



Association between Frontal-Executive Dysfunction and Speech-in-Noise Perception Deficits in Mild Cognitive Impairment

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Background and Purpose Speech-in-noise perception deficits have been demonstrated in patients with mild cognitive impairment (MCI). However, it remains unclear whether the impairment of speech perception varies between MCI subtypes. The purpose of this study was twofold: 1) to compare speech perception performance among MCI subgroups, and 2) to identify the cognitive domains specifically related to speech-in-noise perception.

Methods We studied 46 patients with MCI and 39 hearing-threshold-matched cognitively normal elderly (CNE) subjects. Two different patient classifications were used: 1) patients with amnesic mild cognitive impairment (aMCI) ($n=21$) or nonamnesic mild cognitive impairment (naMCI) ($n=25$), and 2) patients with frontal-executive dysfunction (FED) ($n=16$) or without FED ($n=30$). All of the subjects underwent audiometric, neuropsychological, and speech perception assessments. Speech-in-noise perception was measured using sentence recognition tests in the presence of two types of background noise at four levels.

Results First, as the level of background noise increased, the MCI with FED group scored lower than both the MCI without FED and CNE groups under both types of noise. Second, both the naMCI and aMCI groups scored lower than the CNE group, but there were no differences between the naMCI and aMCI groups in sentence recognition under any noise conditions. Third, significant correlations were found between sentence recognition and executive function scores both in the MCI groups and in the CNE group.

Conclusions Our findings suggest that frontal-executive function is strongly related to speech-in-noise perception and that MCI patients with FED have greater deficits in speech-in-noise perception compared to other subgroups of MCI.

Key Words mild cognitive impairment, frontal-executive dysfunction, speech-in-noise perception, central auditory processing.

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INTRODUCTION

Age-related hearing impairment is the most-prevalent form of sensory loss and is a major cause of chronic disability in older age.^{1,2} Impairments in the peripheral hearing and central auditory processing (CAP) can contribute to age-related hearing impairment.¹ CAP dysfunction is typically characterized by difficulty in perceiving and understanding speech in noisy situations.^{1,3} Several longitudinal studies have suggested that CAP dysfunction could be the main factor contributing to an increased risk of cognitive decline and incident dementia.⁴⁻⁶ Specifically, the presence of CAP dysfunction was associated with a 10-fold higher risk of developing Alzheimer's disease (AD).⁴ These findings also suggest that CAP dysfunction could be an early marker of cognitive disorders such as mild cognitive impairment (MCI) and AD.

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Speech perception is commonly measured using word and/or sentence recognition tests. In the presence of background noise, listeners are required to recall words and/or entire sentences or keywords in sentences as they have heard them. Speech-in-noise perception tests can utilize different types of background noise and different signal-to-noise ratios (SNRs). The SNR is defined as the ratio of the intensity of the target signal to that of the background noise, and it is not surprising that speech perception becomes more challenging as the SNR decreases. Regarding the type of background noise, speech perception is cognitively more demanding when it is masked by interfering speech than meaningless noise.⁷

The findings of the few previous studies that have investigated the association between speech-in-noise perception and MCI or probable AD suggest that speech-in-noise perception deficits exist in patients with MCI.¹ A recent study explored the speech perception performance for different types of background noise in patients with MCI.⁸ That study found that patients with MCI required an SNR that was 3 dB higher than that for age-matched normal controls to reach scores of 50% on sentence recognition tests in the presence of informative maskers. In our previous study,⁹ the patients with amnesic mild cognitive impairment (aMCI) scored significantly lower than both the older adults and the younger adults only when the noise level was high (SNR=-5 dB) in the sentence recognition test. However, because (to the best of our knowledge) no previous studies have focused on speech-in-noise perception according to MCI subtypes, it remains unclear whether speech perception is affected by differences in the impaired cognitive domains.

In the present study we aimed to compare speech perception performance measured in a sentence recognition test among MCI subgroups and cognitively normal elderly (CNE) subjects in two types of background noise conditions (speech-spectrum noise and multitalker-babble noise) at four SNRs (+5, 0, -2, and -5 dB). We also aimed to identify the cognitive domains that are specifically related to speech-in-noise perception in each study group.

METHODS

Participants

We recruited 46 patients with MCI (aged 55 to 80 years) from the Memory and Dementia Clinic at Dong-A University Medical Center (Busan, Korea). A diagnosis of MCI was made according to Petersen's criteria.¹⁰ Two different patient classifications were used in the present study: 1) based on the conventional clinical classification of MCI,¹⁰ MCI patients were classified into aMCI or nonamnesic mild cognitive impairment (naMCI), and 2) given that previous studies have

demonstrated that frontal-executive function affects speech-in-noise perception, the patients were also classified according to whether or not they had frontal-executive dysfunction (FED). Application of the first classification identified 25 patients with naMCI (2 men and 23 women) and 21 with aMCI (10 men and 11 women). For the second classification, patients with FED had to meet the following criteria: 1) age- and education-adjusted scores below -1.0 SD in the animal-naming or phonemic-letter-naming tests of the Controlled Oral Word Association Test (COWAT),¹¹ and 2) age- and education-adjusted scores below -1.0 SD in the color-reading part of the Stroop test.¹² Applying these criteria identified 16 patients with FED (6 men and 10 women) and 30 without FED (6 men and 24 women). The characteristics of the 46 MCI patients are provided in Table 1.

For a control group we recruited 39 cognitively normal older adults (14 men and 25 women) who met the following criteria: 1) no significant underlying medical, neurological, or psychiatric illness; 2) normal performance as defined by age- and education-adjusted scores above -1.0 SD in the Korean version of the Mini Mental State Examination (K-MMSE),¹³ digit span (forward and backward),¹⁴ Seoul Verbal Learning Test (SVLT) (immediate and delayed recall),¹⁵ and COWAT (animal naming and three-phonemic-letter naming); and 3) no subjective memory complaints.

All of the subjects had to meet the following inclusion criteria for hearing acuity: 1) no conductive components in tympanometry and pure-tone audiometry; 2) hearing threshold levels of ≤ 25 dB HL at 0.5, 1, and 2 kHz, ≤ 40 dB HL at 4 kHz, and ≤ 70 dB HL at 8 kHz in each ear; 3) interaural asymmetry in the pure-tone average (PTA) (average at 0.5, 1, 2, and 4 kHz) of no greater than 10 dB HL; 4) speech discrimination score of $\geq 80\%$ for each ear; and 5) no previous or current use of hearing aids. Demographic data and audiometric test results for each group are presented in Table 2.

Table 1. Numbers of patients with MCI in the different subgroups

	MCI subgroups			
	Classification 1	n (%)	Classification 2	n (%)
aMCI		21 (46)	MCI with FED	16 (35)
Single domain		1 (5)		
Multiple domains without FED		11 (52)		
Multiple domains with FED		9 (43)		
naMCI		25 (54)	MCI without FED	30 (65)
Multiple domains without FED		18 (72)		
Multiple domains with FED		7 (28)		
Total		46 (100)	Total	46 (100)

Data are n (%) values.

aMCI: amnesic mild cognitive impairment, FED: frontal-executive dysfunction, MCI: mild cognitive impairment, naMCI: nonamnesic mild cognitive impairment.

Table 2. Demographic data and audiometric test results for each group

	Classification 1		Classification 2		CNE (n=39)	p [†]	p [§]
	naMCI (n=25)	aMCI (n=21)	MCI with FED (n=16)	MCI without FED (n=30)			
Demographics							
Age, years	67.36±6.38	68.47±6.23	66.56±6.12	68.56±6.34	63.92±4.84	0.007*	0.004*
Men/women	2/23	10/11	6/10	6/24	14/25		
Education, years	7.16±4.16	9.45±4.27	7.50±4.57	8.58±4.22	11.60±3.95	<0.001 [†]	0.001*
K-MMSE score	25.44±3.01	25.85±2.61	24.56±2.47	26.20±2.85	28.97±1.11	<0.001 [†]	<0.001 [†]
Audiometric test results averaged across both ears							
PTA	18.96±5.00	20.15±5.95	21.35±5.23	18.52±5.35	18.72±4.52	0.567	0.149
SRT	19.10±4.72	20.23±4.73	21.40±4.07	18.66±4.81	19.03±4.81	0.620	0.150
MCL	59.10±4.83	60.35±4.76	61.09±4.46	58.91±4.85	59.10±4.60	0.573	0.280
SDS	95.68±3.90	95.71±4.25	95.75±4.25	95.66±3.96	97.53±2.98	0.070	0.069
0.25 kHz	16.60±5.58	13.92±6.25	17.34±5.35	14.33±6.12	11.60±4.53	0.002*	0.001*
0.5 kHz	16.40±6.73	13.92±7.68	17.18±6.94	14.25±7.25	15.06±4.07	0.373	0.280
1 kHz	17.10±5.48	17.61±6.95	18.43±6.57	16.75±5.91	17.24±5.15	0.952	0.634
2 kHz	18.70±6.21	20.47±6.25	21.40±6.70	18.50±5.82	18.46±5.02	0.406	0.181
4 kHz	25.60±9.22	30.83±9.66	30.93±8.41	26.41±10.07	25.89±8.61	0.091	0.166
8 kHz	50.20±20.55	48.69±18.53	50.78±15.10	48.83±21.63	40.00±16.79	0.063	0.062

Data are mean±SD values.

* $p < 0.01$, [†] $p < 0.001$, [‡]One-way ANOVA was used to assess differences between the naMCI, aMCI, and CNE groups, [§]One-way ANOVA was used to assess differences between the MCI with FED, MCI without FED, and CNE groups, ^{||}Audiometric test results are expressed as dB HL values, except for SDS being expressed as percentages.

aMCI: amnesic mild cognitive impairment, CNE: cognitively normal elderly, FED: frontal-executive dysfunction, K-MMSE: Korean version of the Mini Mental State Examination, MCI: mild cognitive impairment, MCL: most-comfortable loudness level, naMCI: nonamnesic mild cognitive impairment, PTA: pure-tone average, SDS: speech discrimination score, SRT: speech reception threshold.

Our study was approved by the Institutional Review Board of Dong-A University Medical Center (IRB No. 16-048). We obtained a completed written-consent form from each participant before starting the experimental procedures.

Experimental measurements

Audiometric assessments

Pure-tone audiometry, speech audiometry, and tympanometry tests were applied to all participants. Air- and bone-conduction thresholds were measured with a clinical pure-tone audiometer (GSI 61; Grason-Stadler, Eden Prairie, MN, USA). The PTA was calculated as the average of the values at 0.5, 1, 2, and 4 kHz for each ear. The speech reception threshold, speech discrimination score, and most-comfortable loudness level were determined for each ear. Tympanometry was conducted to assess the status of the middle ear with a clinical impedance audiometer (TYMSTAR; Grason-Stadler, Eden Prairie, MN, USA). The audiometric test results are presented in Table 2.

Neuropsychological assessments

All MCI patients underwent a standardized neuropsychological test, the Seoul Neuropsychological Screening Battery,¹⁵ which covers five cognitive domains: attention, language, vi-

suospatial function, memory (visual and verbal), and frontal-executive function. We also applied the Korean version of the Boston Naming Test¹⁶ and the Rey Complex Figure Test, SVLT, COWAT, Stroop test, and forward and backward digit span tests. Also, the short version of the Geriatric Depression Scale (SGDS)¹⁷ comprising 15 questions was used to evaluate the depression level. Each neuropsychological assessment was applied to all of the MCI patients, while only the K-MMSE, SGDS, SVLT, COWAT, and digit span tests were applied to the CNE group. Table 3 compares the neuropsychological test scores between the MCI subgroups.

Tests of speech perception in noise

Stimuli

We used a standardized speech perception test, the Korean Speech Audiometry,¹⁸ which includes Korean standard-sentence lists for adults and comprises eight sets of sentence lists with keywords. Each set of sentence lists contains 10 sentences with 40 keywords (e.g., what is your favorite food?). Speech stimuli spoken by a male speaker with a standard Korean accent were recorded on a compact disc. We extracted audio files of each sentence list from the compact disc and converted them into WAV files. We then mixed them with speech-spectrum noise (i.e., nonspeech masker) and multi-

Table 3. Comparisons of neuropsychological test scores between MCI subgroups

	Classification 1		p	Classification 2		p
	naMCI	aMCI		MCI with FED	MCI without FED	
K-MMSE	25.44±3.01	25.85±2.61	0.622	24.56±2.47	26.20±2.85	0.059
SGDS	3.76±2.89	6.95±4.48	0.008 [†]	6.06±4.58	4.76±3.65	0.300
Attention: digit span						
Forward	5.76±1.42	6.19±1.63	0.344	6.06±1.65	5.90±1.47	0.734
Backward	3.08±0.86	3.23±0.83	0.532	2.81±0.65	3.33±0.88	0.044*
Language: K-BNT	39.64±7.47	43.00±7.31	0.132	39.81±6.22	41.90±8.12	0.375
Visuospatial function						
RCFT copy	28.82±6.73	31.97±5.77	0.098	28.75±7.93	31.06±5.46	0.308
RCFT copy time, sec	305.36±141.79	239.00±107.52	0.085	285.62±147.12	269.43±122.69	0.693
Verbal memory: SVLT						
Immediate recall	18.72±4.25	13.85±4.26	<0.001*	14.00±4.09	17.83±4.78	0.009 [†]
Delayed recall	5.84±1.57	1.80±1.36	<0.001*	3.12±2.27	4.46±2.52	0.083
Recognition	20.20±1.55	18.33±2.92	0.008 [†]	18.06±2.99	20.03±1.79	0.008 [†]
Visual memory: RCFT						
Immediate recall	9.82±5.45	8.61±6.14	0.486	8.71±6.53	9.56±5.37	0.639
Delayed recall	10.70±5.40	8.45±7.00	0.226	9.03±7.04	10.01±5.82	0.614
Recognition	19.36±2.03	18.42±2.59	0.180	18.50±2.96	19.16±1.93	0.362
Frontal-executive function						
COWAT: semantic						
Animals	12.00±3.73	11.66±3.32	0.753	10.37±3.03	12.63±3.54	0.036*
Supermarket items	14.04±4.79	12.85±4.33	0.389	11.43±3.57	14.60±4.72	0.024*
COWAT: phonemic (Korean letters)						
'ㄱ' (/g/)	5.24±3.97	5.14±2.45	0.923	4.00±2.06	5.83±3.71	0.037*
'ㅇ' (/o/)	5.24±3.46	4.71±3.39	0.608	3.00±2.42	6.06±3.40	0.003 [†]
'ㅅ' (/s/)	5.12±3.55	5.47±3.01	0.718	4.81±3.08	5.53±3.41	0.484
Phonemic, total	15.60±9.56	15.33±7.34	0.917	11.81±5.76	17.43±9.19	0.032*
Stroop test: word reading						
Time per item, sec	104.08±21.80	109.33±9.33	0.310	100.12±26.18	109.86±8.70	0.167
Time per item, sec	1.12±1.37	0.78±0.27	0.267	1.36±1.68	0.76±0.25	0.175
Stroop test: color reading						
Time per item, sec	75.24±23.02	61.23±27.15	0.065	46.93±20.78	80.53±19.87	<0.001 [†]
Time per item, sec	1.68±0.61	1.85±0.61	0.342	2.14±0.61	1.55±0.51	0.001 [†]

Data are mean±SD values.

*p<0.05, [†]p<0.01, [‡]p<0.001.

aMCI: amnesic mild cognitive impairment, COWAT: Controlled Oral Word Association Test, FED: frontal-executive dysfunction, K-BNT: Korean version of the Boston Naming Test, K-MMSE: Korean version of the Mini Mental State Examination, MCI: mild cognitive impairment, naMCI: nonamnesic mild cognitive impairment, RCFT: Rey Complex Figure Test, SGDS: short version of the Geriatric Depression Scale, SVLT: Seoul Verbal Learning Test.

talker-babble noise (with three talkers) (i.e., competing speech masker) at various SNRs using Adobe Audition software (version 3.0; Adobe Systems, San Jose, CA, USA). Different SNRs were obtained by changing the level of the speech sounds while keeping the level of background noise fixed.

Procedures

Speech perception tests were conducted in a sound-attenuated booth. The speech stimuli masked by background noise were delivered from a laptop computer connected to an audiometer and presented binaurally via headphones (TDH-50; Telephonics, Farmingdale, NY, USA). Each sentence test was conducted at four noise levels (SNRs of +5, 0, -2, and -5 dB)

under each type of masking noise (speech-spectrum noise and multitalker-babble noise). To prevent order and fatigue effects, the order of the test lists and noise conditions were randomized for each participant. Participants were told that a speech signal masked by noise would be presented and that they should listen carefully to each sentence and repeat the entire sentence after hearing it. The recorded experiments began after some practicing once it was clear that each participant understood the instructions. Performance was quantified as the percentage of correctly repeated keywords in the sentences.

Statistical analysis

First, a repeated-measures analysis of covariance (ANCOVA)

was carried out with noise levels (SNRs of +5, 0, -2, and -5 dB) and noise types (speech-spectrum noise and multitalker-babble noise) as within-subject factors, and group (classification 1: naMCI, aMCI, and CNE groups; classification 2: MCI with FED, MCI without FED, and CNE groups) as a between-subjects factor. Second, a repeated-measures ANCOVA was carried out with noise level as a within-subject factor and group as a between-subjects factor for each type of background noise. Post-hoc analyses were conducted using pairwise comparisons with Bonferroni corrections to examine the differences among the three groups in the presence of each type of noise. Third, differences between groups in the rates of functional decline in speech perception performance for different noise levels were examined using linear mixed-effect models with random intercepts. Fourth, partial correlation coefficients were computed by controlling for the PTA in each study group to examine which cognitive domains were significantly correlated with speech perception performance. The alpha level was set at $p=0.05$, and statistical analyses were carried out using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA).

RESULTS

Comparisons of sentence recognition scores among the MCI with FED, MCI without FED, and CNE groups

After controlling for age, we found a significant interaction

effect of group by noise level by noise type ($F_{6,158}=3.013, p=0.008$). Other significant interaction effects were group by noise level ($F_{6,158}=9.647, p<0.001$), group by noise type ($F_{2,81}=8.368, p<0.001$), and noise level by noise type ($F_{3,79}=4.696, p=0.005$). We therefore analyzed the interaction between group and noise level separately for each type of noise. First, for the speech-spectrum noise condition, a significant interaction effect between group and noise level was found ($F_{6,158}=5.476, p<0.001$). There were also significant main effects of group ($F_{2,81}=18.360, p<0.001$) and noise level ($F_{3,79}=5.418, p=0.002$). Second, for the multitalker-babble noise condition, we also found a significant interaction effect between group and noise level ($F_{6,158}=10.316, p<0.001$). Although there was a significant main effect of group ($F_{2,81}=31.600, p<0.001$), we found no significant main effect of noise level ($F_{3,79}=1.311, p=0.277$).

Fig. 1 presents the results obtained in post-hoc analyses showing the differences in sentence recognition scores under speech-spectrum noise (Fig. 1A) and multitalker-babble noise (Fig. 1B) conditions among the three groups according to different SNRs.

Comparisons of sentence recognition scores among the naMCI, aMCI, and CNE groups

After controlling for age, we found a significant interaction effect of group by noise level by noise type ($F_{6,158}=3.538, p=0.003$). Other significant interaction effects were group by noise level ($F_{6,158}=7.331, p<0.001$), group by noise type ($F_{2,81}=8.239, p=0.001$), and noise level by noise type ($F_{3,79}=4.670, p=0.005$).

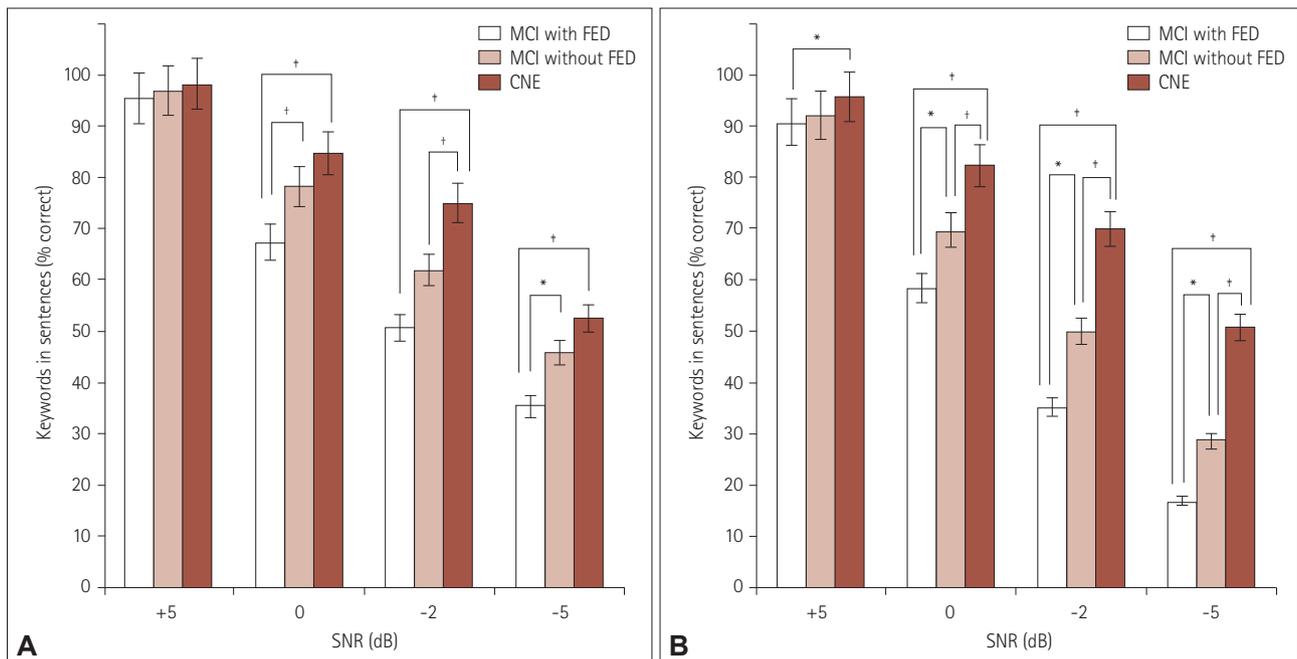


Fig. 1. Percentage of keywords correctly recognized according to SNR for speech-spectrum noise (A) and multitalker-babble noise (B) in the MCI with FED, MCI without FED, and CNE groups. * $p<0.05$, † $p<0.01$, ‡ $p<0.001$. CNE: cognitively normal elderly, FED: frontal-executive dysfunction, MCI: mild cognitive impairment, SNR: signal to noise ratio.

We therefore analyzed the interaction between group and noise level separately for each type of noise. First, for the speech-spectrum noise condition, a significant interaction effect between group and noise level was found ($F_{6,158}=4.528, p<0.001$). There were also significant main effects of group ($F_{2,81}=11.989, p<0.001$) and noise level ($F_{3,79}=3.925, p=0.011$). Second, for the multitalker-babble noise condition, we also found a significant interaction effect between group and noise level ($F_{6,158}=8.272, p<0.001$). Although there was a significant main effect of group ($F_{2,81}=25.018, p<0.001$), we found no significant main effect of noise level ($F_{3,79}=1.235, p=0.302$).

Fig. 2 presents the results obtained in post-hoc analyses showing the differences in sentence recognition scores under speech-spectrum noise (Fig. 2A) and multitalker-babble noise (Fig. 2B) conditions among the three groups according to different SNRs.

Comparisons of rates of functional decline in speech perception performance across noise levels between groups

We additionally examined differences between groups in the rates of functional decline in speech perception performance across noise levels. First, we compared the rates of decline among the MCI with FED, MCI without FED, and CNE groups. In the speech-spectrum noise condition, we found that compared to the CNE group, the decline was significantly faster in the MCI with FED group (difference in slope= $-6.077,$

$p<0.001$) and the MCI without FED group (difference in slope= $-4.525, p=0.001$). The decline did not differ significantly between the MCI with FED and MCI without FED groups (difference in slope= $-1.552, p=0.393$). In the multitalker-babble noise condition, we also found that compared to the CNE group, the decline was significantly faster in the MCI with FED group (difference in slope= $-11.587, p<0.001$) and the MCI without FED group (difference in slope= $-7.251, p<0.001$). The decline was also significantly faster in the MCI with FED group than in the MCI without FED group (difference in slope= $-4.335, p=0.038$).

Second, we compared the rates of decline among the naMCI, aMCI, and CNE groups. In the speech-spectrum noise condition, we found that compared to the CNE group, the decline was significantly faster in the naMCI group (difference in slope= $-3.588, p=0.013$) and the aMCI group (difference in slope= $-6.823, p<0.001$). The decline did not differ significantly between the naMCI and aMCI groups (difference in slope= $3.234, p=0.054$). In the multitalker-babble noise condition, we also found that compared to the CNE group, the decline was significantly faster in the naMCI group (difference in slope= $-8.803, p<0.001$) and the aMCI group (difference in slope= $-8.707, p<0.001$). Also, there was no significant difference between the naMCI and aMCI groups (difference in slope= $-0.095, p=0.962$).

Fig. 3 presents the differences between groups in the rates of functional decline in speech perception performance

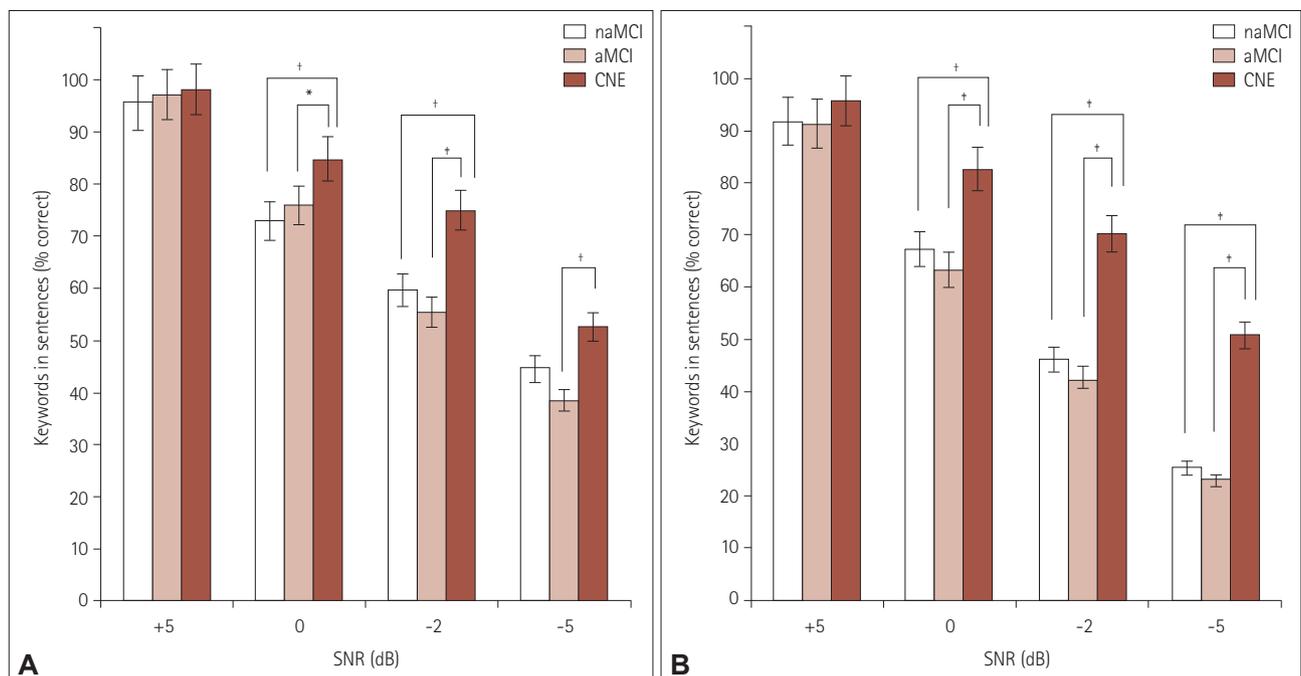


Fig. 2. Percentage of keywords correctly recognized according to SNR for speech-spectrum noise (A) and multitalker-babble noise (B) in the naMCI, aMCI, and CNE groups. * $p<0.05$, † $p<0.01$, ‡ $p<0.001$. aMCI: amnesic mild cognitive impairment, CNE: cognitively normal elderly, MCI: mild cognitive impairment, naMCI: nonamnesic mild cognitive impairment, SNR: signal to noise ratio.

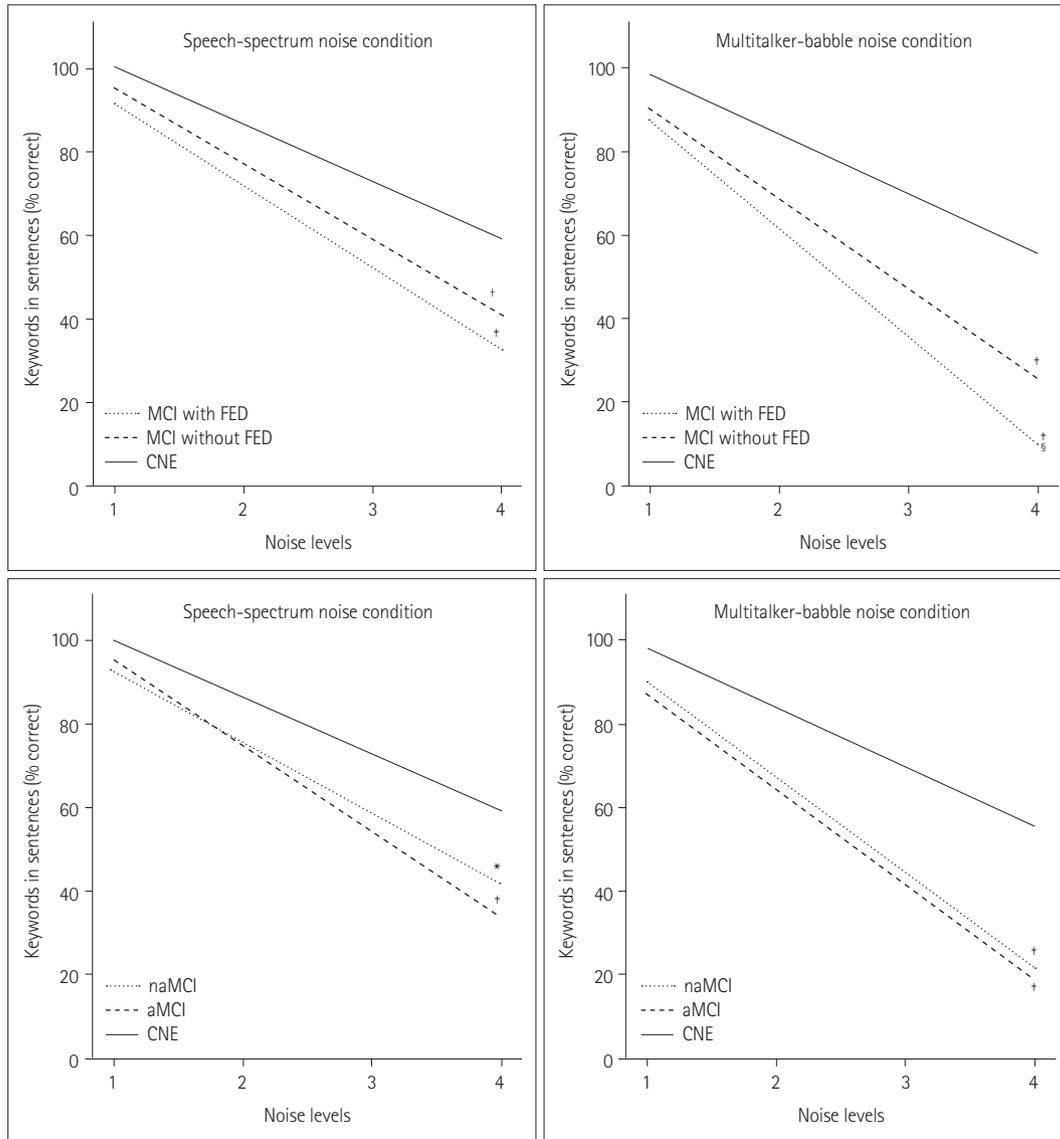


Fig. 3. Differences between groups in the rates of functional decline in speech perception performance across noise levels. Difference in slope: * $p < 0.05$ vs. CNE, † $p < 0.01$ vs. CNE, ‡ $p < 0.001$ vs. CNE, § $p < 0.05$ vs. MCI without FED. aMCI: amnesic mild cognitive impairment, CNE: cognitively normal elderly, FED: frontal-executive dysfunction, MCI: mild cognitive impairment, naMCI: nonamnesic mild cognitive impairment.

across noise levels.

Correlations between sentence recognition scores at an SNR of -5 dB under multitalker-babble noise (the most-difficult listening condition) and neuropsychological test scores for each group

Neuropsychological test results were converted into age- and education-adjusted z scores. After controlling for PTA, we found significant correlations between sentence recognition scores and scores in the animal-naming test of the COWAT for the aMCI ($r=0.615, p=0.004$) and MCI with FED ($r=0.571, p=0.026$) groups. We found no significant correlations for the naMCI and MCI without FED groups. Significant corre-

lations of sentence recognition scores with scores in the digit span backward test ($r=0.352, p=0.030$) and in the phonemic-letter-naming test of the COWAT ($r=0.341, p=0.036$) were found for the CNE group (Table 4).

DISCUSSION

Patients with MCI exhibit CAP dysfunction characterized by deficits in speech-in-noise perception. However, it remains unclear whether the impairment of speech-in-noise perception varies between the clinical subtypes of MCI. Therefore, in the current study we compared speech perception performance among MCI subgroups under various noise conditions.

Table 4. Partial correlation coefficients for sentence recognition scores at a signal-to-noise ratio of -5 dB under multitalker-babble noise with neuropsychological test scores adjusted by the pure-tone average in each group

	Classification 1		Classification 2		CNE [†]
	naMCI	aMCI	MCI with FED	MCI without FED	
K-MMSE	0.333	0.044	-0.349	0.339	0.167
Attention: digit span					
Forward	0.132	0.179	-0.318	0.315	0.028
Backward	0.157	-0.171	-0.351	0.045	0.352*
Language: K-BNT	-0.011	-0.108	-0.402	-0.033	-
Visuospatial function					
RCFT copy	0.141	-0.069	-0.106	0.086	-
RCFT copy time	0.084	-0.365	-0.104	-0.117	-
Verbal memory: SVLT					
Immediate recall	0.160	-0.008	-0.326	0.147	0.136
Delayed recall	0.085	-0.101	-0.097	0.061	0.049
Recognition	0.010	-0.080	-0.196	-0.020	-0.132
Visual memory: RCFT					
Immediate recall	-0.066	-0.427	-0.215	-0.268	-
Delayed recall	-0.025	-0.390	-0.113	-0.259	-
Recognition	0.131	-0.299	-0.386	0.111	-
Frontal-executive function					
COWAT: semantic					
Animals	-0.277	0.615 [‡]	0.571*	-0.228	0.249
Supermarket items	0.227	0.088	-0.220	0.234	0.287
COWAT: phonemic (Korean letters)					
'ㄱ' (/g/)	0.195	0.342	0.080	0.201	0.082
'ㅇ' (/o/)	0.098	0.022	-0.411	0.087	0.341*
'ㅅ' (/s/)	0.065	0.033	-0.044	0.030	0.228
Phonemic, total	0.141	0.159	-0.210	0.130	0.266
Stroop test: word reading					
Time per item	0.060	0.094	-0.072	0.244	-
Stroop test: color reading					
Time per item	0.139	-0.078	-0.305	0.009	-

* $p < 0.05$, [†] $p < 0.01$, [‡]Only the K-MMSE, SVLT, COWAT, and digit span tests were applied to the CNE group.

aMCI: amnesic mild cognitive impairment, CNE: cognitively normal elderly, FED: frontal-executive dysfunction, K-BNT: Korean version of the Boston Naming Test, K-MMSE: Korean version of the Mini Mental State Examination, MCI: mild cognitive impairment, naMCI: nonamnesic mild cognitive impairment, RCFT: Rey Complex Figure Test, SVLT: Seoul Verbal Learning Test.

We also studied cognitive domains specifically related to speech-in-noise perception.

The first major finding of our study was that the MCI with FED group scored lower than both the MCI without FED and CNE groups under both types of background noise as its level increased. However, the speech perception did not differ significantly between the naMCI and aMCI groups in any noise condition. This finding might have been due to the clinical characteristics of our MCI patients. Both the aMCI and naMCI groups included comparable numbers of patients with FED (Table 1), which was probably responsible for the lack of any intergroup difference in the recognition scores. When MCI patients were reclassified according to whether or not they had FED, the MCI with FED group showed sig-

nificantly lower scores than the MCI without FED group under most of the noise conditions. Although the group differences remained consistent as the SNR decreased from 0 to -5 dB in the multitalker-babble noise condition, there were inconsistencies in the group differences in the speech-spectrum noise condition as the noise levels varied. In the presence of speech-spectrum noise, as the SNR decreased from +5 to 0 dB, the performance declined rapidly first in the MCI with FED group, while the MCI without FED group performed consistently relative to the control group. However, as the SNR decreased further, from 0 to -2 dB, both the MCI with and without FED groups showed significantly lower scores than the CNE group. When the SNR reached -5 dB, the performance of the CNE group also declined, resulting in no group differ-

ence between the MCI without FED and CNE groups. However, the MCI with FED group still performed worse than the CNE group.

When we additionally examined differences between groups in the rates of functional decline across noise levels, the MCI with FED and the MCI without FED groups exhibited significantly faster declines than the CNE group both in the speech-spectrum noise and multitalker-babble noise conditions. The decline was significantly faster in the MCI with FED group than in the MCI without FED group in the multitalker-babble noise condition, but did not differ significantly between these two groups in the speech-spectrum noise condition. The discrepancy in performance among the groups was greater in the presence of multitalker-babble noise than in the presence of speech-spectrum noise due to competing speech (e.g., babble noise) being cognitively more demanding than meaningless noise (e.g., speech-spectrum noise).¹⁹ It has been demonstrated previously that the cognitive processing load of speech perception is significantly increased by semantic interference.¹⁹ Cognitive factors that are particularly relevant to speech-on-speech perception are working memory and the ability to ignore irrelevant information contained in the interfering speech.^{20,21} The Ease of Language Understanding model describes these cognitive functions as working-memory-capacity-dependent executive mechanisms that are critical to speech perception.^{22,23}

Our findings indicate that impairments in frontal-executive function are associated with speech-in-noise perception deficits. Consistent with our previous study,⁹ we found significant correlations between speech-in-noise perception performance and scores in verbal fluency tests in the MCI subgroups. As a test of frontal-executive function, verbal fluency requires participants to generate as many words as possible within a certain time. Successfully performing this task requires subjects to keep earlier responses constantly updated in their working memory and to inhibit irrelevant and repetitive responses.²⁴ Likewise, in the speech-in-noise perception test, participants are asked to choose the most-probable word as soon as possible from among several lexical entries activated by perceptual ambiguity due to background noise. They must simultaneously suppress activations of context-irrelevant words and remember previously perceived information. As mentioned above, these executive mechanisms become even more important when the target speech is masked by meaningful speech, because listeners need to inhibit the processing of competing information and focus their attention selectively on the target speech.^{25,26}

The present study found that speech-in-noise perception was significantly correlated with scores in the phonemic verbal fluency and backward digit span tests in the CNE group. In

the backward digit span test, which measures working memory,²⁷ subjects are asked to reorder items that they have heard. Working memory is one of the core executive functions along with response inhibition, interference control (selective attention and cognitive inhibition), and cognitive flexibility.²⁷ Tasks of working memory capacity and frontal-executive function share a common underlying executive attention component.²⁸ Our findings indicate that the effect of frontal-executive function on speech-in-noise perception is not specific to patients with MCI, which is consistent with a previous report³ of an association between frontal-executive function and speech-in-noise perception in older persons both with and without memory loss. In other words, frontal-executive function may be important in speech-in-noise perception in older listeners both with and without cognitive deficits.

Together the results obtained in the current study suggest that frontal-executive function is strongly related to speech-in-noise perception, and thus patients with FED have greater deficits in speech-in-noise perception compared to other subgroups of MCI. Patients with FED may also experience more problems in perceiving and understanding speech masked by intelligible speech (e.g., coffee-shop conversations) than nonspeech noise (e.g., wind noise). Therefore, in order to improve speech perception and auditory comprehension in patients with cognitive impairment, it would be useful to minimize the environmental background noise and in particular to try to avoid environments where interfering speech is present. For these patients, cognitive training focused on frontal-executive function and working memory as well as audiological rehabilitation (e.g., combined with amplification, if needed) can help improve their speech perception during everyday conversations.

The results in the literature on speech perception indicate several issues that future studies need to address. Most importantly, considering that deficits in speech-in-noise perception are related to an increased risk of cognitive decline, longitudinal studies with large samples are needed to explore whether speech-in-noise perception deficits at baseline are related to an increased risk of incident dementia according to MCI subgroups. Also, since previous studies indicated that CAP testing could be regarded in part as a measure of cognitive function,¹ it is important to establish the potential usefulness of the speech-in-noise perception test in diagnosing MCI.

Conflicts of Interest

The authors have no financial conflicts of interest.

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