Improvement of Cognitive Function After Cochlear Implantation in Elderly Patients

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**IMPORTANCE** The association between hearing impairment and cognitive decline has been established; however, the effect of cochlear implantation on cognition in profoundly deaf elderly patients is not known.

**OBJECTIVE** To analyze the relationship between cognitive function and hearing restoration with a cochlear implant in elderly patients.

**DESIGN, SETTING, AND PARTICIPANTS** Prospective longitudinal study performed in 10 tertiary referral centers between September 1, 2006, and June 30, 2009. The participants included 94 patients aged 65 to 85 years with profound, postlingual hearing loss who were evaluated before, 6 months after, and 12 months after cochlear implantation.

**INTERVENTIONS** Cochlear implantation and aural rehabilitation program.

**MAIN OUTCOMES AND MEASURES** Speech perception was measured using disyllabic word recognition tests in quiet and in noise settings. Cognitive function was assessed using a battery of 6 tests evaluating attention, memory, orientation, executive function, mental flexibility, and fluency (Mini-Mental State Examination, 5-word test, clock-drawing test, verbal fluency test, d2 test of attention, and Trail Making test parts A and B). Quality of life and depression were evaluated using the Nijmegen Cochlear Implant Questionnaire and the Geriatric Depression Scale-4.

**RESULTS** Cochlear implantation led to improvements in speech perception in quiet and in noise (at 6 months: in quiet, 42% score increase [95% CI, 35%-49%; P < .001]; in noise, at signal to noise ratio [SNR] +15 dB, 44% [95% CI, 36%-52%, P < .001], at SNR +10 dB, 37% [95% CI 30%-44%, P < .001], and at SNR +5 dB, 27% [95% CI, 20%-33%; P < .001]), quality of life, and Geriatric Depression Scale-4 scores (76% of patients gave responses indicating no depression at 12 months after implantation vs 59% before implantation; P = .02). Before cochlear implantation, 44% of the patients (40 of 91) had abnormal scores on 2 or 3 of 6 cognition tests. One year after implant, 81% of the subgroup (30 of 37) showed improved global cognitive function (no or 1 abnormal test score). Improved mean scores in all cognitive domains were observed as early as 6 months after cochlear implantation. Cognitive performance remained stable in the remaining 19% of the participants (7 of 37). Among patients with the best cognitive performance before implantation (ie, no or 1 abnormal cognitive test score), 24% (12 of 50) displayed a slight decline in cognitive performance. Multivariate analysis to examine the association between cognitive abilities before implantation and the variability in cochlear implant outcomes demonstrated a significant effect only between long-term memory and speech perception in noise at 12 months (SNR +15 dB, P = .01; SNR +10 dB, P < .001; and SNR +5 dB, P = .02).

**CONCLUSIONS AND RELEVANCE** Rehabilitation of hearing communication through cochlear implantation in elderly patients results in improvements in speech perception and cognitive abilities and positively influences their social activity and quality of life. Further research is needed to assess the long-term effect of cochlear implantation on cognitive decline.

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Large prospective studies have established an independent association between hearing impairment and cognitive decline.\textsuperscript{1,2} Individuals with mild to severe hearing loss have a 2- to 5-fold increased risk of developing dementia compared with those with normal hearing.\textsuperscript{3} Moreover, neuroimaging studies\textsuperscript{3,4} report an association between peripheral hearing impairment and temporal lobe cortex and whole brain atrophy. A combination of several interdependent mechanisms could account for this association, such as vascular risk factors, neurodegenerative processes affecting both peripheral auditory pathways and the cerebral cortex, social isolation, and reduced cognitive stimulation. Based on these reports, hearing rehabilitation using conventional hearing aids has logically been proposed as a treatment to help improve neurocognitive performance; however, the impact of the rehabilitation generated controversial results, with a beneficial effect reported in only half of the elderly patients presented in the 6 published analyses.\textsuperscript{5-10}

In cases of acquired severe to profound hearing loss with no benefit from conventional amplification, cochlear implantation that uses direct electrical stimulation of the auditory nerve has proved to be successful; patients 80 years or older are one of the groups receiving benefit.\textsuperscript{11,12} Retrospective studies\textsuperscript{13-24} in the geriatric population report improvement for auditory performance in quiet and noise despite prolonged duration of deafness, as well as age-related degeneration of the spiral ganglion and central auditory pathways. Moreover, similar to younger patients with cochlear implants, most elderly patients who have received implants show an increase in social activities and improved confidence.\textsuperscript{15,20,25} To the best of our knowledge, the relationship between hearing benefit following cochlear implantation and cognitive abilities in elderly patients has not been investigated.

The objective of this prospective, longitudinal multicenter study was to assess speech perception, cognitive abilities, and quality-of-life scores before implantation and at 6 and 12 months after cochlear implant activation in patients 65 years or older. The focus was to determine the effect of hearing rehabilitation including the cochlear implant on cognitive function in addition to the influence of cognitive factors on cochlear implantation outcomes over time.

Methods

Selection Criteria

Patients enrolled in this study were postlingually deafened, 65 years or older, and candidates for cochlear implantation (ie, bilateral severe to profound sensorineural hearing loss and speech recognition scores of ≤50% for French open-set disyllabic words presented at 60 dB sound pressure level in quiet, in the best-aided condition after verification of the optimal hearing aid fitting). Patients were excluded from the study if they were unable to complete the required procedures owing either to evidence of severe cognitive or medical disorders diagnosed during routine medical and psychological evaluation performed before implantation.

This study was approved by the ethics committee (Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale, Groupe Hospitalier, Pitié-Salpêtrière, Paris, 2007). Written informed consent was obtained from each patient before their enrollment in the study. Participants did not receive financial compensation.

Participants

Ninety-four patients were enrolled between September 1, 2006, and June 30, 2009, in 10 tertiary referral centers in this prospective study. The mean age at implantation was 72 years (range, 65-85 years; median, 71 years). Demographic data, hearing loss information, and the educational level of all patients are summarized in eTable 1 in the Supplement.

Ninety-three patients underwent a unilateral cochlear implantation (50 in the right ear, 43 in the left ear), and 1 patient received simultaneous bilateral implantation. Four implant devices were used (Neurelec, 29 patients; MED-EL, 26; Cochlear, 23; and Advanced Bionics, 17). The brand of the device was decided primarily by each referral center during patient counseling, with a view to ensure adequate representation of each of the 4 devices available across the study group. Cochlear implants were activated 2 to 4 weeks after the operation, and subsequent programming sessions were planned to optimize the individual map. All patients entered a postactivation aural rehabilitation program that consisted of individual sessions with a speech therapist, twice weekly, for at least 6 months. This training was based on speech perception tasks and on semantic and cognition tasks that engage memory, attention span, speed of processing, and mental flexibility.

Speech Perception Measures

Speech perception was scored before implantation and at 6 and 12 months after activation in quiet with the device only (hearing aid or cochlear implant) and in best-aided conditions in quiet and in noise. The best-aided condition reflected the patient’s daily listening condition, defined as cochlear implant and a contralateral hearing aid when available or cochlear implant alone, if no contralateral hearing aid was used. Measurements were assessed in a sound-treated room using recorded materials presented at 60 dB sound pressure level from a loudspeaker placed at 0° azimuth. Tests in noise were administrated at a signal to noise ratio (SNR) ranging from +15 dB to 0 dB, with the speech stimuli and a competing white-noise signal presented from the front speaker. Test materials consisted of lists of 10 open-set disyllabic words (Fournier lists\textsuperscript{26}). Two lists of words were presented at each level and responses were scored as the percentage of words correctly identified. The ability of patients to communicate on the telephone with familiar speakers or with strangers was assessed by the use of a questionnaire developed specifically for the study.

Cognitive Measures, Quality-of-Life Assessment, and Depression Scale

Evaluations were performed before implantation and at 6 and 12 months after cochlear implant activation. Participants were assessed by a neuropsychologist with a battery of cognitive
tests currently used in the elderly population to explore episodic memory visuospatial abilities, attention span, speed of processing, mental flexibility, rule of compliance, and executive function: Mini-Mental State Examination (MMSE), 5-word test (FWT), clock-drawing test, verbal fluency test, d2 test of attention, and Trail Making Test parts A and B (TMT-A and TMT-B) (descriptions of the tests and relevant references are presented in the eMethods in the Supplement). Before testing, written instructions were given to participants to avoid an overdiagnosis of cognitive impairment due to a misunderstanding of the test procedure in this hearing-impaired population. Results of each test were expressed as normal or abnormal with respect to the published normative data.

Quality of life was assessed using the Nijmegen Cochlear Implant Questionnaire (NCIQ)27 (eMethods in the Supplement). Depressive symptoms were evaluated using the 4-item version of the Geriatric Depression Scale (GDS-4), which is a widely used validated questionnaire for the detection of these symptoms.27,28

Statistical Analysis

Patients’ characteristics and clinical data are reported as the mean (SD) or median (first through third quartiles) for continuous variables and as percentages and 95% CIs for categorical variables. The χ2 and Fisher exact tests (for categorical variables) and paired t test (for continuous variables) were computed to compare the audiologic, cognitive, and quality-of-life scores measured at the different time intervals. All comparisons were 2-tailed, and the level of significance was set at \( P < .05 \). The Spearman correlation coefficient was used to identify and quantify relationships between NCIQ scores and speech perception scores. For each variable of interest (cognitive scores), a univariate analysis followed by a multivariate analysis was performed using a generalized linear model to explain the audiologic results (speech perception in quiet and noise) at 12 months after implantation. For univariate analyses, each independent factor was tested and included in a multivariate model if \( P < .20 \). Backward selection was then performed, keeping variables with a significance level of \( \alpha = .05 \); \( P < .05 \) was considered significant. All analyses were performed using SAS, version 9.2 (SAS Institute Inc).

Results

Auditory Rehabilitation

Twelve months after cochlear implantation, 97% of the patients (n = 91) used their cochlear implant all day long. The 3% (3 of 94) who did not use it throughout the day wanted to save battery life. Fifty-seven percent of the patients (54 of 94) still used their hearing aid in the contralateral, nonimplanted ear compared with 64% (60 of 94) before implantation (Fisher exact test, \( P = .46 \)). Mean speech perception for disyllabic words in quiet and in noise are shown in Figure 1. In quiet, mean speech perception clearly improved 6 months after cochlear implantation compared with the preimplantation scores, both with the cochlear implant only (paired difference, 52% score increase [95% CI, 45%-57%; \( P < .001 \)) and in best-aided conditions (paired difference, 42% [95% CI, 35%-49%; \( P < .001 \)). Between 6 and 12 months, speech perception scores continued to improve with the cochlear implant alone (paired difference, 6% score increase [95% CI, 1%-10.3%; \( P = .02 \))) and in best-aided conditions (paired difference, 6.7% [95% CI, 2.05%-11%; \( P = .005 \))). In noise, speech perception scores increased 6 months after cochlear implantation compared with preimplantation scores at each SNR (SNR +15 dB: difference, 44% score increase [95% CI, 36%-52%; \( P < .001 \)), SNR +10 dB: difference, 37% [95% CI, 30%-44%; \( P < .001 \)), SNR +5 dB: difference, 27% [95% CI, 20%-33%; \( P < .001 \)), and SNR 0 dB: difference, 18% [95% CI, 12%-25%; \( P < .001 \)). No further significant improvement was observed between 6 and 12 months. Speech perception scores at 12 months in quiet and in noise were simil-
lar between patients aged 65 to 74 years and those older than 75 years (unpaired t test).

Before cochlear implantation, 23 of the 94 patients (22%) used the telephone only with familiar speakers. Twelve months after cochlear implantation, 65% of the patients (n = 61) indicated that they were able to use the telephone (P < .001, Fisher exact test), and half of these could do so with unfamiliar speakers. Sixty-one percent (37) of the 61 telephone users were female (P = .03, Fisher exact test).

### Cognitive Tests

Data for 91 of the 94 participants (97%) were included in the data analysis: the interpretation of 2 tests was not possible for 1 patient with an unknown educational level, and 2 patients refused to continue with the evaluations after having abnormal scores on 3 tests; all 3 of these patients were withdrawn from the cognitive study as a consequence. Before cochlear implantation, 23 patients (25% of the population) obtained normal scores on all 6 cognitive tests, 28 patients (31%) had 1 abnormal test score, 22 patients (24%) had 2 abnormal test scores, and 18 patients (20%) had 3 abnormal test scores (Figure 2A). The mean age at implantation was similar between the groups of patients with and without abnormal cognitive scores. Furthermore, no significant difference (P = .46) was observed in the proportion of each age group with 2 or 3 cognitive tests scores: 46% (31 of 68) of 64- to 75-year-old individuals and 46% (12 of 26) of those older than 75 years. Among the 91 patients who completed preimplantation cognitive testing, 4 individuals (4%) had missing data during the postimplantation test intervals; 3 patients (3%) had only 6-month results, with all obtaining higher scores at the 6-month interval, and 1 patient (1%) who had 2 abnormal test scores before implantation completed only the MMSE and the FWT at 12 months. Twelve months after cochlear implantation, the percentage of 87 patients with normal results of cognitive tests increased to 40% (n = 35), the number of patients with 1 abnormal cognitive test remained stable at 33% (29 of 87), and the number of patients with 2 and 3 tests with abnormal scores decreased to 22% (19 of 87) and 5% (4 of 87), respectively (P = .001, χ² test). Individual available cognitive outcomes in relation to preimplantation results are detailed in Figure 2B. Among the group of 50 patients with good cognitive abilities before implantation (no or 1 abnormal test score), 24% (12 of 50) obtained poorer results on cognitive tests 12 months after implantation. This decline was slight, with only 1 test (2% [1 of 50 patients]) or 2 tests (4% [2 of 50] becoming abnormal. In contrast, among the group of 37 patients with 2 or 3 abnormal test scores before implantation, 81% (n = 30) obtained better results 12 months after implantation, and 19% (7) displayed stable scores. The percentage of patients with 2 and 3 abnormal tests at 12 months after implantation was similar between patients aged 65 to 74 years and those older than 75 years (26% and 31%, respectively). The number of patients with abnormal cognitive scores for each test is detailed in Table 1.

Table 2 summarizes the mean scores for each test before and after cochlear implantation. In patients with abnormal test scores before implantation, paired t test analysis demonstrated an improvement of cognitive performance on most tests. This improvement was significant as early as 6 months for the MMSE, the d2 test of attention (speed), and the TMT-B, and became significant at 12 months for the TMT-A and the number of errors on the d2 test. Although the mean score for the clock-drawing test improved at 12 months, the difference was not significant, presumably because of the small number of patients with abnormal scores before implantation (n = 4). In patients with normal cognitive performance before implantation, scores for the MMSE, the number of errors on the d2 test of attention, TMT-A, and TMT-B remained stable over time. We observed, however, a significant decline in results of the FWT, a test that explores episodic anterograde memory, at 6 and 12 months. When evaluating verbal fluency, the lists of words (ie, names of animals, vegetables, and furniture) and letters (P, R, and V) were changed at each test session to avoid a learning effect from familiarity to the items used; consequently, comparison of the mean scores between the preimplantation and postimplantation evaluations was not possible because normative data differed according to each list.

To evaluate the influence of cognitive function on cochlear implantation outcomes, all cognitive factors assessed in this study, which may have had an effect on speech perception in quiet and in noise, were studied in a multivariate analysis 12 months after implantation. Performance on the verbal fluency test for letters as test items was identified as the sole predictor of improvements in speech perception in noise (SNR + 15 dB, P = .01; SNR + 10 dB, P < .001; and SNR + 5 dB, P = .02). Moreover, no other significant difference in the mean speech perception scores at 12 months was observed between the 17 patients who had the poorest cognitive abilities (2 and 3 abnormal test scores before and after implantation) and the 64 patients who obtained no or 1 abnormal cognitive test score at 12 months (unpaired t tests).

### Quality of Life and Depression

The NCIQ scores showed significant improvements in all 6 subdomain scores at 6 months after implantation (basic sound perception: difference, 27% score increase; [95% CI, 22%-33%; P < .001]; advanced sound perception: difference,
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14% [95% CI, 9%-19%; \( P < .001 \)]; speech production: difference, 18% [95% CI, 14%-22%; \( P < .001 \)]; self-esteem: difference, 13% [95% CI, 9%-16%; \( P < .001 \)]; activity: difference, 21% [95% CI, 17%-25%; \( P < .001 \)]; and social interactions: difference, 23% [95% CI, 18%-27%; \( P < .0001 \)]. The results remained stable between the 6- and 12-month intervals (Figure 3). A correlation was found between the improvement of NCIQ and the increase in speech perception scores at 12 months after implantation compared with preimplantation results (Table 2 in the Supplement).

Before cochlear implantation, 55 of the 94 patients (59%) gave responses indicating no depression on the GDS-4, and 27 (29%), 8 (8%), 3 (3%), and 1 (1%) of the patients gave 1, 2, 3, or 4 responses indicating depression, respectively. At 12 months after implantation, the number of patients without depression improved to 72 (76%; \( P = .02 \), Fisher exact test), whereas 10 (11%), 9 (10%),

### Table 1. Abnormal Test Scores 12 Months After Cochlear Implantation in 94 Patients

<table>
<thead>
<tr>
<th>Cognitive Test (Missing Data at Baseline)</th>
<th>Abnormal Scores Before Implantation</th>
<th>Abnormal Scores After Implantation</th>
<th>Missing Data</th>
<th>Normal Scores Before Implantation</th>
<th>Abnormal Scores After Implantation</th>
<th>Missing Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMSE (0)</td>
<td>13 (14)</td>
<td>3 (3)</td>
<td>2</td>
<td>81 (86)</td>
<td>4 (4)</td>
<td>2</td>
</tr>
<tr>
<td>5-Word test (0)</td>
<td>22 (23)</td>
<td>10 (11)</td>
<td>2</td>
<td>72 (77)</td>
<td>11 (12)</td>
<td>3</td>
</tr>
<tr>
<td>Clock-drawing test (0)</td>
<td>4 (4)</td>
<td>1 (1)</td>
<td>1</td>
<td>90 (96)</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

**Fluency tests**

- Categories (2): 10 (7) 1 (1) 0 82 (89) 2 (2) 4
- Letters (2): 6 (7) 0 0 86 (93) 1 (1) 4

**d2 Test of attention**

- Errors (3): 11 (12) 1 (1) 0 80 (88) 3 (3) 4
- Speed (3): 39 (43) 14 (16) 4 52 (57) 13 (13) 0

**Trail Making Test**

- Part A (1): 19 (20) 5 (6) 0 74 (80) 3 (3) 4
- Part B (3): 23 (25) 6 (7) 2 68 (75) 5 (6) 2

**Abbreviation:** MMSE, Mini-Mental State Examination.

* The percentages indicate the number of patients with normal and abnormal scores among patients who performed the test before and after implantation. Of 94 patients, educational level was unknown for 1 individual, so interpretation of the verbal fluency test and the Trail Making test was not possible. The d2 test of attention was also missing for this patient. Before implantation, 2 patients did not complete all cognitive tests. After implantation, cognitive data were missing for 4 patients (including 1 patient who did not complete all cognitive tests before implantation) and 1 patient performed only the MMSE.

### Table 2. Effect of Cochlear Implantation on Mean Cognitive Test Scores in 94 Patients

<table>
<thead>
<tr>
<th>Cognitive Test</th>
<th>Before, Mean (SD)</th>
<th>Group (No.)</th>
<th>6-mo Mean (SD)</th>
<th>Differences, Mean (95% CI)</th>
<th>( P ) Value</th>
<th>12-mo Mean (SD)</th>
<th>Differences, Mean (95% CI)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMSE</td>
<td>22.1 (3.4)</td>
<td>Abnormal (13)</td>
<td>25.8 (2.7)</td>
<td>3.7 (0.6 to 6.8)</td>
<td>.02</td>
<td>26.3 (2.7)</td>
<td>3.8 (1.0 to 6.6)</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>27.8 (1.7)</td>
<td>Normal (81)</td>
<td>27.9 (1.8)</td>
<td>-0.04 (-0.4 to 0.5)</td>
<td>.85</td>
<td>28.1 (1.8)</td>
<td>0.2 (-0.3 to 0.6)</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>8.2 (3.2)</td>
<td>Abnormal (22)</td>
<td>9.6 (0.1)</td>
<td>1.4 (0.5 to 2.3)</td>
<td>.004</td>
<td>9.4 (0.7)</td>
<td>1.3 (0.6 to 1.9)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>10.0 (0.0)</td>
<td>Normal (72)</td>
<td>9.7 (1.1)</td>
<td>-0.4 (-0.6 to -0.1)</td>
<td>.002</td>
<td>9.7 (0.8)</td>
<td>-0.7 (-0.7 to -0.2)</td>
<td>.002</td>
</tr>
<tr>
<td>Clock-drawing test</td>
<td>2.5 (0.6)</td>
<td>Abnormal (4)</td>
<td>3.3 (0.6)</td>
<td>0.7 (-0.8 to 2.1)</td>
<td>.18</td>
<td>4 (2.6)</td>
<td>1.3 (-6.3 to 9.0)</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>6.1 (0.9)</td>
<td>Normal (90)</td>
<td>6.1 (1.0)</td>
<td>-0 (-0.3 to 0.3)</td>
<td>.99</td>
<td>6.3 (0.9)</td>
<td>0.2 (0.3 to 0.4)</td>
<td>.046</td>
</tr>
<tr>
<td>d2 Test (errors)*</td>
<td>27.7 (9.0)</td>
<td>Abnormal (11)</td>
<td>21.0 (14.6)</td>
<td>-6.6 (-18.3 to 5.0)</td>
<td>.23</td>
<td>9.4 (7.1)</td>
<td>-18.3 (-25.3 to -11.9)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>6.2 (4.7)</td>
<td>Normal (80)</td>
<td>6.2 (6.2)</td>
<td>-0.2 (-1.8 to 1.4)</td>
<td>.82</td>
<td>5.7 (5.6)</td>
<td>-0.6 (-2.1 to 0.8)</td>
<td>.37</td>
</tr>
<tr>
<td>d2 Test of attention (speed)*</td>
<td>262 (68.2)</td>
<td>Abnormal (39)</td>
<td>701 (79.0)</td>
<td>46.4 (13.0 to 79.8)</td>
<td>.008</td>
<td>342 (81.7)</td>
<td>60.1 (30.5 to 89.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>429 (81.2)</td>
<td>Normal (52)</td>
<td>411 (80.2)</td>
<td>-19.3 (-44.4 to 4.7)</td>
<td>.11</td>
<td>409 (76.5)</td>
<td>-19.6 (-42.8 to 3.6)</td>
<td>.09</td>
</tr>
<tr>
<td>TMT-A*</td>
<td>77.3 (43.0)</td>
<td>Abnormal (19)</td>
<td>60.2 (14.1)</td>
<td>-17.1 (-39.7 to 3.8)</td>
<td>.09</td>
<td>52.2 (11.3)</td>
<td>-25.1 (-46.3 to -3.9)</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>43.8 (10.9)</td>
<td>Normal (74)</td>
<td>43.1 (12.8)</td>
<td>0.01 (-3.2 to 3.2)</td>
<td>.99</td>
<td>44.3 (12.6)</td>
<td>1.2 (-1.9 to 4.4)</td>
<td>.43</td>
</tr>
<tr>
<td>TMT-B*</td>
<td>181 (56.0)</td>
<td>Abnormal (23)</td>
<td>152 (64.7)</td>
<td>-29.5 (-55.9 to -3.9)</td>
<td>.03</td>
<td>142 (65.9)</td>
<td>-32.5 (-61.5 to -3.6)</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>105 (33.9)</td>
<td>Normal (68)</td>
<td>106 (41.2)</td>
<td>2.7 (-5.9 to 11.3)</td>
<td>.52</td>
<td>111 (46.7)</td>
<td>4.9 (-4.6 to 14.5)</td>
<td>.30</td>
</tr>
</tbody>
</table>

Abbreviations: FWT, five-word test; MMSE, Mini-Mental State Examination; TMT, Trail Making Test; TMT-A, TMT part A; TMT-B, TMT part B.

* Before implantation, results of each test were expressed as normal and abnormal, considering age, educational level, and normative data for the MMSE, d2 test of attention, and TMT.

* Scores are reported as the number of recalls (scores <10 were abnormal).

* Scores of less than 10 were abnormal.

* Scores are reported as the total percentage of errors and as the number of items processed (speed).

* Scores were based on the total time of test completion (seconds).
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Discussion

Impact of Hearing Rehabilitation on Cognitive Functions

This prospective study demonstrates that cochlear implantation improves speech perception in an elderly population in quiet and in noise at 6 months after implantation, which is consistent with previously reported research.11-24 Speech perception continues to improve in quiet between 6 and 12 months, and was shown to remain stable for performance in noise after 6 months. At the same time, our study provides evidence that hearing rehabilitation using cochlear implantation is associated with an improvement in cognitive function in all cognitive domains as early as 6 months after implantation in elderly patients who had abnormal test scores at baseline. More than 80% of the patients (30 of 37) who had the poorest cognitive scores before implantation improved their cognitive function at the 1-year postimplantation interval. In contrast, patients with the best cognitive performance before implantation demonstrated stable results (≤1 abnormal test score), although a slight decline was observed in 24% of the patients. Mean age at implantation was similar between patients with normal hearing and patients with moderate to severe hearing loss demonstrated a 30% to 40% accelerated rate of cognitive decline and a 24% increased risk for incident cognitive decline during a 6-year period compared with participants with normal hearing.9 Mechanisms underlying this association are probably multifactorial. Some studies suggested that hearing impairment and cognitive decline may share a neurodegenerative process. Histologic changes involved in central auditory dysfunction are unknown; nonetheless, the association between central auditory dysfunction and executive dysfunction and dementia in elderly patients supports this hypothesis.36-39 The evaluation of central auditory function using formal cognitive testing could assess the effect of speech therapy alone on cognitive abilities in elderly patients with severe to profound hearing loss. A learning effect through repeated cognitive testing cannot be ruled out, especially for the tests including the clock-drawing test and FWT. In any case, scores were observed to improve only for 2 patients for the clock-drawing task and decreased for the FWT task. For verbal fluency tests, lists were changed at each session and other cognitive tests are clearly too complex to be learned; therefore, it is unlikely that a test learning effect could influence the outcome of this study.

To date, the effect of hearing rehabilitation on cognitive abilities has been studied only in patients fitted with hearing aids, with a beneficial effect reported in 3 of the 6 published studies.5,7,8 Heterogeneity in the population and variability in methodology across studies are likely to explain the discrepancies in these results. In our work, despite variability in hearing loss duration and in hearing aid use before implantation, participants represent a homogeneous population characterized by a preimplantation, severe to profound sensorineural hearing loss, and a similar postimplantation auditory training program.

The association between peripheral hearing loss and cognitive decline and dementia has been well established in several cross-sectional and longitudinal studies.1,2,9,30-36 Lin36 showed that a greater level of hearing loss is significantly associated with lower scores on cognitive tests, especially for memory and executive function, and concluded that the decline in cognitive performance associated with a 25-dB hearing loss is equivalent to the reduction associated with an older age difference of 7 years. Individuals having hearing loss demonstrated a 30% to 40% accelerated rate of cognitive decline and a 24% increased risk for incident cognitive impairment during a 6-year period compared with participants with normal hearing.9 Mechanisms underlying this association are probably multifactorial. Some studies suggested that hearing impairment and cognitive decline may share a neurodegenerative process. Histologic changes involved in central auditory dysfunction are unknown; nonetheless, the association between central auditory dysfunction and executive dysfunction and dementia in elderly patients supports this hypothesis.36-39 The evaluation of central auditory function using formal cognitive testing could assess the effect of speech therapy alone on cognitive abilities in elderly patients with severe to profound hearing loss.
tion disorders was not possible in our cochlear implantation candidates because of the severity of the hearing loss; however, with respect to the significant improvement for speech perception in noise after cochlear implantation, we can speculate that a central auditory dysfunction is unlikely for most of the patients included in this study.

In hearing-impaired patients, the listening effort required to improve communication leads to mental fatigue with a negative effect on cognitive resources being available for other cognitive tasks, resulting in cognitive decline.29-35 Our results suggest that, by improving hearing for verbal communication, cochlear implantation decreases the cognitive load and, as a consequence, may have a positive effect on attention, concentration, and executive function.

A socially active lifestyle can prevent cognitive decline in old age, suggesting that social isolation can be an additional causal pathway for cognitive impairment.5,9-10 Hearing loss impairs social relationships, leading to loneliness and degraded quality of life in elderly persons.8,41-47 The findings of our study demonstrate an improvement in the NCIQ scores in each of its subdomains as early as 6 months after implantation, correlated with the speech perception benefit in quiet and in noise at 12 months. Through these results, which are consistent with those of previous retrospective studies,15,20,25,43,44 we can hypothesize that by improving verbal communication, cochlear implantation restores the possibility for social networking and, as a consequence, has a positive effect on quality of life and social activity that contributes to better cognitive function.

Although an association between hearing impairment and depression in the elderly is still debated, depression has been recognized as a major risk factor for mild cognitive impairment and dementia.30,31,45,46 As a consequence, we can also hypothesize that the reduction in depressive symptoms observed 12 months after implantation could contribute to the improvement of cognitive abilities.

A limitation of our study is the short postimplantation observation interval. A recent study47 reported that at 13.5 years after implantation, 83% of elderly patients who received cochlear implants at age 60 years or older continued to use the implant consistently. In another study,23 elderly patients with unilateral implants maintained their earlier speech perception ability in noise 10 years or more after receiving an implant. Further research is needed within our population to assess the long-term effect of cochlear implant use on cognitive abilities, quality of life, and depression.

Influence of Cognitive Factors on Cochlear Implantation Outcomes

The role of cognitive processing in listening performance in noise and hearing-aid benefit for speech perception tasks has been clearly demonstrated in the elderly population.48-51 Consequently, we examined, via multivariate analysis, whether cognitive abilities before implantation can contribute to variability in cochlear implantation outcomes. We observed that results for the verbal fluency test for letters, which evaluates long-term memory, was the only cognitive test that correlated with speech perception scores in noise. Unexpectedly, neither attention deficit nor executive dysfunction showed a correlation with speech perception scores in noise. Very few studies have evaluated the influence of cognitive factors in adult cochlear implant recipients. Heydebrand et al52 found that better scores for word recognition in quiet were observed in adults with good verbal working memory and learning before implantation (mean age, 54 years; range, 24-80 years). Poorer speech perception in quiet was observed 2 years after implantation in patients with lower cognitive scores.53 A key limitation of our study is that working memory was not assessed, although it plays a major role in cases of degraded speech information and might account for the correlation between cognition and speech perception scores in the aforementioned studies.51,54 Another limitation of the present study is that we applied basic tests used to evaluate cognitive function in the elderly population. Additional studies more precisely examining the role of specific cognitive factors involved in speech perception in difficult conditions are needed. Finally, one of the selection criteria routinely used in the investigating clinics for cochlear implantation was the absence of major cognitive impairment; indeed, cognitive problems, as well as low motivation, may influence the outcome of hearing rehabilitation.

Conclusions

Epidemiologic studies54 demonstrate that the anticipated number of people aged 60 years or older will double by the year 2050. As a consequence, the number of people with cognitive impairment and dementia will dramatically increase, reaching more than 100 million worldwide by 2050. Because there is no curative treatment available for cognitive decline, clinical research is needed that focuses on identification of risk factors to establish preventive measures that may reduce the burden of the disease. Interventions that could delay dementia onset by 1 year, as well as its progression, would lead to a decrease of more than 9 million in the worldwide prevalence of dementia by 2050.55 Our study demonstrates that hearing rehabilitation using cochlear implants in the elderly is associated with improvements in impaired cognitive function. Further research is needed to evaluate the long-term influence of hearing restoration on cognitive decline and its effect on public health.

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