Study on the impact of hearing care on cognition

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Rome
Some considerations to start..

Most of epidemiological studies have found an association between HL and incident dementia.

Previous studies (Linn 2011, Ronnberg 2010) have shown a correlation between ARHL and memory and between ARHL and executive functions.

The analysis of the neuropsychological features of hearing impaired people can help us to clarify the relationship between ARHL and dementia according to two different hypothesis:

- Parallel and independent events, both linked to aging
- Sensorial deprivation
  - Altered input and encoding of verbal materials
  - Modified mechanism of neural plasticity
Greater hearing loss was significantly associated with lower scores on measures of mental status (Mini-Mental State Exam), memory (Free Recall), and executive function (Stroop Mixed, Trail Making B).

The reduction in cognitive performance associated with a 25 dB hearing loss was equivalent to the reduction associated with an age difference of 6.8 years.

Linn et al 2011

347 hearing impaired subjects

Neurocognitive battery including tests of mental status, memory, executive function, processing speed, and verbal function
Previous findings about memory..

160 hearing aid users from the Swedish prospective cohort aging study (Betula)

Worse performances in episodic memory tasks

Mechanism involved:
• Attentional Resources
• Information Degradation
• Mismatch/disuse
AIM OF OUR STUDY

The purpose of our work was to study the audiological and neuropsychological characteristics of a sample of hearing impaired cognitively healthy subjects, who went to the Audiology Service of the Institute of Otolaryngology between September 2014 and September 2016.

We have studied a population of patients with mild / moderate presbycusis, analyzing two perspectives

  a) the correlation between neuropsychological, linguistic and audiological variables;

  b) comparisons between the neuropsychological profile of these subjects and a group of age-matched control;
82 subjects:
• Age > 60 years
• Absence of neurological diseases
• Education level ≥ 8 years
• Mild, moderate or deep post-lingually hearing loss

19 subjects with mild hearing loss (PTA 21-40 db)
23 subjects with moderate hearing loss (PTA 40-55 db)

19 subjects with mild hearing loss (n. 23)
23 subjects with moderate hearing loss (n.19)
40 subjects - not demented
- No alterations in speech comprehension and communication
- PTA = 25 db
- Normal Audiometric thresholds except for 6000-8000 Hz.

<table>
<thead>
<tr>
<th></th>
<th>Mild Hearing loss (n. 23)</th>
<th>Moderate Hearing Loss (n.19)</th>
<th>Healthy Controls (n.40)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>73,5</td>
<td>76,3</td>
<td>73,6</td>
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<td>9,6</td>
<td>10</td>
<td>9,8</td>
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<td>MMSE</td>
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<td>25,1</td>
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<td>Mean PTA right ear</td>
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<tr>
<td>Mean PTA left hear</td>
<td>32,54</td>
<td>51,30</td>
<td>25</td>
<td>P&lt;0,05</td>
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</tbody>
</table>
## METHODS

### Neuropsychological battery

| Memory          | Rey Auditory Verbal Learning Task (RAVLT) - Immediate Recall, Delayed Recall, recognition, Primacy and recency effect  
|                 | Rey-Osterreith complex Figure Recall  
| Attention       | Multiple Features Target Cancellation (MFTC)  
| Executive Funcitons | Raven’s Coloured Matrices  
|                 | Stroop Test  
|                 | Copy of Rey-Osterreith Figure  
|                 | Phonological Verbal Fluency (PVF)  
| Language        | Phonological Semantic Fluency (FVS)  
|                 | Oral Nouns and Actions Denomination  

### Linguistic tasks (from Battery for Aphasia, Miceli and Capasso)

- Battery for Aphasia (B.A.D.A.)
  - Phonemic discrimination
  - Word repetition
  - Non-words repetition
  - Sentences repetition
  - Non-words writing
  - Auditory lexical decision
  - Visual lexical decision
  - Auditory nouns comprehension
  - Visual nouns comprehension
  - Auditory actions comprehension
  - Visual actions comprehension
  - Auditory Grammar judgement
  - Visual Grammar judgement
  - Auditory sentences comprehension
  - Phonological Verbal Memory

### Pure Tone Audiometry

### Speech Audiometry

### Auditory Brain Responses
Participants are given a list of 15 unrelated words repeated over five different trials and are asked to repeat. The subject is requested to recall the same list of 15 words after 15 minutes.

**Immediate Recall**

**Delayed Recall:** It is a pure measure of verbal long term memory!

**Mnesic qualitative index**
- *Primacy/Recency effect*: This is the tendency for the first/last items presented in a series to be remembered better or more easily;
- *Learning*: (recalled words in 4th and 5th series) – (recalled word in 1st and 2nd series)
- *Forgetting*: delayed recall/(recalled words in 4th and 5th series)
RAVLT - recognition

<table>
<thead>
<tr>
<th>Vagone</th>
<th>Sole</th>
<th>Fiammifero</th>
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<tbody>
<tr>
<td>Violino</td>
<td>Brodo</td>
<td>Casa</td>
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<tr>
<td>Uomo</td>
<td>Giornale</td>
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<td>Bastone</td>
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<td>Finestra</td>
<td>Letto</td>
<td>Camino</td>
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<td>Tromba</td>
<td>Isola</td>
<td>Paesano</td>
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<td>Baffi</td>
<td>Sera</td>
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<td>Cappello</td>
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<td>Giardino</td>
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<tr>
<td>Monte</td>
<td>Pane</td>
<td>Pagina</td>
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<td>Colore</td>
<td>Freccia</td>
<td>Lampada</td>
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<tr>
<td>Lago</td>
<td>Palazzo</td>
<td>Parete</td>
</tr>
<tr>
<td>Notte</td>
<td>Lira</td>
<td>Manico</td>
</tr>
</tbody>
</table>

**Corretti** | **Falsi** | **Accuracy** |

Recognition of the 15 RAVLT words among 30 distractors after another 15 min from delayed recall.

3 scores are computed:
- number of correct recognition
- number of false recognition.
- Accuracy:

\[
\text{correct hits} + \frac{30 - \text{false rec}}{2} = \frac{15}{30} = \frac{2}{2}
\]
Correlation between neuropsychological performances and ARHL degree - One-way MANOVA with univariate F effects

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<tbody>
<tr>
<td>RAVLT IR</td>
<td>27.87 1.63</td>
<td>33.04 1.82</td>
<td>37.02 1.25</td>
<td>&lt; 0.001</td>
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<tr>
<td>RAVLT DR</td>
<td>5.18 0.51</td>
<td>6.13 0.49</td>
<td>8.22 0.41</td>
<td>&lt; 0.0001</td>
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<tr>
<td>RAVLT REC HITS</td>
<td>11.31 0.59</td>
<td>11.7 0.63</td>
<td>12.45 0.30</td>
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<td>RAVLT REC FAL</td>
<td>2.18 0.82</td>
<td>1.73 0.5</td>
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<tr>
<td>Learning</td>
<td>4.27 0.72</td>
<td>5.81 0.60</td>
<td>7.45 0.38</td>
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<tr>
<td>Forgetting</td>
<td>0.43 0.07</td>
<td>0.39 0.06</td>
<td>0.98 0.04</td>
<td>&lt; 0.01</td>
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<tr>
<td>Recency</td>
<td>0.45 0.03</td>
<td>0.44 0.03</td>
<td>0.31 0.02</td>
<td>&lt; 0.0002</td>
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<tr>
<td>Primacy</td>
<td>0.31 0.04</td>
<td>0.35 0.03</td>
<td>0.39 0.03</td>
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### LOGISTIC REGRESSION ANALYSES

<table>
<thead>
<tr>
<th>DEFLING - Likelihood Type 1 Test (studio ipoacusia 3) Distribution : BINOMIAL, Link function: LOGIT Modeled</th>
<th>probability that DEFLING = S</th>
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<tbody>
<tr>
<td>Degr. of - Freedom</td>
<td>Log- - Likelihood</td>
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<tr>
<td>Intercept</td>
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<tr>
<td>Age</td>
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<tr>
<td>mean PTA ds (dbHL)</td>
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<tr>
<td>mean PTA sin (dbHL)</td>
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<tr>
<td>threshold at 4000 Hz – right</td>
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<tr>
<td>threshold at 4000 Hz - left</td>
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<tr>
<td>threshold at 8000 Hz – right</td>
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<tr>
<td>threshold at 4000 Hz - left</td>
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<tr>
<td>Speech audiometry right %</td>
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<td>Speech audiometry left %</td>
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<tr>
<td>Global Vocal Detection</td>
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<tr>
<td>Verbo-tonal dissociation – R</td>
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<tr>
<td>Verbo-tonal dissociation – L</td>
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</table>

<table>
<thead>
<tr>
<th>Predicted - S</th>
<th>Predicted - N</th>
<th>% correct</th>
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</thead>
<tbody>
<tr>
<td>Yes</td>
<td>9</td>
<td>2</td>
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<tr>
<td>No</td>
<td>2</td>
<td>32</td>
</tr>
</tbody>
</table>
In our sample memory performances are worse in subjects with hearing loss comparing with HS. Subjects with ARHL have worse learning, increased forgetting and increased recency effect

Altereted post processing of learned informations → defective consolidation of memory track due to a reducted efficiency of lexical processes for the semantic conversion of acquired data.

Our hypothesis is confirmed by the regression analysis results

Memory deficit are predicted by audiological variables linked to the intelligibility of spoken words (speech audiometry and verbo-tonal dissociation)
Executive functioning is broadly defined as control processes responsible for planning, assembling, coordinating, sequencing, and monitoring other cognitive operations.

The executive functioning concept is loosely based on an analogy to a business executive who is not necessarily a specialist in any particular domain but instead is responsible for supervising and managing many different domains.

Executive Tasks

- working memory
- set shifting
- inhibition
- Selective and divided attention
- problem solving

executive functioning clearly has the potential to affect performance in a wide variety of cognitive variables
Span forward and Span backward - *Working memory*

Participants hear a sequence of numerical digits and are tasked to recall the sequence correctly, with increasingly longer sequences being tested in each trial. The participant's span is the longest number of sequential digits that can accurately be remembered. Digit-span tasks can be given forwards or backwards, meaning that once the sequence is presented, the participant is asked to either recall the sequence in normal or reverse order.

It measures *working memory*'s number storage capacity and the integrity of the phonological loop.
Working memory - Corsi Span

It involves mimicking a researcher as he/she taps a sequence of up to nine identical spatially separated blocks. The sequence starts out simple, usually using two blocks, but becomes more complex until the subject's performance suffers.

The **Corsi block-tapping test** assesses **visuo-spatial short term working memory** through evaluation of the visuo-spatial sketchpad.
Stroop Test
(inhibition of automatic response, cognitive flexibility)

1° series:
Lecture of name of colours in black fonts

2° series
Denomination of colours

3° series
Interference: naming the colours of the words → note that the name of a color (e.g., "blue", "green", or "red") is printed in a color that is not denoted by the name

<table>
<thead>
<tr>
<th>Tempo</th>
<th>Lettura</th>
<th>Colori</th>
<th>Interferenza</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20&quot;</td>
<td>42&quot;</td>
<td>58&quot;</td>
</tr>
<tr>
<td>Errori</td>
<td>0</td>
<td>1</td>
<td>4</td>
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</table>
Stroop Test

Stroop effect

naming the color of the word takes longer and is more prone to errors than when the color of the ink matches the name of the color

Cognitive interference
MFTC - MULTIPLE FEATURES TARGETS CANCELLATION TEST

Visual search - Attentional task

Subjects are requested to identify a target item in an array of distractors. The target consists of a square (side = 1 cm), with two segments inside, oriented toward the center of the square; distractors have different orientation or origins of the two lines.

We evaluate:

Time

Accuracy = \left(\frac{\text{correct answers} + \frac{(67-\text{false alarms})}{67}}{13}\right)
Phonological Fluency

This test involved lexical retrieval on the basis of an initial letter.

Given the initial letter (A,F,S) the participants orally retrieved as many words as possible starting during one minute.

This test reflects the integrity of lexical competences but also of the executive functioning.
Linear regression analysis between neuropsychological and audiological variables

<table>
<thead>
<tr>
<th></th>
<th>Mean thresholds right ear</th>
<th>Mean thresholds left ear</th>
<th>Threshold at 4000 Hz right ear</th>
<th>Threshold at 4000 Hz left ear</th>
<th>Threshold at 8000 Hz right ear</th>
<th>Threshold at 8000 Hz left ear</th>
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</thead>
<tbody>
<tr>
<td>RAVLT IR</td>
<td>-0.197920</td>
<td>-0.239143</td>
<td>-0.266778</td>
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<td>RAVLT DR</td>
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<td>-0.151659</td>
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<td>-0.154393</td>
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<td>0.179858</td>
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<td>Span forward</td>
<td><strong>-0.277477</strong></td>
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<td>Span backward</td>
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<td>-0.036309</td>
<td>-0.040404</td>
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<td>Corsi forward</td>
<td>-0.054329</td>
<td>-0.073060</td>
<td>0.036298</td>
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<td>Corsi backward</td>
<td>-0.114004</td>
<td>-0.065949</td>
<td>0.043959</td>
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<td>Raven</td>
<td>-0.214048</td>
<td>-0.228237</td>
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<td>-0.156975</td>
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<td>Costr. Praxis</td>
<td>-0.233276</td>
<td>-0.130156</td>
<td>-0.125942</td>
<td>-0.014704</td>
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<td>Costr. Praxis with landmarks</td>
<td><strong>0.127034</strong></td>
<td>-0.092687</td>
<td>-0.060155</td>
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<td>MFTC accuracy</td>
<td><strong>-0.411289</strong></td>
<td><strong>-0.379404</strong></td>
<td>-0.255880</td>
<td>-0.314863</td>
<td>-0.225356</td>
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<td>MFTC – f</td>
<td><strong>0.558013</strong></td>
<td><strong>0.272585</strong></td>
<td>0.187706</td>
<td>0.042996</td>
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<td>MFTC time</td>
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<td>PVF</td>
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<td>Stroop Interf. Time</td>
<td><strong>0.280850</strong></td>
<td>0.044502</td>
<td>0.204356</td>
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<td>Stroop Interf. errors</td>
<td><strong>0.337081</strong></td>
<td><strong>0.125285</strong></td>
<td>0.210758</td>
<td>0.057922</td>
<td>0.091655</td>
<td><strong>0.175787</strong></td>
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</table>
We have correlated neuropsychological profile of Hearing impaired people with audiological variables linked to the extent of the hearing impairment (mean PTA).

Mean PTA → test sensitive to executive damage

Many measures of central auditory functioning (SSI-ICM, DDT, and DSI) and cognitive tests of executive functions (Trail-making Tests A and B, Stroop Colour Test, Word Test) explore similar dimensions (for example, behavioural inhibition) of executive control.

Subjects Hearing impaired allocated attentional resources to comprehend spoken language, and they have less attentional resources to carefully perform other cognitive tasks

OR

Does executive disfunctions reflect a CAP deficit?
Language

Phonological buffer

Input Phonological lexicon

Semantic-lexycal system

Output Phonological lexicon

Orthographic buffer

Input orthographic lexicon

Orthographic lexicon

phonological buffer

phonoma-graphema conversion

Graphema-phonema conversion

Syllables

Output

Input

kæt

cat

cat

kæt
### Battery for Aphasia (B.A.D.A.)

<table>
<thead>
<tr>
<th>Tasks</th>
</tr>
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<tbody>
<tr>
<td>Phonemic discrimination</td>
</tr>
<tr>
<td>Word repetition</td>
</tr>
<tr>
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<tr>
<td>Sentences repetition</td>
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<td>Non-words writing</td>
</tr>
<tr>
<td>Auditory lexical decision</td>
</tr>
<tr>
<td>Visual lexical decision</td>
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<tr>
<td>Auditory nouns comprehension</td>
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<tr>
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<tr>
<td>Auditory actions comprehension</td>
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<tr>
<td>Visual actions comprehension</td>
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<tr>
<td>Auditory Grammar judgement</td>
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<tr>
<td>Visual Grammar judgement</td>
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<tr>
<td>Auditory sentences comprehension</td>
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<td>Phonological Verbal Memory</td>
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### Comprehension tasks

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<td>Auditory and visual nouns and actions comprehension</td>
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<table>
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<td>Auditory sentences comprehension</td>
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### Transcoding tasks

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<table>
<thead>
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<td>Sentences repetition</td>
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Linear correlation between linguistic performances and audiological variables

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<th>Threshold at 8000 Hz left ear</th>
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<tbody>
<tr>
<td>Phonemic discrimination</td>
<td>-0.11934</td>
<td>0.132247</td>
<td>0.063634</td>
<td>0.276200</td>
<td>0.027584</td>
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<td>Non-words writing</td>
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<td>-0.121993</td>
<td>-0.169774</td>
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<tr>
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<td>0.078457</td>
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<td>Auditory actions comprehension</td>
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<td>0.179643</td>
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<td>0.233280</td>
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<td>-0.115000</td>
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<tr>
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<td>0.146758</td>
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<tr>
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<td>0.110275</td>
<td>0.044339</td>
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<td>0.014051</td>
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<td>-0.146867</td>
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</tbody>
</table>
Correlation between linguistic performances and ARHL degree - One-way MANOVA

<table>
<thead>
<tr>
<th></th>
<th>Moderate hearing loss (n.19)</th>
<th>Mild hearing loss (n.23)</th>
<th>Healthy controls (n.40)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonemic discrimination</td>
<td>2,12</td>
<td>2,81</td>
<td>0,14</td>
<td>0,29</td>
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<tr>
<td>Word repetition</td>
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<td>1,72</td>
<td>0,142</td>
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<td>Non-words repetition</td>
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<td>7,72</td>
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<td>Non-words writing</td>
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<td>4,72</td>
<td>2,71</td>
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<td>8,54</td>
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<td>Visual lexical decision</td>
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<td>1,43</td>
<td>0,90</td>
<td>1,00</td>
<td>0,16</td>
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<tr>
<td>Visual actions comprehension</td>
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<td>2,00</td>
<td>0,57</td>
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<td>2,37</td>
<td>2,81</td>
<td>2,14</td>
<td>0,77</td>
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<td>Phonological Verbal Memory</td>
<td>3,43</td>
<td>3,86</td>
<td>3,57</td>
<td>0,86</td>
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</table>
LOGISTIC REGRESSION ANALYSIS

<table>
<thead>
<tr>
<th>Observed linguistic deficit</th>
<th>Predicted (pt n.)</th>
<th>Not predicted (pt n.)</th>
<th>% of correctly identified subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>15</td>
<td>6</td>
<td>71.43</td>
</tr>
<tr>
<td>No</td>
<td>5</td>
<td>19</td>
<td>79.17</td>
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</tbody>
</table>

DEFLING - Likelihood Type 1 Test (studio ipoacusia 3) Distribution: BINOMIAL, Link function: LOGIT Modeled probability that DEFLING = S

<table>
<thead>
<tr>
<th></th>
<th>Degr. of - Freedom</th>
<th>Log- - Likelihd</th>
<th>Chi- - Square</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>-31,0915</td>
<td></td>
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<tr>
<td>Age</td>
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<td>-30,9648</td>
<td>0,253463</td>
<td>0,614647</td>
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<tr>
<td>mean PTA ds (dbHL)</td>
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<td>-27,3214</td>
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<tr>
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<td>1,286871</td>
<td>0,256625</td>
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<tr>
<td>Vocal left%</td>
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<td>Verbo-tonal dissociation – L</td>
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<td>-21,8718</td>
<td>0,391490</td>
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</table>
Numerous studies over the past 60 years have affirmed the fundamental principle in perception that, the higher the probability of occurrence of a stimulus, the less sensory information will be needed for its correct recognition (Howes 1954).

For spoken words, it means that a word is more easy to recognize in a meaningful context. This phenomenon is even more pronounced in hearing impaired people.

Our data show different performances in subjects with ARHL vs HC only in transcoding tasks for non-word or single context free words (in which there were only phonological mistakes).
✓ In our sample, sublexycal transcoding tasks are associated with the amount of hearing loss.

In cognitive health people, even if hearing impaired, the activation of semantic-lexycal system can compensate for auditive deficits

✓ Furthermore, the mean PTA correlate also with tasks of repetition of phrases

✓ This task request a working memory effort

✓ These data confirm our previous hypothesis about the correlation between executive impairment and audiological variables

Hearing loss request an additional attentional effort → evident in more complex tasks
Summarizing

HL affects language comprehension

More attentional resources are requested to understand spoken language

Less attentional resources are available for other cognitive processes

Concerning memory

Phonological information implicitly unlocks the lexicon by matching extracted phonological input with stored phonological representations in semantic LTM.

However, when suboptimum conditions prevail (e.g., hearing impairment), the probability of a mismatch between input and stored phonological representations increases.

Lexical access suffers

Less information is therefore encoded into episodic LTM.

In the long term, this is assumed to lead to an increasing disuse of episodic LTM and a subsequent decline of episodic LTM function.
IN CONCLUSION..

- Physiological impairment of working memory
- Good comprehension of spoken language
- Good compensatory mechanisms (different networks activated)

Normal aging

- Sensorial deafferentation
- Defective consolidation of memory tracks
- Different allocation of working memory resources.
- Reduced activation of compensatory mechanism of synaptic plasticity

ARHL

Cognitive Reserve

Early onset of cognitive symptoms

Change of synaptic plasticity

dementia
Other open queries..

Role of the features of languages studied

Transparent versus non-transparent languages

Italian, Spanish...

Trasparency

= one-to-one relationships between meaning and form

English, german...

/ˈlibro/

/bʊk/
Transcultural studies doesn’t exist

HL could affect spoken language comprehension in a different manner for different languages

- Different consequences of the HL-relates disability
- Different attentional effort to compensate comprehension difficulties
• To evaluate the cognitive functions of hearing impaired patients who are candidates for acoustic aid or cochlear implant
• To compare changes in the cognitive profile of these patients (with a follow up of 6 and 12 months);
• Cognitive tests will also be related to audiologic parameters, with particular reference to the evaluation tests of the central auditory function.
Study design

*Inclusion criteria*

- age > 60 years
- Absence of neurological diseases (Dementia, Parkinson Disease, Multiple Sclerosis)
- Education level ≥ 8 years
- Absence of significative visual impairment
- Patient’s consent
- Moderate, severe or deep HL
- Post-lingually HL

Audiological evaluation for both peripheral and central auditory function

Neuropsychological evaluation including attentional, memory, executive and linguistic tasks
15 subjects with IC
Evaluated at baseline

15 with 6 months follow up
10 with 1-year follow up

10 subjects candidates for hearing aids

7 with 6 months follow up

Roma – work in progress..
Greetings

Prof. Gaetano Paludetti
Prof Guido Conti
Dr.ssa Pasqualina Picciotti
Dr.ssa Anna Rita Fetoni
Dr.ssa Roberta Anzivino

Prof. Paolo Maria Rossini
Prof. Camillo Marra
Dott.ssa Giovanna Masone Iacobucci

.. And all the neurologist and psychologist of our Neuropsychology Unit

..and my family!!!