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Aging, Cognitive Load, Dementia and Hearing Loss

Alessandro Martini[a], *Alessandro Castiglione*[b], *Roberto Bovo*[c], *Antonino Vallesi*[b,d], *Carlo Gabelli*[e]

[a]Department of Neurosciences, Otolaryngology and Otosurgery, [b]Department of Neurosciences, University of Padova, [c]Otolaryngology and Otosurgery Unit, Padova Hospital, [d]Center for Cognitive Neuroscience, and [e]Regional Center for the Study and Treatment of the Aging Brain, Department of Internal Medicine, University of Padova, Padova, Italy

Key Words
Aging brain · Hearing loss · Cognitive decline · Hearing aid · Cochlear implant · Dementia · Neurodegenerative disorders · Cognitive load

Abstract
Sensorineural systems play a crucial role in the diagnosis, treatment and management of several neurological disorders. The function of the eye and ear represents a unique window for testing various conditions in cognitive decline or dementia. Touch and smell have also been found to be strongly involved in neurodegenerative conditions, and their decline has been significantly associated with the progression of the disease; hence, the idea that restoring sensory function in cognitively impaired adults might enable a significant improvement in their cognitive status, reducing the worldwide incidence and prevalence of dementia. Not all sensorineural 'windows' can benefit equally from the same procedures; however, hearing and vision can certainly gain the most from dependable therapeutic and other diagnostic options. The ear, including the vestibular system, deserves an honored place among the sensory organs in this context due mainly to the sophisticated electrical devices available that have amply demonstrated their effectiveness in treating hearing loss. Restoring an individual's hearing can reduce the cognitive 'load', i.e. the neural activity needed to understand/recognize the spoken word – an activity that becomes more demanding if the brain is obliged to recruit different neural populations to achieve the same performance, as happens in older adults with sensory impairments. The sensory interfaces may also facilitate the early diagnosis of conditions characterized by a lengthy preclinical phase, as well as enabling noninvasive, follow-up procedures to assess the outcome of rehabilitation measures and distinguish physiological brain aging from neurodegenerative disorders. The present study is a brief literature review on the issues and prospects relating to the unique relationship between hearing and cognitive decline, with a general introduction to the main topics before focusing on rehabilitation training with hearing aids and cochlear implants to combat cognitive decline.

Introduction

Several published associated studies have clearly shown a statistically significant correlation between hearing loss and cognitive decline. The meaning of these findings is less clear, however. Should the hearing loss be seen as a risk factor, a screening tool, or a pathological event? It has so far been impossible to establish a cause-effect link, especially with respect to factors relating to timing between hearing impairment and cognitive decline. Which comes first? This essential point can have a huge impact on potential treatments.

The scientific community has proposed three different theories to explain the significant association between hearing loss and cognitive function. First of all, neurophysiological studies, supported by neuroimaging, have used the concept of 'cognitive load' in referring to the brain activity needed to understand and recognize a voice – although neural plasticity compensates for any decline in working memory, hearing and neural organization, even in adults. Second, social isolation and depression lead to a negative perception of one's own health and a decline in daily activities. Third, the roll of the peripheral and central nervous system with aging can further alter the synapses and neural anatomy. These three theories are not mutually exclusive; they tend to overlap and can influence an individual's general clinical condition. When the consequences of these theories give rise to an irreversible neural disorganization, this triggers a decline in the ability to understand speech. Other specific conditions, such as cardiovascular disease, Alzheimer's disease, comorbidities, and long hospital stays, can also precipitate this trend.

Among the above-mentioned predisposing conditions, some factors are modifiable, while others are not. Age is naturally a given, but hearing loss can be modified with appropriate treatment. An 'aging brain' does not necessarily mean 'cognitive decline', and sensory impairments should not be accepted as inescapable: 'healthy aging' is always possible. It has become increasingly clear that even very old people can benefit from procedures that were previously only recommended for younger patients, such as cochlear implantation. In fact, reviewing the literature revealed that the most convincing evidence of its therapeutic potential in the acoustic-vestibular system concerned elderly people. Having said that, the direct impact of auditory and vestibular rehabilitation on cognitive decline remains to be scientifically demonstrated.

Epidemiology

Available demographic data from the main international research centers indicate that the world's population is continuing to expand. It was 7 billion individuals just after 2010, and is expected to reach 9 billion by 2045 [Van Bavel, 2013]. All health organizations confirm, moreover, that the average lifespan in industrialized countries is increasing (it is, currently, approximately 80 years): the population's age distribution shows a constant growth in the proportion of people over 65 years old, which has more than doubled in the last 35 years (from 1980 to 2014), rising from 250 to over 550

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E-Mail karger@karger.com
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million. The median age is also rising continuously, and has gone from 23.5 years in 1950 to 29 in 2014. The epidemiological data on hearing-impaired people and patients with cognitive decline are consequently a cause for concern, especially when we consider adults over 65 or 75 years old. There are 360 million people in the world today with disabling hearing loss (5.3% of the world's population) and 91% of them are adults. The prevalence of hearing loss increases with age, so that approximately 1 in 3 people over 65 years suffers from disabling hearing loss (http://data.worldbank.org/). Disabling hearing loss refers to a hearing loss greater than 40 dB HL (averaged across 0.5–4 kHz) in the better-hearing ear (in adults).

The age-standardized prevalence of dementia varies from 2 to 8.5% among people over 59 years of age, exceeding 10% beyond the age of 65, and rising to 25–30% for people over 85, and more than 90% of dementia patients have hearing problems. The prevalence of dementia was 7.1 million in 2000, and 35.6 million in 2010. What is more, 58% of all people with dementia live in countries with low or mid-range incomes [Prince et al., 2013; Wancata et al., 2003].

In short, as life expectancy has increased, the number of healthy years lost to disability has also risen in most countries [Salomon et al., 2012]. But while hearing loss and/or cognitive decline continue to be common among the elderly, that does not necessarily mean that aging and hearing loss or dementia go hand in hand: healthy aging is possible at every stage of life [Kolovou et al., 2014].

Issues and Perspectives

Literature Review. Systematic research on the connections between hearing loss and cognitive decline began in the 1980s thanks mainly to publications of several authors [Jerger, 1992; Jerger et al., 1989; Peters et al., 1988; Uhlmann et al., 1986; Weinstein and Amsel, 1987]. Generally speaking, researchers focused on the significant association between cognitive decline and several factors that might be responsible for neurological diseases or other conditions, including: hearing loss, diabetes, cardiovascular diseases and alcohol consumption. But socioeconomic conditions, gender and education also emerged as potentially influencing the risk of dementia [Maggi et al., 1998].

The subsequent scientific publications remained fairly constant until a renewed interest was aroused in the last 5 years, especially in the light of data from neurophysiological measurements obtained with EEG, MRI/fMRI, genetic investigations and demographic studies. An indirect aspect may have been played by the difficulty of finding effective drug therapies for cognitive decline, and the continuously expanding clinical indications for the most advanced auditory function rehabilitation methods, including digital hearing aids and cochlear implants. This renewed interest has definitely been sustained by recent works brought to light in the literature [Lazard et al., 2013; Lin, 2011; Lin et al., 2011, 2013, 2014]. The studies are remarkably heterogeneous, but the results all seem to converge on certain basic shared key issues: (1) The neurosensory systems, hearing in particular, are important windows for shedding light on neurodegenerative diseases. (2) The cortical activity of patients with hearing loss is characterized by neuron reorganization and adaptive plasticity, but not always with positive results (maladaptive plasticity). (3) Elderly patients with cognitive impairment, even severe, should not be denied the auditory rehabilitation options currently available. (4) Changes in anatomy have been documented, such as brain volume shrinkage, synaptic degeneration and subsequent compensatory mechanisms (with greater neural activity) [Kotak et al., 2005; Lazard et al., 2013; Lin et al., 2014]. (5) Working memory has a crucial role in the difficulty of understanding speech in noisy environments.

Modifiable Factors. The meaning of a 'risk factor' is strongly linked to a cause-effect correlation on a precise and particular temporal axis: it cannot come after the disease. The early signs of a disease, including hearing loss in patients with dementia, and variability in the risk factors identified may, consequently, be rather confusing. In short, hearing loss and vestibular disorders could be early symptoms of a cognitive decline and, therefore, *effects*, not causes.

This aspect has been amply cited in relation to the preclinical diagnosis of dementias [Wong et al., 2014], as seen for vision and the eye [Chang et al., 2014; Kerbage et al., 2013]. So, hearing loss can be seen both as a screening method (to test for cognitive decline or dementia) and as a modifiable risk factor for preventing cognitive impairment [Gurgel et al., 2014; Lin et al., 2011; Parham et al., 2013]. Hearing loss can also be considered an independent pathological process that shares some pathophysiological processes and etiologies with cognitive decline (genetics, trauma and vascular diseases, for example) [Kurniawan et al., 2012].

Auditory Rehabilitation. In the auditory rehabilitation of patients with early cognitive impairment, it is important to consider the clinical indications and the feasibility of preventive and diagnostic screening for other diseases. In clinical practice, there is no reason why a cognitively impaired patient should not be able to benefit from valid and documented rehabilitation methods involving hearing aids and/or cochlear implants [Allen et al., 2003; Lupsakko et al., 2005; Petitot et al., 2007]. More timely rehabilitation may yield greater benefits – even in the very elderly (85 years and over). The optimal time window for intervention may be much narrower, however, than the one considered today for children with congenital hearing loss [Arlinger, 2003]. Experimental studies in animal models suggest that some developmental processes may become irreversible even after as little as 30 days [Leake et al., 2008].

Objective Measurements. It is widely accepted that auditory rehabilitation with hearing aids or cochlear implants is a valid option even for very old adults, and there are several reports in the literature documenting their benefits. A positive outcome is clearly desirable, but stopping, delaying and containing cognitive decline are three different goals of auditory rehabilitation, any and all of which would have positive effects. It is not easy to establish comparable, reliable and valid objective means for measuring the clinical stages of cognitive decline, however. How do we measure the effect of a treatment on a disease that may have begun to develop 20 years earlier, having now reached a time of life characterized by comorbidities and higher incidence of systemic diseases? Objective test methods are needed, generating results that are easy to compare over a lifetime. The data generated through MRI, EEG, and biochemical analyses may help us to elucidate the value of treating hearing loss in cognitively impaired individuals.

Several studies support the use of electroencephalography (including brainstem and cortical potentials) to assess patients with hearing and/or cognitive impairment. Alpha activity has proved essential to the central processes for distinguishing signals from noise [Strauss et al., 2014]. Particularly in healthy individuals, an increased alpha activity is always needed in the selective attention paid to sound sources in competition. This parameter may help us to differentiate between the peripheral (hearing) and the central contribution (neurodegeneration) to cognitive impairment in patients with hearing loss, especially when combined with data on auditory brainstem responses, and from tonal and speech audiometric tests. The Mini Mental State Examination, the Montreal Cognitive Assessment, the Geriatric Depression Scale, and other such cognitive tests are useful, but can hardly be considered objective.

The potential contribution of new methods such as functional MRI or functional NIRS (near-infrared spectroscopy) seems very promising, but these are still mainly only experimental options and are not used routinely at most specialized centers.

Rationales for Treatment. From a review of the literature, it is not clear how auditory rehabilitation might actually have direct or indirect effects on cognitive decline, especially at the central nervous system level in a neurodegenerative condition. In general, there are five rationales to consider.

First of all, reducing social isolation and improving depression symptoms could explain some early effects. Social isolation is a risk factor for cognitive decline because speech is the main way to transmit thoughts between individuals [Acar et al., 2011; Boi et al., 2012; Ertel et al., 2008]. Second, there is the preservation of the function and three-dimensional structure of the peripheral and central synapses [Kumar and Foster, 2007; Wong et al., 2010]. Third, partly as a consequence of the second, comes the contraposition and reversibility of negative neuroplastic processes. Fourth, we have the release of biochemical neural factors [Leake et al., 2008] that may sustain neural cell populations. Fifth, there is the effect of auditory/speech training, which can influence working memory.

Reviewing the literature, we can also propose a hypothetic timing and average audiometric threshold at which auditory rehabilitation should be considered mandatory, and beyond which, hearing treatments would be expected to be less effective. This audiometric limit could be set at 70 dB HL (PTA 0.5, 1, 2, 4 kHz) in the better-hearing ear, and the timing would be within a month of the hearing loss being diagnosed or suspected [Lazard et al., 2011, 2013].

The diagnosis of cognitive decline or dementia requires a multidisciplinary assessment, a battery of tests, and a rather long period of observation. The benefits achievable with these efforts are much greater when the cognitive decline is still mild or in a preclinical stage. In fact, some of the most relevant, recent studies have concentrated on the preclinical diagnosis of dementia because this would be the best starting point for efforts to prevent or treat it.

Discussion and Conclusions

Hearing loss is an important public health concern with substantial economic costs and social consequences. Hearing impairment is the most frequent sensory deficit in human populations and affects newborns, children, adults, and elderly people. The population over 65 years old is growing at a faster rate than the population as a whole, and it has been predicted that 20% of the population will be 65 or older by 2030. In 2006, from 35 to 50% of people aged 65 or more reportedly had presbycusis, a sensory impairment that contributes to social isolation and loss of autonomy, and is associated with anxiety, depression, and cognitive decline [Parham et al., 2011].

Conventional medical assessment is often not enough to assess older people with multiple comorbidities, and this acknowledged problem has prompted the development of geriatric assessment procedures that take a broader approach to examining contributors to health in older people, including: hearing impairment, visual impairment, functional decline, balance disorders and falls, urinary incontinence, cognitive impairment, depression, and malnutrition [Elsawy and Higgins, 2011; Rosen and Reuben, 2011].

Sensory measures are generally good predictors of higher levels of cognitive functioning, especially in older age, although cross-sectional studies have shown that hearing loss is a better predictor than visual acuity of age-related decline in more complex intellectual abilities [Baltes and Lindenberger, 1997; Granick et al., 1976]. Consistent with these earlier works, a recent longitudinal study confirmed that hearing loss is associated with a greater cognitive decline [Lin et al., 2013].

The magnitude of the relationship between sensory and cognitive functioning does not seem to depend exclusively on the level of sensory or cognitive performance, the type of task, or the severity of any brain-related pathology. Other measures of sensorimotor functioning (e.g. balance, gait) correlate with intellectual functioning too, just like visual and auditory acuity. Based on these findings, a common brain-related cause has been suggested to explain the increasingly strong correlation between sensory and intellectual abilities as a function of age [Lindenberger and Baltes, 1994], although the evidence to support it is mainly correlational and needs to be confirmed by experiments directly testing this and other hypotheses.

In future research, it will be crucially important to unravel how sensory abilities are linked to cognitive functioning in aging. Understanding these mechanisms will have important implications when it comes to promoting appropriate strategies for better diagnostic or rehabilitation programs.

If a decline in sensory function and intellectual performance share a common cause, as suggested by Lindenberger and Baltes [1994], studies on sensory functioning would generate much the same insight as investigations on more complex cognitive processes, with the added advantage that a greater experimental control could be exerted when studying more straightforward sensory abilities.

If it can be demonstrated that sensory functioning affects cognitive aging, either directly or via some mediating factors (e.g. mood improvement, promotion of social life, and stimulation of cognitive reserves), then rehabilitation protocols designed to boost sensory function are bound to have the effect of improving higher-level cognitive abilities too. Although similar issues have occasionally been investigated with promising results [Mulrow et al., 1992a, b], future experimental research should concentrate more on the cognitive benefits of hearing rehabilitation in aging.

The signs of age-related hearing loss are slow to become apparent in many older adults, and hearing loss, consequently, is often perceived as an unfortunate but inconsequential part of the aging process. But then again, research suggests that hearing loss may speed up the age-related cognitive decline and that treating hearing loss more aggressively could help delay cognitive decline and dementia by enabling cognitive rehabilitation through oral communication – the most important tool available for use in patient relations.

It is important to emphasize that healthy aging is possible even in the later stages of life, but this may sometimes rely on behavioral and clinical decisions made even decades earlier.

There is still much to be done to improve our understanding of the pathophysiology and treatment of various neurodegenerative disorders, and further studies are needed to investigate the real value of treating sensory deficits in cognitively impaired or very elderly patients. This could influence the way in which elderly patients are assessed by physicians and surgeons who need a better understanding to enable a more effective management of certain conditions. In the end, a multidisciplinary approach is still the best option, and geriatrics should include specific sensorineural investigations to manage elderly patients who are generally at risk of cognitive decline and hearing loss.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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Corresponding author:
Alessandro Castiglione, MD, PhD St
Department of Neurosciences, Otolaryngology
via Giustiniani 2, IT–35128 Padova (Italy)
E-Mail alessandro.castiglione @ unipd.it

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