to the prevalence of hearing loss in the population of the Rotterdam study. The age categories 55-64 years, 65-years and 75-85 years and the definition of hearing loss as described in table 1 were used for this comparison. For the patients who were not subjected to a PTA, the average loss at 500, 1000, 2000 and 4000 Hz of the better ear was assumed to be the same as the shift of the discrimination curve at the 50%-point compared to the reference curve. In case the patients were wearing hearing aids, the results from the test without the help of hearing aids was included in this analysis.The corresponding null hypothesis is: *The prevalence of hearing loss in the patient population of the memory clinic with the suspicion of dementia is equal to the prevalence of hearing loss in a general population of the same age.* This hypothesis is as expected from a previously performed literature

study, merely showing a higher prevalence of hearing loss in cognitively impaired populations due to higher age levels in this population compared to a healthy population[8].
For the validation of the free field word discrimination test as a stand alone hearing screening method for patients at the memory clinic, the relation between the scores of the free field word discrimination test with the average loss at 500, 1000, 2000 and 4000 Hz of the PTA was analyzed using he Pearson Correlation Coefficient for the patients who completed the PTA and scored higher than 50% at the word list represented at 55 dB.
The test-retest reliability of the word discrimination test in free field was also evaluated with the Pearson Correlation Coefficient, using the test-retest scores at 55 dB and 45 dB of all patients.

### 3.5.3 *Memory Clinic Patients - Hearing Loss and the Cognitive Function*

The neuropshycholigical tests that were executed by 50% or more of the participants were included for the investigation in the relation between hearing loss and the results of the neuropsychological tests. For each of the neuropsychological tests, the z-score was calculated for every participating patient. The neuropsychological tests were divided in 5 domains:

1. Memory
2. Attention and executive function
3. Processing speed
4. Language
5. Visuoconstructive

For every domain, the z-scores were averaged for every patient separately, resulting in one score for each of the patients for every domain of the neuropsychological tests.
Next, the patients were divided in a group with normal hearing and in a group with hearing loss based on the word discrimination test. Patients with a shift < 20 dB of the discrimination curve at the 50% score point with respect to the normal curve were classified as "normal hearing patients" for this analysis. Patients with a shift of 20 dB or more of the discrimination curve at the 50% score point with respect to the normal curve or a lower score than 50% at the wordlist of 55 dB, were classified as "patients with hearing loss".
The average domain scores from the neuropsychological test were calculated for both patient groups. Patients who did not complete any of the neuropsychological test of a certain domain, were left out in this calculation.
A One-way ANCOVA was applied to compare the neuropsychological domain scores of the patient group with hearing loss to the patient group with normal hearing. Using this statistical test, it was possible to control for covariates, such as age, gender and level of education, which might confound the results.
Next to that, another division of the neuropsychological tests was made: auditory verbal tests and non-auditory verbal tests. Again, the mean score of each type of neuropsychological test was calculated for every patient separately. Subsequently the mean score of the non-auditory verbal tests was compared to the mean score of the auditory verbal tests for each patient separately. An overview was made in how many cases the non-auditory verbal tests was performed better by the group without hearing loss and for the group with hearing loss.
Finally, the effect of hearing aids was investigated. The results from the neuropsychological examination from the patients wearing hearing aids during their visit were compared to those from patients with a hearing loss, but who did not have hearing aids. For every domain, the mean score of patients with and without hearing aids were compared using a One-way ANCOVA with the correction for age, gender and level of education.

#### 3.5.4 *Audiology Patients*

Patients from the audiology department were matched to patients from the memory clinic based on the average hearing loss in the better ear at 500, 1000, 4000 and 8000 Hz. If there was no PTA available from the patients of the memory clinic, the shift in dB at the 50% score compared to the reference curve of the word discrimination test (without hearing aids) was used for the analysis, as it is assumed to be the same as average hearing loss in the better ear at 500, 1000, 2000 and 4000 Hz. The discrimination curves of matched cases were compared with each other. The average difference in SRT and the average differences of the phoneme scores on the measured sound levels were calculated and analyzed through an independent t-test or a Mann-Whitney test as appropriate.

#### 3.5.5 *Questionnaire*

Each question of the survey was assigned a score between 1 and 5. For questions 1 until 4 the answer "totally disagree" scored 1 point, "totally agree" 5 points and the answers in between 2, 3 or 4 points in corresponding order. The answers on question 5 were scored reversed.

# 4 Results

## 4.1 *Ambient sound levels at the memory clinic*

The broadband values of the ambient noise as measured in the consulting rooms of the memory clinic are LAeq = 38.42 dB, LAFmin = 36.17 dB and LAFmax = 46.78 dB in room 110 and LAeq = 40.33 dB, LAFmin = 37.45 dB and LAFmax = 52.67 dB in room 112. Continuous background noise is therefore expected to be between 36 and 38 dB SPL LA weighted with outliers of 46 - 53 dB due to surrounding noises such as closing doors. The sound level values of the audio frequency spectrum are shown in Appendix D. Particularly the lower frequencies are forthcoming in the measurements. This is in accordance with the experience from physicians and patients who have spent time in the consulting rooms, who mention the presence of the low pitched sound of the ventilation. Overall, the main background noise was caused by the ventilation at the memory clinic and other noise was due to closing doors or conversations at the hallway.

## 4.2 *Healthy volunteers*

Ten healthy subjects participated in the study, including two males and eight females with an age ranging from 21 to 26 years (mean [SD]: 24.6 [1.5]). In all cases, measurements at 55 dB, 45 dB, 35 dB and 25 dB were performed at both the memory clinic and audiometric cabin. Measurements at 15 dB were performed in all cases in the audiometric cabin, but only in three cases at the memory clinic. The mean SRT retrieved in the audiometric cabins was 18.55 dB (SD = 3.75 ) compared to the mean SRT of 27.95 dB (SD = 1.82 ) retrieved at the memory clinic, showing a mean difference of 9.4 dB and therefore significantly better results at the audiometric cabins ($p<0.001$). An overview of the mean scores for the different sound levels of both locations is shown in table 2.

Table 2: Mean scores of the word discrimination test at the memory clinic and audiometric cabin

| Soundlevel | N | Score (%) Memory Clinic | Score (%) Audiometric Cabin |
|---|---|---|---|
| 55 dB | 10 | 99.4 | 99.7 |
| 45 dB | 10 | 97.3 | 100 |
| 35 dB | 10 | 86.2 | 97.9 |
| 25 dB | 10 | 32.9 | 82.9 |
| 15 dB | 3 | 0.0 | 37.0 |

The outcomes of the scores on the sound levels 35 dB and 25 dB show a normal distribution. The mean scores retrieved for lists presented at 35 dB amounted to 86.2% (SD = 7.38) and 97.9% (SD = 2.47) ($p < 0.001$) at the memory clinic and audiometric cabin respectively. For lists presented at 25 dB, the difference in score for the two locations was noticeably larger with a mean score of 32.9% (SD = 14.37) at the memory clinic and 82.9% (SD = 16.00) ($p < 0.001$) for the audiometric cabin. The word discrimination test in free field at 35 dB and 25 dB is significantly better performed in an audiometric cabin in comparison to the consulting rooms of the memory clinic. The outcomes of the scores on 55 dB, 45 dB and 15 dB did not comply with the assumption of normality. The Wilcoxon Signed-Rank test revealed no significant differences in the participant's performance on the hearing test between the two locations for these sound levels. Figure 6 displays the average discrimination curves of the healthy volunteers for both the hearing test at the memory clinic and in the audiometric cabin.

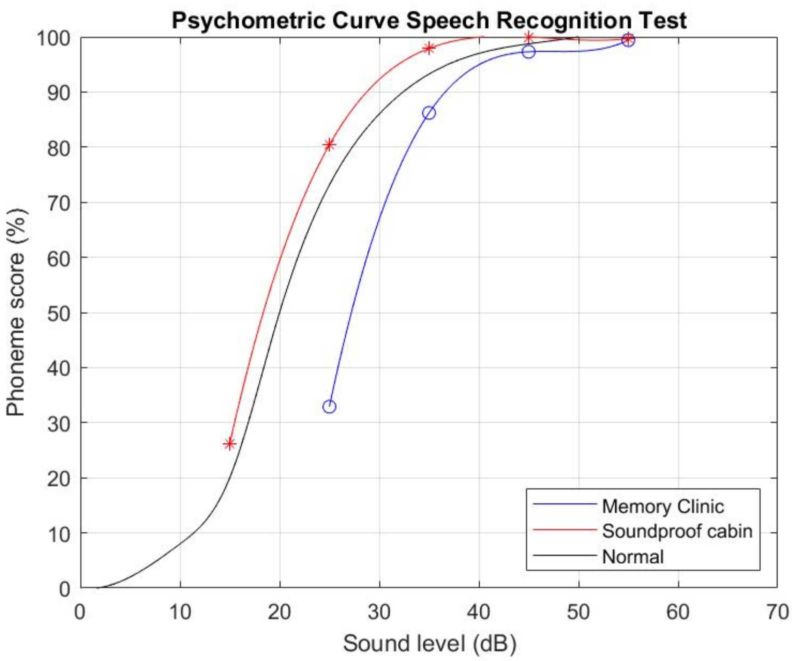


Figure 6: The average discrimination curves of healthy volunteers retrieved with the word discrimination test in free field at the memory clinic and in audiometric cabins

## 4.3 *Memory Clinic Patients - Prevalence of hearing loss*

Measurements on patients from the memory clinic were conducted between January and May 2023. A total of 31 patients from the memory clinic were subjected to the hearing screening. This population consisted of 21 (67.7%) male and 10 (32.3%) female patients with the age raging from 58 to 84 years (mean [SD], 72.29 [8.83]).

All of the patients finished the free field word discrimination test and 22 patients also completed a PTA with headphones. Reasons for not performing the PTA encompassed a lack of time or the patient was wearing hearing aids. During 18 of the speech discrimination tests, the duration test was recorded which resulted in an mean time of 5,67 minutes (range 4.10 - 6.55). From 15 measurements the duration of the total hearing screening (word discrimination test and PTA) was recorded, leading to a mean of 13.24 minutes (range 11.35 - 15.20).
Resulting from the word discrimination test, 11 (35.5%) patients had a discrimination curve with a shift of less than 15 dB with respect to the reference curve, 4 (12.9%) patients a shift between 15 and 20 dB, 13 (41.9%) patients a shift of more than 20 dB and 3 (9.7%) patients did not reach a score of 50% or higher (table 3).

Table 3: The prevalence of reduction in speech perception among memory clinic patients

| Shift of discrimination curve[1] | N (%) | Average shift in dB (SD)[1] | Mean age (SD) |
|---|---|---|---|
| <15 dB | 11 (35.5) | 12.0 (1.5) | 67.6 (8.8) |
| 15-20 dB | 4 (12.9) | 16.9 (1.0) | 75.0 (6.2) |
| > 20 dB | 13 (41.9) | 25.3 (4.8) | 73.0 (8.9) |
| <50% score at 55 dB | 3 (9.7) | NA[2] | 80.5 (2.6) |

[1] The shift of the discrimination curve at the 50%-score point relative to the reference curve of the speech recognition test
[2] The 50% point was never reached

Generally, the mean age increased with a decrease in speech perception. According to the One-way ANOVA, the effect size for age is large and the between group difference of age was a borderline case of being statistically significant (F(3,27)=2.799, p=0.06, eta-squared=0.237). According to the Pearson Correlation Coefficient, the mean age and speech perception are moderately correlated (r = 0.433) and the relationship is statistically significant (p = 0.015).
According to the the PTA tests administered to 22 of the patients, 7 (31.8%) patients had a normal hearing function, 12 (54.5%) patients had a mild hearing loss and 3 (13.6%) patients had a moderate to severe hearing loss. Again, the age clearly increased with the severity of hearing loss. The difference of the age between the various hearing impairment groups was however, not statistically significant, but does have a large effect size according to the One-way ANOVA (F(2,19)=1.898, p=0.177, eta-squared=0.167). Next to that, the mean age and results from the PTA are moderately correlated (r = 0.351), but the relationship is not statistically significant (p = 0.109).

Table 4: Prevalence and severity of hearing loss among memory clinic patients according to the PTA

| Hearing impairment category | N (%) | Average HL[1] in dB (SD) | Mean age (SD) |
|---|---|---|---|
| Normal hearing (-10 - 19.99 dB) | 7 (31.8) | 14.6 (3.1) | 70.2 (11.5) |
| Mild hearing loss (20 - 34.99 dB) | 12 (54.5) | 26.9 (4.6) | 70.9 (8.6) |
| Moderate to severe hearing loss (35+ dB) | 3 (13.6) | 41.3 (7.6) | 81.0 (5.2) |

[1] Average hearing loss in dB on 500, 1000, 2000 en 4000 Hz in the better ear

From the 22 patients who completed the PTA, 21 patients retrieved a score of 50% or higher on the word discrimination test at a sound level of 55 dB. Those 21 patients were included in the analysis of the correlation between the results of the word discrimination in free field and the PTA with headphones. The shift in dB of the discrimination curve at the 50%-point relative to the reference curve resulting from the word discrimination test and the average hearing loss in the better ear at 500, 1000, 2000 and 4000 Hz resulting from the PTA of each participant have been compared in a scatter plot as seen in figure 7. The line of best fit exposes that the PTA on average measured a slightly higher hearing loss compared to the word discrimination test. The Pearson Correlation Coefficient between the two tests is 0.828 with a significance of p<0.001, indicating a strong relationship between the two tests.

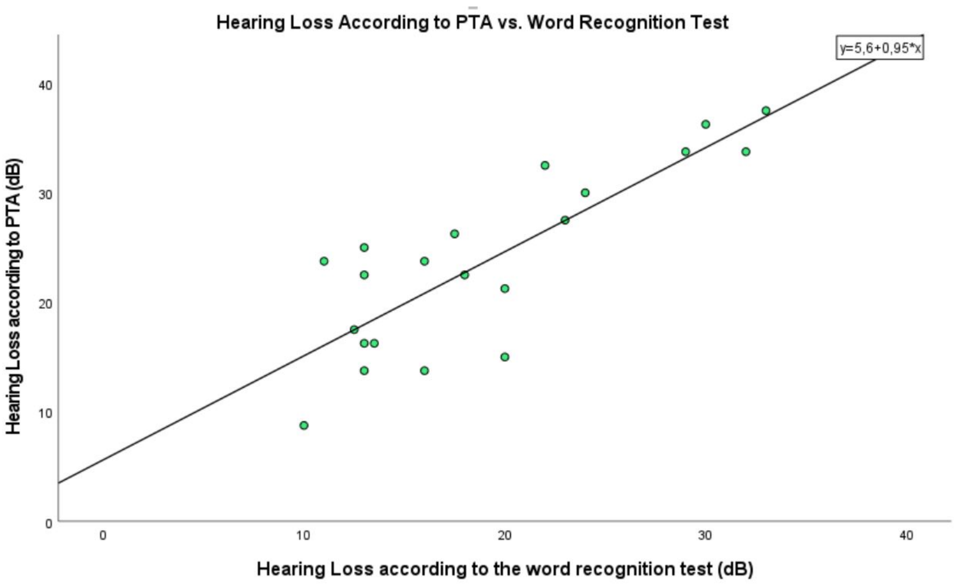


Figure 7: The correlation between the results of the PTA and the word discrimination in a scatter plot.

All of the participants from the memory clinic were included in the analysis of the test-retest reliability of the word discrimination test. The Pearson Correlation Coefficient between the tests and retests are 0.890 and 0.909 for the word lists presented at 55 dB and 45 dB respectively. Both correlations were found to be highly significant (p < 0.001).

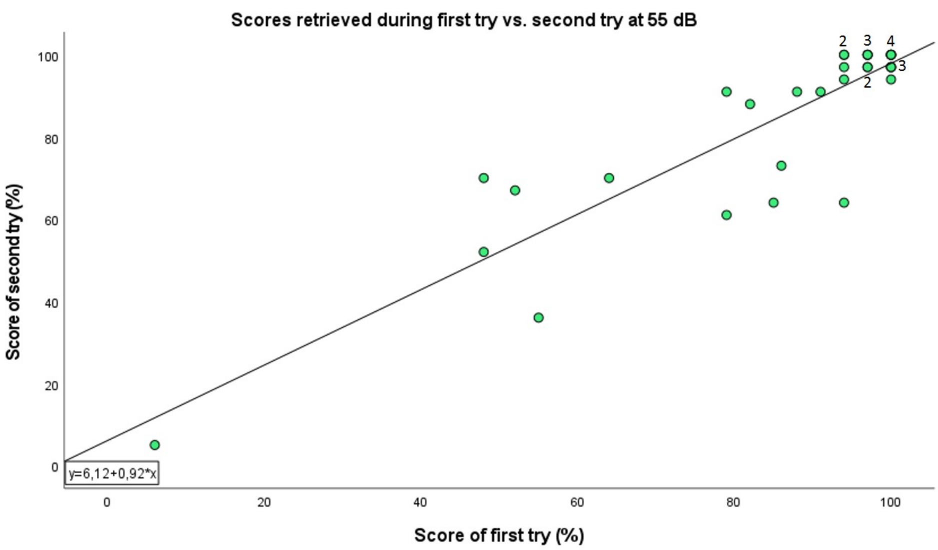


Figure 8: The correlation between the results of the first and second try of the word discrimination test at 55 dB

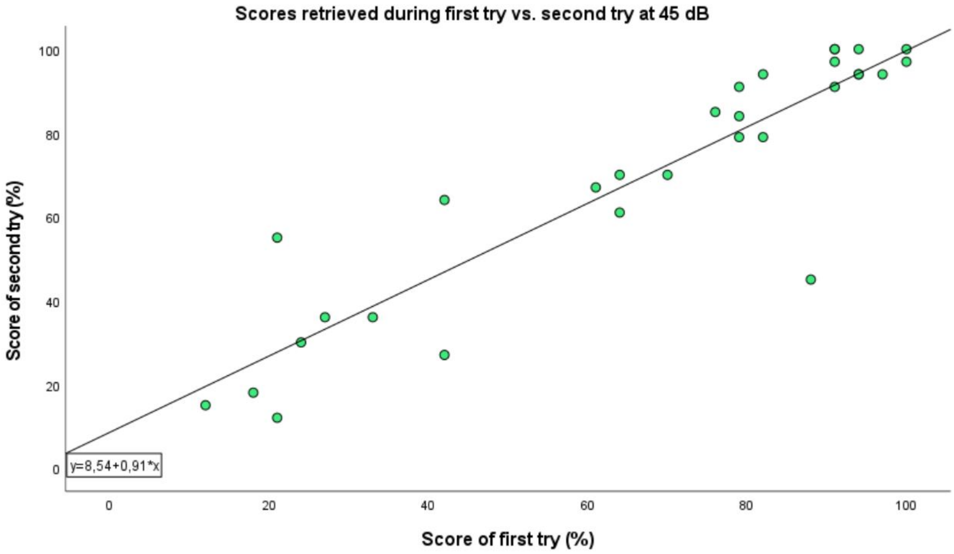


Figure 9: The correlation between the results of the first and second try of the word discrimination test at 45 dB

The scatter plots of the test-retest results are shown in figure 8 and figure 9. Numbers next to data points indicate the contribution of the amount of cases to this data point. On average, the patients scored slightly better on the hearing test during their second try.
Another way to test the relationship between the results from the PTA and the word discrimination test was done by comparing advises on follow-up actions. Two opinions of what advise would be given to the patient about a follow-up action based on the results from their hearing tests were created. One advise was based on all the available information about their hearing function and one advise was based on the word discrimination test only. An overview of these results can be found in Appendix E.

When including data of the patients who were not administered the PTA in the overall prevalence of hearing loss (by accepting their shift of the discrimination curve of the word discrimination test as the average hearing loss in dB on 500, 1000, 2000 en 4000 Hz in the better ear), 10 (32.3%) patients had a normal hearing, 16 (51.6 %) patients were diagnosed with a mild hearing loss and 5 (16.1 %) patients with a moderate to severe hearing loss. Patients who scored below 50% at the word list represented at 55 dB, were assigned to the category of moderate to severe hearing loss. Almost half of the patients (n=14) belonged to the oldest part of the population (75-85 years), 9 patients were aged between 65 and 74 years old and 8 patients between the 55 and 64 years. Figure 10 shows the distribution of hearing loss among the different age groups of the population of the memory clinic compared to the population of the Rotterdam Study. For the age groups of 55-64 and 75-85 years, the distributions are similar, but for the age group of 65-74 years the distributions seem different from each other. No patients of 65-74 years with a severe hearing loss were present among the patients of the memory clinic, but 77.8% of this group was diagnosed with mild hearing loss. In the population from the Rotterdam Study of this age, any form of hearing loss was found in 60.4% of the population. Comparing the prevalence of hearing loss among the population of the memory clinic to prevalence of hearing loss among the population of the Rotterdam study using a Chi-Square test, no statistical differences were found between the distributions for every age group ($X^2(2) = 0.56$, $p < 0.05$ for the age group of 55-64 years, $X^2(2) = 4.56$, $p < 0.05$ for the age group of 65-74 years and $X^2(2) = 0$, $p < 0.05$ for the age group of 75-85 years). More detailed information of the statistical comparison between the population of the memory clinic and of the Rotterdam study for the different age groups can be found in Appendix F.

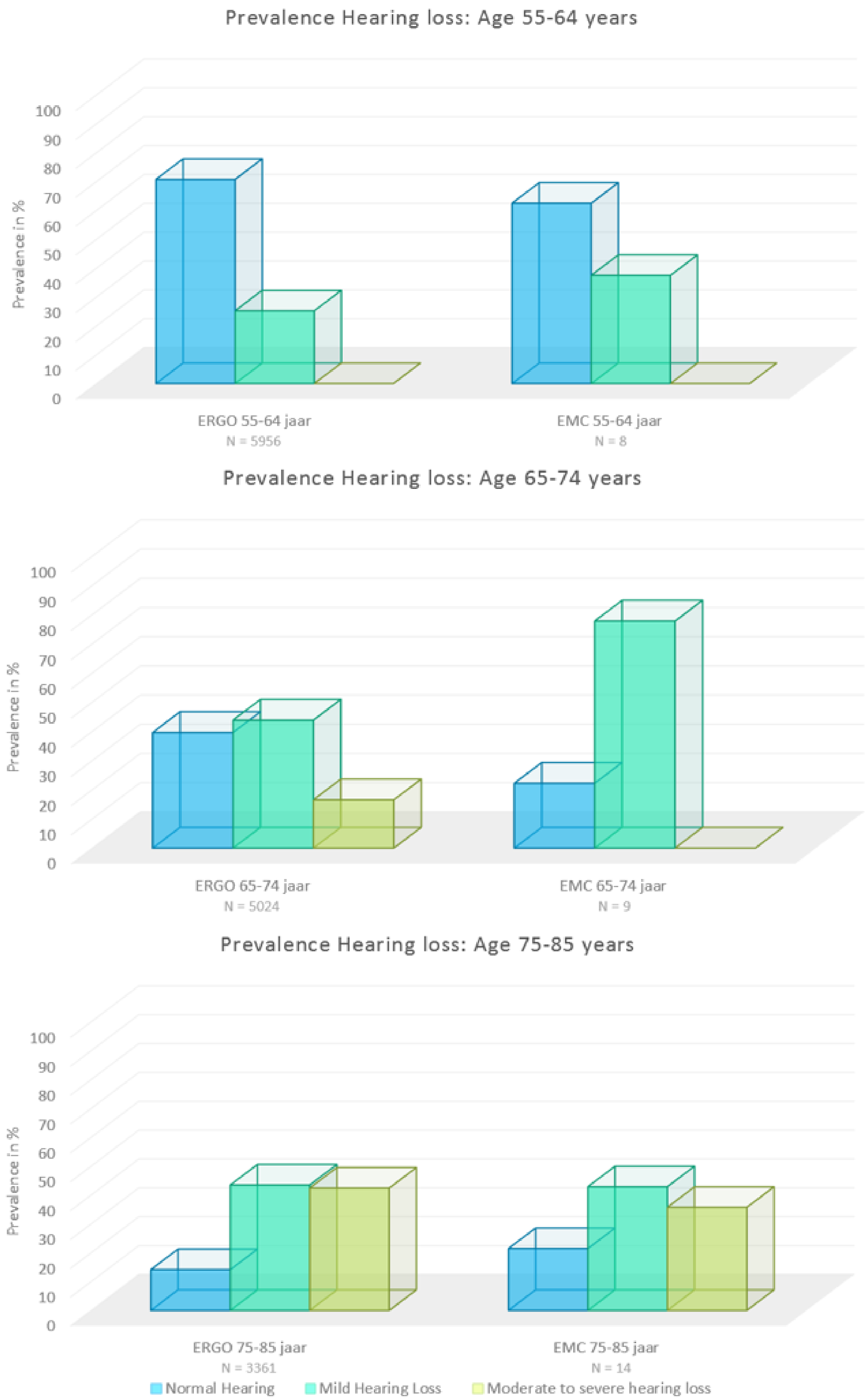


Figure 10: The prevalence of hearing loss in the population of the Rotterdam Study compared to the population of the memory clinic

### 4.4 *Memory Clinic Patients - Hearing Loss and the Cognitive Function*

Data from the neuropsychological examinations was available for 30 of the patients. Dividing these patients into a group with normal hearing and a group with hearing loss based on the shift of the discrimination curve at 50%-point relative to the reference curve of the word discrimination test, 16 (53.3%) patients had a normal hearing (shift <20 dB) and 14 (46.7%) patients had a hearing loss (shift of 20 dB or more, or a score of <50% at 55dB). The characteristics of these patients are shown in table 5. The age of the two groups was compared using the independent samples t-test (the data was approximately normally distributed). No statistical significant difference in age between the two groups was found (p=0.144).

Table 5: Division of patients in two groups according to the word discrimination test

| Population | Average shift[1] in dB (SD) | Mean age (SD) |
|---|---|---|
| Normal hearing | 14.5 (3.7) | 70.4 (8.4) |
| Hearing loss | 26.6 (4.9) [2] | 75.1 (8.8) |

[1] The shift of the discrimination curve at the 50% point relative to the reference curve of the word discrimination test

[2] Data of three patients is missing (never reached a score of 50%)

Table 6 gives an overview of the tests from the neuropsychological examination that were completed by at least 50% of the participants for each of the domains. A description of these tests can be found in Appendix G. The mean scores shown in table 6 are the scores retrieved from the raw data, not the z-scores. The scores of the Stroop and TMT tests are based on the amount of seconds the patients needed to finish the test. The faster the test was finished the better the test was executed, with maximum time of 300 seconds. The time measured was subtracted from the maximum time to retrieve the scores for the Stroop and TMT test. The scores of TMT B/A were retrieved by dividing the times measured during the TMT B test by the times measured during the TMT A and taking the reverse of this score by multiplying with -1. The same calculations were performed with the scores of Stroop 2 and Stroop 3 to retrieve the Stroop 3/2 scores. Higher scores indicate a better performance of the tests. The normal hearing group scored better on half of the tests.

Table 6: The domains and the the test of the neuropsychological examination

| Domain | Test | Mean score<br>Normal Hearing (SD) | Mean score<br>Hearing loss (SD) |
|---|---|---|---|
| **Memory** | 15 WT | 25.7 (1.5)<br>N = 13 | 23.7 (4.2)<br>N = 7 |
| | 15 WT delay | 2.9 (0.6)<br>N = 13 | 3.6 (1.5)<br>N = 8 |
| | VAT total | 7.75 (1.2)<br>N = 12 | 7.9 (1.1)<br>N = 10 |
| **Processing Speed** | Stroop 1 | 229.2 (7.1)<br>N = 13 | 213.8 (12.6)<br>N = 9 |
| | Stroop 2 | 208.1 (9.1)<br>N = 13 | 189.3 (17.1)<br>N = 9 |
| | TMT A | 210.9 (17.5)<br>N = 15 | 186.1 (25.5)<br>N = 10 |
| **Attention & Executive Function** | TMT B/A | -3.6 ( 0.5)<br>N = 12 | -3.2 (0.8)<br>N = 10 |
| | Stroop 3/2 | -1.8 (0.1)<br>N = 13 | -2.2 (0.3)<br>N = 9 |
| **Language** | BNT | 42.4 (3.2)<br>N = 16 | 45.7 (32.0)<br>N = 12 |
| | Fluency Animals | 5.7 (1.9)<br>N = 15 | 12.4 (1.2)<br>N = 11 |
| | Fluency Letters | 27.8 (4.0)<br>N = 15 | 20.7(3.0)<br>N = 11 |
| **Visuoconstructive** | Clock drawing | 9.0 (0.9)<br>N = 16 | 9.5 (1.2)<br>N = 8 |

The mean domain scores retrieved from the z-scores of the patients with and without hearing loss are shown in figure 11. The higher the score, the better the tests were performed. The patient group with a normal hearing function retrieved higher scores for all of the domains, except for the visoconstructive tasks. The largest contrast in scores was found in the processing speed domain with a value of 0.4965 which was not found to be statistically significant (p = 0.280) when corrected for age, gender and level of education. The inequality in scores of the other domains ranged from 0.0407 to 0.143 including no statistical differences with age, gender and level of education as covariates (p-value memory = 0.369, p-value attention & executive function = 0.374, p-value language = 0.758 and p-value visuoconstructive = 0.725). The overall averaged score of all domains differed with a value of 0.2315 between the population with and without a hearing loss (p = 0.180).
The 15 WT and the 15 WT delay tests from the neuropsychological examination were included in the category of auditory verbal tests. Complete data of 20 patients was available for the comparison of the results between non-auditory verbal and auditory verbal tests. When taking the shift of 20 dB of the discrimination curve relative to the reference curve of the word discrimination test as the discriminator, 8 patients were diagnosed with a hearing loss and 12 patients had a normal hearing. Figure 12 shows the amount of patients scoring better on the non-auditory verbal tests. A positive difference means a better score on the non-auditory verbal tests and a negative score means a better score on the auditory verbal tests. The data of the calculated differences was normally distributed with a standard deviation of 0.8. When the absolute value of the difference in scores was one time the standard deviation or larger, it was concluded that either the auditory or non-auditory verbal

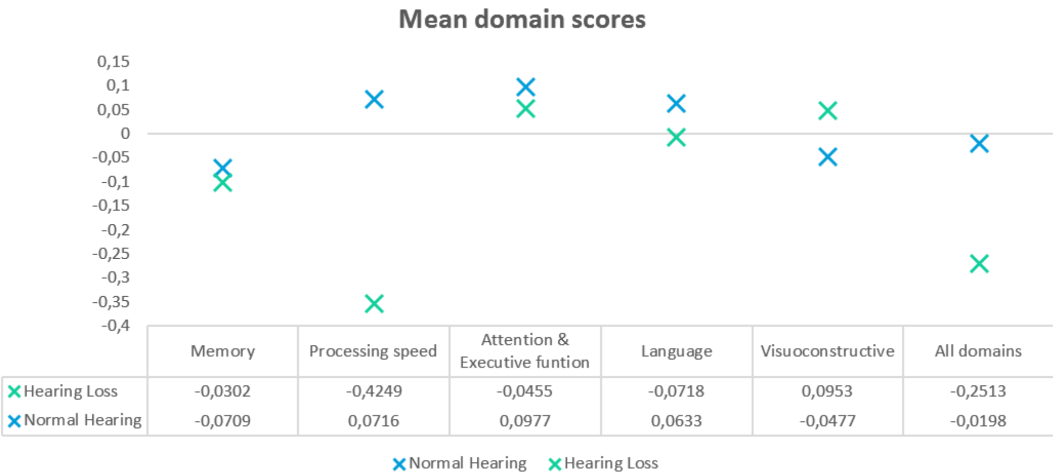


Figure 11: The mean domain scores of the patients from the memory clinic with and without hearing loss

test was made considerably better. From the normal hearing group, ten patients scored equally on both kind of tests and two patients scored noticeably better on the auditory verbal tests. In case of the patients with a hearing loss, six patients scored equally on the two different sort of tests, one patient scored better on the non-auditory verbal test and one patient scored better on the auditory verbal test. In conclusion, no remarkable differences were found in the scores of auditory verbal and non-auditory verbal tests.

| Population | Non-auditory tests | Auditory tests | Difference |
|---|---|---|---|
| Normal Hearing | -0,32 | -0,65 | 0,32 |
| | 0,33 | 0,6 | -0,27 |
| | -0,18 | 0,61 | -0,78 |
| | -1,26 | -0,96 | -0,3 |
| | -0,2 | -0,77 | 0,57 |
| | 0,84 | -0,45 | 1,29 |
| | 0,32 | 0,96 | -0,63 |
| | -0,1 | 0,15 | -0,25 |
| | 0,13 | -0,12 | 0,25 |
| | 0,21 | 0,74 | -0,53 |
| | 0,9 | -0,02 | 0,92 |
| | 0,58 | -0,15 | 0,73 |
| Hearing Loss | -0,25 | -1,1 | 0,85 |
| | -0,45 | -0,77 | 0,32 |
| | -1,27 | -0,84 | -0,43 |
| | 0,17 | -0,41 | 0,58 |
| | 0,55 | 2,82 | -2,28 |
| | -0,06 | -0,4 | 0,34 |
| | 0,25 | 0,93 | -0,68 |
| | 0,39 | 0,3 | 0,09 |

Figure 12: The difference in scores between auditory verbal and non-auditory tests

Hearing aids were present during the hearing screening in five patients from the memory clinic. The results of their neuropshycological examination were compared to the results of 11 patients with a hearing problem, but who did not have hearing aids on them during the appointment at the memory clinic. For this analysis, new z-scores were retrieved by deriving them from the data of the patients with hearing loss and hearing aids only. The mean domain scores retrieved from those z-scores from the patients with and without hearing aids are shown in figure 13. The scores from the patients with hearing aids were compared to the scores from the patients without hearing aids through a One-way ANCOVA. Patients wearing hearing aids during the neuropsychological examination retrieved a higher score on the processing speed, attention & executive function, visuoconstructive and all domains together. The differences in scores varied from 0.0045 to 0.8485 with p = 0.981 for the memory domain, p = 0.474 for the processingspeed domain, p = 0.332 for the attention & executive function domain, p = 0.482 for the language domain, p = 0.477 for the visuoconstructive domain and p = 0.690 for all domains together when correcting for age, gender and level of education. None of these differences was found to be statistically significant.

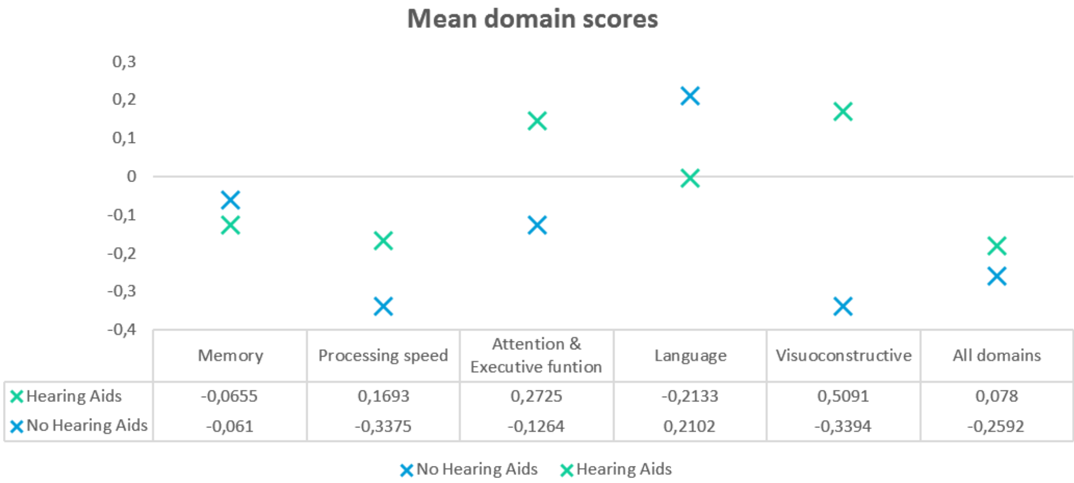


Figure 13: The mean domain scores of the patients fro the memory clinic with hearing loss and hearing aids.

Complete data of 10 patients from the group with hearing aids or hearing loss was available for the comparison of the results from the auditory with the non-auditory verbal tests. Three of these patients were wearing hearing aids during the neuropsychological examination. The scores of the patients on the auditory and non-auditory verbal tests and the differences in those scores per patient, are represented in figure 14. The data of the difference in scores was normally distributed with a standard deviation of 0.7. Again, when the absolute difference in score was one time this standard deviation or larger, it was concluded that the auditory verbal tests were completed with noticeably higher or lower scores than the non-auditory verbal tests. All of the patients wearing hearing aids, scored equally on both kind of tests. From the patients with a hearing loss but who were not wearing hearing aids, two patients scored noticeably better on the non-auditory tests, one patient scored noticeably better on the auditory test and four patients scored equally on the two groups of tests.

| Column1 | Non-auditory tests | Auditory tests | Difference |
|---|---|---|---|
| Hearing Aids | -0,02 | 0,49 | -0,51 |
| | -0,2 | -0,59 | 0,4 |
| | 0,46 | 0,26 | 0,2 |
| No Hearing Aids | -0,14 | -0,85 | 0,71 |
| | -0,19 | -0,59 | 0,41 |
| | -1,23 | -0,64 | -0,59 |
| | 0,42 | -0,31 | 0,73 |
| | 0,73 | 2,24 | -1,5 |
| | 0,04 | -0,31 | 0,36 |
| | 0,31 | 0,64 | -0,34 |

Figure 14: The difference in scores between auditory verbal and non-auditory tests for patients with hearing loss and hearing aids

## 4.5 *Audiology patients*

At total of 13 patients visiting the audiology department for their appointment between January and May 2023 participated in the study (5 female and 8 male, mean age 51.2 years (SD = 15.0)). Six of these patients had a normal hearing and seven patients had a mild hearing loss according to the average hearing loss on 500, 1000, 2000 and 4000 Hz in the better ear. All of the patients with a normal hearing according to this classification of hearing impairment, had a mild hearing loss or worse in their poor ear. The 6 patients of the audiology department with normal hearing were matched to 10 patients of the memory clinic with a normal hearing and the 7 patients of the audiology department with a mild hearing loss were matched to 16 patients from the memory clinic with a similar hearing loss. Three of the patients with a normal hearing and three of the patients with a mild hearing loss from the memory clinic did not complete a PTA. Their shift of the discrimination curve at the 50%-point compared to the reference curve of the word discrimination test was assumed to be the same as the average hearing loss at 500, 1000, 2000 and 4000 Hz in the better ear. The characteristics of the patients included for the analysis of the influence of cognitive impairment are presented in table 7.

Table 7: Characteristics of the participants included for the analysis on the influence of the cognitive component

| | Department | N (Male) | Mean age (SD) | Mean HL [1] |
|---|---|---|---|---|
| **Normal Hearing** | Audiology | 6 (4) | 47.0 (14.1) | 8.5 |
| | Memory Clinic | 10 (7) | 68.9 (10.0) | 13.4 |
| **Mild HL [2]** | Audiology | 7 (4) | 54.7 (16.0) | 27.1 |
| | Memory Clinic | 16 (13) | 72.0 (16.0) | 26.7 |

[1] Average hearing loss in dB on 500, 1000, 2000 en 4000 Hz in the better ear
[2] HL = Hearing Loss

None of the patients reached a score of 50% or higher at the list of words represented at 25 dB. Therefore no scores were retrieved at 15 dB. Two of the patients from the audiology department and three of the patients from the memory clinic with a normal hearing reached a score lower than 50% at the list of 35 dB and thus finished the test at this stage. From the patients with a mild hearing loss, only one patient from the audiology department and three patients from the memory clinic reached a score of 50% or higher at the list represented at 35 dB and therefore also realised the test at 25 dB. Three of the patients from the memory clinic with a mild hearing loss did not score 50% or higher at the list of 45 dB and the test was not further continued at lower sound levels.

The retrieved scores at 55 dB for both the normal hearing and mild hearing loss group and the scores at 45 dB of the normal hearing group did not comply with the assumption of normality and were analysed using the Mann-Whitney U test comparing mean ranks. The rest of the data was analysed through an independent samples t-test. In general, the patients from the audiology department gained slightly higher scores on the word discrimination test than the patients from the memory clinic, but only for the test at 25 dB in normal hearing patients a statistically significant difference was found. Contradictory, in the group of patients with a mild hearing loss, the test at 25 dB was performed better by patients from the memory clinic. One should notice that only one patient from the audiology department completed the hearing test at this sound level. Overall, the patient groups scored equally on the word discrimination test in free field.

Table 8: The mean SRT and scores at different sound levels of the word discrimination test for the different patient groups

| | Parameter | Audiology | Memory clinic | p-value |
|---|---|---|---|---|
| | SRT in dB | 31.7 (N=6) | 33.1 (N=10) | 0.362 |
| | Score at 55 dB in % | 97.8 (N=6) | 96.7 (N=10) | 0.792 |
| **Normal** | Score at 45 dB in % | 96 (N=6) | 91.9 (N=10) | 0.562 |
| | Score at 35 dB in % | 66.8 (N=6) | 55.3 (N=10) | 0.230 |
| | Score at 25 dB in % | 24 (N=4) | 9.3 (N=7) | 0.017 |
| | SRT in dB | 39.6 (N=7) | 41.1 (N=16) | 0.490 |
| | Score at 55 dB in % | 92.7 (N=7) | 88.5 (N=16) | 0.820 |
| **Mild HL[2]** | Score at 45 dB in % | 75.3 (N=7) | 63.7 (N=16) | 0.247 |
| | Score at 35 dB in % | 27.1 (N=7) | 13 (N=13) | 0.640 |
| | Score at 25 dB in % | 6.0 (N=1) | 8.3 (N=4) | 0.885 |

[1] SRT = Speech Recognition Threshold
[2] HL = Hearing Loss

The averaged psychometric curves of the normal hearing patients and patients with hearing loss from both the memory clinic and audiology department are shown in figure 15 and 16.

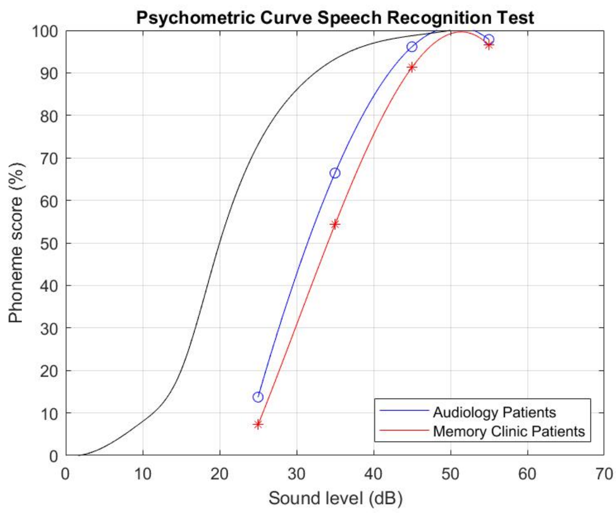


Figure 15: discrimination curves for normal hearing

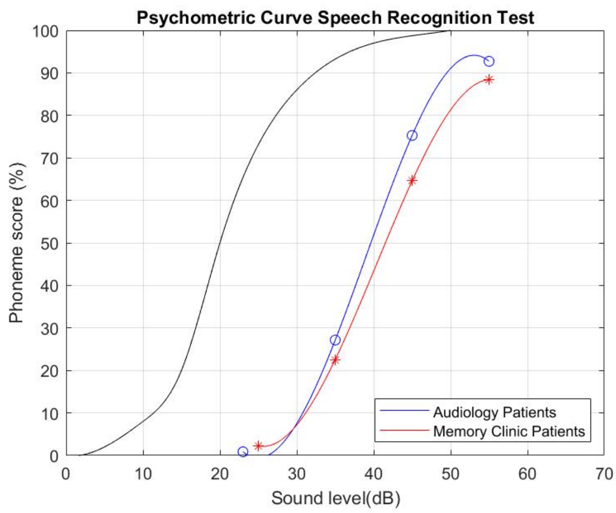


Figure 16: discrimination curves for mild hearing loss

### 4.6 Questionnaire

Three trainee neuropsychologists who performed the neuropsycholgic examination at the memory clinic completed the survey. The question on whether hearing problems regularly causes complications during the neuropsychological tests, scored an average of 4.7 out of 5 points. The trainees agreed (4.3 out of 5 points) that they used the knowledge on the hearing function of the patients during the neuropsychological tests and that this knowledge helped them to perform the neuropsychological examination more enhanced (4.7 out of 5 points). Whether a hearing test would fit in the series of neuropsychological tests, scored a 4 out of 5 and and if a hearing test would be of added value for the understanding of the disease of the patients, scored 3.7 points out of 5.

## 5 Discussion

This study investigated the prevalence and severity of hearing loss in a population of patients visiting the memory clinic of the Erasmus MC. Next to that, research was being conducted into the interaction of hearing loss with the results from the neurospychological examination. Lastly, the applicability and reliability of a hearing screening at the memory clinic were tested.

Hearing loss was diagnosed in approximately half of the participants from the memory clinic. Drawing a conclusion on the comparison of the prevalence of hearing loss with a general population based on all three age groups, the prevalence of hearing loss is not significantly different in the population of the memory clinic compared to a general population of the same age. Therefore, the null hypothesis has been accepted. This is in conflict with some of the evidence found in the literature, showing a higher prevalence of hearing loss in cognitively impaired populations compared to populations without cognitive impairment [15, 27, 28, 29]. Nonetheless, in most of the studies, the age of the population with a cognitive impairment was significantly higher than the population without cognitive impairment, and as described in the introduction, the prevalence of hearing loss exponentially increases with the age. A systematic review including 14 articles on the prevalence of hearing loss in cognitively impaired populations, stated that the burden of hearing loss is considerably higher in cognitively impaired populations compared to populations without any form of cognitive impairment, but that the difference in prevalence of hearing loss between the two populations does not turn out to be statistically significant when adjusting for age [8].
Despite hearing loss not being significantly more common in the population of the memory clinic compared to a general population, knowing that half of the patients from the memory clinic have hearing problems, the evaluation of the hearing function remains important. Most patients diagnosed with hearing loss mentioned to never or rarely experience hearing problems. Without a hearing screening, these patients would have not been familiar with their hearing problems, while the treatment of hearing loss could potentially help in slowing down the progress to a more severe stage of dementia. Next to that, hearing loss is associated with a reduced social engagement, loneliness and depression, which are independently associated with a poor cognitive function [30]. Further research should investigate the effect of the treatment of hearing loss on the cognitive function in patients from the memory clinic.

No statistical significant differences were found in the performance on the tests of the neuropsychological examination between patients with and without hearing loss. The largest difference in scores between the two patient groups was found in the domain of processing speed. Although this difference is not statistically significant, it is interesting to see that the relation between processing speed and cognitive decline are mentioned together in other studies. A population wearing cochlear implants were found to score lower on processing

speed tests and a negative correlation between hearing handicaps and processing speed was found in healthy older adults [31]. The cascade hypothesis as described in the introduction could be related to this: an impoverished environment due to auditory deprivation has lead to the decreased stimulation of cognitive processing.
A limitation of this study in the investigation on the relationship between hearing loss and results of the neuropsychological examination, was the knowledge of the trainee neuropsychologists on the hearing status of their patient. This made them decide to leave out certain tests of the neuropsychological examination. Therefore, patients who were clearly having hearing problems, might have been left out of the analysis of specific domains of the neuropsychological tests. This was mainly the case in the auditory verbal tests.
The auditory verbal tests were not consequently performed better or worse by both the patients with and without a hearing loss. A limitation in this comparison was the small amount of auditory verbal tests. Only the WT 15 and WT delay scores were included in the auditory verbal tests which are both tests from the memory domain. The memory functioning of a patient might therefore have distorted the comparison between the results of auditory and non-auditory verbal tests. No significant differences were found between the results of the neuropscyhological examination from patients wearing hearing aids and patients having a hearing loss. Taking the results related to the neuropsychological exam all together, there is no significant interaction between having a hearing loss or wearing hearing aids and the results of the neuropsychological tests.

The word discrimination test in free field as hearing screening method is an applicable, reliable and quick method to investigate the hearing ability of patients from the memory clinic. The results from the word discrimination test show a strong relation ship with the results from the PTA (the golden standard of hearing tests in adults). Next to that, the relationship between the test-retest results were found to be strong and statistically significant, indicating a good reliability of the test. Patients scored generally better on their second try of the test at a certain sound level, probably due to conditioning. On the other hand, the concentration of the patients decreased during the test which could have influenced the results of retest negatively. A test-retest variability is by any means already proven to be existent in the word discrimination test with the NVA word lists [32]. The differences in the test-retest results in the population of the memory clinic are therefore judged to be normal. Lastly, the influence of the cognitive component on the results of the word discrimination test was questioned in this research. During the hearing screening at the memory clinic, cognitive problems sometimes seemed to influence the performance of the paients on the test. From objective observations, the patients were having trouble with staying concentrated and had a very slow reaction. Regularly, a patient would repeat a word when the next word was already being presented by the speaker. Occasionally, patients seemed to be hearing the words correctly, but they could not process and repeat the same word properly. One patient for example repeated with "six", after the word "five". Nonetheless, the discrimination curves of the patients from the memory clinic were similar to those of patients from the audiology department with a complementary hearing loss and no cognitive problems. These results imply that the cognitive impairment in the patients of the memory clinic is not of significant influence on the results of the word discrimination test in free field. A limitation here is that an assumption was made about the patients of the audiology department having a normal cognitive function, since their cognitive function was not tested for this study. For future research or implementation of a hearing screening at the memory clinic, it should be considered to use another discriminator, for example by looking at the shift of the discrimination curve at the 80% curve. An alternative hearing assessment method could also be an option, for example the speech audiometry method which is also used in children. During this test, patients are presented a word and four pictures. The patient has to point out which picture he or she had just heard. Although a hearing assessment method like this should be easier to complete, the extra action of pointing out a picture could also be a difficulty for persons with cognitive problem.
Notwithstanding, the hearing screening method used in this study is a very convenient method to use at the

memory clinic of the Erasmus MC and potentially in other hospitals too. The consultation rooms of the memory clinic at the Erasmus EMC are plainly equipped and ambient sounds were not specifically rare or highly present. Only the sound of the ventilator was highly noticeable. When removing this specific noise, the word discrimination test in free field would deliver more accurate results. Next to that, the test population of this study is a good representation of a typical population visiting a memory clinic. Overall, the test setup used in this study should be applicable in memory clinics of other hospitals.
The administration of a hearing screening in advance of the neuropsychological examination was highly appreciated by the trainee neuropsychologists performing the neuropsychological examination. When knowing the hearing function of the patients, the trainees said it was easier to cope with the hearing loss during the neuropsychological examination by eliminating certain tests and putting more effort in the articulation of their own speech.

Normally, a free field hearing test is performed in a sound proof cabin. Background noise in the consulting rooms of the memory clinic definitely have had an influence on the results of the word discrimination test in free field. The discrimination curves of the healthy volunteers at the memory clinic and in the sound proof cabins were significantly different from each other and the sound-level meter revealed a broadband value of 36-37 dB SPL LAFmin in both rooms of the memory clinic. This explains why the test was performed significantly better in the sound proof cabins for lists at 35 and 25 dB SPL. When administering a list of words at the same sound level as the broadband LAFmin value, there would be a signal to noise ratio (SNR) of 0. According to the NVA, normal hearing persons using both ears and receiving both noise and speech from the same direction, would understand 50% of the administered speech at a SNR of approximately -7 dB [33]. Therefore it is expected that the healthy volunteers would score 50% at the word discrimination test at the memory clinic when a word list is presented at 30 dB (making the SNR approximately -7). Taking the discrimination curve from the healthy subjects at the memory clinic, a 50% score is achieved at 27 dB. This slightly better result than expected can be explained by the spectrum of the noise. The sound levels of the background noise are higher in the lower frequencies, while higher frequencies are more important for speech discrimination (Figure 17). Next to that, the speech was administered from a speaker positioned in front of the subject at a distance of one meter, while ambient noise is present from all around and mainly more distant, making it easier to separate the speech.

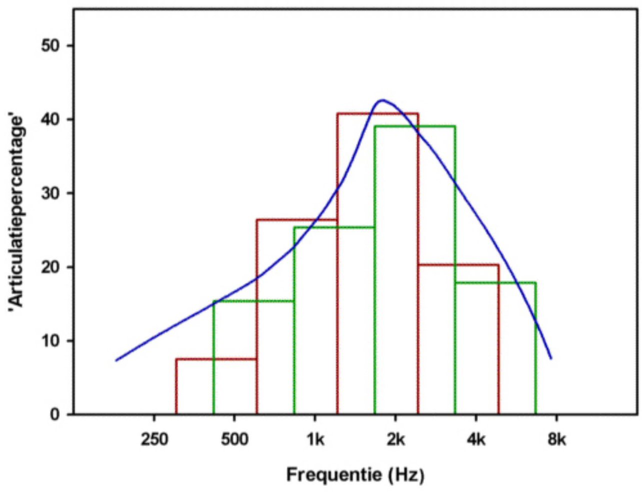


Figure 17: The contribution of different frequency bands to speech perception

In conclusion, when analyzing the results from the word discrimination tests of the patients from the memory clinic, a systematic shift in the discrimination curve must be taken in account, especially the results from the word lists presented at 25 dB or lower are less reliable due to the ambient sound levels. At the level of 35 dB and higher, no problems are expected, and only at a sound level of 40 dB the discriminator between normal hearing and hearing loss (20 dB shift of the discrimination curve compared to the reference curve) occurs. Meaning, the score at higher levels determine the difference between normal hearing and hearing problems and therefore ambient sound is not expected to cause problems for hearing screening purposes.
A shift of 20 dB of the discrimination curve at the 50% point compared to the reference curve was used as the discriminator between normal hearing and hearing loss. In 5 of the patients, the conclusion on the hearing function based on this discriminator was not in accordance with the conclusion made based on both the PTA and word discrimination test. However, all these patients were borderline cases and reflecting on figure 7, the 20 dB as discriminator creates a good distinction of the group with relative poor PTA scores, which are the cases we would explicitly like to detect with a hearing screening. Another factor that should be kept in mind, is that the reference curve was created based on hearing tests with headphones. The reference curve of the word discrimination test in the free field has a small shift to the left, meaning that the estimated hearing losses are actually slightly higher (more information on this topic can be found in appendix H). This compensates the strict discriminator of 20 dB used in this study. Taking all these factors together, the discriminator of a 20 dB shift is suitable do differentiate between normal hearing and hearing loss.

Overall, a hearing screening at the memory clinic could help physicians to better perform the neuropsychological examination and help patients by acting on one of the largest modifiable risk factors of dementia, but to be completely sure about this, a larger test population is needed. The implementation of a hearing screening will make it possible to discover hearing problems in patients who believe to have no hearing handicap. These patients could be advised or referred for a visit to the audiologist or ENT doctor. Hearing aids could then potentially help in a slower decline of the cognitive function and help in a reduction of social engagement, loneliness and depression. Further research is necessary to investigate whether the treatment of hearing loss in the population of the memory clinic will indeed have a positive effect on the cognitive function and delay the progress of cognitive decline.

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# Appendix A: Questionnaire

## Enquête gehoorscreening op de geheugenpoli – Zorgverleners

De afgelopen maanden zijn er bij tientallen patiënten met het vraagstuk dementie gehoortesten afgenomen. Hierover wil ik graag jullie mening weten. Graag het best passende antwoord op de volgende beweringen aankruisen (het gaat hierbij dus om de patiëntengroep met het vraagstuk dementie).

1) Gehoorproblemen vormen regelmatig moeilijkheden bij de testjes van het neuropsychologisch onderzoek

| Helemaal mee oneens | Oneens | Niet mee oneens en niet mee eens | Eens | Helemaal mee eens |
|---|---|---|---|---|
| O | O | O | O | O |

2) Ik heb de kennis van het functioneren van het gehoor van de patiënt gebruikt in het verder uitvoeren van het NPO.

| Helemaal mee oneens | Oneens | Niet mee oneens en niet mee eens | Eens | Helemaal mee eens |
|---|---|---|---|---|
| O | O | O | O | O |

3) Wanneer ik de kennis had over het gehoorverlies van een patiënt, kreeg ik het gevoel dat ik het NPO beter kon uitvoeren dan wanneer ik deze kennis niet had gehad.

| Helemaal mee oneens | Oneens | Niet mee oneens en niet mee eens | Eens | Helemaal mee eens |
|---|---|---|---|---|
| O | O | O | O | O |

4) Een gehoortest past goed in de reeks van neuropsychologische testen

| Helemaal mee oneens | Oneens | Niet mee oneens en niet mee eens | Eens | Helemaal mee eens |
|---|---|---|---|---|
| O | O | O | O | O |

5) Ik denk niet dat een gehoortest meerwaarde geeft aan de inzichten van het ziektebeeld van de patiënt

| Helemaal mee oneens | Oneens | Niet mee oneens en niet mee eens | Eens | Helemaal mee eens |
|---|---|---|---|---|
| O | O | O | O | O |

# Appendix B: Measurement setup

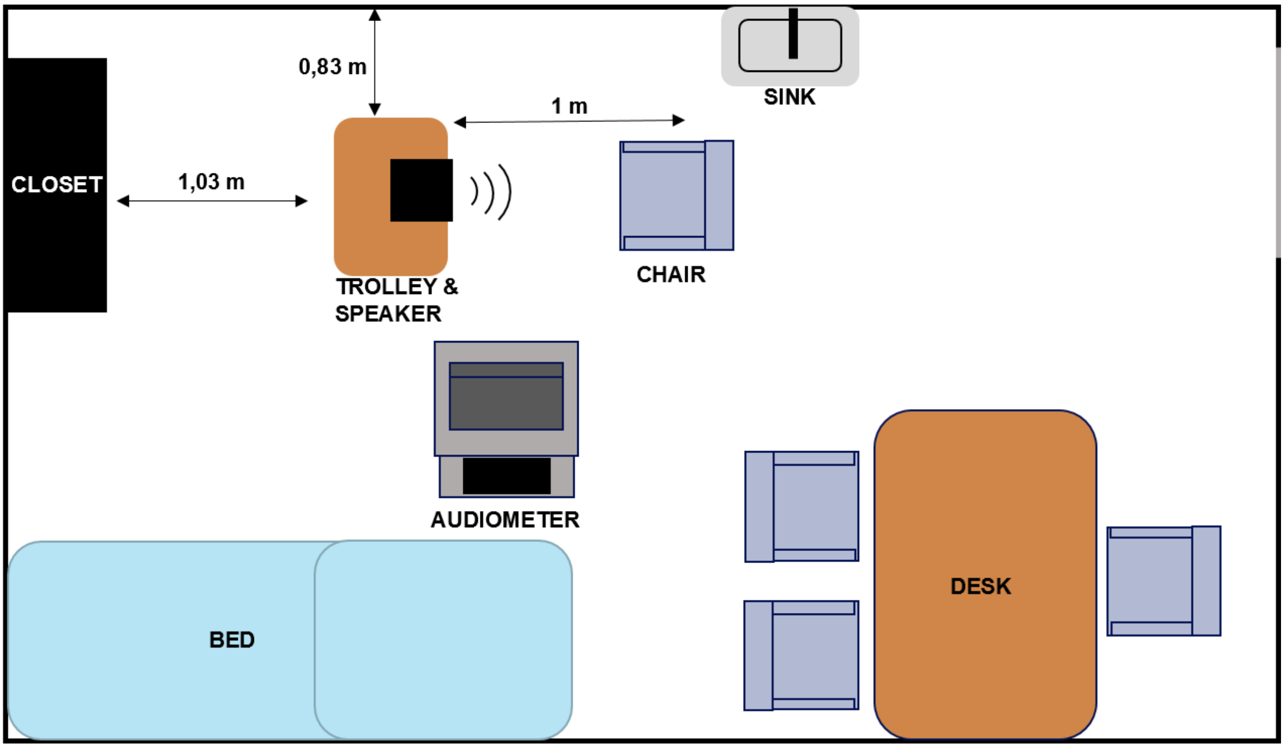


Figure 18: Top view of consulting room 1 with the measurement setup of the audiometer

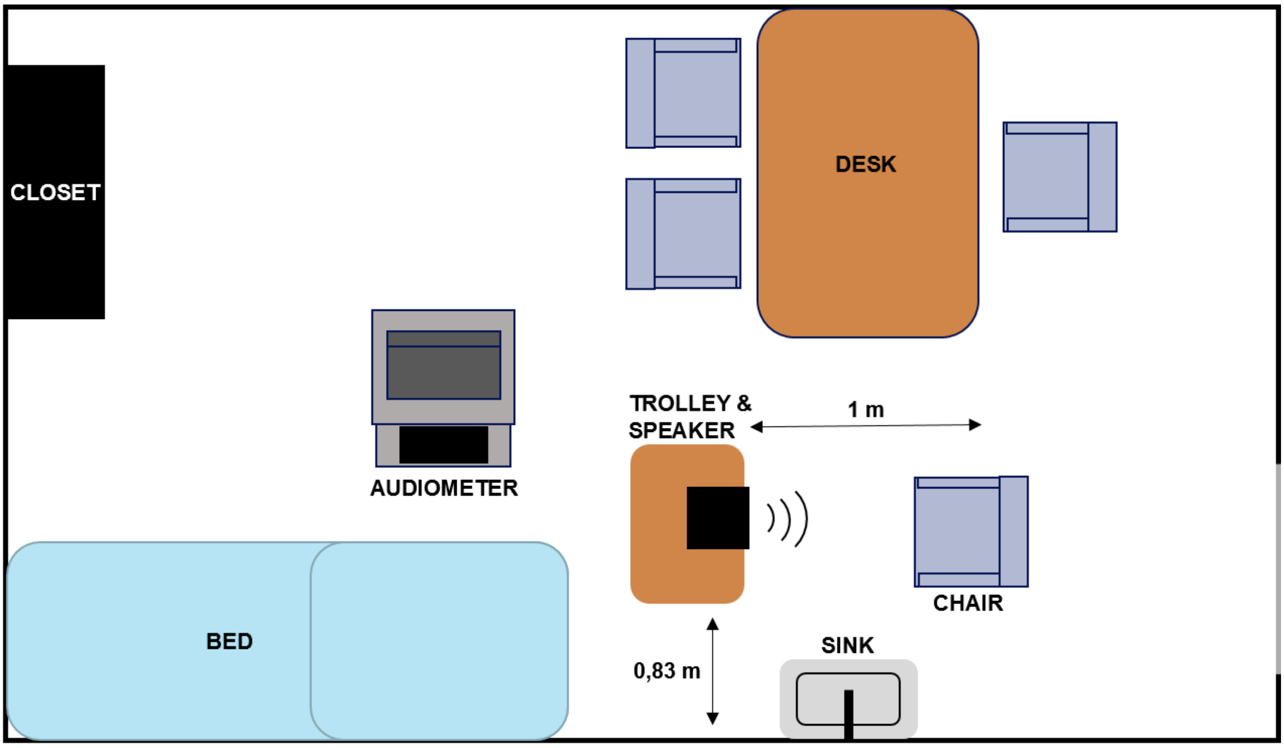


Figure 19: Top view of consulting room 2 with the measurement setup of the audiometer

# Appendix C: Subject information and form of consent



## Proefpersoneninformatie voor deelname aan medisch-Wetenschappelijk onderzoek: gehoorscreening op de geheugenpolikliniek

**Inleiding**
Geachte heer/mevrouw,

Op de geheugenpolikliniek van het Erasmus MC zien wij mensen met verschillende vormen van dementie of een vermoeden daarvan. Voor de diagnostiek van dementie worden veel verschillende onderzoeken uitgevoerd. Een gehooronderzoek wordt hier niet uitgevoerd, terwijl er een samenhang blijkt te zijn tussen gehoorvlies en cognitieve achteruitgang. Momenteel zijn we bezig om een geschikte gehoorscreening op te zetten voor de patiënten op de geheugenpoli. Hiervoor willen wij ook weten hoe deze gehoortest wordt uitgevoerd door personen zonder cognitieve klachten.
Met deze informatiebrief willen we u vragen of u wilt meedoen aan dit medisch-wetenschappelijk onderzoek. Meedoen is vrijwillig. U krijgt deze brief omdat u een afspraak heeft (gehad) voor een gehooronderzoek. U leest hier om wat voor onderzoek het gaat, wat het voor u betekent en wat de voordelen en nadelen zijn. We verzoeken u de informatie door te nemen, daarna kunt u beslissen of u mee wilt doen. Als u wilt meedoen, lees dan onder paragraaf 7 wat u moet doen.

1. **Algemene Informatie**

Dit onderzoek is opgezet vanuit de KNO en de neurologie van het Erasmus MC. Het onderzoek wordt uitgevoerd door medewerkers en studenten van het Erasmus MC.

2. **Wat is het doel van het onderzoek?**

In dit onderzoek bekijken we wat de relatie is tussen gehoorverlies en de cognitieve functie van patiënten met dementie of een vermoeden hiervan.

3. **Wat de achtergrond van het onderzoek?**

Patiënten die op de geheugenpoli komen worden niet getest op hun gehoor, terwijl een gehoorverlies invloed kan hebben op de cognitieve functie. Om deze relatie tussen het gehoorverlies en de cognitieve functie te onderzoeken, voeren we nu gehoortesten uit op de spreekuren van de geheugenpoli. Daarnaast willen we kijken of de gehoortest die gebruikt wordt, goed werkt en geschikt is voor op de geheugenpoli. Hiervoor willen wij weten hoe de test wordt uitgevoerd door personen zonder klachten van cognitieve problemen.

4. **Hoe verloopt het onderzoek?**

Het onderzoek bestaat uit een korte gehoortest van ongeveer 10 minuten. Deze test kan aansluitend op uw normale afspraak worden uitgevoerd. Het onderzoek vindt plaats op de geheugenpoli, direct naast de Audiologie.

5. **Wat zijn de voordelen en de nadelen als u meedoet aan het onderzoek?**

Door mee te doen draagt u bij aan ons onderzoek. Meedoen aan het onderzoek kost u extra tijd. Verder zijn er geen voor- of nadelen voor u als u mee doet aan het onderzoek. U beslist zelf of u meedoet aan het onderzoek. Als u besluit om niet mee te doen aan dit onderzoek, heeft dit geen nadelen voor u.

6. **Wat doen we met uw gegevens?**

Doet u mee met het onderzoek? Dan geeft u ook toestemming uw gegevens te verzamelen, gebruiken en bewaren. We verzamelen, gebruiken en bewaren uw gegevens om de vragen van dit onderzoek te kunnen beantwoorden. En om de resultaten te kunnen publiceren.

We bewaren de volgende gegevens:

- Uw geslacht
- Uw geboortedatum
- Gegevens over uw gehoorverlies
- Gegevens die we tijdens het onderzoek verzamelen

*Hoe beschermen we uw privacy?*

Om uw gegevens te beschermen anonimiseren wij alle gegevens. Uw gegevens worden gekoppeld aan een code.

*Wie kunnen uw gegevens zien?*

De onderzoekers kunnen wel uw naam en andere persoonlijke gegevens inzien.

*Mogen we uw gegevens gebruiken voor ander onderzoek?*

Uw gegevens kunnen na afloop van dit onderzoek ook nog van belang zijn voor ander wetenschappelijk onderzoek op het gebied van audiologie. Daarvoor zullen uw gegevens 10 jaar bewaard worden in het ziekenhuis. In het toestemmingsformulier geeft u aan of u dit goed vindt. Geeft u geen toestemming? Dan kunt u nog steeds meedoen met dit onderzoek.

*Kunt u uw toestemming voor het gebruik van uw gegevens weer intrekken?*

U kunt uw toestemming voor het gebruik van uw gegevens op ieder moment intrekken. Dit geldt voor het gebruik in dit onderzoek en voor het gebruik in ander onderzoek. Maar let op: trekt u uw toestemming in, en hebben onderzoekers dan al gegevens verwerkt voor publicatie? Dan mogen zij deze gegevens nog wel gebruiken.

7. **Hoe geeft u toestemming voor het onderzoek?**

U kunt eerst rustig nadenken over dit onderzoek. Daarna vertelt u de onderzoeker of u de informatie begrijpt en of u wel of niet wilt meedoen. Wilt u meedoen? Geef dit dan aan bij de onderzoeker. U vult het toestemmingsformulier in dat u bij deze informatiebrief vindt. U en de onderzoeker krijgen allebei een getekende versie van deze toestemmingsverklaring.

## Bijlage A: toestemmingsformulier proefpersoon

Behorende bij

Onderzoek naar de relatie tussen gehoorverlies en de cognitieve functie

- Ik heb de informatiebrief gelezen. Ook kon ik vragen stellen. Mijn vragen zijn goed genoeg beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen vrijwillig is. Ook weet ik dat ik op ieder moment kan beslissen om toch niet mee te doen met het onderzoek. Of om ermee te stoppen. Ik hoef dan niet te zeggen waarom ik wil stoppen.
- Ik geef de onderzoeker toestemming om mijn gegevens te verzamelen en gebruiken. De onderzoekers doen dit alleen om de onderzoeksvraag van dit onderzoek te beantwoorden
- Wilt u in de tabel hieronder ja of nee aankruisen?

| | | |
|---|---|---|
| Ik geef toestemming om mijn gegevens te bewaren om dit te gebruiken voor ander onderzoek, zoals in de informatiebrief staat. | Ja ☐ | Nee☐ |

- Ik wil meedoen aan dit onderzoek.

Mijn naam is (proefpersoon): …………………………………..
Handtekening: ……………………….   Datum : __/ __/ __

-----------------------------------------------------------------------------------------------------------------

Ik verklaar dat ik deze proefpersoon volledig heb geïnformeerd over het genoemde onderzoek.

Wordt er tijdens het onderzoek informatie bekend die die de toestemming van de proefpersoon kan beïnvloeden? Dan laat ik dit op tijd weten aan deze proefpersoon.

Naam onderzoeker (of diens vertegenwoordiger):………………………………….
Handtekening:……………………….   Datum: __/ __/ __

-----------------------------------------------------------------------------------------------------------------

*De proefpersoon krijgt een volledige informatiebrief mee, samen met een getekende versie van het toestemmingsformulier*

**Contact gegevens**

Onderzoeker: Sabine van Mierlo, s.vanmierlo@erasmusmc.nl

# Appendix D: Ambient noise at the memory clinic

Table 9 contains the audio frequency spectrum sound levels of ambient sound measured in the consulting rooms of the memory clinic.

Table 9: The measured values of LAeq in the consulting rooms of the memory clinic

| **Frequency** | **LAeq (dB) room 110** | **LAeq (dB) room 112** |
|---|---|---|
| 250 Hz | 23.33 | 33.27 |
| 500 Hz | 26.40 | 25.73 |
| 1000 Hz | 32.17 | 26.60 |
| 2000 Hz | 19.59 | 23.25 |
| 4000 Hz | 12.90 | 17.42 |
| 8000 Hz | 8.56 | 9.52 |

# Appendix E: The comparison of estimated advises on follow-up action

The advise could comprise 1) no follow-up action needed, 2) a visit to the audiologist or ENT doctor in five years or earlier when experiencing hearing complaints, or 3) a visit to the audiologist or ENT doctor. Figure 20 provides an overview of the estimated advises and the answer of the patients to the question whether they experience any hearing problems. Five of the patients were already known with their hearing problems and were in the position of hearing aids. In four cases, only information of the word discrimination was available, of which one diagnosed with hearing problems and three with a normal hearing. Of the 22 remaining patients, the advises were in accordance with each other in 17 cases. From these cases, ten patients were diagnosed with hearing problems, five with a normal hearing and two doubtful cases. Remarkably, four of the patients diagnosed with a hearing loss mentioned to never experience hearing problems, three patients indicated to rarely experience hearing problems and only three patients experienced hearing problems often. In 5 cases, the advises were not in accordance with each other.

| Case | Inquiry: Hearing Loss? | Advise 1 | Advise 2 |
|---|---|---|---|
| 1 | Never | | |
| 2 | Never | | |
| 3 | Never | | |
| 4 | Often | | |
| 5 | Never | | |
| 6 | Never | | |
| 7 | Never | N.A | |
| 8 | Seldom | | |
| 9 | Seldom | | |
| 10 | Never | | |
| 11 | Always | | |
| 12 | N.A. | | |
| 13 | Sometimes | | |
| 14 | Seldom | | |
| 15 | Seldom | | |
| 16 | Often | | |
| 17 | Often | N.A | |
| 18 | Never | N.A | |
| 19 | Seldom | | |
| 20 | Never | | |
| 21 | Never | | |
| 22 | Never | N.A | |
| 23 | Often | | |
| 24 | Often | | |
| 25 | Never | | |
| 26 | Sometimes | | |
| 27 | Never | | |
| 28 | Never | | |
| 29 | N.A. | | |
| 30 | Never | | |
| 31 | Never | | |

Advise 1 = based on all available information
Advise 2 = based on word discrimination test only

No follow-up action required.
Visit to the audiologist or ENT doctor in 5 years or earlier when having complaints.
Visit to the audiologist or ENT doctor..
Patient already has hearing aids.

Figure 20: An overview of the advises on follow-up actions

# Appendix F: Statistical comparison of the prevalence of hearing loss

Table 10 provides an overview of the observed and expected values of the prevalence of hearing loss in the population of the memory clinic. The expected value is based on the prevalence of hearing loss in the population of the Rotterdam Study.

Table 10: The observed and expected values

| Population | Observed Value | Expected value | $(O-E)^2$ |
|---|---|---|---|
| **Normal Hearing 55-64 years** | 5 | 5.66 | 0.08 |
| **Mild Hearing Loss 55-64 years** | 3 | 2.02 | 0.48 |
| **Moderate to severe Hearing loss 55-64 years** | 0 | 0 | 0 |
| **Normal Hearing 65-74 years** | 2 | 3.56 | 0.68 |
| **Mild Hearing Loss 65-74 years** | 7 | 3.94 | 2.38 |
| **Moderate to severe Hearing loss 65-75 years** | 0 | 1.49 | 1.5 |
| **Normal Hearing 75-85 years** | 3 | 3.00 | 0 |
| **Mild Hearing Loss 75-85 years** | 6 | 6.00 | 0 |
| **Moderate to severe Hearing loss 75-85 years** | 5 | 5.00 | 0 |

For every age group, the Chi-squared was calculated. The critical value for this test was 5.99. No significant difference was found between the expected and observed values and therefore the distribution of the prevalence of hearing loss among the memory clinic is the similar to that of the population of the Rotterdam Study: $X^2(2) = 0.56$, $p < 0.05$ for the age group of 55-64 years, $X^2(2) = 4.56$, $p < 0.05$ for the age group of 65-74 years and $X^2(2) = 0$, $p < 0.05$ for the age group of 75-85 years.

## Appendix G: Tests from the neuropsychological examination

**15 WT:** The 15-words test consists of 15 words that are read out loud to the patient five times. After every presentation of the list of words, the patient has to mention the words that he or she has remembered.

**15 WT delay:** After 15-20 minutes of the last presentation of the 15 WT, the patient is asked again to repeat the words he or she has remembered from the 15-words test.

**Vat total:** The Visual association test consists of six combinations of two connected images. To test whether the presented combinations have been remembered by the patient, half of the combination is being shown with the question to mention the other part of the combination.

**Stroop:** The Stroop colour-word test consists of three versions of stimuli that have to be read aloud as fast as possible. Version 1 contains the names of the colours red, green, yellow and blue. Version two contains squares printed in the these colours. Version 3 has the names of the colours printed in non-matching colours, causing interference.

**TMT:** The Trail Making Test is a series of timed tests. Part A consists of 25 circles on a piece of paper with the numbers 1 to 25 written randomly in each. The patient is tasked with drawing a line from one circle to the next in ascending numerical order as fast as possible. TMT Part B also consists of 25 circles on a piece of paper, but hey contain numbers (1 to 12) and letters (A through L). The patient is tasked with connecting the circles in ascending order, alternating back and forth from numbers to letters.

**BNT:** The Boston Naming test consists of 60 black line drawings. The patient is showed each of the pictures one at a time. The patient is given 20 seconds to say what the drawing depicts. If the patient is not able to identify the drawing, specific verbal clues are given and the patient is given another 20 seconds.

**Fluency Tests** During the Verbal Fluency tests, the patient is given 60 seconds to verbally list as many things as possible in a certain category (e.g. Animals, or words starting with a certain letter).

**Clock Drawing** During the clock-drawing test, the patient is first asked to draw a clock. Next, the patient is asked to draw the hands of the clock to show a specific time.

# Appendix H: The reference curve

According to the ANSI S3.6 standards, the correction factor between the free-field and headphones word discrimination test is 3.1 dB. This in accordance with the results from the healthy volunteers in the sound proof cabins, showing a small shift of their averaged curve to the left. A recently conducted study found a correction factor of 7.5 dB, which would mean that the 50% point of the reference curve is found at a level of 12,5 dB SPL instead of 20 dB SPL (figuur 21) [34]. Taking the average of those two, the correction factor would be around 5 dB. A correction factor of 5 dB is in accordance with the offset of 5 dB in the regression curve of the results from the PTA with respect to the results from the word discrimination test as seen in figure 7.
In conclusion we could say that the shift of the discrimination curves compared to the reference curve should systematically be increased with approximately 5 dB.

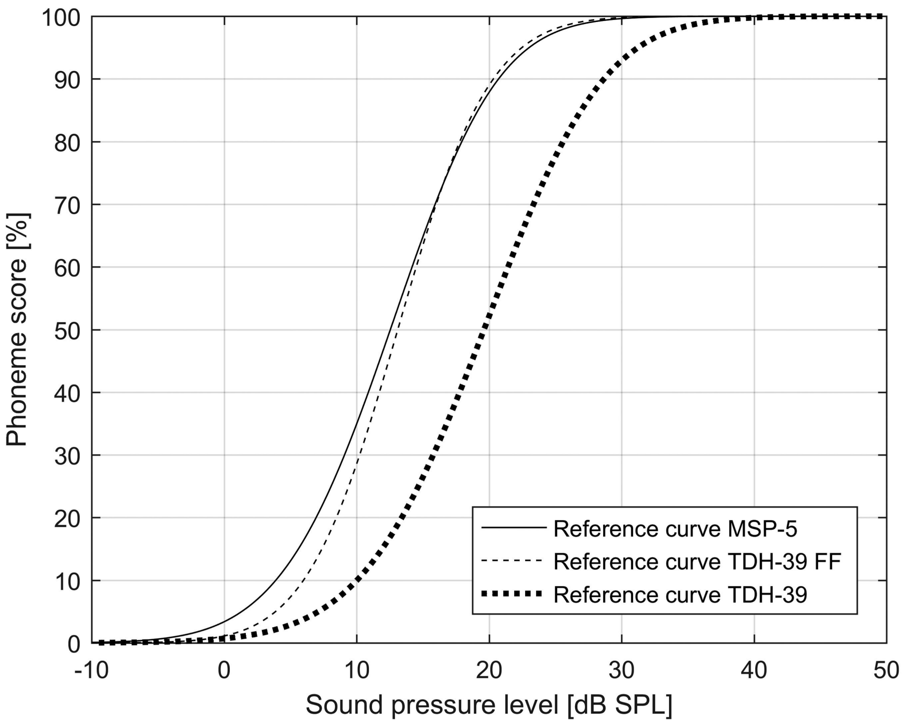


Figure 21: Determined reference curves for NVA-CVC words for free field and headphone conditions