The hearing brain

The close correlation between hearing and cognition

Introduction

Methodology

This publication is the outcome of a critical evaluation of the latest clinical trials and laboratory tests published in scientific literature on the association between hearing and cognitive skills, and on the possibility of preserving cerebral function by diagnosing and providing prompt and appropriate treatment for hearing loss.

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Contents

1. Summary

The human brain is still a mystery, one that it is far more complex than we imagined even in the recent past. It does not work like a series of "sealed compartments", and no areas are allocated to the performance of only one function. Instead, it is a huge network of cognitive resources that interact within dynamic neuronal networks: thinking, for instance, that sight or hearing only activates specific areas (and just those) is an over simplification. Although we are still far from explaining the mysteries of the mind, understanding this sheds more light on the correlation between the functional status of the brain and correct sensory stimulation.

The latest scientific research infers that exposure to sounds does not only "switch on" the auditory cortex located in the temporal lobe, but stimulates and links up to many functional locations in diverse cerebral areas, thus contributing to general brain functional activation and stimulation. The above explains, at least partly, why sensory deprivation associated with hearing loss might encourage cognitive decline.

While the correlation between hearing loss and cognitive decline has been demonstrated in many studies, methodological inconsistencies across studies need to be better understood prior to the development of prevention approaches. Research assessing the appropriate evaluation and interpretation of hearing deficiencies, their actual correction through the appropriate use of hearing aids, cochlear implants and appropriate hearing rehabilitation is crucial.

With the gradual increase of life expectancy, the number of people with impaired cognitive performance is growing. All factors related to this phenomenon need to be correctly assessed, including hearing loss. Indeed, loss of hearing is not an unavoidable life sentence for older adults; it is a modifiable risk factor for cognitive decline that can and must be addressed.

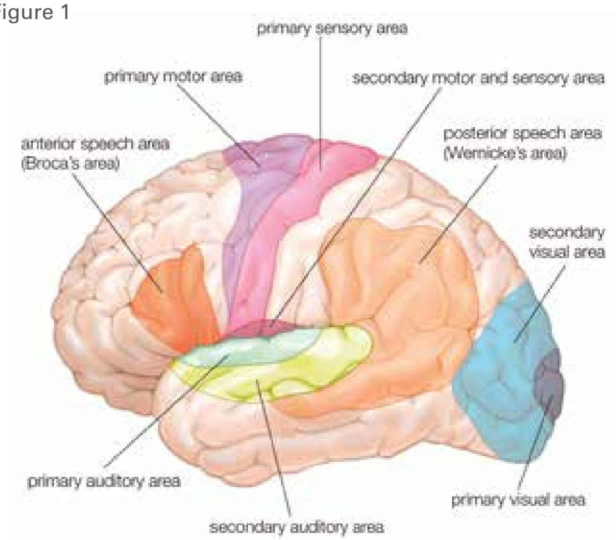
Starting by reviewing the latest scientific literature, this Consensus Paper provides information on the close relationship between hearing loss and cognitive impairment, exploring the causal mechanisms that are known to date. By underscoring the changes that take place in the brain following low sensory stimulation in people with hearing loss, this paper also explores the importance of preserving physiological hearing function and of promptly initiating the necessary ongoing hearing habilitation or rehabilitation for early prevention of cognitive decline and also of many forms of dementia.

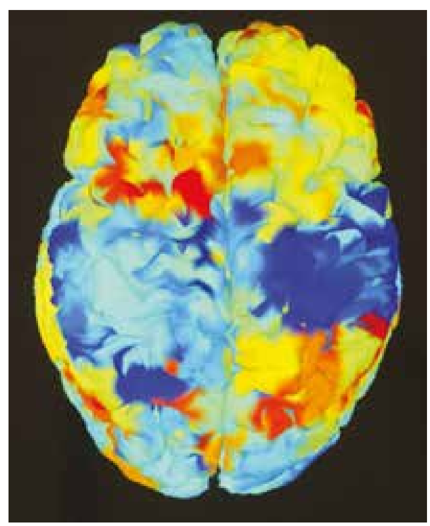
2. The (very close) link between hearing and the brain

Until a few years ago the brain was largely conceived as being divided into function-specific areas; the posterior occipital cortex for visual processing, Broca's area for speech production, the auditory cortex located in the temporal lobe for sound processing, and so on. This is a gross simplification however, as recent research suggests that cognitive functions are actually the result of a huge and especially dynamic network of connections with a multitude of branches.

As far as hearing is concerned, we do not "hear" using a single part of our brains, but, in other words, hearing stimuli "switch on" several brain areas.

Figure 1





Left: *map of cerebral cortical areas that perform several sensory and motor functions, as known until a few years ago.*
Right: *map of the brain indicating multiple areas that respond to hearing.*

The overall picture is gaining clarity as a result of many neuro-linguistic studies that, in recent years, have sought to establish how words are processed by the brain when they are heard. Research based on functional magnetic resonance imaging has made it possible to understand how the brain is activated in response to words, and the complex bonds between hearing, speech and cognitive capacity.
For instance, imaging has revealed that Broca's area - deemed the site of spoken language and grammar, and the area where the words produced are represented - is not only the area where words are "formed". Instead, Broca's area seems to play a crucial role in the interactions between linguistic experience and biological substrate that are essential for learning a new language. Hence, it is a crucial "bridge" not only for hearing and speech, but also for learning. Indeed, Broca's area is only activated when grammar rules that are consistent with the universal grammar that underpins every language are proposed. This indicates a far more complex function than the mere production of spoken language[1] and infers that the area also plays a role in the syntax-grammar comprehension mechanisms associated with the mother tongue and languages learnt.

In considering how single words and phrases are comprehended, it is impressive to note that even a simple word has the capacity to activate not only the auditory cortex where the word is "heard", but also several other areas where it is "understood" or semantically or cognitively connected.

The multi-area cerebral activation triggered by single words reveals distinct distributions of knowledge for specific semantic categories of words. These cerebral semantic maps illustrate how speech is processed through the entire cortex and in both hemispheres[2]. Word groups are mutually associated based on meaning; hence, for instance, an area lights up when one hears words correlated with social relations (such as wife, family, pregnant), and other areas are activated following words related to numbers and quantities. Researchers have mapped the semantic system and the selectivity of the various semantic regions located in different cortical areas by performing functional magnetic resonance imaging on volunteers who listened to stories and narratives of various genres. By observing the areas with the greatest increase in blood flow, they were able to identify intricate activation patterns that, interestingly, remain quite similar across the various individuals. The representation of conceptual knowledge, therefore, seems to be dynamic and different for various categories of knowledge.
Two main theories have been proposed to explain how concepts are formed and recognitions are activated in the brain[3]. The first suggests that knowledge is tied to certain experiences and, therefore, related sensory attributes determine which areas of the brain are more important for certain concepts (the most frontal areas seem to be important for verbs of motion, while some animals prevalently trigger perceptive occipito-temporal areas). The other theory claims that experience is important, but that there are intrinsic anatomo-functional foundations that underpin the organisation of knowledge. The latter position considers that intrinsic anatomical connectivity and cortical cytoarchitecture create a sort of limit to the organisation of

high standard semantic representations: in other words, the way in which the brain "is made" does not allow each person to create a personal semantic map with total freedom; hence, the existence of a sort of general semantic atlas that can be reconstructed is certain[3].

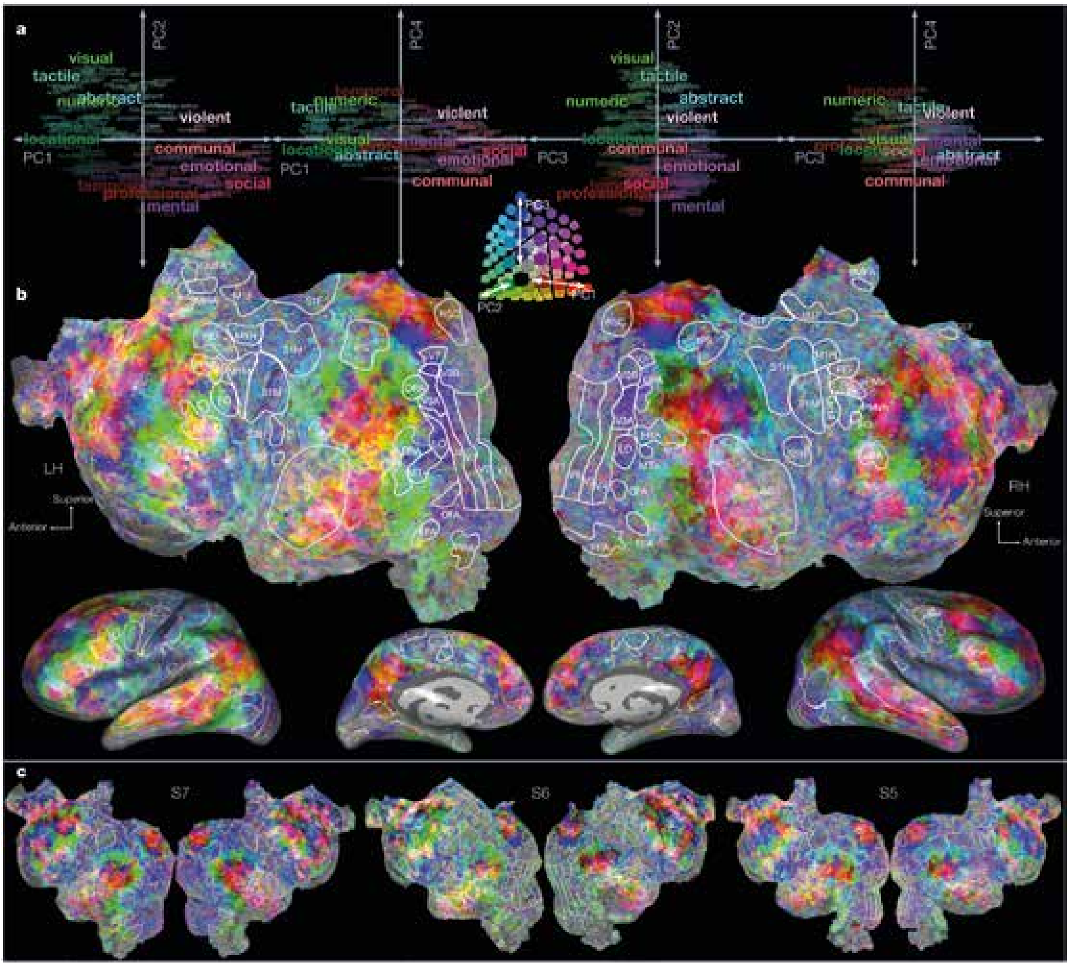
Regardless of our preference for innate or experience-based knowledge and formation of concepts, the important point remains the capacity of the word that is heard to activate very distinct and distant brain areas, depending on the network of established knowledge. The word "top", for example, lights up the area where words referred to the aspect of things are grouped, as well as the area related to measurements and places, because the meaning of the term can vary depending on the context.

The word "mother" activates the auditory cortex and also activates a series of recollections, sensations and cultural associations that reach far beyond a single cerebral area. A hearing stimulus is, therefore, not only that; it "reverberates" several other meanings in the brain and is, therefore, an element that possesses a clearly higher cognitive impact than supposed when it was considered to activate only the cortex in charge of processing sounds. The sensory hearing stimulus of a certain word does not only semantically activate the perceptive representation of phonemes that form words, but also remodulates the anatomical and functional organisation of the brain in a plastic manner. This determines a "widespread" semantic and cognitive correlate in the entire brain.

Hence it comes as no surprise that the reverse is also true. Just as an auditory stimulus lights up and affects cognitive capacity and the organisation of knowledge, cognitive processes influence the perception of sound.

This is also shown by the experience with acoustic amplification, which teaches us that the information provided by the audiogram is scarcely relevant for the choice of intervention. Indeed, the test only measures when a person starts perceiving a pure tone at different frequencies, in other words starts hearing the "bips". However, today it is clear that appropriate clinical decisions need all dimensions of hearing performance to be considered, in addition to taking into account how the individual person perceives these various dimensions. This is why, along with hearing, which can be assessed with the audiogram, it is equally essential to consider the intelligibility of speech in noise and silence, the acceptability of noise, aspects of auditory processing in the central nervous system and aspects of cognitive capacity, such as working memory[4-8], or episodic memory or short-term memory that is used to plan a task or a job.

Figure 2



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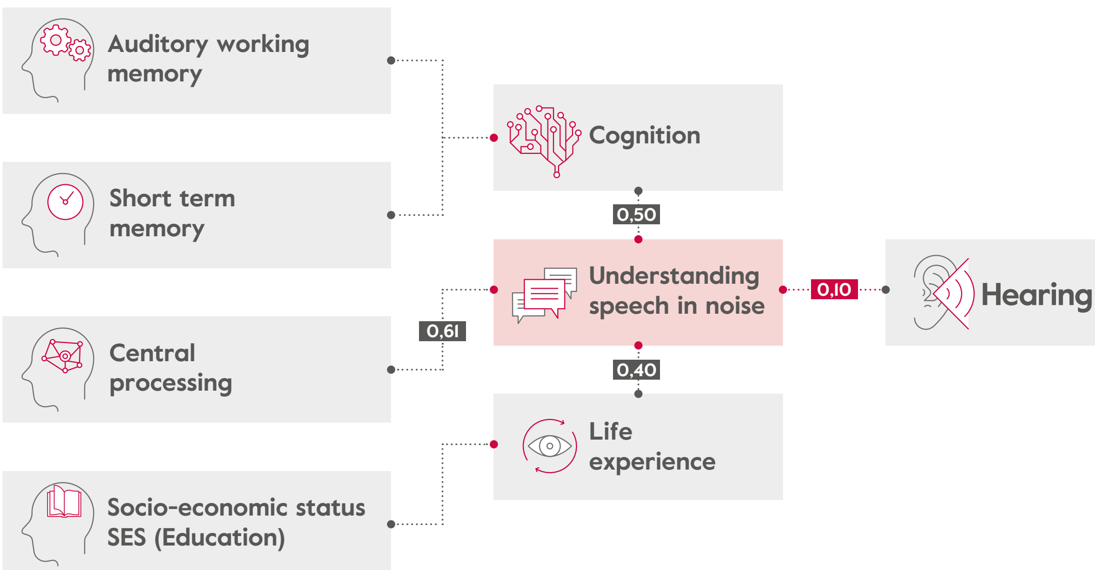
The different colours on the semantic map define areas where the various word clusters are located based on meaning (i.e., the area of words that refer to numbers and quantities, social relations, the aspect of things, and so on). Every word lights up more than one area and the various areas are present in many parts of the cortex and in both hemispheres. Subsequently, the sensory auditory stimulus has a "widespread" semantic and cognitive correlate in the entire brain (Huth et al., Nature 2016).

Recent studies have provided evidence that the link between hearing and the brain is so close that, when considering the capacity to understand speech-in-noise, the actual hearing capacity ranks last in a series of factors that highlight elements such as central processing or cognition.

Figure 3



The capacity to understand speech-in-noise is especially influenced by cognitive elements, such as central processing, cognition or life experiences. Only 10% is influenced by the actual hearing capacity (Anderson et al., 2013).

Experiments on people aged 50 to 79 included tests to evaluate peripheral hearing capacity, central auditory processing and cognitive skills. The most predictive factor of speech comprehension in a difficult situation, such as a noisy environment, was central processing of sound information, followed by cognitive skills (such as working memory and short-term memory), and by life experiences, such as socioeconomic status[9]. Hearing sensitivity based on the audiogram is the "weakest" of those elements in predicting how well the person could hear in a noisy setting. Among cognitive factors, working memory seemed to play a central role[10]. Tests conducted on people with hearing loss with and without hearing aids revealed that working memory (which is indicative of the skill to manipulate and use auditory information to perform a task, e.g., reading a few phrases aloud and recalling only the last word of each) accounted for 27% of the capacity to perceive speech-in-noise among people who do not have acoustic amplification, and for 40% in those wearing a hearing aid[10].

Additional evidence for the impressive capacity of the brain to manipulate peripheral information comes from studies that have examined how words are processed in and out of semantic context. Words are more easily perceived when inserted in a significant phrase than when presented without a verbal context. This suggests that the brain can modulate acoustic stimuli with compensatory and normalisation processes that allow the person affected by hearing loss to be less aware of and/or distressed by the peripheral disorder.

Taken together, the evidence presented above demonstrates the very close, "dual track" association between hearing and cognition. On the one side auditory stimuli are important because they activate the entire cerebral cortex, and on the other, cognitive processes influence "how" we hear.

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3. Hearing loss will change the brain

If hearing is essential to stimulate the brain, what happens to the brain when hearing is reduced? The question is now beginning to be answered.

The central nervous system is comprised of grey and white matter. White matter is composed of bundles of myelinated nerve cell projections which connect various grey matter areas of the brain to each other, and carry nerve impulses between neurons. Grey matter contains motor neuron cell bodies, dendrites and glial cells, which select and send information to the peripheral nervous system. When white matter bundles are not intact, their life and functioning might be altered causing changes to the relating cerebral functions.

Nowadays there is evidence that hearing deficiency is associated with cerebral alterations. Specifically, evidence from magnetic resonance imaging studies demonstrates that hearing loss is correlated with reduced volume of the primary auditory cerebral cortex in the temporal lobe[1]. The magnetic resonance diffusion tensor imaging technique that analyses the diffusion and direction of water molecules in tissues *in vivo* allows a highly detailed study of the microstructural architecture of the brain (e.g., to map connections or to reconstruct the 3D structure of the white matter). This has revealed that the integrity of white matter in the hearing area is altered in people with hearing loss[2].

Figure 1

Green: grey matter volume reduction; red: compensatory increments in people with unilateral hearing loss (Wang et al., 2016).

Moreover, a longitudinal study[3] reported that hearing deficiency is accompanied by accelerated cerebral atrophy, with a considerable reduction in overall cerebral volume. The atrophy was more evident in the superior, median and inferior temporal gyri, critical areas for auditory processing and which are also involved in many other cognitive skills.

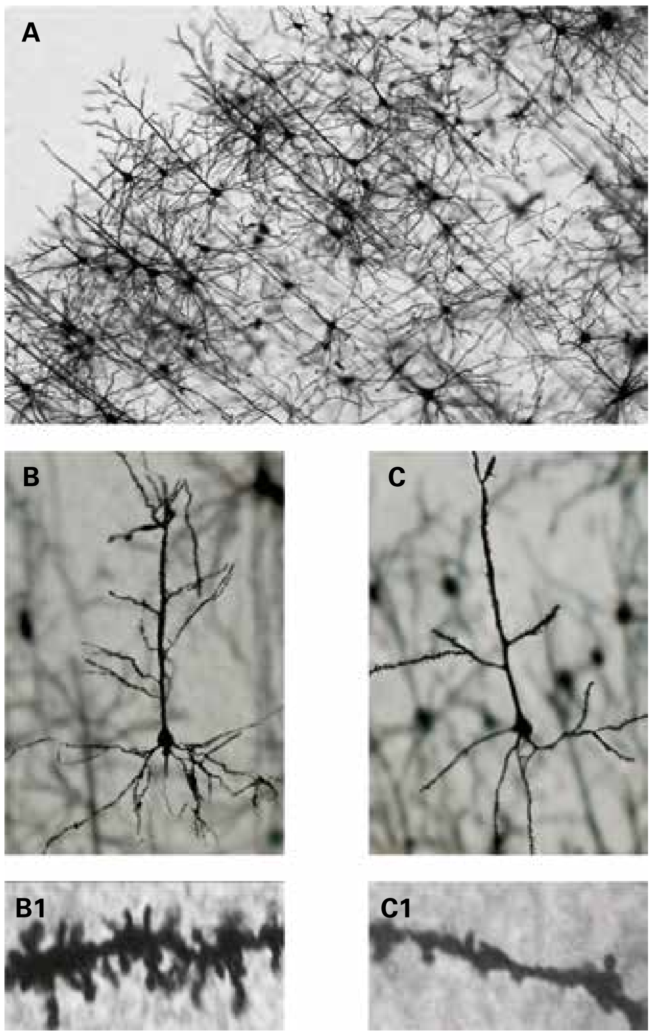
Alterations were also observed in cases of monolateral hearing loss, as observed in certain people with acoustic neuroma[4]. Grey matter volume was diminished not only in the temporal area where the primary auditory cortex is located, but also in structures involved in high level cognitive control functions, such as the dorsolateral prefrontal cortex or the anterior cingulate cortex.

Moreover, it appears that beyond loss of neurons, hearing loss is also associated with a reduction in the number of branches of neurons which, therefore, "communicate" less among them[5].

In parallel, hearing loss is associated with an increase in stimuli coming from other sensory organs such as the eyes. This can lead to "compensatory" increases in volume in other areas, thus confirming the extreme plasticity of the brain that always seeks to remedy deficiencies.

Hearing decline in older adults is often "hidden". Indeed, it can depend on damage induced by over exposure to noise of the hearing functions that translate frequencies which are not usually assessed by conventional tests[6]. In such cases, cochlear neuropathy, which cannot be detected by a conventional audiogram, interferes with auditory processing at all levels, including cortical responses[7].

Figure 2



What happens to the auditory cortex following damage that determines neurosensory hearing loss?
A) Image of the normal cortical layers with neurons projecting into different layers.
B) Detail of a normal neuron with "branches with many spines", or dendrites, which create a sort of tree presenting dendritic spines (B1), which are responsible for synapses, i.e. the exchange of information between neurons, and hence for the plasticity of the nervous system.
C) After damage, such as repeated exposure to noise or ageing, neurons reduce the dendritic tree, compared to the healthy neuron (B), and a large number of spines are lost (C1) (Professor Paludetti's Laboratory).

Hearing loss is associated not only with changes in brain structure, but also in function. Along with the diminished volume of the primary auditory cortex, there is also a reduction in neuronal activity in the same areas and in other sub-cortical regions[8]. This bond between structure and function is very clear. Moreover, it is equally evident that the brain compensates for the loss by attempting to activate collateral circuits. However, this increases cognitive processes, requiring greater expenditure of mental resources.
Hearing loss has a negative impact on neuronal resources used for cognitive control, and this has a considerable effect on the capacity to perceive and process sounds, requiring, for instance, greater cognitive effort to suppress irrelevant information in auditory signals (e.g., background noise) and other types of sensory signals[9].

Hearing loss increases the concentration required for hearing as it causes signal decay, increasing the possibility of distraction and reducing perceptive learning. All this entails a cognitive load during data processing that “tires” the brain and reduces the attention and cognitive resources available for other tasks.

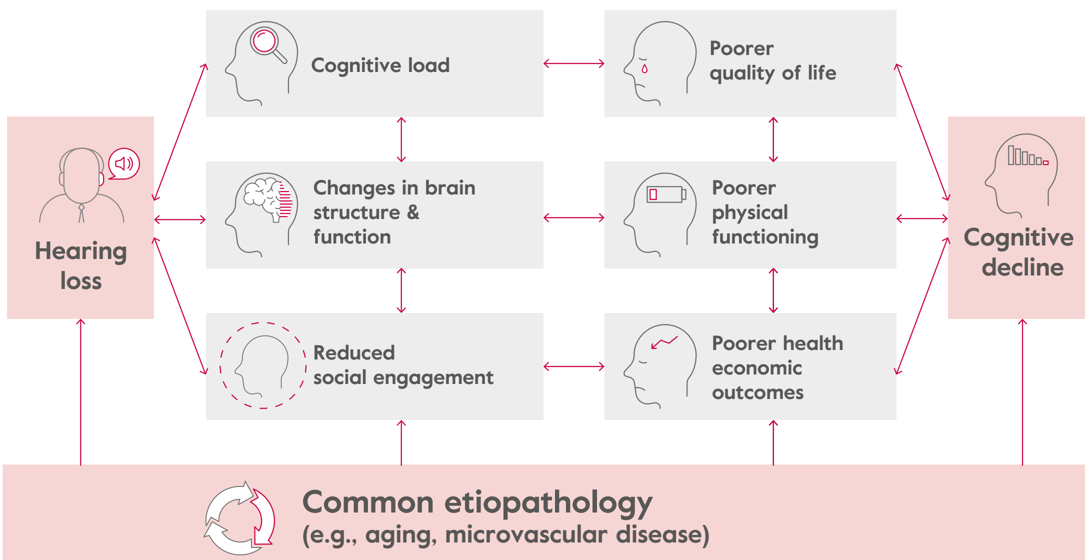
There is evidence that people with hearing loss show reduced cognitive performance especially regarding executive functions, rather than linguistic ones, during neuropsychological assessments. This is explained by the deviation of attention-related resources to listening tasks, with a lower percentage of residual attention for the remaining cognitive activities. So, for instance, people with considerable hearing loss, which prevents them from having a conversation, present a 24% higher probability of demonstrating impairment in cognitive skills such as concentration, memory and planning capacity[10].
Hence, the brain of a person with hearing loss will change and experience distress. The reasons why hearing loss leads to structural and functional cerebral alterations are multiple. One is doubtless the impoverishment of acoustic signals, which causes a “sub-stimulation” of cortical areas that are normally activated by sounds. Some studies have also theorised that the association between hearing loss and cerebral alterations might depend on common etiopathological mechanisms because in both cases the “driving force” at the base of the damage might be, for instance, a microvascular condition or Alzheimer’s disease[11].

Social isolation might be another mechanism underlying the link between hearing loss and cerebral alterations. Communication difficulties associated with hearing loss can encourage solitude, which is considered a risk factor for cognitive disorders.

Social isolation is associated with diminished psychological wellbeing and impaired self-esteem due to a reduced capacity to react to external stimuli. It may also result in diminished physical wellbeing because it is associated with poorer lifestyle choices such as smoking, harmful diet, sedentary habits and poor compliance with physician-prescribed therapies. Social isolation also promotes negative biological mechanisms, such as increased transcription of pro-inflammatory genes and, therefore, an increase in the general inflammatory status, which is a major risk factor for damage even to cerebral functions[12,13].

Finally, the increased exploitation of cognitive resources might have a deleterious effect on hearing loss and cognitive decline. Both ageing and hearing loss entail a more or less evident atrophy in the auditory cortical regions. The brain is forced to adapt to face this problem; hence, it increases attention and "enrols" accessory neuronal networks, ultimately resulting in cognitive effort. This typically occurs in young people who need to understand speech-in-noise, but it is normal in older adults with hearing loss who find the entire listening process more difficult. The consequence is a constantly high cognitive load that reduces the proportion of cerebral resources available to process all other data. This constant "effort", combined with reduced cognitive sparing capacity typical of age, might accelerate cognitive decline with a negative effect on hearing capacity and cognitive skills[9].

Figure 3



The complex vicious circle that leads to hearing loss and cognitive decline.

The outcome is a sort of bi-directional vicious circle, in which on the one hand hearing loss involves structural and functional changes to the brain, and on the other hand cognitive decline correlated with age facilitates the onset of hearing deficiency and entails a loss of perception and verbal comprehension.

Besides that, there are factors that can affect both such as stress and general weariness, which can impair cerebral compensatory mechanisms and enhance the effects of hearing loss and cognitive decline.

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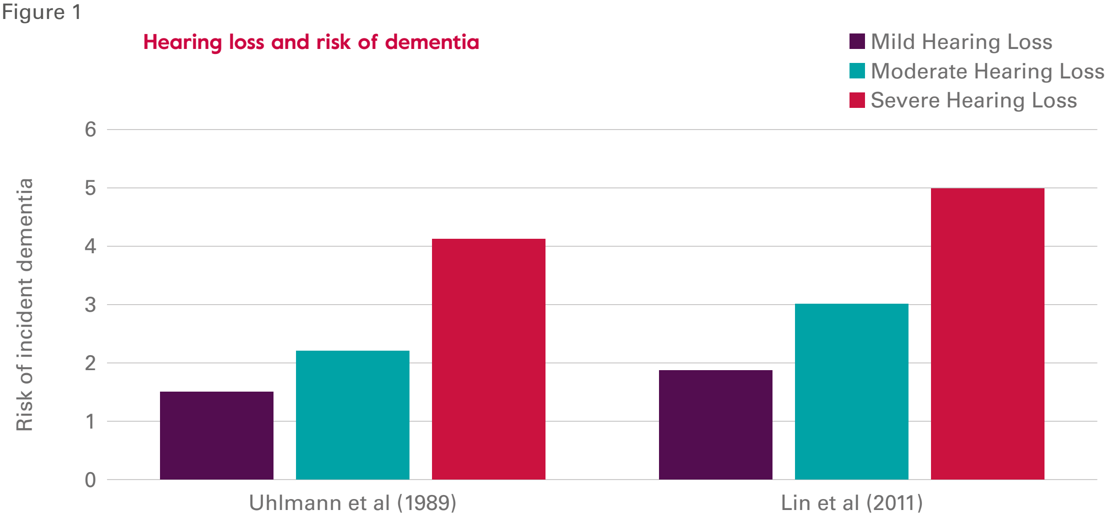
4. The association between hearing loss and dementia

Hearing loss entails structural, anatomical and functional changes to the brain that not only encourage cognitive decline, but also pave the way for an increased risk of dementia.

The correlation between dementia and hearing loss emerged in the late 1980s, when it was observed that a greater degree of hearing loss corresponded to a higher risk of developing severe cognitive decline[1].

The collected data indicated that about one case of dementia out of three can potentially be attributed to impaired hearing. Moreover, even in people who had no diagnosis of dementia the loss of hearing was correlated with impaired cognitive function. Additional investigations conducted during the subsequent years confirmed this "dangerous association". The epidemiologist and otorhinolaryngologist Frank Lin of Johns Hopkins University monitored, for twelve years, more than 600 older adults with no initial diagnosis of dementia, who had submitted to an audiometric test. He found that a mild, moderate or severe hearing loss was associated with a risk of cognitive decline that was respectively two, three and five-fold higher than in people who had no hearing disorders[2]. The correlation remained even taking into account other risk factors, including age, sex, diabetes, hypertension, thus indicating that the association is very strong.

Figure 1



The risk of dementia rises as hearing loss increases (Uhlmann et al 1989; Lin et al 2011).

The following years witnessed additional studies that monitored participants for a longer period of time, confirming and strengthening the theory of a very close correlation between hearing loss and dementia. Data collected on a group of over one thousand men who were monitored for 17 years, for instance, indicated a strong association between hearing loss, cognitive decline and dementia. Indeed, the risk of developing dementia was 2.7-fold higher for every 10 dB of hearing loss[3]. A similar result was obtained from a study on almost 600 men and women without dementia who were monitored for a mean period of eight years. People diagnosed with dementia had a hearing problem in 77% of cases versus 46% of those who did not present cognitive disorders.

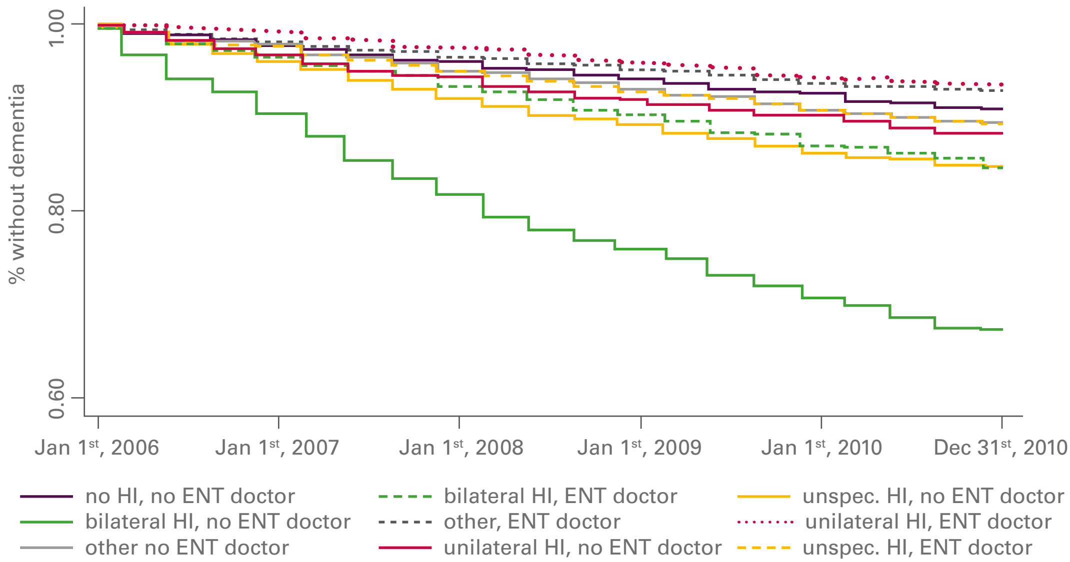
After taking into account confounding factors, such as age, gender and lifestyle, the presence of age-related hearing loss was associated with an over 3-fold increase in the probability of manifesting dementia[4].

A survey on more than 3,600 people aged 65 and older, whose degree of hearing loss was evaluated at the time of enrolment in the study, monitored and reassessed the presence of cognitive disorders every two years, confirming that worse hearing was associated with lower cognitive efficiency scores and with greater decline in cerebral activity over a period of 25 years[5].

Other studies involved a very large number of people and again the results confirmed the association between hearing loss and dementia. A study enrolling about 165,000 adults aged 40-69, whose data are filed in the UK Biobank, revealed that "frail" hearing is associated with higher levels of cognitive impairment[6], while a longitudinal study conducted on about 155,000 people aged 65 and older (including over 14,000 cases of dementia) revealed that bilateral hearing loss is associated with a 43% increase in the probability of developing dementia, and unilateral hearing loss with a 20% increase[7].

A recent meta-analysis[8] - conducted by re-analysing 33 studies, both published and not, on the correlation between hearing loss and cognitive function to trace a complete picture of the literature available today - indicates that hearing loss is connected with cognitive impairment, and also that data available is still insufficient to clarify the mechanisms that underpin this correlation.

Figure 2 **Treatment of hearing loss and dementia**



Reduction in the percentage of patients without dementia related to hearing impairment (HI) under treatment or not with an otorhinolaryngologist (ENT) (Fritze 2016).

The possibilities are many. Some suggest that a common disease, for instance a vasculopathy, might trigger both problems; others, instead, claim that weariness caused by decoding sounds, which is typical of people with hearing difficulty, might "tire" people's brain in the course of the years to such an extent as to make it more vulnerable to dementia. Moreover, social isolation correlated with hearing loss is a known risk factor for the onset of dementia and other cognitive disorders. It must be said that reduced auditory stimulation of the brain is one of the elements that expose older people to the highest risk of developing of dementia because it determines an accelerated loss of cognitive compensation and a reduced cerebral connectivity, a phenomenon that underpins the loss of cognitive reserve.

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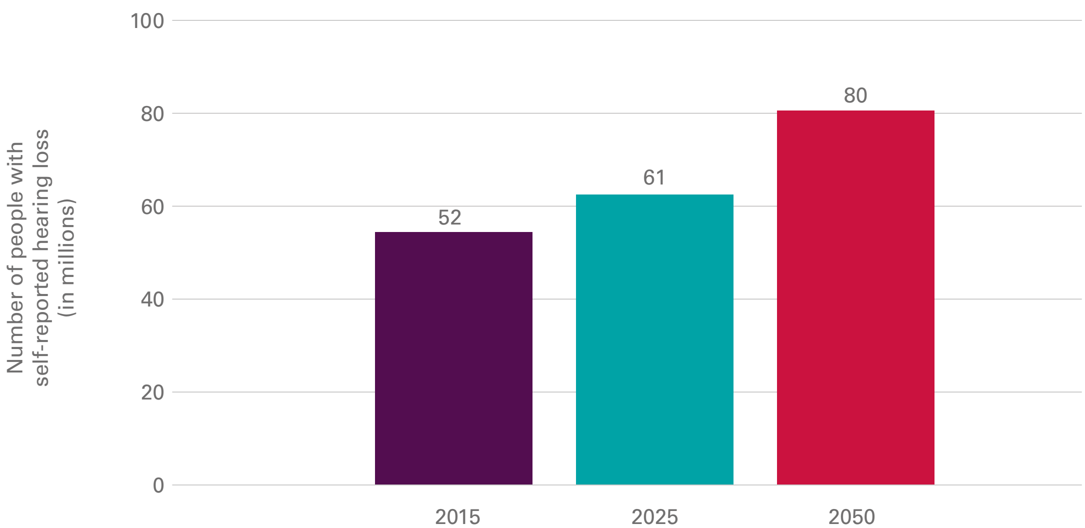
5. A contemporary challenge

Hearing loss and dementia are two very topical emergencies. Hearing loss is increasingly common, on the one hand because exposure to loud sounds is increasingly frequent since a very young age, and on the other hand because life expectancy is ever increasing thus enlarging the elderly population. The global number of people with hearing loss is estimated at 360 million by the World Health Organisation and this number is expected to at least double to 720 million by 2050[1]. In Europe, the number of people with self-reported hearing loss is 52 million today and this number will increase to 80 million in 2050[2].

Figure 1 **People in Europe with self-reported hearing loss**



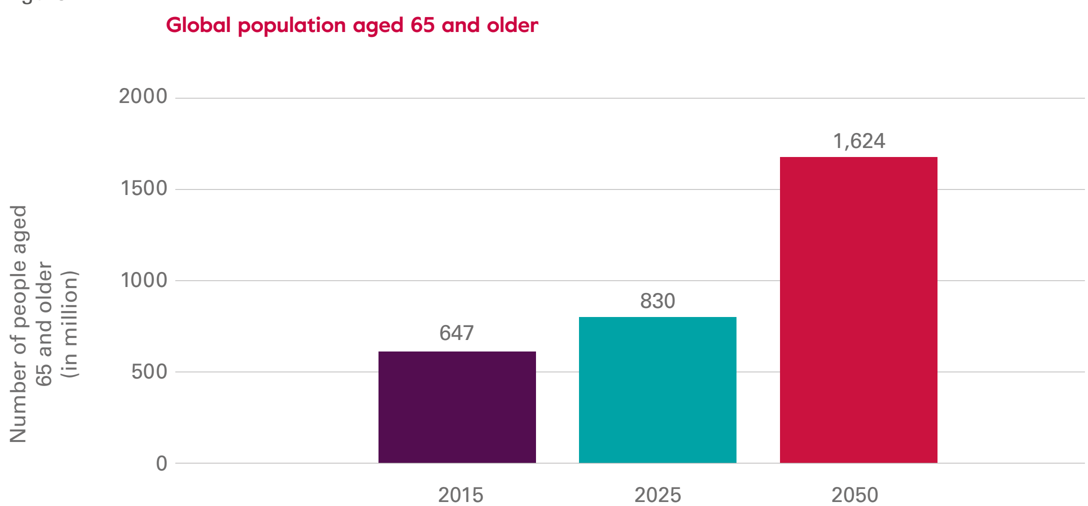
Estimated growth of the number of people with self-reported hearing loss in Europe (Laureyns 2017).

The incidence of dementia is also steadily rising due to increasing longevity. More than half of people aged 85 or older are affected by cognitive impairment. The impressive impact on patients and their families is worrying to the point that prevention and treatment of dementia are a healthcare priority throughout the Western world today[3].

> **If, starting from today, we were to successfully delay the onset of cognitive decline by just one year, the global prevalence of dementia would diminish by over 10% by 2050[4].**

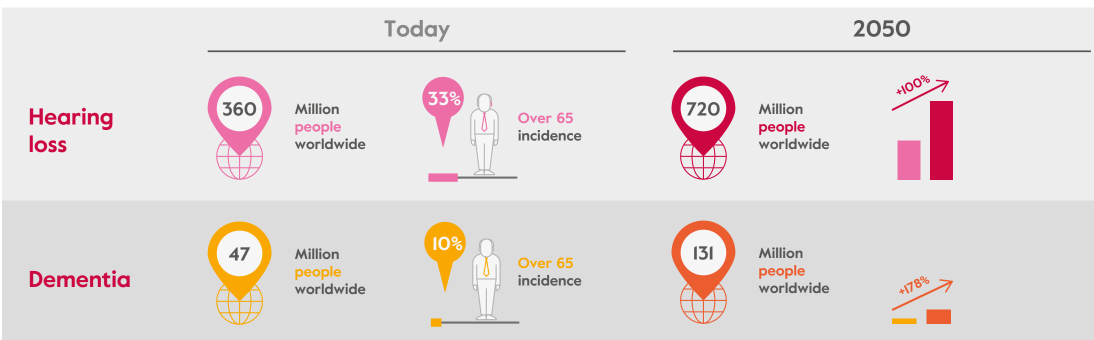
Epidemiological data on general ageing population tells the story of the development of the two parallel phenomena of hearing loss and dementia. The most recent UN World Population Ageing Report estimates an overall growth of the world population from 7.5 billion people in 2015 to 8.1 billion in 2025 and 9.7 billion in 2050. People aged 65 and older are 8.8% of the total today, equal to 660 million, but they will become 10.2% in 2025 (830 million) and 16.7% in 2050 (equal to 1.6 billion)[5].

Figure 2



Estimated growth of the population of people aged 65 and older in 2015, 2025 and 2050 (United Nations World Population Ageing Report 2015).

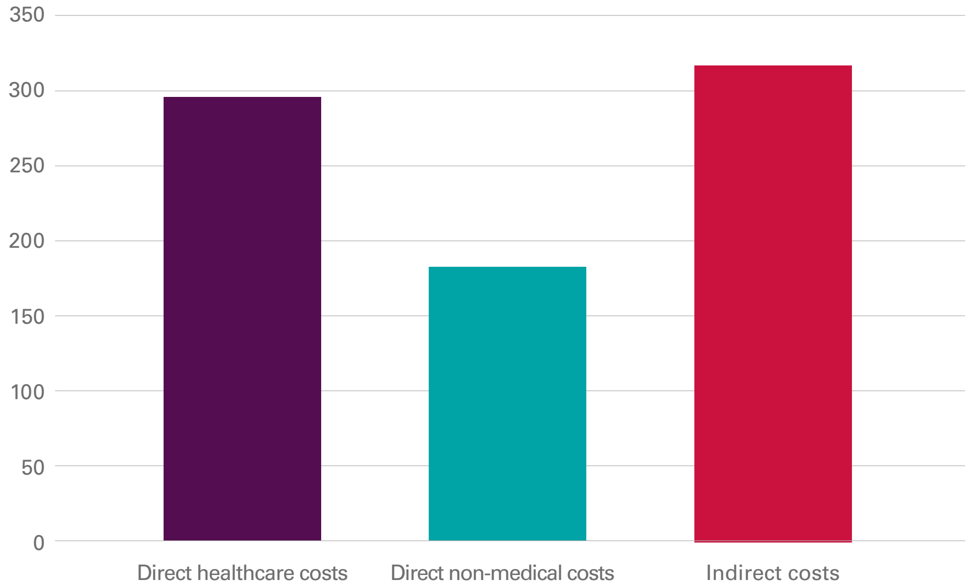
Data projecting the estimated increase in the prevalence of Alzheimer's disease is unfortunately quite worrying. According to the World Alzheimer Report of 2016, today the world counts 47 million patients who must live with dementia. The number is expected to rise to 63 million in 2025 and to over 131 million in 2050. These are huge numbers for a disease that is among the most feared and most costly for both individuals and society, with overall healthcare expenses far exceeding those of tumours, strokes and cardiovascular diseases considered together[6].
In Europe, the prevalence of dementia in people aged 60 and older is estimated in the range of 6.5% of the population in France, 6.4% in Italy, with a mean value of 5.5% in the countries that have adhered to the Convention on the Organisation for Economic Co-operation and Development (OECD)[7]. Every year, from six to nine million Europeans, especially women, live with dementia and things are not much better on the opposite shores of the Atlantic, where the estimated prevalence among people aged 70 and older is in the range of 14.7%[8].



The costs of dementia vary from country to country but they are, however, very high and include the expense of the diagnosis, which is often made by the general medicine practitioner, but at times by specialists; of initial treatments and post-diagnostic support for both the patient and his relations; of ongoing care that often lasts for years, including medicines and also the management of behavioural and psychological symptoms; and of end of life treatments. Throughout the journey, the cost of specialised visits, pharmacological treatment and specialised support for the patient and his/her family, as well as the expense borne to meet the many demands related to lack of self-sufficiency are very high and are continuously increasing. In the United States, for instance, the costs have risen by 35.4% from 604 billion dollars in 2010 to 818 billion in 2015, representing 1.09% of the overall gross domestic product of the United States. The estimated cost per patient ranges from almost 42,000 to over 56,000 dollars a year, depending on the parameters used to evaluate costs related to informal care[8].

In Europe, the annual economic impact of both direct and indirect costs of neurological diseases exceeds 790 billion euros versus 200 billion of cardiovascular diseases and 150 billion of tumours[9].

Figure 3 **Costs of neurological diseases in Europe**



Total costs of neurological diseases in Europe (billion euros) (Olesen et al., 2012).

Unfortunately, also the cost of untreated hearing loss is very high. The World Health Organisation estimates the global cost of untreated hearing loss at 750 billion dollars per year and at 178 billion euros per year for Europe. The cost is so high since untreated hearing loss leads to: difficulties in finding and retaining employment, earlier retirement, reduced personal income, social isolation, depression, cognitive decline, reduced activities of daily life, reduced quality of life, frailty, and loss of independence[10,11].

Figure 4

AEA Country	Population (mln) Jan 2016	Cost of untreated hearing loss (million euros)	Number of people with self-reported hearing loss (mln)	People with recommendation for hearing care
Austria	8.7	3,045	0.8	0.4
Belgium	11.3	3,951	1.1	0.6
France	66.7	2,332	6.4	3.1
Germany	82.2	29,578	9.9	5.0
Greece	10.8	3,774	1.2	0.6
Italy	60.7	21,233	7.0	3.5
Netherlands	17.0	5,943	1.7	0.8
Poland	38.0	13,668	6.0	2.2
Portugal	10.3	3,619	1.1	0.6
Romania	19.8	6,916	1.8	0.9
Spain	46.4	16,253	4.5	2.3
Switzerland	8.3	2,914	0.8	0.4
United Kingdom	65.4	22,230	6.9	3.5
European Union	178.6	178,553	52.0	26.0

The number of people with self-reported hearing loss and the cost of untreated hearing loss in 13 European Countries (AEA, 2017)[2].

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6. Hearing well to safeguard the mind

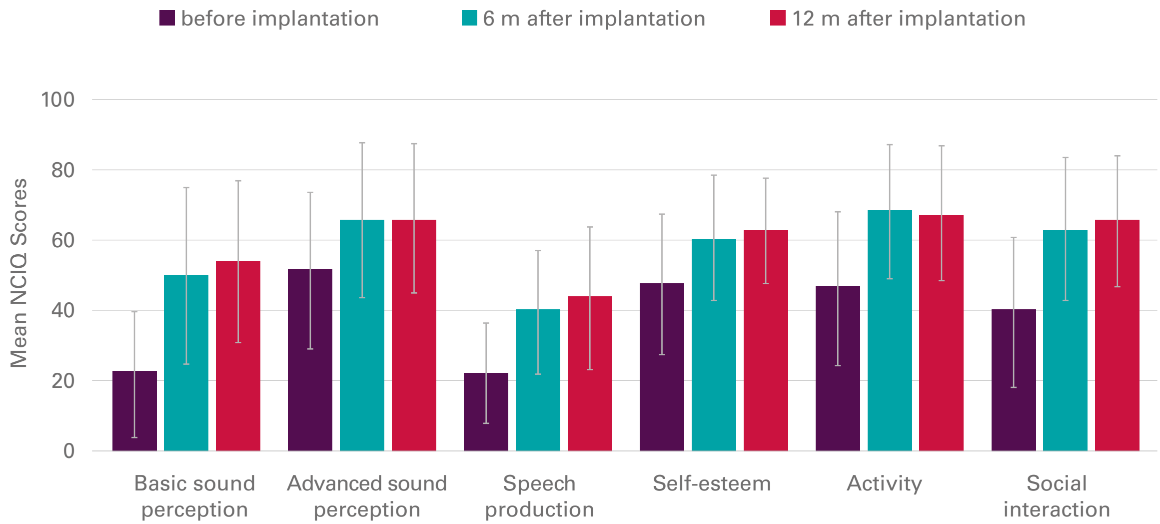
Children with hearing loss are proposed hearing solutions, and if a person finds it difficult to read well at the age of fifty, he/she wears eyeglasses. As far as hearing is concerned, out of 52 million people with self-reported hearing loss in Europe, only 26 million get medical recommendation to go for hearing care. Of those 26 million, 58% wear hearing aids[1]. In Italy alone, out of the 7 million people with hearing loss, 1.8 million actually wear hearing aids[2].

And yet, in the light of what is now known about the association between hearing loss and cognitive decline, the solutions to hearing well again (which exist and are effective) are essential not only to maintain good quality of life for a long time, but also to safeguard the brain.

Scientific studies are now providing evidence that treatment of hearing impairment through hearing solutions is effective in delaying the onset of cognitive impairment while maintaining good cerebral function. It was observed in a small study that the use of hearing aids in people between 60 and 65 years old was associated with a higher score on cognitive tests[3] and this finding was later confirmed in a larger sample of people aged 65 and older who were monitored for 25 years. The analysis of the 3,670 participants in the Personnes Agées QUID Study revealed that the use of hearing aids was associated with slower cognitive decline over a period of 25 years, compared to people with hearing loss not compensated for in any way[4]. Moreover, those with hearing loss who wear hearing aids demonstrated trajectories of cognitive decline which were comparable to those who had no hearing loss. The result is similar to observations made by analysing the data of almost 165,000 people aged 40-69: the use of hearing aids is associated with better cognitive performance, whereas unaddressed hearing loss is the premise for cognitive decline[5]. Hélène Amieva, University of Bordeaux, stated during her lecture at the UNSAF congress in Paris in March 2017, that one of the few modifiable risks to prevent the early onset of dementia is treating hearing loss with professional hearing care[6].

In the event of severe and profound hearing loss, solving the hearing problem contributes to cognitive benefits. A study of 94 people subjected to cochlear implantation for one year observed that cognitive capacity, measured by testing attention, memory, mental flexibility, executive function and other skills, improves after the intervention. Eighty-one percent of patients with cognitive impairment prior to implantation showed an overall improvement in cognitive functions, while the other 19% remained stable. Moreover, among patients with the best cognitive performance before implantation, 76% remained stable and only 24% showed a very slight decline[7].

Figure 1 **The effects of cochlear implants**



In the course of time, the use of cochlear implant improves all parameters related to the perception of sound and to the production of speech, besides elements such as social interaction or self-esteem (Mosnier et al. 2015).

Until now, studies have not been able to explain the exact mechanisms of the causal reaction between the use of hearing aids and the improvement of cognitive capacity[8]. It is, therefore, early to know with certainty how and why this happens. However, it is now an ascertained fact that the solution of hearing impairment entails an improvement in cognitive performance as "side effect" and slows down the progress of age-related cognitive decline.

Considering the close link between cognitive capacity and hearing, cognitive skills must be considered when a hearing aid is applied because the different conditions of patients might modify the results that can be achieved with the various devices available. There is evidence, for instance, that cognitive test results might be useful in the selection of the device. Indeed, in a group of 50 patients with bilateral hearing loss, hearing aids that change the gain slowly resulted in better understanding in noise in subjects with reduced cognitive ability, whereas devices that change the gain very fast are more effective in patients with higher cognitive capacity[9]. This result is confirmed by another study according to which the working memory influences the choice of device. In a group of people with mean age 82 who underwent working memory tests and were tested with three different types of hearing aids, it was observed that people with good working memory benefit more from solutions that ensure a rapid compression of the incoming sounds and vice versa[10].

The above considerations indicate that the provision of the most appropriate acoustic amplification for each individual case, which is also chosen based on cognitive performance, is essential for optimal hearing and for an effective protection of cognitive skills. Action must obviously be promptly implemented to prevent cognitive decline as fast as possible.

It is estimated that slowing down the clinical progress of hearing loss even only by one year might lead to a 10% reduction in the rate of prevalence of dementia in general population at large, with considerable savings in terms of human and economic resources.

It is equally important to safeguard hearing as far as possible during people's lives through prevention and implementation of strategies designed to preserve hearing ability in the long-term. It is known, for instance, that listening to music with harmonious tonal changes at moderate volume such as classical music, protects against hearing loss and reduces age-related alterations[11]. The effects of listening to contemporary dodecaphonic music, especially if heard at a high volume as youth are used to doing, are still being studied. Certainly, noise is negative for the health and wellbeing of the auditory system; hence, adequate protection from very high decibels is a good rule to maintain hearing in the long-term.

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7. Conclusions

At the age of two our brain completes its physiological development but at the age of twenty it already starts diminishing its volume. A one-hundred - year-old healthy person without cognitive impairment has lost 20% of the nerve mass. In a patient with Alzheimer's disease or with another neurodegenerative disease the loss is even more extensive. In the course of time the myelin lining of the nerves gradually undergoes deterioration, neurons present reduced functional capacity, and mutual connections between them get weak. The decline is not uniform everywhere and some cerebral areas are more affected, for instance, the hippocampus where short and medium term memories are stored, or the prefrontal cortex that is activated for planning and decision-making. This is another reason why the first signs of cognitive decline include difficulty recalling recent events rather than data stored for a long time, such as words or numbers[1].

Hearing loss, which often precedes cognitive decline in older adults, belongs to this scenario. The manifestations of age-related hearing loss are often considered an unavoidable corollary of the ageing process. Actually, when there is a hearing loss, the consequences on global health and on cerebral wellbeing are considerable[2]. Today we know that hearing loss is an independent modifiable risk factor for the development of cognitive decline, with those with mild, moderate or severe hearing loss having a risk of dementia that is respectively two, three and five-fold higher than in people who have good hearing[3].

Cognitive decline is associated with a progressive limitation in cognitive skills, functional independence and social relations; hearing loss has similar effects; hence, in recent years the need to strengthen research that investigates the connections between the two conditions is surfacing with increasing force in order to find adequate clinical answers[4]. Some questions have been answered but certainly an effective medical and political approach for the prevention of hearing loss and of subsequent cognitive decline is still lacking.

Unfortunately, medicine has often faced the various diseases individually, as if the organs and systems acted and lived independently with no mutual relations. Today we know that this is not the case and that the optimal function of any single system requires the overall health of the entire body; hence, it is increasingly clear that correlations and interdependence between organs, tissues and systems need a multi-scale analysis that takes into account the powerful connections between them in order to understand and solve the various problems associated with ageing without allowing them to develop into chronic diseases or to end up in diminished functional capacity.

So far, the role of ageing in the susceptibility to diseases and disability has been extensively discussed, whereas the other side of the coin, that is how much the diseases contribute to ageing, has been less explored at molecular and cellular level. For instance, we know that exposure to certain diseases or therapies during childhood or in early adulthood can accelerate the onset of typical problems of older age, but the biological bases of all this are still not clear[5]. The acceleration in the loss of functional capacity and an earlier onset of clinical symptoms of diseases related to the old age are evident in such cases, but the correlation with the "trigger" event in the early phases of life is not always obvious. Hence today we are increasingly focused on understanding how the events of the first decades of life can affect the health and disease of the years to come. Understanding causes and relations will actually mean strengthening the prevention of non-transmissible chronic diseases, such as hearing loss, cognitive decline and dementia[6]. Our "human capital" is decided in the early years of life and is then influenced by the conditions of our living environment. A clear understanding of the correlations will contribute towards a genuine social health policy.

The same is also true for the correlation between hearing and cognition. Knowing its mechanisms is essential to prevent the onset of hearing disorders and, hence, of cognitive impairment.

> **It is equally essential to promptly recognise hearing loss. Indeed, intervening to solve the problem means implementing a genuine therapy against cognitive decline with huge benefits for the individual person and society.**

Thanks to the prevention and a prompt, appropriate treatment of the diseases and conditions that can impact general wellness, people can now reach 75 or 90 years of age in the best possible shape, autonomy and health and enjoy a good quality of life.

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