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Research Article

Relationship Between Domain-Specific Cognitive Function and Speech-in-Noise Performance in Older Adults: The Atherosclerosis Risk in Communities Hearing Pilot Study

Sara K. Mamo,[a] Nicholas S. Reed,[a,b] A. Richey Sharrett,[c] Marilyn S. Albert,[d] Josef Coresh,[a,e,f] Thomas H. Mosley,[g] David Knopman,[h] Frank R. Lin,[a,b,c] and Jennifer A. Deal[a,b,c]

Purpose: The purpose of this study was to investigate associations between performance on a clinical speech-in-noise measure with a comprehensive neurocognitive battery of tests.

Method: A group of older adults (N = 250, M_{age} = 77 years, age range: 67.3–89.1 years) enrolled in the Atherosclerosis Risk in Communities Neurocognitive Study took part in the hearing pilot study (2013) that included testing for audiometric thresholds and speech-in-noise performance (Quick Speech-in-Noise Test; Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). This research study analyzed the associations between domain-specific cognitive function and speech-in-noise performance after adjusting for hearing thresholds and other demographic and cardiovascular factors.

Results: Multivariable-adjusted associations were found between all cognitive domains and speech-in-noise performance in the full sample, but the observed associations varied when participants with varying levels of moderate to moderately severe hearing loss were excluded from the analysis.

Conclusions: The findings are discussed in terms considering the cognitive status of older adults in relation to their speech-in-noise performance during audiological evaluation and implications for aural rehabilitation.

Understanding speech-in-noise is fundamental to human communication. However, the ability to understand speech in the presence of background noise deteriorates with age due to both peripheral and central changes in auditory processing and cognitive decline (e.g., Baltes & Lindenberger, 1997; Committee on Hearing, Bioacoustics, and Biomechanics, 1988; Goossens, Vercammen, Wouters, & van Wieringen, 2017; Humes, 2013). Peripherally, age-related hearing loss, which affects two thirds of adults over the age of 70 years (Lin, Niparko, & Ferrucci, 2011), degrades precise encoding of the speech signal (e.g., Hao et al., 2018). Centrally, auditory processing requires the decoding and integration of peripheral input while complex cognitive processes disentangle and discern the target speech from the presence of other auditory distractors (e.g., Craik, 2007). The full contribution of cognitive processes in speech-in-noise performance is likely complex, with converging evidence from imaging and behavioral

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[a] Department of Otolaryngology–Head and Neck Surgery, Johns Hopkins School of Medicine, Baltimore, MD
[b] Johns Hopkins Cochlear Center for Hearing and Public Health, Baltimore, MD
[c] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD
[d] Department of Neurology, Johns Hopkins School of Medicine, Baltimore, MD
[e] George W. Comstock Center for Public Health Research and Prevention, Johns Hopkins Bloomberg School of Public Health, Hagerstown, MD
[f] Department of General Internal Medicine, Johns Hopkins School of Medicine, Baltimore, MD
[g] The MIND Center, University of Mississippi Medical Center, Jackson
[h] Department of Neurology, Mayo Clinic, Rochester, MN

Correspondence to Jennifer A. Deal: jdeal1@jhu.edu

Sara K. Mamo is now at the University of Massachusetts Amherst.
Sara K. Mamo and Nicholas S. Reed are co-first authors on this article.

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studies to suggest that various brain regions and cognitive processes are activated depending on the auditory task (for a review, see Peelle, 2018).

There is an extensive literature investigating the effects of aging on speech-in-noise performance (for a comprehensive review of the topic, see Humes & Dubno, 2010). Some of this literature aims to isolate auditory processing aspects of speech understanding, while others focus on the cognitive demands of the task. First among the multitude of auditory factors that contribute to speech-in-noise perception, reduced audibility among older adults is associated with declines in speech-in-noise performance (e.g., Humes & Roberts, 1990; Humes et al., 1994; van Rooij & Plomp, 1992). Moreover, with sensorineural hearing loss, there are changes in spectral resolution that contribute to difficulties with speech-in-noise perception (e.g., Smith, Pichora-Fuller, Wilson, & Macdonald, 2012). Furthermore, even in older adults with clinically normal or near-normal auditory thresholds, reduced temporal processing abilities are associated with declines in speech-in-noise performance (e.g., Dubno, Horwitz, & Ahlstrom, 2002; Füllgrabe, Sęk, & Moore, 2018; Gifford, Bacon, & Williams, 2007; Hopkins & Moore, 2011). Finally, the interactions between audibility and auditory processing changes for older adults cannot be easily disentangled from central auditory processing and cognitive changes associated with advancing age (e.g., Divenyi, Stark, & Haupt, 2005; Füllgrabe, Moore, & Stone, 2015; Humes et al., 2012; Schneider, Daneman, & Pichora-Fuller, 2002).

Above and beyond the associated auditory factors, cognitive changes likely contribute to age-related difficulties with speech-in-noise performance (e.g., Wingfield, 1996). Older adults show performance deficits on speech-in-noise tasks when the cognitive load for the task is manipulated. For example, in a dual-task interference paradigm, older adults (with and without age-related hearing loss) exhibit secondary task deficits, even when the presentation level for the auditory task allows for correct word identification in the single-task condition (Tun, McCoy, & Wingfield, 2009). Furthermore, evidence from the literature on speech-on-speech masking demonstrates that older adults are more distracted by speech maskers with meaningful semantic content compared to younger adults, suggesting reduced cognitive processing abilities necessary for selectively attending to a target message (Helfer, Chevalier, & Freyman, 2010; Rossi-Katz & Arehart, 2009; Tun, O'Kane, & Wingfield, 2002).

Previous literature directly investigating the relationship between speech-in-noise understanding and cognitive performance has often used single measures of cognitive function, which may contribute to overly simplistic conclusions and measurement error (Akeroyd, 2008; Dryden, Allen, Henshaw, & Heinrich, 2017). For example, a relatively consistent finding in the speech-in-noise and aging literature points to associations with working memory abilities (for reviews, see Akeroyd, 2008; Dryden et al., 2017). However, within the working memory literature, it is unclear whether older adults have poor working memory skills or whether poor perceptual sensitivity induces excessive demands on the working memory resources of older adults (e.g., Füllgrabe & Rosen, 2016; Gordon-Salant & Cole, 2016; Pichora-Fuller, Schneider, & Daneman, 1995). Additionally, as highlighted by a recent systematic review and meta-analysis, many studies do not control for important potential confounders (e.g., age), are limited by small sample size, and investigate a limited number of cognitive domains (Dryden et al., 2017).

The current population-based investigation examined a relatively large sample (N = 250) of older adults in a cross-sectional study of associations between four specific cognitive domains, as measured with a comprehensive neurocognitive battery, and speech-in-noise performance. Based on evidence that older adults show broad activation networks during speech-in-noise tasks (Peelle, Troiani, Wingfield, & Grossman, 2010), we hypothesized that all cognitive domains are associated with speech-in-noise performance after adjusting for audibility, age, and other demographic and cardiovascular risk factors. The rationale for this hypothesis is based on the broad and complex cognitive processes that contribute to the understanding of speech in noisy backgrounds.

Method

Study Population

The Atherosclerosis Risk in Communities (ARIC) Study is a population-based prospective cohort study of 15,792 men and women aged 45–64 years recruited in 1987–1989 from four U.S. communities (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; and Minneapolis, Minnesota). In 2011–2013, ARIC participants returned for a fifth visit as part of the ARIC Neurocognitive Study. At that time, the Washington County site invited 307 participants to complete hearing testing as a pilot investigation. Six declined, and 46 did not complete the examination (primarily due to impacted cerumen). Two non-White participants were excluded, as were three who were missing complete cognitive data, resulting in an analytic sample of 250. Compared to all 2011–2013 ARIC Neurocognitive Study participants, participants in our hearing pilot study tended to be older and to have fewer years of education (Deal et al., 2015).

Hearing Thresholds and Speech Perception Assessment

Pure-tone hearing thresholds and speech-in-noise performance were measured in a sound-attenuated booth by a trained technician. All testing was completed using insert earphones (EARTone 3A, 3M) and an Interacoustics AD629 audiometer (Interacoustics A/S). Hearing thresholds were measured at octave frequencies between 0.5 and 8 kHz; a speech frequency pure-tone average (PTA) was calculated by taking the average across four octave frequencies: 0.5, 1, 2, and 4 kHz. The PTA from the better hearing ear was modeled both as a continuous variable and categorized into clinically defined cut-points (normal hearing: ≤ 25 dB HL, mild loss: 26–40 dB HL, moderate/severe loss: > 40 dB HL).

Speech-in-noise performance was assessed using the Quick Speech-in-Noise Test (QuickSIN), which presents sentences in the presence of multitalker babble (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). While no speech-in-noise performance test has been evaluated in population-based/nationally representative studies, in clinical trials, the QuickSIN has been shown to be sensitive to speech-in-noise difficulty and has been recommended for speech-in-noise assessment (Wilson, McArdle, & Smith, 2007). The listener was asked to repeat aloud what they heard and was instructed to guess if uncertain. A score of 0–5 was assigned per sentence based on correct identification of five target words. Each list contains six sentences that were presented at successively more difficult signal-to-noise ratios (SNRs) ranging from +25 to 0 dB SNR in 5-dB decrements. The sentences were presented binaurally via insert earphones with a fixed presentation level for the speech (70 dB HL) and incremental increases in noise level for each SNR condition. Each sentence was syntactically correct with limited semantic meaning or contextual clues. The score at the end of each list was a calculation of the necessary SNR for the person to get 50% of the target words correct and was reported as "SNR loss" against the expected SNR necessary for someone with audiometrically normal hearing.

In this study protocol, listeners heard one practice list and then two test lists. SNR loss was recorded as the average score from the two test lists. In the primary analysis, SNR loss was modeled continuously. In secondary analyses, SNR was modeled categorically according to manufacturer-defined cut-points (no loss: 0–3 dB, mild SNR loss: 4–7 dB, moderate SNR loss: 8–15 dB, severe SNR loss: ≥ 16 dB). Due to of the small number of participants with severe SNR loss (n = 28), the moderate and severe categories were combined.

Cognitive Outcomes

A comprehensive neurocognitive battery was administered during the fifth ARIC clinic visit (2011–2013). Multiple standardized tests from several domains were administered (see Table 1 for individual tests). In order to facilitate effect estimate comparisons across cognitive domains, domain-specific z scores were calculated for the domains of memory, language, and speed of processing/executive function based on a priori cognitive test categorization and previous work in this cohort (Deal et al., 2015; see Table 1). A global composite score was created by averaging the three domain-specific scores. The global composite score and all domain-specific scores were scaled so that a one-unit change is equivalent to 1 *SD* of that score.

Other Independent Variables

Demographic information was collected in 1987–1989, including age (years), sex, and education (highest grade or year of school completed). For analysis, education was defined as less than high school versus greater than or equal to high school. Smoking status was self-reported and coded as "ever" or "never" for analysis. Hypertension was considered present if diastolic blood pressure was ≥ 90 mm Hg, systolic blood pressure was ≥ 140 mm Hg, or the participant took antihypertensive medication. Diabetes was defined as fasting blood glucose level of ≥ 126 mg/dl, nonfasting blood glucose level of ≥ 200 mg/dl, self-reported physician's diagnosis of diabetes, or use of medication for diabetes. Depressive symptoms were measured using the Center for Epidemiological Studies Depression Scale (Kohout, Berkman, Evans, & Cornoni-Huntley, 1993), and premorbid intelligence was measured using the Wide Range Achievement Test (WRAT; Wilkinson, 1993). Both the Center for Epidemiological Studies Depression and the WRAT were modeled as continuous variables. Sex and education were measured at the ARIC study baseline (1987–1989), and all other covariates were measured at the time of audiometric testing.

Statistical Analysis

Distributions of demographic and disease covariates and cognitive test performance were compared across SNR loss categories using Kruskal–Wallis (continuous variables) and chi-square (categorical variables) tests. In order to assess which cognitive domains may be associated with central auditory processing, we used multivariable linear regression to model the relationship between domain-specific cognitive performance and central auditory processing as measured by speech-in-noise performance. Each of three specific cognitive domains (memory, language, and processing speech/executive function) and a global composite score were regressed on speech-in-noise performance in independent models. In secondary analyses, multivariable-adjusted ordinal logistic regression was used to model the association between domain-specific cognitive performance and QuickSIN SNR loss categories. The use of standardized domain-specific z scores and independent models for each domain addresses the primary research question by allowing for the direct comparison of effect estimates across models without concern that correlation between cognitive domain scores may statistically influence results if all domains were included in the same model. Pearson correlation coefficients among the cognitive scores ranged from .55 to .58 between the specific cognitive domains and from .77 to .90 between specific domains and the global composite score (note that the global score was constructed from the scores of the independent domains, so the correlation is understandably high).

Models were adjusted for hearing thresholds (PTA), demographic, and disease covariates. Model 1 adjusted for hearing thresholds (PTA). Model 2 added the demographic factors of age, sex, and education. Finally, Model 3 also adjusted for cardiovascular risk factors, as well as depressive symptoms and premorbid intelligence (WRAT). Hearing thresholds and age were both modeled using linear and

Table 1. Descriptive characteristics of study participants and distributional characteristics of raw cognitive tests scores by speech-in-noise performance category, Atherosclerosis Risk in Communities Neurocognitive Study (*N* = 250), 2013.

	Total cohort	**Speech-in-noise performance (QuickSIN) category**		
	(*N* = 250)	**No SNR loss (*n* = 77)**	**Mild SNR loss (*n* = 86)**	**Moderate or worse SNR loss (*n* = 87)**
Characteristic	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
Age, years***	77.3 (5.4)	74.7 (4.3)	76.9 (5.0)	80.1 (5.4)
Hearing level (PTA dB HL)***	35.0 (15.0)	22.6 (9.2)	33.6 (8.9)	47.4 (14.1)
Wide Range Achievement Test***	45.5 (6.1)	47.5 (6.1)	45.2 (5.8)	43.9 (5.8)
Depression	3.4 (3.0)	3.2 (2.9)	3.5 (3.1)	3.5 (2.9)
	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
High school education or less	147 (59)	38 (49)	58 (67)	51 (59)
Male sex***	97 (39)	19 (25)	29 (34)	49 (56)
Ever smoker	119 (48)	39 (51)	39 (45)	41 (47)
Diabetes	86 (34)	25 (32)	24 (28)	37 (43)
Hypertension	181 (72)	54 (70)	62 (72)	65 (75)
Depression (above median score)	102 (41)	27 (35)	34 (40)	41 (47)
Hearing category***				
Normal hearing	72 (29)	52 (68)	15 (17)	5 (6)
Mild loss	95 (38)	24 (31)	52 (60)	19 (22)
Moderate loss or worse	83 (33)	1 (1)	19 (22)	63 (72)
Hearing aid use	52 (21)	3 (4)	12 (14)	21 (36)
Duration of hearing aid use	4 (2, 10)	3 (1, 7)	3 (1.5, 6)	4 (2, 7)

Note. Hearing loss categories defined as normal (PTA ≤ 25 dB HL), mild loss (PTA > 25–40 dB HL), and moderate loss or worse (PTA ≥ 40 dB HL). Hearing aid use was based on a yes/no question. Duration of hearing aid use reported in median years (interquartile range). QuickSIN = Quick Speech-in-Noise Test; SNR = signal-to-noise ratio; PTA = pure-tone average.

***$p < .001$.

quadratic splines to account for nonlinear associations with SNR performance.

Out of concern that QuickSIN performance in participants with a high degree of hearing loss could be driven by peripheral auditory impairment, two sensitivity analyses were conducted. First, models were rerun excluding all participants with a difference in PTA between ears of > 15 dB ($n = 20$) out of concern that these participants might perform worse than expected on the QuickSIN due to reliance on only the better hearing ear rather than binaural hearing. Second, models were rerun excluding participants with a better ear PTA of > 40 dB HL ($n = 83$), > 50 dB HL ($n = 41$), > 55 dB HL ($n = 21$), and > 60 dB HL ($n = 16$) in order to ensure audibility of the sentences and to investigate robustness of findings to varying assumptions of the impact of peripheral hearing on the modeled association.

Results

Of 250 participants, 77 (30%) had no SNR loss, 87 (34%) had mild SNR loss, and 89 (35%) had moderate or greater SNR loss (see Table 1). Mean age at the time of hearing assessment was 77.4 years (*SD* = 5.4), and mean PTA in the better hearing ear was 35.2 dB HL (*SD* = 15.2), consistent with a mild hearing loss. On average, participants with more SNR loss (i.e., poorer performance) tended to be older (80.1 years), male (56%), have poorer scores on the WRAT, and have poorer hearing thresholds (better hearing ear PTA = 47.8 dB HL, consistent with a moderate hearing loss). In addition, unadjusted analyses suggested distributions that all cognitive tests differed by SNR loss category, except for Digit Span Backward Test (Wechsler, 1981) and Trail Making Test Part A (Spreen & Strauss, 1991; see Table 2).

In multivariable-adjusted analyses, SNR loss score was significantly associated with each of the cognitive domains in all three models (see Table 3). After adjusting for PTA and other demographic and disease factors, each 1-dB increase in SNR loss (i.e., worse performance) was associated with a significantly lower *z* score for all cognitive domains and the global composite factor: memory, $\beta = -0.80$, 95% CI [−1.35, −0.24]; language, $\beta = -0.92$, 95% CI [−1.49, −0.34]; processing speed/executive function, $\beta = -0.65$, 95% CI [−1.20, −0.09]; and global composite score, $\beta = -1.11$, 95% CI [−1.72, −0.50] (see Table 3). Inferences were unchanged in the secondary analyses of QuickSIN categories and in the first sensitivity analysis that excluded asymmetrical hearing loss (data not shown).

However, in a second sensitivity analysis that excluded participants with moderate to moderately severe PTA, the number of significant associations was reduced, and these associations varied by the PTA cut-point used for exclusion. No significant associations were observed when the analysis excluded all participants with a moderate or greater hearing loss (> 40 dB HL). When excluding participants with a PTA of > 50 dB HL, only memory and the

Table 2. Distributional characteristics of raw cognitive tests scores by speech-in-noise performance category, Atherosclerosis Risk in Communities Neurocognitive Study (N = 250), 2013.

Cognitive domain and individual tests	Total cohort (N = 250)	Speech-in-noise performance (QuickSIN) category: No SNR loss (n = 77)	Mild SNR loss (n = 86)	Moderate or worse SNR loss (n = 87)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Memory				
Delayed Word Recall Test[a]***	5.6 (1.7)	6.2 (1.5)	5.7 (1.6)	4.9 (1.6)
Incidental learning***	3.7 (2.4)	4.8 (2.6)	3.3 (2.3)	3.3 (2.1)
Logical memory[b]***	20.3 (7.0)	23.3 (6.4)	18.8 (7.0)	19.2 (6.6.)
Language				
Word Fluency[a]**	33.5 (11.2)	37.2 (10.8)	32.3 (11.1)	31.4 (11.0)
Animal Naming Test**	16.7 (4.4)	18.2 (4.3)	16.5 (4.1)	15.5 (4.3)
Boston Naming Test[c]**	26.6 (3.3)	27.7 (2.0)	26.2 (3.2)	25.9 (4.1)
Processing speed/executive function				
Digit Symbol Substitution Test***	40.3 (9.8)	45.1 (9.0)	39.8 (9.3)	36.7 (9.3)
Digit Span Backward Test[b]	5.8 (1.7)	6.2 (1.9)	5.7 (1.5)	5.5 (1.7)
Trail Making Test Part A[a]	35.2 (12.7)	33.8 (10.0)	36.1 (13.1)	35.4 (14.3)
Trail Making Test Part B[d]**	117.4 (52.7)	102.1 (47.1)	118.3 (49.9)	131.1 (57.1)

Note. There are missing data on some of the individual cognitive tests; all missing data were from the moderate or worse signal-to-noise ratio (SNR) loss group unless otherwise stated. QuickSIN = Quick Speech-in-Noise Test.

[a] Delayed Word Recall, Word Fluency, and Trail Making Test Part A measured in N = 249 participants. [b] Logical Memory and Digit Span Backward Test measured in N = 247 participants. [c] Boston Naming Test measured in N = 248 participants. [d] Trail Making Test Part B measures in N = 235 participants (one missing from no SNR loss and seven missing from mild SNR loss group).

**p < .01. ***p < .001.

global composite score were significantly associated with speech-in-noise performance after full adjustment (β = −0.67 and β = −0.79, respectively). A significant association for language was recovered when the cut-point for exclusion was moved to > 55 dB HL (β = −0.74), but a relationship for processing speed/executive function was not recovered, even at a threshold for exclusion of > 60 dB HL (see Table 4).

Discussion

In this pilot study of 250 older adults from Washington County, Maryland (M_{age} = 78 years), we found that poorer cognitive performance in the domains of memory, language, executive functioning, and global function was associated with poorer speech-in-noise performance, independent of peripheral audiometric hearing thresholds and demographic and disease factors. However, the domain-specific relationships with poorer speech-in-noise performance were attenuated, and many not statistically significant, when participants with moderate or greater hearing loss were excluded from the analysis.

Previous studies that have looked at the relationship between speech-in-noise and domain-specific cognitive function have generally found mixed and inconsistent associations with measures of IQ, processing speed, inhibitory control, memory, and working memory (Akeroyd, 2008).

Table 3. Regression analysis of cognitive domains on central auditory processing as measured by speech-in-noise performance (Quick Speech-in-Noise Test), Atherosclerosis Risk in Communities Neurocognitive Study (N = 250), 2013.

	Model 1				Model 2				Model 3			
Cognitive domain	β	95% CI	p	R^2	β	95% CI	p	R^2	β	95% CI	p	R^2
Memory	−1.32	[−1.82, −0.81]	< .001	.63	−1.10	[−1.62, −0.59]	< .0001	.65	−0.80	[−1.35, −0.24]	.014	.67
Language	−1.30	[−1.81, −0.80]	< .001	.62	−1.26	[−1.77, −0.75]	< .0001	.65	−0.92	[−1.49, −0.34]	.006	.67
Processing speed/ executive function	−1.18	[−1.65, −0.70]	< .001	.62	−0.95	[−1.46, −0.45]	.014	.65	−0.65	[−1.20, −0.09]	.021	.66
Global composite score	−1.51	[−2.00, −1.01]	< .001	.64	−1.39	[−1.90, −0.88]	< .001	.67	−1.11	[−1.72, −0.50]	.003	.68

Note. Results for each domain and for the global composite score come from separate models. Model 1 adjusts for hearing thresholds as defined by a pure-tone average calculated as the average thresholds across four octave frequencies important for hearing speech (0.5–4 kHz) and entered into the model as a continuous variable. Model 2 adjusts for hearing thresholds and demographic factors, which includes the continuous variable of age and the categorical variables of education (high school degree or less) and sex. Model 3 adjusts for hearing thresholds, demographics, and potential risk factors, such as cardiovascular risk factors including ”ever smoker,” diabetes, and hypertension as well as depression (measured with the Center for Epidemiological Studies Depression Scale; all categorical) and premorbid intelligence (continuous; measured with the Wide Range Achievement Test).

Table 4. Sensitivity analysis of the association between cognitive domain performance and speech-in-noise performance (Quick Speech-in-Noise Test) excluding participants with pure-tone averages above varying cut-points, Atherosclerosis Risk in Communities Neurocognitive Study (*N* = 250), 2013.

	PTA > 40 db HL (excluded) (*N* = 167)			**PTA > 50 db HL (excluded) (*N* = 209)**			**PTA > 55 db HL (*N* = 229)**			**PTA > 60 db HL (*N* = 234)**		
Cognitive domain	**β**	**95% CI**	**R^2**	**β**	**95% CI**	**R^2**	**β**	**95% CI**	**R^2**	**β**	**95% CI**	**R^2**
Memory	–0.51	[–1.09, 0.07]	.26	**–0.67**	**[–1.25, –0.09]**	.39	**–0.63**	**[–1.20, –0.06]**	.50	**–0.65**	**[–1.21, –0.08]**	.57
Language	–0.36	[–0.96, 0.24]	.26	–0.57	[–1.17, 0.04]	.38	**–0.74**	**[–1.34, –0.14]**	.51	**–0.84**	**[–1.42, –0.26]**	.58
Processing speed/ executive function	–0.25	[–0.82, 0.32]	.25	–0.35	[–0.92, 0.22]	.38	–0.50	[–1.06, 0.06]	.50	–0.52	[–1.07, 0.04]	.57
Global composite score	–0.51	[–1.15, 0.12]	.26	**–0.79**	**[–1.42, –0.16]**	.39	**–0.92**	**[–1.55, –0.28]**	.50	**–0.99**	**[–1.60, –0.37]**	.58

Note. Adjusted for hearing thresholds as defined by a pure-tone average (PTA) calculated as the average thresholds across four octave frequencies important for hearing speech (0.5–4 kHz) and entered into the model as a continuous variable; demographic factors, including age (continuous), education (high school degree or less), and sex; and potential risk factors, including ever smoking, diabetes, hypertension, depression (measured with the Center for Epidemiological Studies Depression Scale; all categorical), and premorbid intelligence (continuous; measured with the Wide Range Achievement Test).

For example, Humes (2002) found, using principal component analysis, that after hearing loss (standardized coefficient = 0.73) the next two cognitive factors taken from the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981) that were most predictive were verbal IQ and nonverbal IQ (standardized coefficients = 0.27 and 0.23, respectively). On the other hand, a meta-analysis by Dryden et al. (2017) found significant associations in pooled analyses for processing speed, inhibitory control, working memory, and episodic memory, but no relationship for crystallized IQ. Our findings contribute to the literature because, (a) in comparison, this is a large community-based sample of older adults with varying degrees of hearing thresholds, (b) we utilized a comprehensive neurocognitive battery to define domain-specific cognitive performance, and (c) our regression models (as compared to simple correlations, which are more commonly found in this literature) adjust for age, sex, education, depression, premorbid intelligence, and cardiovascular risk factors. Much like the meta-analysis by Dryden and colleagues, the current study found associations between speech-in-noise performance and multiple cognitive domains.

In a sensitivity analysis that excluded participants with a better ear PTA of > 40 dB HL, no cognitive domain was significantly associated with speech-in-noise performance. As participants with more severe hearing loss were increasingly added back into the model, memory was the only cognitive domain consistently associated with speech-in-noise performance. The language domain association was significant when participants with a PTA of > 50 dB HL were included. One potential explanation for this finding is that hearing loss continues to confound the relationship between cognitive function and speech-in-noise performance, even after adjusting for PTA in the model. However, it is also noteworthy that the confidence intervals are wide (related to decreased sample size), and so inference is limited as to whether the effect estimates from the different models truly differ from each other. When Dryden et al. (2017) separated studies that included normal to mild hearing loss and studies that included normal to moderate hearing loss participants, they found consistent associations between speech-in-noise performance and cognition collapsed across all cognitive tests. As such, their evidence does not seem to suggest that particular cognitive domains are differentially impacted by the degree of hearing loss.

On the other hand, based on the results presented here, one might surmise that if mild peripheral hearing loss is not causing audibility problems in the speech task, then the cognitive domains of language and processing speed are less important for speech understanding. The Ease of Language Understanding model suggests that degrading the acoustic signal (e.g., by presenting speech in the presence of noise) causes phonological mismatches as it relates to our long-term memory for the automatic processing of speech (Rönnberg et al., 2011). Perhaps the reliance on episodic long-term memory as proposed by the Ease of Language Understanding model explains why memory emerged as the cognitive domain that was most associated with speech-in-noise performance when issues of audibility were minimized.

Generalizability of these results may be limited due to the single-center, all-White study cohort. Nevertheless, the current sample is larger than other studies that have considered the associations of cognition with speech-in-noise performance, and unlike prior studies, which are primarily clinical or convenience samples (Akeroyd, 2008), ARIC is a community-based random sample. In addition, the adjustment for hearing thresholds was based on a four-frequency PTA in the better hearing ear, but the speech material was presented binaurally. To address this, a sensitivity analysis was performed that excluded all participants with a difference in PTA of > 15 dB, and there was no difference in the pattern of the results.

These findings may have important implications for auditory rehabilitation and clinical practice. Previous rehabilitation research has focused on auditory perceptual training of individual speech sounds, word-based training, and specific cognitive-based tasks related to working memory skills (Ferguson & Henshaw, 2015; Humes, Kinney, Brown, Kiener, & Quigley, 2014). However, the significant association across all cognitive domains to speech-in-noise performance in this cohort could possibly suggest that auditory rehabilitation may benefit from enhancing not only perceptual acuity and executive function but also language and memory domains. Given mixed results regarding generalization of auditory training to everyday listening situations (Ferguson & Henshaw, 2015), perhaps a more global cognitive training approach would be beneficial based on the broad contribution of all cognitive domains to speech-in-noise performance in this cohort.

Clinically, there have been recent calls for audiologists to screen for cognitive decline during the hearing appointment (Shen, Anderson, Arehart, & Souza, 2016). Much of this discussion is motivated by research demonstrating hearing loss as a risk factor for cognitive decline and the nature of serving older adult populations. In the context of speech understanding, screening for cognitive decline may also be beneficial. Importantly, the sensitivity results of this study suggest that cognitive domains are not significantly associated with speech-in-noise understanding when more severe hearing loss is excluded. In other words, it is possible that persons with greater degrees of hearing loss will be more impacted by their cognitive processing abilities when it comes to understanding speech in noisy environments. More research is needed, but one might consider a clinical model whereby higher degrees of hearing loss trigger an in-office cognitive screening by appropriately trained audiologists in order to (a) assess target areas for auditory rehabilitation to improve speech-in-noise understanding or (b) to help expectation management with speech understanding when using hearing aids.

In conclusion, this study documented an independent association between poorer cognitive performance in the domains of memory, language, executive function, and global cognitive function and poorer speech-in-noise performance in 250 community-dwelling older adults with an average age of 77 years. These findings could have implications for auditory rehabilitation. Although not assessed as part of this study, given the broad network of cognitive processing required for speech understanding in noisy backgrounds, auditory rehabilitation plans that emphasize training across a range of cognitive domains could potentially be more successful in supporting communication among adults with age-related hearing loss. Future studies of auditory rehabilitation should address these possible clinical implications.

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