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Research Article

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Speech-in-Noise Test results of compensation claimants for noise induced hearing loss in Korean male workers: Words-in-Noise Test (WIN) and quick-Hearing-in-Noise Test (HINT)

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Abbreviations
HINT: Hearing-in-Noise Test; HL: hearing level; KS-SL-A: Korean Standard Sentence Lists for Adults; MCL: most comfort level; NSHG: non-serviceable hearing group; PRR: positive response rate; PTA5123: average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000 Hz; SDS: speech discrimination score; SHG:

ABSTRACT

Background: Pure-tone audiometry is used as a gold standard for hearing measurement. However, since communication in the work environment occurs in noise, it might be difficult to evaluate the actual communication ability accurately based on pure-tone audiometry only. Therefore, the purpose of this study is to evaluate speech intelligibility in noisy environments by using Speech-in-Noise Tests and to check its relationship with pure-tone audiometry.
Methods: From January 2017 to September 2018, for 362 workers who visited a university hospital for the purpose of compensating for noise-induced hearing loss, several tests were conducted: pure-tone audiometry, speech reception threshold, speech discrimination score, and Speech-in-Noise Tests (Words-in-Noise Test [WIN] and quick-Hearing-in-Noise Test [quick-HINT]). The subjects were classified into serviceable hearing group and non-serviceable hearing group based on 40 dB hearing level (HL) pure-tone average. In both groups, we conducted age-adjusted partial correlation analysis in order to find out the relationship between pure-tone threshold, speech reception threshold, speech discrimination score and WIN and quick-HINT respectively.
Results: In non-serviceable hearing group, all results of partial correlation analysis were statistically significant. However, in serviceable hearing group, there were many results which showed little or no significant relationship between pure-tone threshold and Speech-in-Noise Tests (WIN and quick-HINT).
Conclusions: The relationship between Speech-in-Noise Tests and the pure-tone thresholds were different by the hearing impairment levels; in mild to moderate hearing loss workers, there was little or no relationship; in severe cases, the relationship was significant. It is not enough to predict the speech intelligibility of hearing-impaired persons, especially in mild to moderate level, with pure-tone audiometry only. Therefore, it would be recommended to conduct Speech-in-Noise Test.

Keywords: Noise-induced hearing loss; Pure-tone threshold; Speech intelligibility; Speech-in-Noise Test

serviceable hearing group; SNR: signal-to-noise ratios; SPL: sound pressure level; SRT: speech reception threshold; WIN: Words-in-Noise Test.

Competing interests
The authors declare that they have no competing interests.

Author contributions
Conceptualization: Lee JH, Kwon JK, Kim JS; Data curation: Kim NJ; Formal analysis: Kim JS; Investigation: Kim JS, Kim NJ; Methodology: Lee JH, Kim JS; Project administration: Lee JH; Resources: Kim JS, Kim NJ; Software: Kim JS; Supervision: Lee JH, Kwon JK; Validation: Lee JH, Kim JS; Writing - original draft: Kim JS; Writing - review & editing: Lee JH, Kwon JK, Kim JS.

BACKGROUND

Hearing is an ability to use both ears at the same time to grasp the sound source. Moreover, it is not just to sense sound, but also to integrate peripheral hearing organs and cerebral functions to understand speech. When hearing is impaired, these abilities also deteriorate; the frequency selection ability, the position perception of the sound source, and the cognitive ability of the danger signal. The deterioration of those abilities lead to safety-related problems. Also, the disturbance of communication can cause poor work performance, poor family relationship, social isolation, and deteriorated quality of life. One third of hearing loss is due to noise, and when age-related damage is added, social problems associated with hearing loss can be serious.

Frequency-specific information, such as pure-tone audiometry, provides important data in determining hearing status. In other words, it may be helpful to decide the level and characteristics of hearing loss and to find out the location of pathological causes. Pure-tone audiometry is also used as a standard test for judging the level of hearing ability and disability. In addition, it is used as a basic test in the screening and determination of noise-induced hearing loss in the noise special medical examination.

In general, speech audiometry includes speech reception threshold (SRT) and speech discrimination score (SDS). SRT is the threshold at which the examinee correctly answers 50% of the bisyllable words presented in the test. SDS is a percentage of how accurately the examinee answers the monosyllable words at the most comfortable level. Speech audiometry is related to the ability to understand the language, and can evaluate not only the signal detection ability of the cochlea, but also the auditory system function. In addition, it is known that it can function as a screening test for exaggerated or false hearing loss in pure-tone audiometry [1,2].

Words are the most basic unit of language recognition, and have been widely used in hearing screening. Words-in-Noise Test (WIN), which uses words as test items, has the advantage that it is easy to standardize the test because the test time is relatively short and the factors to be considered for evaluation are simple [3]. Furthermore, WIN is not only a very sensitive test for differentiating speech intelligibility, but also has a high relevance to cognitive function. Therefore, it is thought that it can reflect the function of the auditory center [4,5].

Hearing-in-Noise Test (HINT) is a test that compares the level of cognition of a simple conversational sentence under quiet and noisy conditions. And it is a test to assess hearing by measuring the understanding of sentences in noise situation comprehensively [6].

According to some former studies, there were studies in which the signal-to-noise ratios (SNRs) were −13.4 dB to −11.5dB when WIN was performed in normal hearing persons [7]. On the other hand, some studies showed −0.8 dB to 3.7 dB [8]. In the case of HINT, depending on the studies, SNRs were −3.0 dB to −1.1 dB [9,10].

Although pure-tone audiometry is used as a gold standard for hearing measurement, it is difficult to accurately understand the communication ability only with the result of pure-tone audiometry, since communication in work environment occurs in noise. In addition, a communication disorder in noisy environment is one of the most uncomfortable symptoms of people with hearing loss, and in particular, since the hearing ability related to consonants is impaired, speech intelligibility may be different [11,12].

This study evaluated speech intelligibility in noisy environment according to the degree of hearing loss by using Speech-in-Noise Test (WIN and quick-HINT) to compensation claimants for noise-induced hearing loss. The purpose of this study is to determine the relationship between pure-tone audiometry and Speech-in-Noise Tests. Furthermore, we intend to provide the basis for the preparation of an inspection method for the evaluation of the fitness for work related to noise-induced hearing loss.

METHODS

Subjects

We initially enrolled 454 workers into this study, who visited a university hospital for the purpose of compensating for noise-induced hearing loss from January 2017 to September 2018. Among them, 92 workers were excluded, who missed at least one response at subset of tests or could not meet the criteria for the workers' compensation. Finally, 362 workers were included.

Subjects were exposed to noise at or above 85 dB(A) for three years or more, and the hearing loss of one ear was 40 dB HL or more. In addition, they showed sensorineural hearing loss, excluding hearing loss due to auditory diseases, trauma, or drugs. Moreover, there were no obvious damage to the eardrum and middle ear. Also, in the results of pure-tone audiometry there was no clear air-bone gap, and hearing loss was more severe in the high frequency range than in the low one.

Pure-tone threshold, SRT, SDS, SNR of WIN, and positive response rate of quick-HINT were checked on the same day.

In order to confirm the normal reference value of the test, the same tests were conducted on 20 adults without hearing loss in 20s and 30s (ten men and ten women, and an average age of 27.8 years).

Method

Pure-tone audiometry

GSI 61 audiometer, TDH-50P headphones and a soundproof booth (2.4 × 2.4 m double wall) were used. The tests were conducted by an experienced examiner who has completed auditory quality control training and maintenance training conducted by the Occupational Safety & Health Research Institute.

The preferred ear was tested first. If both hearings were same or the hearing test was never done before, the right ear was tested first. The frequency measurement was started from 1,000 Hz, followed by 2,000, 3,000, 4,000, 6,000, 1,000, and 500 Hz. Hearing threshold measurement was conducted with a modified ascending method that started with 30 dB and decreased by 10 dB if there was a response and increased by 2 dB if there was no response. The stimulation sound was given for 1–2 seconds, and the stimulation interval was irregular.

Speech audiometry

1. SRT and SDS

Among the bisyllabic words of the spondee, easy words that are frequently used in everyday life were selected as the signal words of the SRT test. The examinations were conducted with the voice of the examiner.

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First, it started at an intensity of 30 dB added to pure-tone threshold so that the subject could be familiar with the test speech. And then, the intensity was lowered by 10 dB until approaching the threshold and if the subject successfully recognized 2 or 3 words, it was lowered by 5 dB continuously. Thus, the intensity of the sound that the subject answered at least 50% correctly was regarded as a threshold. Then, the most comfort level (MCL) was checked by finding the intensity of the sound that the subject can hear the sound most comfortably. The SDS was calculated as a percentage by presenting 50 monosyllable words at MCL.

The monosyllabic and bisyllabic words used for SRT and SDS were selected from the words lists produced by Ham Tae-Young in 1962.

2. Background noise used in Speech-in-Noise Test

Multi-talker babble noise was used as background noise, which was made of sixteen adults' polyphonic noise recording files produced by Hallym University Hearing Research Institute. The recording files were produced by having eight men and eight women in their 20s (average age 21.7 years old) read for 2 minutes in a soundproofing room with different lists of Korean Standard Sentence Lists for Adults (KS-SL-A)

3. WIN

It was conducted by sound field test in a soundproofing facility, and the two speakers installed at 45 degrees to the left and right of the subject's 1 meter front side provided multi-talker babble and speech signals at the same time in a diotic method.

Under the background noise of the intensity of 50, 60, and 70 dB sound pressure level (SPL), the bisyllabic words of KS-SL-A, which were well-informed to the subject in advance, were simultaneously presented in live voices. After finding out the threshold with positive response over 50% using a 2 dB interval mixed method, SNR was calculated by subtracting the noise intensity from the speech threshold intensity.

4. quick-HINT

The conventional HINT provides a speech signal from the front speaker 1 meter in front of the subject, while the noise signal was given from the front, right or left. As speech signals, a total of 12 lists consisting of 20 sentences per list are used.

On the other hand, the quick-HINT used in this test provided the multi-talker babble noise and speech signal at the same time in a diotic method from two speakers installed at 45 degrees to the left and right of the subject's 1 meter front side.

As speech signals, a Korean standard sentence list was used, which includes eight lists made of 10 sentences and 40 words each.

The speech signals were provided with live voice of 60 and 70 dB SPL intensity, and the test was conducted under no-noise condition and background noise of 60 dB SPL intensity. In the test score, the positive response rates for 10 sentences and 40 words, which are speech signals, was expressed as a percentage.

Data analysis method

Subjects were classified into two groups based on 40 dB HL by the average hearing with using pure-tone average (average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000

Hz; PTA5123) of the ear with better hearing on both ears: groups below 40 dB HL or less (hereinafter serviceable hearing group; SHG) and groups above 40 dB HL (hereinafter non-serviceable hearing group; NSHG) [13]. This was to find the difference in speech intelligibility results according to the degree of hearing loss.

For each group, we performed age-adjusted partial correlation analysis to find out the relationship among pure-tone threshold, pure-tone average, SRT, SDS and the results of WIN and quick-HINT.

For all data analysis, IBM's SPSS ver. 21 (IBM Corp., Armonk, NY, USA) was used. The significance level was set to 0.05, and when the *p*-value was less than this, it was interpreted as significant.

This study was conducted after the approval of Institutional Review Board of Ulsan University Hospital (IRB File No. UUH 2020-06-016).

RESULTS

General characteristics of subjects

The subjects were men with an average age of 62.3 years, and the general characteristics are shown in **Table 1**. Of the initial 454 subjects, only 2 persons were female. These two persons were excluded from this study because they did not satisfy the inclusion criteria. Therefore, only male subjects remained.

In SHG and NSHG, the average age was 61.5 and 63.1 years respectively, and the pure-tone average was 34.1 and 48.9 dB HL, respectively. SRT was 33.8 and 47.9 dB HL respectively, and SDS was 89.7% and 85.9% respectively.

WIN and quick-HINT results by pure-tone average

As shown in **Table 2**, when the background noise was 50, 60, and 70 dB SPL, the average SNR of WIN was 1.9, 1.2, and 1.7 dB HL respectively, in SHG. In NSHG, it was 4.9, 3.4, and 3.3 dB HL respectively. The SNRs of NSHG were significantly higher than those of SHG ($p < 0.01$).

Table 1. General characteristics of the subject

Characteristics	SHG (n = 170)	NSHG (n = 192)	Normal hearing (n = 20)
Age (year)	61.5 ± 3.9	63.1 ± 4.2	27.8 ± 4.4
Pure-tone audiometry (dB)			
500 Hz	20.8 ± 7.4	31.9 ± 11.1	2.8 ± 3.9
1,000 Hz	26.4 ± 7.6	41.0 ± 11.2	2.3 ± 4.0
2,000 Hz	37.5 ± 9.3	56.1 ± 10.4	0.8 ± 3.0
3,000 Hz	51.6 ± 11.3	66.5 ± 10.7	2.2 ± 4.9
4,000 Hz	60.6 ± 11.0	72.4 ± 11.6	−0.5 ± 4.0
6,000 Hz	61.7 ± 13.5	72.8 ± 12.7	−0.3 ± 3.8
PTA5123	34.1 ± 5.0	48.9 ± 7.9	2.0 ± 3.0
Speech audiometry			
SRT (dB)	33.8 ± 6.3	47.9 ± 9.2	10.4 ± 2.9
SDS (%)	89.7 ± 13.1	85.9 ± 14.5	99.4 ± 1.3

SHG: serviceable hearing group; NSHG: non-serviceable hearing group; PTA5123: average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000 Hz; SRT: speech reception threshold; SDS: speech discrimination score.

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Table 2. WIN and quick-HINT results by pure-tone average

Variables	SHG (n = 170)	NSHG (n = 192)	t	*p*-value	Normal hearing (n = 20)
WIN (dB SNR)					
50	1.9 ± 3.5	4.9 ± 4.8	6.827	< 0.01	−5.3 ± 1.2
60	1.2 ± 3.4	3.4 ± 3.8	5.823	< 0.01	−5.9 ± 2.3
70	1.7 ± 3.0	3.3 ± 3.4	4.887	< 0.01	−5.4 ± 2.0
Quick-HINT (PRR, %)					
Quiet condition					
60 dB SPL, sentence	72.6 ± 28.2	48.1 ± 32.4	−7.697	< 0.01	100 ± 0.0
60 dB SPL, word	85.4 ± 19.0	65.8 ± 30.6	−7.400	< 0.01	100 ± 0.0
70 dB SPL, sentence	89.2 ± 18.6	73.9 ± 30.3	−5.858	< 0.01	100 ± 0.0
70 dB SPL, word	94.6 ± 12.1	83.9 ± 24.1	−5.409	< 0.01	100 ± 0.0
Noise condition					
60 dB SPL, sentence	24.6 ± 26.4	12.8 ± 18.5	−4.873	< 0.01	99.1 ± 1.5
60 dB SPL, word	45.0 ± 27.5	29.0 ± 25.1	−5.799	< 0.01	97.5 ± 4.4
70 dB SPL, sentence	67.4 ± 26.0	54.7 ± 30.1	−4.314	< 0.01	99.9 ± 0.6
70 dB SPL, word	82.2 ± 18.1	68.2 ± 28.7	−5.601	< 0.01	99.5 ± 2.2

SHG: serviceable hearing group; NSHG: non-serviceable hearing group; WIN: Words-in-Noise Test; SNR: signal-to-noise ratio; HINT: Hearing-in-Noise Test; PRR: positive response rate.

In quick-HINT results, both groups showed the highest positive response rate (PRR) of the word test in quiet condition with 70 dB SPL signal (94.6% in SHG and 83.9% in NSHG). In the noise condition with 60 dB SPL signal, the PRR of the sentence test was the lowest (24.6% in SHG and 12.8% in NSHG). In each subset of the quick-HINT, the PRRs of SHG were higher than those of NSHG ($p < 0.01$).

As a reference for the test, the average result of normal hearing adults is as follows. The pure-tone average was 2 dB, SRT was 10 dB, and SDS was 99%. In WIN, the SNRs were −5.9 dB to −5.3 dB. The PRRs of all subsets in the quick-HINT were over 97%.

Partial correlation analysis

The age-adjusted partial correlation coefficients between pure-tone threshold, pure-tone average, SRT, SDS, and the results of WIN and quick-HINT were as follows.

In WIN, the SNRs of SHG under the 50 and 60 dB SPL background noise condition had significant positive correlations with pure-tone thresholds at 500 and 1,000 Hz, pure-tone average and SRT and had significant negative correlations with SDS ($p < 0.05$). However, the result under the 70 dB SPL background noise condition had no significant correlation with pure-tone threshold and pure-tone average. Regardless of the magnitude of the background noise, the SNRs of NSHG had significant positive correlations with pure-tone thresholds of all frequency, pure-tone average, and SRT ($p < 0.01$) and had significant negative correlations with SDS ($p < 0.01$) (**Table 3**).

Table 3. Age-adjusted partial correlation analysis between pure-tone thresholds, SRTs, SDS, and SNR of WIN

Groups	WIN	Hearing threshold							SRT	SDS
		0.5 Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	PTA5123		
SHG (n = 170)	50 dB SPL	0.245[b]	0.180[a]	0.096	−0.005	0.038	0.065	0.201[b]	0.384[b]	−0.206[b]
	60 dB SPL	0.190[a]	0.167[a]	0.124	0.107	0.084	0.059	0.252[b]	0.325[b]	−0.198[a]
	70 dB SPL	0.145	0.098	0.059	0.168	0.029	0.024	0.146	0.216[b]	−0.215[b]
NSHG (n = 192)	50 dB SPL	0.534[b]	0.556[b]	0.511[b]	0.358[b]	0.340[b]	0.342[b]	0.679[b]	0.699[b]	−0.564[b]
	60 dB SPL	0.407[b]	0.377[b]	0.352[b]	0.263[b]	0.252[b]	0.255[b]	0.485[b]	0.545[b]	−0.543[b]
	70 dB SPL	0.328[b]	0.257[b]	0.311[b]	0.206[b]	0.219[b]	0.243[b]	0.381[b]	0.421[b]	−0.508[b]

SRT: speech reception threshold; SDS: speech discrimination score; SNR: signal-to-noise ratio; WIN: Words-in-Noise Test; SHG: serviceable hearing group; NSHG: non-serviceable hearing group; SPL: sound pressure level; PTA5123: average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000 Hz.
[a]*p*-value < 0.05, [b]*p*-value < 0.01.

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Table 4. Age-adjusted partial correlation analysis between pure-tone thresholds, SRTs, SDS, and PRR of quick-HINT quiet condition

Groups	Quick-HINT quiet condition	Hearing threshold							SRT	SDS
		0.5 Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	PTA5123		
SHG (n = 170)										
60 dB SPL	Sentence	−0.252[b]	−0.245[b]	−0.124	−0.141	−0.219[b]	−0.199[a]	−0.324[b]	−0.373[b]	0.401[b]
	Word	−0.272[b]	−0.198[a]	0.014	−0.005	−0.140	−0.103	−0.173[a]	−0.296[b]	0.422[b]
70 dB SPL	Sentence	−0.237[b]	−0.190[a]	0.014	−0.050	−0.181[a]	−0.144	−0.183[a]	−0.259[b]	0.401[b]
	Word	−0.219[b]	−0.154[a]	0.034	−0.092	−0.185[a]	−0.168[a]	−0.177[a]	−0.236[b]	0.378[b]
NSHG (n = 192)										
60 dB SPL	Sentence	−0.432[b]	−0.457[b]	−0.408[b]	−0.306[b]	−0.297[b]	−0.369[b]	−0.556[b]	−0.581[b]	0.497[b]
	Word	−0.517[b]	−0.562[b]	−0.469[b]	−0.323[b]	−0.323[b]	−0.370[b]	−0.649[b]	−0.672[b]	0.527[b]
70 dB SPL	Sentence	−0.419[b]	−0.405[b]	−0.382[b]	−0.364[b]	−0.398[b]	−0.419[b]	−0.544[b]	−0.514[b]	0.582[b]
	Word	−0.431[b]	−0.437[b]	−0.403[b]	−0.355[b]	−0.385[b]	−0.399[b]	−0.563[b]	−0.550[b]	0.558[b]

SRT: speech reception threshold; SDS: speech discrimination score; PRR: positive response rate; HINT: Hearing-in-Noise Test; SHG: serviceable hearing group; NSHG: non-serviceable hearing group; SPL: sound pressure level; PTA5123: average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000 Hz,.
[a]*p*-value < 0.05, [b]*p*-value < 0.01.

Table 5. Age-adjusted partial correlation analysis between pure-tone thresholds, SRTs, SDS, and PRR of quick-HINT 60 dB SPL condition

Groups	Quick-HINT 60 dB SPL condition	Hearing Threshold							SRT	SDS
		0.5 Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	PTA5123		
SHG (n = 170)										
60 dB SPL	Sentence	−0.048	−0.031	−0.121	−0.073	−0.101	−0.129	−0.127	−0.153[a]	0.298[b]
	Word	−0.050	−0.012	−0.105	−0.074	−0.084	−0.163[a]	−0.114	−0.153[a]	0.394[b]
70 dB SPL	Sentence	−0.198[a]	−0.042	0.036	0.000	−0.100	−0.121	−0.073	−0.199[a]	0.414[b]
	Word	−0.169[a]	−0.042	0.002	−0.029	−0.069	−0.132	−0.095	−0.191[a]	0.453[b]
NSHG (n = 192)										
60 dB SPL	Sentence	−0.189[b]	−0.162[a]	−0.279[b]	−0.258[b]	−0.314[b]	−0.342[b]	−0.305[b]	−0.282[b]	0.213[b]
	Word	−0.246[b]	−0.272[b]	−0.374[b]	−0.314[b]	−0.360[b]	−0.375[b]	−0.415[b]	−0.398[b]	0.374[b]
70 dB SPL	Sentence	−0.366[b]	−0.286[b]	−0.356[b]	−0.365[b]	−0.398[b]	−0.444[b]	−0.474[b]	−0.433[b]	0.565[b]
	Word	−0.354[b]	−0.323[b]	−0.334[b]	−0.316[b]	−0.365[b]	−0.395[b]	−0.459[b]	−0.449[b]	0.562[b]

SRT: speech reception threshold; SDS: speech discrimination score; PRR: positive response rate; HINT: Hearing-in-Noise Test; SHG: serviceable hearing group; NSHG: non-serviceable hearing group; SPL: sound pressure level; PTA5123: average of pure-tone thresholds at 500, 1,000, 2,000, and 3,000 Hz.
[a]*p*-value < 0.05, [b]*p*-value < 0.01.

In quick-HINT quiet condition, the PRRs of SHG had significant negative correlations with the pure-tone thresholds of 500 and 1,000 Hz, pure-tone average and SRT, and had significant positive correlations with SDS ($p < 0.05$). The PRRs of NSHG had significant negative correlations with all frequency thresholds, pure-tone average, and SRT ($p < 0.01$), and had significant positive correlations with SDS ($p < 0.01$) (**Table 4**).

In quick-HINT 60 dB SPL background noise condition, the PRRs of SHG had significant negative correlations with SRT and had significant positive correlations with SDS. However, it had no significant relationship with pure-tone average and pure-tone threshold except the threshold at 500 Hz in 70 dB SPL condition. The PRRs of NSHG had significant negative correlations with pure-tone threshold, pure-tone average and SRT ($p < 0.01$), and had significant positive correlations with SDS ($p < 0.01$) (**Table 5**).

DISCUSSION

It is well known that the correlation between SRT and pure-tone threshold is very high [14]. In particular, one of the studies on the noise-exposed workers showed the correlation coefficient of 0.85 to 0.95 [15]. Both of test methods are conducted under quiet condition. The purpose of this study was to evaluate the speech intelligibility of the subjects who claimed compensation for noise-induced hearing loss in background noise condition. In

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addition, it was to find out the relationship between the results of Speech-in-Noise Tests and pure-tone audiometry, which is used as the gold standard for hearing tests.

The subjects with hearing loss, compared to the normal hearing persons, showed greatly reduced speech intelligibility in quick-HINT background noise conditions. In other words, it was found that background noise can cause great difficulties in communication to hearing impaired persons. These results were similar in both groups divided based on pure-tone average of 40 dB HL. This reflects the results of previous studies that a noise-induced cochlear damage can cause the deterioration of cochlear frequency selective mechanisms and that results in the speech intelligibility under background noise condition to be weakened more compared to quiet condition [16].

In SHG, the age-adjusted partial correlation analysis showed that SNRs of WIN in 50 and 60 dB SPL background noise condition and PPRs of quick-HINT in quiet conditions had significant correlations with pure-tone thresholds at 500 and 1,000 Hz, pure-tone average, SRT and SDS. However, most of the results had little or no significant relationship between the Speech-in-Noise Test results and pure-tone thresholds at from 2,000 to 6,000 Hz. In the early stage of noise-induced hearing loss, the degree of hearing impairment of 3,000 to 6,000 Hz, which is responsible for the consonant part, is greater than that of 500 to 2,000 Hz, which is responsible for general speaking intelligibility. For this reason, there are discrepancies between good pure-tone recognition and poor speech selectivity [17]. Also, although not considered in this study, tinnitus usually occurs in the early stage of noise-induced hearing loss, and tinnitus is mostly in a high-frequency region of 3,000 Hz or above, which may degrade the speech selectivity, too.

Another cause can be interpreted as the two mechanisms of hearing presented by Plomp: attenuation and distortion [18]. Attenuation appears relatively linearly and is the most predictable part of the relationship between the pure-tone threshold and speech intelligibility. Pure-tone audiometry and the speech test in quiet condition can be seen as quantifying the attenuation factor of hearing loss. Also, in this aspect, it is considered that the listener's deteriorated understanding for speech can be improved by increasing the speech signal volume. Distortion is a collective term for various abstract elements of hearing loss, which includes auditory phenomena such as frequency resolution, temporal resolution, and suppression, etc. [19]. The distortion factor is nonlinear and makes it difficult to predict the relationship between pure-tone threshold and speech intelligibility in quiet and noise conditions [20]. For example, even two people of the same age, same attenuated hearing loss, and same speech intelligibility in quiet conditions can significantly differ in performance under test in noise conditions.

Next, in NSHG, the pure-tone thresholds of all frequency had significant correlations with SNRs of WIN and PRRs of quick-HINT in age-adjusted partial correlation analysis. This can be seen as the ability to detect sound in speech intelligibility, that is, the influence of pure-tone threshold itself matters much when hearing loss is relatively advanced. In other words, in NSHG, the hearing losses had progressed in the entire frequency range at 500 to 2,000 Hz, responsible for general speaking and at 3,000 to 6,000 Hz, responsible for the consonant part. So, the less pure-tone hearing ability deteriorates, the better the speech intelligibility is. In addition, the correlation between pure-tone audiometry and speech audiometry (WIN and quick-HINT) was smaller in background noise condition than in quiet condition. And this corresponds to the results of studies by Vermiglio et al. [21] and Wilson et al. [22]; the correlation between pure-tone average and speech intelligibility under the background noise condition is low.

Some clinical implications of this study are as follows. First, by dividing a large number of people with noise-induced hearing loss into 2 groups, the difference in speech intelligibility could be found depending on the degree of hearing loss in pure-tone audiometry. In addition, a new test method with higher efficiency than the conventional HINT was conducted to seek the test method with high practical applicability. The conventional HINT takes a lot of time and costs, so the test has been rarely conducted these days [23]. Therefore, by applying a method that can simplify this, it was drastically shortened from 90 to 15 minutes. Moreover, the background noise intensity of the conventional HINT is fixed at 65 dB SPL. In this case, when the signal speech intensity was set to 75 dB SPL, which was raised by 10 dB from background noise intensity, many of the subjects complained of discomfort with the sound. Therefore, in this study, the intensity of background noise was set to 60 dB SPL, which is 5dB lower than the conventional HINT. This is the level of normal conversation sound presented by the US Centers for Disease Control and Prevention. This can reduce the discomfort of the subjects and protect their hearing during the tests.

This study has some limitations. First, in order to check the validity and reliability, the quick-HINT test results should be directly compared with the results of references. Although, the reliability of Speech-in-Noise tests and WIN were approved in previous studies [24], it is considered that further studies will be necessary to directly confirm the reliability with test-retest method. In terms of validity, there was a difference of the sound presentation method; the conventional HINT was dichotic, and the quick-HINT method of this study was diotic. From a previous study, the diotic method was better or similar to dichotic method to the subjects with hearing loss [25], so the diotic method of this study would be also valid and useful. Moreover, the study did not reflect health behaviors such as smoking and obesity, various medical history such as hypertension, diabetes, and tinnitus, etc., and occupational history related to noise exposure, which may affect the hearing of the subject. Also, the characteristics of the test speech (high and low context, familiar and unfamiliar speakers), and the environmental effects such as the location between the sound source and the subjects could be different [26].

CONCLUSIONS

The deterioration of speech intelligibility in noisy environment is rarely evaluated, even though it is the most common complaint that people with hearing loss have. From the results of this study, it is difficult to say that pure-tone audiometry completely reflects the deterioration of speech intelligibility under background noise conditions, especially in mild to moderate noise-induced hearing loss. Furthermore, speech intelligibility can be affected by in accordance with the intensity of the background noise and hearing level.

Therefore, in order to evaluate the communication ability and social adaptability of workers with hearing loss, it would be recommended to conduct Speech-in-Noise Tests. In the future, further studies are needed to evaluate the fitness for work and the speech intelligibility of workers with noise-induced hearing loss in noisy worksite.

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