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# Aging, Hearing Acuity, and the Attentional Costs of Effortful Listening

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## Abstract

A dual-task interference paradigm was used to investigate the effect of perceptual effort on recall of spoken word-lists by younger and older adults with good hearing and with mild-to-moderate hearing loss. In addition to poorer recall accuracy, listeners with hearing loss, especially older adults, showed larger secondary task costs while recalling the word-lists even though the stimuli were presented at a sound intensity that allowed correct word identification. Findings support the hypothesis that extra effort at the sensory-perceptual level attendant to hearing loss has negative consequences to downstream recall, an effect that may be further magnified with increased age.

**Keywords**

hearing loss; aging; speech processing; dual-task; memory

Age-related hearing loss is the third most prevalent chronic medical condition among older adults (Lethbridge-Ceijku, Schiller, & Bernadel, 2004). When accompanied by age-related declines in attentional resources (Craik & Byrd, 1982), working memory capacity (Kausler, 1994), and processing speed (Salthouse, 1996), one can see the challenge facing many older adults as they attempt to comprehend and remember fast-paced speech in their everyday lives. In addition to missed or incorrectly identified words, diminished hearing may also lead to impoverished, less discriminable memory traces (Surprenant, 2007). There is, however, an additional concern. As argued initially by Rabbitt (1968, 1991), and subsequently supported by others, successful perception in the face of degraded input may come at the cost of attentional resources that might otherwise be available for encoding what has been heard in memory (e.g., McCoy, Tun, Cox, Colangelo, Stewart & Wingfield, 2005; Murphy, Craik, Li & Schneider, 2000; Pichora-Fuller, 2003; van Boxtel et al., 2000; Suprenant, 1999, 2007; Wingfield, Tun & McCoy, 2005).

This potential contributor to poorer memory performance associated with hearing loss, a so-called "effortfulness hypothesis", has until now been inferred from performance on the memory task itself. This hypothesis would thus be strengthened by an independent measure of resource allocation attendant to successful recognition by individuals with good versus poor hearing. One solution is to use a dual-task paradigm in which participants are asked to listen to and recall speech materials as a primary task while also conducting a concurrent secondary task.

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Changes in secondary task performance between single-task and dual-task conditions, or "cost", are then taken as an index of attentional resources allocated to the primary task (Kerr, 1973). To the extent that age and hearing loss impose an extra burden on processing resources, this should be reflected not only in the level of speech recall as a primary task, but also as an increase in secondary task cost.

We use the terms "resources" and "resource capacity" in Kahneman's (1973) original sense, to refer to a limited pool of attentional resources that must be allocated among tasks or mental operations. The more difficult or resource demanding a particular task, the fewer resources will be available for use elsewhere in the system (e.g., Craik & Byrd, 1982). Operational definitions of resources often center on Baddeley's (2002) notion of a limited-capacity central executive in working memory, as further developed in terms of executive flexibility or attentional control (cf., Engle et al., 1999; Miyake & Shah, 1999; Verhaeghen & Hoyer, 2007). At the neural level resources have been reified in terms of increases in area-specific neural activation in the face of complex language and non-language tasks (see Wingfield & Grossman, 2006, for a review).

For our investigation we wished to use a concurrent secondary task that would not itself be affected by hearing acuity. We chose as a secondary task a visual target-pursuit task, in which we would monitor a participant's moment-to-moment accuracy in using a computer mouse to track a randomly moving visual target, a method that has been used successfully in the past to explore age-related declines in resource capacity and its allocation (Naveh-Benjamin, Craik, Guez & Kreuger, 2005; Naveh-Benjamin, Craik, Perretta & Tonev, 2000; Naveh-Benjamin, Guez, & Sorek, 2007). In order to tease apart effects of aging from those of hearing loss, we used a four-group design consisting of older adults with good hearing (meeting a criterion of clinically normal hearing for speech) versus poor hearing (those with mild-to-moderate hearing loss), and young adults with either good or poor hearing.

Based on extant literature, one would expect under dual-task conditions to see differentially poorer memory performance and larger secondary task costs for older adults relative to younger adults, independent of hearing acuity (e.g., Anderson, 1999; Anderson, Craik & Naveh-Benjamin, 1998; Naveh-Benjamin et al., 2005). This would follow from the argument that aging is associated with generally reduced attentional resources (Anderson, 1999; Craik & Byrd, 1982; Naveh-Benjamin et al., 2005). Our specific question was whether mild-to-moderate hearing loss would be associated not only with a decrement in recall performance, but also with a corresponding increase in secondary task costs. To the extent that older adults begin with more limited resources than younger adults, one would expect the dual-task cost to be greatest for older adults with poor hearing relative to the other three groups.

## Method

### Participants

Participants were 24 younger adults (5 men and 19 women) ranging in age from 20 to 46 years (*M* = 27.9, *SD* = 7.4), and 24 older adults (6 men and 18 women) ranging in age from 67 to 80 years (*M* = 73.9, *SD* = 4.1). The groups did not differ significantly in years of education (*M* younger = 17.2, *SD* = 2.2; *M* older =15.9, *SD* = 2.1; *t*(46)= 1.96, *n.s.*) or performance on the Shipley vocabulary test (Zachary, 1991), (*M* younger =15.1, *SD* = 1.6; *M* older = 15.7, *SD* = 1.9; *t*(46) < 1.0). All participants were native speakers of American English, and all reported themselves to be in good health, with no known history of stroke, Parkinson's disease, or other neuropathology that might compromise the ability to carry out this research. Participants were healthy volunteers drawn from the university and local communities who took part in audiometric screening as enrollees in our laboratory participant pool. The participants described here were selected from this larger database on the basis of an audiometric matching process described below.

The 48 participants were divided into four equal groups based on two factors: age (younger, older) and hearing acuity (good hearing, poor hearing). This resulted in the formation of four groups of 12 participants: (i) *older good-hearing*, (ii) *older-poor hearing*, (iii) *younger good-hearing*, and (iv) *younger poor-hearing*. Participants were matched such that there was no significant difference in age between the older good-hearing and poor-hearing groups, $t(22) = 1.75$, *n.s.*, or between the younger good-hearing and poor-hearing groups, $t(22) = 1.07$, *n.s.* Analysis of variance (ANOVA) showed no significant differences among the 4 groups in level of education, $F(3,44) = 2.41$, *n.s.*, $MSE = 4.57$, or on Shipley vocabulary scores, $F(3,46) < 1.0$, $MSE = 3.16$.

**Audiometric Matching—**All participants were tested for pure-tone hearing acuity across the frequencies ranging from 250 – 8000 Hz. using standard audiometric procedures (Harrell, 2000). Following otoscopic examination, tympanometry was conducted on all participants to document middle-ear integrity and to rule out conductive hearing loss. The younger and older adults with poor hearing were well-matched across the primary speech frequency range: pure-tone average (PTA; 500, 1000, 2000, 4000 Hz) was 31.1 dB HL for the young poor-hearing group, and 31.7 dB HL for the older poor-hearing group ($t(22) < 1.0$, n.s.), with both groups showing similar audiometric profiles with a gradual decline in acuity at the higher frequencies. Although the ideal would be also to match the young and older good-hearing participants this closely, it is rare to find older adults whose auditory thresholds are as low as those of young adults (Morrell et al., 1996). PTAs for the young and older good-hearing groups were 5.9 dB HL and 14.7 dB HL, respectively, $t(22) = 6.04$, $p < .001$. Although different, both groups fell within the range that is typically considered to be clinically normal for speech (Hall & Mueller, 1997).

**Cognitive Matching—**In order to insure that there were no significant differences in cognitive ability between the good- and poor-hearing groups, we assessed: (1) Backward digit span (Wechsler, 1981) for working memory; (2) visually presented word-list recall for episodic memory; and (3) Trail Making Test Parts A and B for executive control (Lezak, 1995). A multivariate ANOVA with Age (2: younger, older) and Hearing group (2: good-hearing, poor-hearing) was performed on these data. As expected, there were significant main effects of age on all three tests: backward digit span ( $p < .01$), visually-presented word-list recall ($p < .001$), Trails A ($p < .001$), and Trails B ($p < .001$). Most important, however, the good-hearing and poor-hearing groups did not differ significantly on any of the three cognitive measures, nor were there any significant interactions between age and hearing. These findings thus give us confidence that experimental differences between the hearing acuity groups would not be due to differences in basic processes of memory or executive function.

**Speech Materials—**The stimuli were based on 24, 15-word lists drawn from words that share semantic associations (Russell and Jenkins, 1954). From these *related lists*, 24 additional *unrelated lists* were constructed by randomly reordering the words from the related sets. (In the experiment, each participant heard a word only once, in either a related or an unrelated list; lists were counterbalanced across participants.) All word-lists were recorded by a female speaker of American English at a rate of one word every 3 seconds onto computer sound files using SoundEdit 16 (Macromedia, San Francisco, CA) for the Macintosh computer (Apple, Cupertino, CA), which digitized (16-bit) at a sampling rate of 44,000 Hz.

## Procedure

**Intelligibility check—**Prior to the experiment participants performed an intelligibility check to insure that words would be presented at a sound intensity that would allow the words to be correctly identified. For this purpose participants heard a single 12-item list of unrelated words spoken at a rate of one word every 3 seconds by the same speaker and at the same sound intensity as would be used in the main experiment. The participant was asked to repeat each word aloud as it was heard. Mean repetition accuracy ranged from 99.2% to 100% across the four participant groups. This pretest insured that any differences across participant groups or conditions would not be due to an inability of participants to correctly identify stimulus words heard at the sound level used in the main experiment. As we shall develop, however, meeting this intelligibility criterion need not necessarily imply equivalence of perceptual effort by the good-hearing and poor-hearing listeners.

**Experimental conditions—**Each participant received the following 3 conditions.

**(1) Single-task tracking:** Participants received 2 baseline single-task visual tracking trials, one at the beginning and one at the end of the study, using a computerized pursuit tracking program (Willingham, Hollier, & Joseph, 1995). At the start of the tracking trial the target, a black circle approximately .84 cm in diameter appeared at the center of the computer screen at a distance of 65 cm from the participant. The participant initiated the tracking trial by a mouse-click at which point the target began to move around the computer screen in a random pattern. Participants were instructed to use the computer mouse to track the circle’s movement by attempting to keep the cursor within the target diameter. Pilot testing was used to determine target movement speeds that would yield an average of 50–60% on-target tracking accuracy for younger and older participants of similar ages to our test participants. This allowed both age groups to be placed on the same baseline level of tracking accuracy under single-task conditions.

Each tracking trial lasted 50 seconds, with tracking accuracy sampled at a rate of 5 times per second over the trial period; the first 5 seconds were considered as a warm-up. The remaining 230 samples were averaged to yield a measure of percent time-on-target, representing the percentage of the time that the cursor was anywhere inside of the circle. These trials lasted 50 seconds to correspond to the total tracking time in the to-be-described dual-task recall condition.

**(2) Single-task recall:** Participants performed 4 trials of single-task recall (i.e., recall without the concurrent tracking task), 2 trials at the beginning and 2 at the end of the study (half related and half unrelated lists). The word-lists were presented monaurally to the better ear at an intensity level of 70 dB HL through an Eartone 3A (E-A-R Auditory Systems, Aero Company, Indianapolis, IN) insert earphone coupled to a GSI 61 audiometer (Grason-Stadler, Inc., Madison, WI). Following the method of Anderson et al. (1998) to eliminate recency effects, word-list presentation and the request for recall were separated by a 30-second counting task in which participants were given a starting number and asked to count aloud by 3s. Following this interpolated counting period participants were asked to recall aloud as many words as possible from the just-heard list. Responses were audio recorded for later scoring. The order of related and unrelated word-lists was varied between participants.

**(3) Dual-task recall with tracking:** In this condition eight lists were presented for recall, four related lists and four unrelated lists. After each list was presented participants performed the 30-second interpolated counting task described above, then began tracking the target on the screen using the computer mouse. Five seconds into the tracking task participants were instructed to begin their recall. Forty-five seconds was allowed for recall, making the total duration for the tracking and recall portion of the dual-task condition 50 seconds, equivalent to the length of the trials in the single-task tracking trials.

## Results

### Memory Task Performance

The left side of Table 1 shows the percent words recalled from related and unrelated word-lists under single-task and dual-task conditions for the 4 groups of participants. These data were submitted to a 2 (Age: younger, older) X 2 (Hearing: good-hearing, poor-hearing) X 2 (Task: single-task, dual-task) X 2 (List type: related, unrelated) mixed-design ANOVA with task and list type as within-participants variables. As would be expected from extant literature (e.g., Naveh-Benjamin et al., 2005), there were main effects of age, task, and list type, reflecting better recall by the younger relative to the older adults, $F(1,44) = 53.84$, $p <.001$, $MSE= 402.11$, $\eta_p{}^2= .55$, better memory in single-task recall relative to recall while concurrently engaged in visual target tracking, $F(1,44) = 14.95$, $p <.001$, $MSE= 58.37$, $\eta_p{}^2= .254$, and better recall for related than unrelated word-lists, $F(1,44)= 62.94$, $p < .001$, $MSE= 68.04$, $\eta_p{}^2 = .589$. A significant Age X List type interaction also confirmed a differentially greater benefit of list relatedness for the older relative to the younger adults, F(1,44)= 5.10, $p <.05$, $MSE= 68.04$, $\eta_p{}^2= .104$. As found by Naveh-Bejamin et al. (2005), who also examined recall under dual-task tracking conditions, recall accuracy was not differentially impaired by concurrent tracking for the older relative to the younger adults; Age X Task; $F(1,44)< 1.0$, $MSE= 58.37$, $\eta_p{}^2=.010$. (None of the remaining interactions was significant.)

As we predicted (e.g., McCoy et al., 2005), there was a main effect of hearing acuity, reflecting lower recall accuracy for those with impaired hearing, $F(1,44) = 19.92$, p <.001, MSE= 402.11, $\eta_p{}^2=.312$. This detrimental effect of hearing acuity on recall accuracy confirms the effect of interest, with hearing loss affecting recall even with stimuli presented at an intensity level confirmed on pre-test to allow for near-perfect recognition for all 4 participant groups.

We also observed a significant Age X Hearing acuity interaction, $F(1,44) = 4.69$, $p <.05$, $MSE= 402.11$, $\eta_p{}^2=.096$, reflecting a differentially greater effect of hearing acuity on recall for the younger than for the older participants. We attribute this counter-intuitive effect to the previously noted greater disparity in hearing acuity between the good- and poor-hearing younger adults, as compared to the narrower range in acuity in the older group. The Hearing acuity X List type interaction was not significant, F(1,44)< 1.0, $MSE=68.00$, $\eta_p{}^2=.008$.

### Effects of Age and Hearing on Dual-task Tracking

The right side of Table 1 shows mean percent time on target for tracking alone (single-task), and as a dual-task in which participants engaged in visual target tracking while recalling related or unrelated word lists. These data were submitted to a 2 (Age: Younger, Older) X 2 (Hearing: Good-hearing, Poor-hearing) X 3 (Task: single-task, dual-task related lists, dual-task unrelated lists) ANOVA with task as a within-subjects variable. Overall, there was a main effect of age, F(1,44)= 8.01, p<. 01, $\eta_{\mathrm{p}}{}^2=.154$, but not of hearing, F(1,44)=2.81, $\eta_{\mathrm{p}}{}^2=.060$, nor an Age X Hearing interaction, F(1,44)<1.0, n.s., MSE=.390.49. As expected, a significant main effect of Task, F(2,88)= 58.85, p<.001, MSE= 16.82, $\eta_{\mathrm{p}}{}^2=.572$, reflected better tracking performance in the single-task condition than in the dual-task condition. Relatedness of the word lists had no effect on dual-task tracking performance, consistent with Naveh-Benjamin et al. (2005).

As will be recalled, the target speed on single-task tracking was adjusted for the younger and older groups to minimize age differences on this baseline condition, shown in Table 1. As expected, a significant Task X Age interaction, F(2,88)= 15.07, p<.001, $\eta_{\mathrm{p}}{}^2=.255$, reflected a differentially greater negative impact on tracking accuracy in the dual-task condition for the older group, in spite of the initial equivalence of the two age groups on single-task tracking. Most important for our hypothesis, however, was the appearance of a significant Task X Hearing interaction, F(2,88)= 6.25, p<.01, $\eta_p{}^2$=.124, moderated by a significant Task X Age X Hearing interaction, F(2,88)= 3.92, p<.05, MSE= 16.82, $\eta_p{}^2$=.082. That is, hearing acuity had a significant negative impact on tracking accuracy with the effect primarily attributed to the older poor hearing group.

This downstream effect of perceptual effortfulness attendant to hearing loss in the older adults, as revealed by target tracking in a non-auditory modality, is best illustrated in terms of “cost” scores, with cost calculated as the difference between single-task and dual-task tracking accuracy. Figure 1 shows this mean cost (collapsed across list type) for younger good-hearing and poor-hearing, and older good-hearing and poor-hearing participants. Two Bonferroni paired-comparisons tell the story. The first comparison shows that, for the younger adults shown in the two bars on the left, hearing acuity has only a small effect on downstream tracking cost that fails to reach significance (p> .05). It is the dramatic difference between good-hearing and poor-hearing older adults, shown in the two right bars, that clearly demonstrates the cost of hearing loss to older adults. The poor-hearing older adults, even though initially matched with their good-hearing peers in terms of cognitive abilities, showed significantly greater performance costs in carrying out tracking while they were recalling (p< .01).

## Discussion

Regardless of hearing acuity, the older participants in this study showed greater reductions in tracking accuracy during recall than the younger participants, consistent with arguments that retrieval is more effortful for older adults than for younger adults (Anderson et al., 1998; Naveh-Benjamin et al., 2005). This emphasis on effort in retrieval can be contrasted with dividing attention while listening to speech, which produces decrements in memory and in secondary task costs to an approximately equivalent degree for young and older adults (Anderson, 1999; Anderson, et al., 1998; Naveh-Benjamin et p.al., 2005; Whiting, 2003). Unpublished work in our laboratory has confirmed these findings, while also showing effects of hearing acuity on recall and tracking costs that were approximately equivalent for both younger and older adults.

The dissociation of effects of list-item relatedness on recall but not on tracking costs, was also found by Naveh-Benjamin et al. (2005) who examined age effects on paired-associate recall with dual-task tracking. Effects of inter-item relatedness on recall are typically interpreted as reflecting older adults’ use of preserved semantic knowledge to compensate for age declines in the efficacy of episodic memory (e.g., Kausler, 1994; Wingfield & Kahana, 2002). The finding that item relatedness has no effect on tracking costs and does not ameliorate effects of hearing loss on either recall or tracking accuracy is not in accord with a general resource argument. Such an argument might lead to the expectation that resources freed up from the memory task by relatedness of stimulus items would be available for performing the concurrent tracking task. It may be, however, that the inter-item binding occurring with associatively related items is an automatic process that neither draws nor releases general resources (Naveh-Benjamin et al., 2005).

What is clear from the present data is that the cost of dividing attention while recalling a just-heard word-list was significantly greater for older adults with poorer hearing than for young and older adults with better hearing. It is important to emphasize that this effect of hearing acuity on secondary tracking costs occurred with a presentation level that was confirmed in a pretest to allow correct identification of stimulus words by participants in all four groups, albeit with different degrees of perceptual effort leading to this success. To the extent that the recall differences and concurrent tracking costs were not a result of failure to correctly identify the stimulus words, these results suggest that the additional effort required for successful perception by older adults, even with the relatively milder sensory losses as represented here, significantly exacerbated age-related memory deficits. One sees in these data an echo of subjective reports by many older adults of mental fatigue associated with the constant perceptual and cognitive effort needed to maintain successful perception of speech input through the filter of reduced auditory acuity (Pichora-Fuller, 2003; Kramer, Kapteyn & Kuik, 1997).

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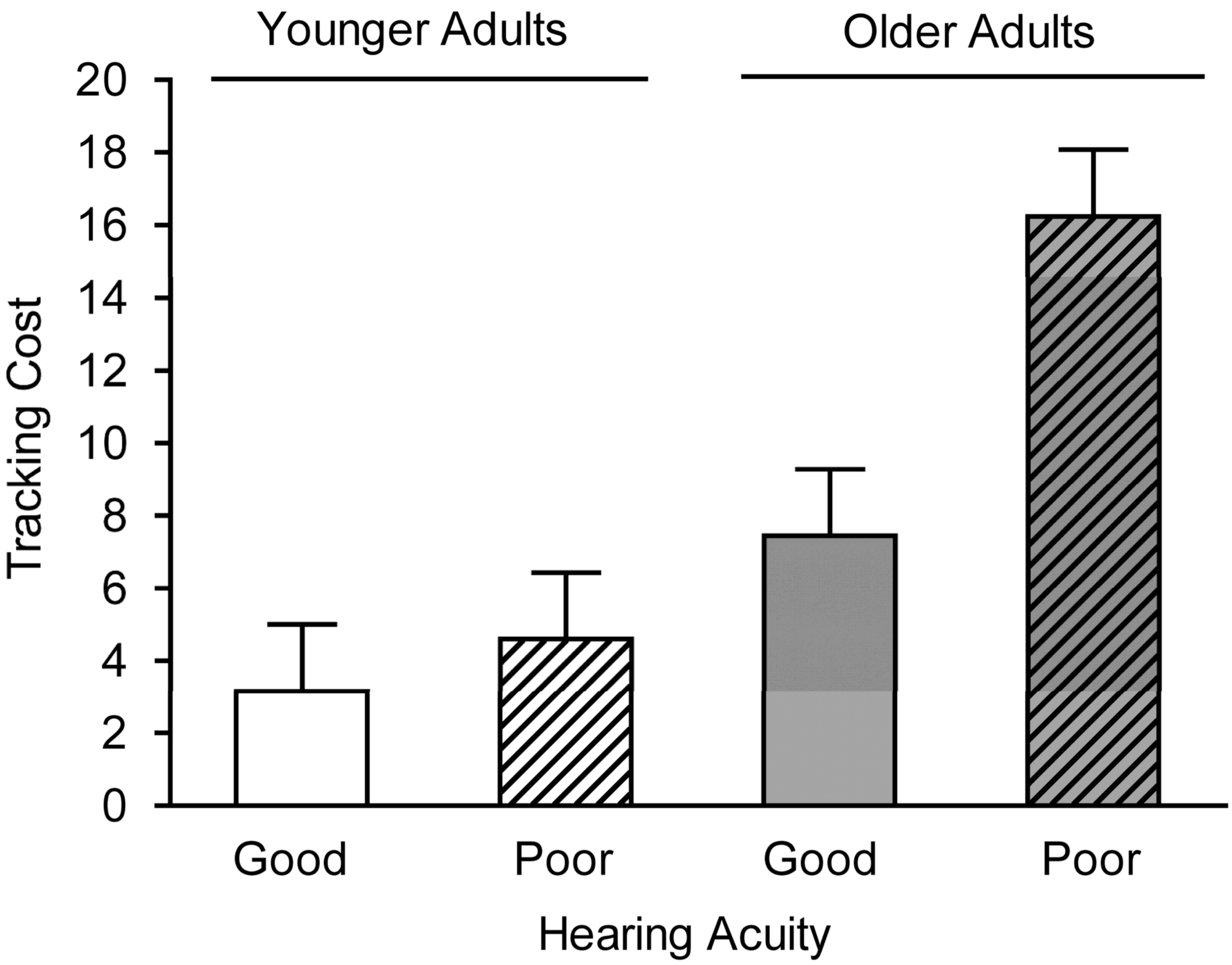

**Figure 1.**

Dual-task costs in secondary task tracking performance during word-list recall for four groups of participants (younger and older adults with good hearing and poor hearing), with cost calculated as [(Single-task percent time-on-target) - (dual-task percent time-on-target)]. (Error bars represent one standard error.)

## Table 1

Word-list recall and tracking accuracy

| | Recall accuracy (% words correct) | | | | Tracking accuracy (% time-on-target) | | |
|---|---|---|---|---|---|---|---|
| | **Single-task related lists** | **Single-task unrelated lists** | **Dual-task related lists** | **Dual-task unrelated lists** | **Single-task** | **Dual-task related lists** | **Dual-task unrelated lists** |
| Young good-hearing | 70.82 (13.19) | 68.13 (15.93) | 67.72 (12.12) | 62.06 (15.02) | 68.93 (7.70) | 66.49 (7.93) | 65.05 (8.52) |
| Young poor-hearing | 53.07 (13.70) | 45.41 (13.60) | 52.26 (11.50) | 41.25 (15.71) | 64.22 (7.41) | 59.19 (9.12) | 60.05 (9.90) |
| Older good-hearing | 49.50 (10.20) | 33.69 (8.02) | 43.13 (10.63) | 32.39 (16.31) | 62.33 (14.60) | 54.55 (15.18) | 55.21 (15.66) |
| Older poor-hearing | 42.41 (8.25) | 29.80 (9.43) | 34.63 (9.46) | 25.26 (5.46) | 62.80 (12.26) | 47.07 (15.50) | 46.05 (13.65) |

*Note*. The numbers in parentheses are standard deviations.