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# Acceptable range of speech level for both young and aged listeners in reverberant and quiet sound fields

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The speech level of verbal information in public spaces should be determined to make it acceptable to as many listeners as possible, while simultaneously maintaining maximum intelligibility and considering the variation in the hearing levels of listeners. In the present study, the universally acceptable range of speech level in reverberant and quiet sound fields for both young listeners with normal hearing and aged listeners with hearing loss due to aging was investigated. Word intelligibility scores and listening difficulty ratings as a function of speech level were obtained by listening tests. The results of the listening tests clarified that (1) the universally acceptable ranges of speech level are from 60 to 70 dBA, from 56 to 61 dBA, from 52 to 67 dBA and from 58 to 63 dBA for the test sound fields with the reverberation times of 0.0, 0.5, 1.0 and 2.0 s, respectively, and (2) there is a speech level that falls within all of the universally acceptable ranges of speech level obtained in the present study; that speech level is around 60 dBA.

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## I. INTRODUCTION

A public address (PA) system is frequently used in public spaces, since it can supply verbal information to many people at the same time. Needless to say, verbal information should be transmitted to all listeners accurately. PA systems can amplify verbal information to transmit it accurately. However, the optimum sound pressure level of verbal information in public spaces has not been clarified. There are two reasons for this problem. First, the loudness of verbal information depends on the hearing level of individual listeners. Second, different listeners are present in public spaces, such as facilities for passengers, shopping malls, and hospitals. Furthermore, the proportions of age, sex and hearing loss of listeners depend on the type of public space. Therefore, it can be easily surmised that one listener may feel the loudness of verbal information to be comfortable while another listener may feel it to be too loud or soft, and yet another listener might not be able to understand the information presented. The fact that the number of elderly with hearing loss due to aging are increasing in such public spaces accelerates this problem. Although hearing aid systems have some potential to alleviate this problem, most listeners with mild or moderate hearing loss do not wear hearing aids unless they encounter serious difficulty in verbal communication in daily life.

Common hearing aids amplify not only speech but also detrimental sounds such as noise and reverberation sounds, and they are still expensive. Therefore, the sound pressure level of verbal information presented in public spaces should be determined to make it acceptable for as many listeners as possible, while simultaneously maintaining maximum intelligibility and considering the variation of hearing levels of listeners.

The most comfortable loudness or listening level (MCL) is useful in determining the acceptable speech level of verbal information presented in public spaces. There are several studies of MCL for monaural speech in a quiet condition with normal-hearing listeners, and the results of these studies demonstrate that MCL for speech in quiet fields ranges from 50 to 70 dB sound pressure level (SPL).<sup>1–4</sup> In addition, those studies include other important suggestions relevant to the present study. Ventry and Woods<sup>2</sup> and Hochberg<sup>4</sup> suggested that MCL would increase when the attention to intelligibility was instructed before starting listening tests. This tendency should be considered because intelligibility is essential to verbal information in public spaces. Meanwhile, Berger and Lowry<sup>3</sup> recommended regarding MCL as MCR: the most comfortable range, because the standard deviations of MCL were larger than those generally shown in threshold measurements. In other words, MCL is not a particular level but it has a broad range. For example, Pollack<sup>5</sup> reported that the difference between the upper and lower limits of MCL for

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the pure tone of 1 kHz was more than 30 dB. Hochberg<sup>4</sup> reported a wider MCR variance of 40–92 dB SPL for speech.

Noise and reverberation sounds are also important factors in determining the acceptable speech level of verbal information in public spaces. While the effect of reverberation sounds on MCL is rarely studied, there are many studies of the effect of noise on MCL. The results of such studies showed that MCL increased with increasing noise level. Richards<sup>6</sup> measured MCLs for speech in the presence of masking noise of 55–85 dB SPL, and suggested that the slope of MCL growth as a function of noise level was 0.70 dB/dB. Heusden *et al.*<sup>7</sup> measured the preferred listening level of speech in a reverberant and noisy room, using a similar method and instruction to those of MCL. The results showed that the preferred listening level begins to increase from 50 dBA when the noise level exceeded 35 dBA, and that the slope of preferred listening level growth as a function of noise level was 0.31 dB/dB for noise levels of 50 dBA and higher.

From the viewpoint of the optimization of hearing aid gains, the effects of hearing level on MCL and the upper limit of MCL for speech (ULCL) have been well studied.<sup>8–11</sup> Generally speaking, the results of these studies demonstrated that MCL and ULCL increase with increasing hearing level or speech reception threshold. However, the slopes of MCL and ULCL as a function of hearing level or speech reception threshold varied widely from 0.18 to 0.72 dB/dB. These findings correspond to MCL measured by Nábělek and Robinette<sup>12</sup> who used MCL to determine the presentation level of speech stimuli.

Meanwhile, Kobayashi *et al.*<sup>13</sup> obtained the optimum speech level for the young by measuring listening difficulty<sup>14</sup> as a function of speech level. Listening difficulty is a subjective rating that is the ratio of listeners who find difficulty in listening to words. They defined the optimum speech level as the level that minimizes listening difficulty. They reported that the optimum speech level for the reverberant time of 0.5 s is around 50–55 dBA when noise level is less than 40 dBA, and that the optimum speech level is higher than the noise level by at least 15 dB when noise level is from 40 to 55 dBA. Note that they measured speech level when only the direct sound was presented. The test conditions adopted by Kobayashi *et al.* are similar to those used by Heusden *et al.*,<sup>7</sup> and their results qualitatively correspond to each other.

In the present study, the acceptable speech level was obtained by the same method as used by Kobayashi *et al.*,<sup>13</sup> because it has several advantages for determining the acceptable speech level of verbal information in public spaces. First, listening difficulty<sup>14</sup> is measured using the most familiar words as the test signals. In general, the words used for verbal information in public spaces are selected to be very familiar to all listeners. Therefore, listening difficulty for the most familiar words coincides with listening difficulty in real situations. Second, listening difficulty is rated just after taking dictation of each test signal. As mentioned previously, the attention to intelligibility increases MCL.<sup>2,4</sup> Considering that intelligibility is essential to verbal information in public spaces, listeners' attention must be directed to intelligibility

in listening tests on the optimum speech level. In the method of measuring listening difficulty, listeners' attention is directed to intelligibility by forcing listeners to take dictation of test signals. Furthermore, word intelligibility scores can be calculated from the results of the dictation. Word intelligibility scores are useful in evaluating a lower speech transmission performance that cannot be evaluated by listening difficulty ratings.<sup>14</sup> Finally, listening difficulty as a function of speech level is useful in investigating the upper and lower limits of the acceptable speech level.

To clarify the acceptable speech level in public spaces, it is necessary to consider speech level, background noise, reverberant sounds, and hearing loss of listeners as parameters of the listening test. However, it seems to be difficult to consider all parameters at once. Therefore, the purpose of the present study was focused on the effect of detrimental reverberant sounds on the acceptable speech level for both the young and the aged.

The acceptable range of speech level for both young listeners with normal hearing level and aged listeners with hearing loss due to aging were investigated in quiet and reverberant sound fields. The procedure of the present study is described below.

First, the acceptable ranges of speech level for the young and aged were obtained, respectively. The acceptable speech level is defined as the level that does not cause a statistically significant increase in listening difficulty relative to the minimum listening difficulty, and simultaneously maintains the maximum word intelligibility. Next, the acceptable ranges for the young and the aged were compared to clarify the overlapping range, that is, the universally acceptable range for both the young and the aged.

## II. TEST I: ACCEPTABLE SPEECH LEVEL IN REVERBERATION-FREE AND QUIET SOUND FIELD

### A. Method

Two groups of listeners participated in the listening test. The young group consisted of ten young adults (four males, six females) in their twenties. The aged group consisted of 20 adults (nine males, 11 females) whose age ranged from 65 to 77 years old. No listener wears a hearing aid in daily life. Hearing levels for both ears were measured using an audiometer in 5 dB steps in a sound-treated room. Figure 1 represents the mean hearing levels for the two groups and the estimated mean hearing levels for 20-, 60-, 70-, and 80-year-old listeners based on ISO 7029.<sup>15</sup>

The mean hearing levels for the young (open circles in Fig. 1) were close to the estimated mean hearing levels for 20-year-old listeners. This indicates that the young listeners had normal hearing levels. Meanwhile, the mean hearing levels for the aged (open triangles in Fig. 1) were almost the same as that for 70-year-old listeners at frequencies above 1 kHz. Considering that the average age of the aged group was 68.8 years old, the aged listeners used in the listening test were representative samples of typical aged people in terms of hearing levels at frequencies above 1 kHz that affect listening difficulty and word intelligibility.<sup>16</sup> The differences between measured and estimated hearing levels were

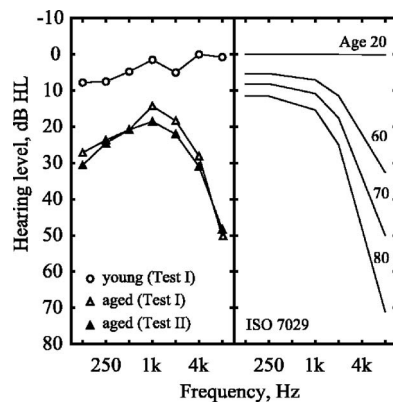


FIG. 1. Audiograms for listeners used in tests I and II. Open circles and triangles respectively represent those for the young and the aged in test I. Closed triangles represent that for the aged in test II. Solid lines in the right panel represent mean hearing levels for 20-, 60-, 70- and 80-year-old listeners estimated according to ISO 7029. The estimated hearing levels are the average of those for male and female listeners.

relatively large at frequencies from 125 to 500 Hz. This increase in hearing levels at low frequencies was common to the young and the aged. Therefore, it might be due to the background noise of the sound-treated room.

The listening tests were performed in an anechoic chamber. A total of 200 different Japanese words were used as test words. The test words were selected from the word lists by Sakamoto *et al.*<sup>17</sup> as most familiar words to both the young and the aged. The verbal information supplied by PA systems generally comprises sentences consisting of very familiar words that also minimize the cognitive effect of word familiarity on word intelligibility and listening difficulty. All test words have four syllables. The test words recorded in an anechoic chamber were used as the test signals. The test signals were presented from a loudspeaker (Fujitsu Ten, TD512) at a distance of 2 m in front of the listener. The frequency characteristics of the loudspeaker are flat within  $\pm 5$  dB in the range from 100 to 10 kHz. The sound pressure levels of the test signals (speech level) were changed in ten steps of 5 dB from 30–75 dBA at the position of the center of the listener's head. The speech level was the A-weighted slow peak level measured using a sound level meter.

Twenty of the 200 test words were presented to each listener for each of the ten different speech levels. Thus, each listener listened to a set of 200 test signals in total (20 words  $\times$  10 speech levels) in a random order. Moreover, each word was presented to a listener only once. The interstimulus interval was 10 s. The listening test was separated into four sessions of listening to 50 test signals. A different set of 200 test signals was presented to each listener. In the whole of the listening test, 200 test signals were presented for each speech level for the young group (20 test signals  $\times$  10 listeners), and 400 test signals for each speech level for the aged group (20 test signals  $\times$  20 listeners). Each listener was tested individually. Each listener was asked to take dictation of each test signal as they listened using kana characters (Japanese phonogram) and simultaneously to rate the listening difficulty into one of the four categories shown in Table I.<sup>14</sup> Before the listening tests, as an exercise, each listener listened to ten test signals that consisted of ten words other than the 200 test

TABLE I. Categories of listening difficulty (see Ref. 14).

1	Not	difficult
2	A little	difficult
3	Fairly	difficult
4	Extremely	difficult

words. The exercises for the aged listeners were repeated until they could complete the task within the interstimulus interval.

## B. Results and discussion

Word intelligibility scores and listening difficulty ratings were obtained from the results of the listening test. The word intelligibility score is the percentage of test signals written down correctly. The listening difficulty rating is the percentage of the sum of the responses rated listening difficulty of the test signal from “2” to “4” in Table I. Note that listening difficulty ratings decrease when conditions for speech improve, contrary to word intelligibility scores.

Figure 2 represents word intelligibility scores and listening difficulty ratings as a function of speech level. Closed and open symbols respectively represent word intelligibility scores and listening difficulty ratings. Circles and triangles respectively represent the results for the young and for the aged.

A one-way repeated measures analysis of variance (ANOVA) with speech level as the within-subjects factor was used to analyze the effect of speech level on the word intelligibility scores and listening difficulty ratings. In the present study, all ANOVAs were performed in the same way.

### 1. Results for the young

The word intelligibility scores for the young (closed circles in Fig. 2) were close to 100% for all speech levels. The result of ANOVA revealed that the main effect of speech level was not significant ( $F(9, 81) = 1.7, p = 0.09$ ).

In contrast, the listening difficulty ratings for the young (open circles) were strongly affected by speech level, and varied widely from 3% to 90%. The optimum speech level that minimizes listening difficulty ratings was 60 dBA. The

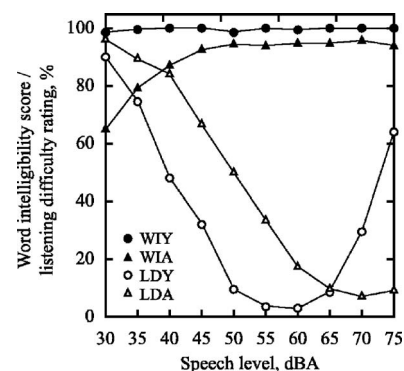


FIG. 2. Word intelligibility scores and listening difficulty ratings as a function of speech level in the reverberation-free and quiet sound field. Closed and open symbols respectively represent word intelligibility scores and listening difficulty ratings. Circles and triangles respectively represent the results for the young and the aged.



result of ANOVA revealed that the main effect of speech level was significant ( $F(9,81)=25.4$ ,  $p<0.05$ ). Tukey's honestly significant difference (HSD) test<sup>18</sup> was employed for multiple comparisons between listening difficulty ratings. HSD for the listening difficulty ratings for the young was calculated to be 28.8% ( $p<0.05$ ). This means that differences between listening difficulty ratings greater than 28.8% would be statistically significant. The minimum listening difficulty rating was not significantly different from the listening difficulty ratings for the speech level from 50 to 70 dBA. Considering that the word intelligibility scores for the young were maximized for all speech levels, the acceptable range of speech level for the young in the reverberation-free and quiet sound field was from 50 to 70 dBA.

## 2. Results for the aged

The word intelligibility scores for the aged (closed triangles in Fig. 2) increased with increasing speech level, and seemed to be maximized when speech level exceeded 45 dBA. The word intelligibility scores varied from 65% to 95%. Note that the word intelligibility scores for the aged did not reach 100%, though there were not detrimental sounds such as reverberation sounds and noise. The result of ANOVA revealed that the main effect of speech level was statistically significant ( $F(9,171)=25.1$ ,  $p<0.05$ ). HSD for the word intelligibility scores for the aged was calculated to be 9.1% ( $p<0.05$ ). This result revealed that there were significant differences between the maximum word intelligibility score and the word intelligibility scores for 40 dBA and lower. In other words, the minimum speech level to maximize word intelligibility scores for the aged was 45 dBA.

Similar to the young group, the listening difficulty ratings for the aged (open triangles) varied more greatly than their word intelligibility scores. The optimum speech level for the aged was 70 dBA, and it was higher than that for the young by 10 dB. The result of ANOVA revealed that the main effect of speech level was significant ( $F(9,171)=94.7$ ,  $p<0.05$ ). HSD for the listening difficulty ratings for the aged was calculated, to be 16.8% ( $p<0.05$ ). The minimum listening difficulty rating was not significantly different from the listening difficulty ratings for 60 dBA and the higher speech levels, and the speech level of 60 dBA is sufficiently high to maximize word intelligibility scores for the aged. In conclusion, the acceptable speech level for the aged in the reverberation-free and quiet sound field was 60–75 dBA and higher.

## III. TEST II: ACCEPTABLE SPEECH LEVELS IN REVERBERANT AND QUIET SOUND FIELDS

### A. Method

Two groups of listeners participated in test II. The young group consisted of 43 young adults (23 males, 20 females) in their twenties. The young listener group did not have their hearing level tested, but none of them reported any known hearing impairment. The aged group consisted of 49 adults (24 males, 25 females) whose age ranged from 59 to 77 years old. No aged listener wears a hearing aid in daily life. All listeners were different from those in test I. Figure 1 also

represents the mean hearing levels for the aged group for test II. The hearing levels for the aged for test II (closed triangles) were almost the same as those for test I. This means the aged listeners used in test II were also representative samples of typical aged people, similar to test I.

A total of 120 different Japanese words were used. All test words were also used in test I. The parameters of the test were reverberation time and sound pressure level. Test words were preliminarily convolved with artificial impulse responses using software on a computer to add reverberant sounds. The impulse responses were composed of a direct sound followed by reverberant sounds. The reverberant sounds started at 50 ms after the direct sound to simplify test sound fields by setting all reverberant sounds to be detrimental to speech perception. The sound pressure ratio of the onset component of the reverberant sounds to the direct sound (Pr/Pd) was constant at 0.1. The reverberation time was set at 0.5, 1.0 and 2.0 s. The frequency characteristic of reverberation time was flat. The reverberant sounds were generated using a digital reverberator (YAMAHA, SPX-900).

The sound pressure level of the test signal was changed in eight steps of 5 dB from 35 to 70 dBA. The sound pressure level was measured as the A-weighted slow peak level at the position of the center of the listener's head when only the direct sound was presented. The sound pressure level in the presence of reverberant sounds increased with increasing reverberation time. The sound pressure levels in the presence of reverberant sounds averaged over all test words for each of the reverberation times were higher than those without reverberant sounds by 5.6 dBA for 0.5 s, 6.7 dBA for 1.0 s, and 8.2 dBA for 2.0 s. In the present study, speech level is defined as the sound pressure level of the test signal including reverberant sounds. For example, the speech level for the reverberation time of 0.5 s changed from 40.6 to 75.6 dBA in 5 dB steps. A total of 24 sound fields (3 reverberation times  $\times$  8 speech levels) were tested.

Five of the 120 test words were presented to each listener for each sound field. Thus, each listener listened to a set of 120 test signals in total (5 words  $\times$  24 sound fields) in a random order. Moreover, each word was presented to a listener only once. A different set of 120 test signals was presented to each listener. The interstimulus interval was 10 s. The listening test was separated into three sessions of listening to 40 test signals. In the whole of test II, 215 and 245 test signals were presented for each sound field for the young group (5 test signals  $\times$  43 listeners) and for the aged group (5 test signals  $\times$  49 listeners), respectively. The test signals were presented to two listeners at a time from a loudspeaker (Technics, SBM300M2) in an anechoic room. The listening positions were located at a distance of 2 m from the loudspeaker and at  $\pm 30^\circ$  from the central axis of the loudspeaker. The frequency characteristics of the loudspeaker measured at the listening positions are flat within  $\pm 5$  dB in the range from 100 to 10 kHz. The listener's task was the same as that in test I. The exercises of test II were performed in the same way as those for test I.

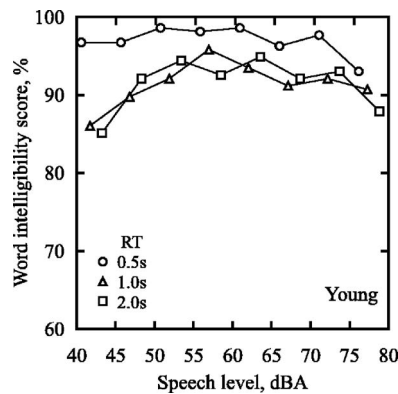


FIG. 3. The word intelligibility scores for the young in reverberant and quiet sound fields. Open circles, triangles and squares represent the word intelligibility scores for the reverberation times of 0.5, 1.0 and 2.0 s, respectively.

## B. Results and discussion

Also in test II, a one-way repeated measures analysis of variance (ANOVA) with speech level as the within-subjects factor was used to analyze the effect of speech level on word intelligibility scores and listening difficulty ratings. The analyses were separately performed for each test sound field.

### 1. Results for the young

Figure 3 represents the word intelligibility scores for the young as a function of speech level. Although the word intelligibility scores for the young were 85% or higher for all sound fields and speech levels, reverberation time and speech level seemed to affect word intelligibility scores. The word intelligibility scores for 1.0 s (open triangles) and 2.0 s (open squares) were lower than those for 0.5 s (open circles), particularly for lower speech levels. The word intelligibility scores for the highest speech levels seemed to be lower than those for other speech levels for all reverberation times, except those for the lowest speech level for the reverberation times of 1.0 and 2.0 s, which also seemed to be lower than those for other speech levels. The results of ANOVA revealed that the main effect of speech level was significant for all reverberation times ( $F(7,294)=2.6$ ,  $F(7,294)=2.3$ , and  $F(7,294)=3.1$  for the reverberation times of 0.5, 1.0, and 2.0 s, respectively) at the 5% significant level. Tukey's honestly significant differences (HSDs) for the word intelligibility scores for the young were calculated to be 4.9, 8.1 and 8.2% ( $p<0.05$ ) for the reverberation times of 0.5, 1.0 and 2.0 s, respectively. For the reverberation time of 0.5 s, the word intelligibility score for the highest speech level of 75.6 dBA was significantly lower than the maximum word intelligibility score. The scores for the lowest speech levels of 41.7 and 43.2 dBA for the reverberation times of 1.0 and 2.0 s, respectively, were significantly lower than the maximum word intelligibility score for each reverberation time. Therefore, the minimum speech levels to maximize word intelligibility scores for the young are 46.7 and 48.2 dBA for the reverberation times of 1.0 and 2.0 s, respectively.

Figure 4 represents the listening difficulty ratings for the young. The listening difficulty ratings for the young were affected by speech level and reverberation time, while word intelligibility scores for the young were almost never af-

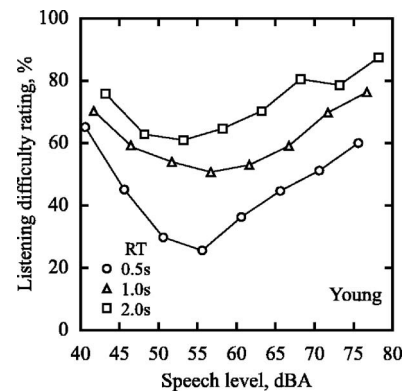


FIG. 4. The listening difficulty ratings for the young in reverberant and quiet sound fields. Open circles, triangles and squares represent the listening difficulty ratings for the reverberation times of 0.5, 1.0 and 2.0 s, respectively.

ected. The optimum speech levels that minimize listening difficulty ratings were 55.6, 56.7, and 53.2 dBA for the reverberation times of 0.5, 1.0, and 2.0 s, respectively. The minimum listening difficulty ratings increased with increasing reverberation time, and they were 26, 51 and 61% for the reverberation times of 0.5, 1.0, and 2.0 s, respectively. The results of ANOVA revealed that the main effect of speech level was significant for all reverberation times ( $F(7,294)=17.2$ ,  $F(7,294)=8.5$ , and  $F(7,294)=13.2$  for the reverberation times of 0.5, 1.0, and 2.0 s, respectively) at the 5% significant level. HSDs for the listening difficulty ratings for the young were calculated to be 14.4, 14.0 and 11.3% ( $p<0.05$ ) for the reverberation times of 0.5, 1.0 and 2.0 s, respectively. The minimum listening difficulty ratings were not significantly different from the listening difficulty ratings for the speech levels from 50.6 to 60.6 dBA, from 46.7 to 66.7 dBA, and from 48.2 to 63.2 dBA for the reverberation times of 0.5, 1.0, and 2.0 s, respectively.

The word intelligibility scores for the ranges of speech level described above were maximized for all reverberation times. Therefore, in conclusion, the acceptable ranges of speech level for the young are from 50.6 to 60.6 dBA, from 46.7 to 66.7 dBA, and from 48.2 to 63.2 dBA for the reverberation times of 0.5, 1.0, and 2.0 s, respectively.

Although the optimum speech level for 2.0 s was rather smaller than those for 0.5 and 1.0 s, the optimum speech levels for reverberant and quiet sound fields were not very different from each other, or from the optimum speech level of 60 dBA for the reverberation-free and quiet sound field. The optimum speech level averaged over all sound fields used in the present study is 56.4 dBA. Kobayashi *et al.*<sup>13</sup> reported that the optimum speech level of direct sound was around 50–55 dBA in the sound field with the reverberation time of 0.5 s and the noise level less than 40 dBA. The reverberant sounds used by Kobayashi *et al.* are the same as those used in the present study. This means that the optimum speech level obtained by Kobayashi *et al.* would increase to around 55–60 dBA in the presence of the reverberant sounds. Therefore, the optimum speech level averaged over all sound fields used in the present study corresponds to the optimum speech level obtained by Kobayashi *et al.*<sup>13</sup> These

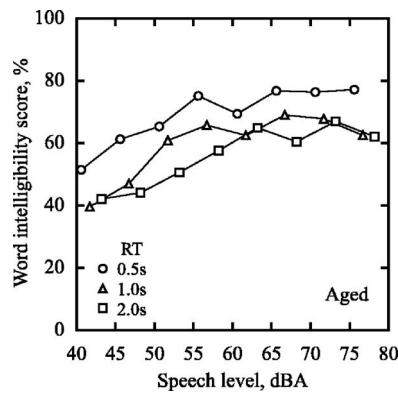


FIG. 5. The word intelligibility scores for the aged in reverberant and quiet sound fields. Open circles, triangles and squares represent the word intelligibility scores for the reverberation times of 0.5, 1.0 and 2.0 s, respectively.

results indicate that, for the young, the optimum speech level including reverberant sounds is not affected by reverberation time.

These results also indicate that the effect of reverberant sounds on the optimum speech level is different from that of noise. In general, MCL for noisy sound fields increases with increasing noise level.<sup>6,7</sup> Kobayashi *et al.*<sup>13</sup> also reported that the optimum speech level increased with increasing noise level, possibly because the detrimental energy of reverberant sounds also increases with increasing speech level. In other words, the speech-to-detrimental energy ratio is not improved by increasing the speech level in reverberant sound fields, while the ratio is improved in noisy sound fields.

## 2. Results for the aged

Figure 5 represents the word intelligibility scores for the aged. The word intelligibility scores for the aged increased with increasing speech level and seemed to be maximum at around 60 dBA. However, the word intelligibility scores for the aged did not exceed 80%, and the maximum scores were 77, 69, and 67% for 0.5, 1.0 and 2.0 s, respectively. The results of ANOVA revealed that the main effect of speech level was significant for all reverberation times ( $F(7,336)=12.7$ ,  $F(7,336)=12.5$ , and  $F(7,336)=12.7$ , for reverberation times of 0.5, 1.0, and 2.0 s, respectively) at the 5% significant level. HSDs were calculated to be 11.2, 12.8 and 11.4% for the reverberation times of 0.5, 1.0 and 2.0 s, respectively. The results of multiple comparisons based on HSD revealed that the word intelligibility scores for the aged were not significantly different from the maximum scores for the speech levels above 55.6, 51.7 and 58.2 dBA for the reverberation times of 0.5, 1.0 and 2.0 s, respectively.

According to results of both tests I and II, the minimum speech level that maximizes word intelligibility seems to increase with increasing reverberation time. However, the minimum speech levels correspond to the speech levels of direct sound of 45, 50, 45, and 50 dBA for the reverberation times of 0.0 (reverberation-free), 0.5, 1.0 and 2.0 s, respectively. This suggests that the speech level of direct sound, or perhaps that of direct sound plus early reflections,<sup>19</sup> might determine the speech level that maximizes word intelligibility scores for the aged in reverberant and quiet sound fields,

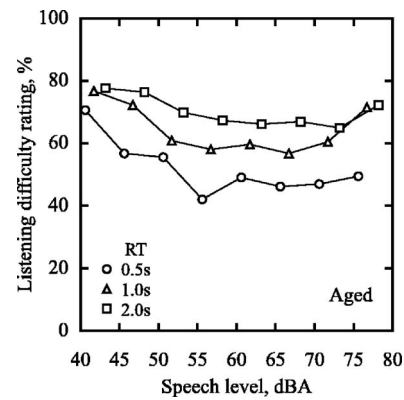


FIG. 6. The listening difficulty ratings for the aged in reverberant and quiet sound fields. Open circles, triangles and squares represent the listening difficulty ratings for the reverberation times of 0.5, 1.0 and 2.0 s, respectively.

and also that the speech level of direct sound of at most 50 dBA is required to maximize the word intelligibility scores for the aged, regardless of reverberation time.

Figure 6 represents the listening difficulty for the aged. The listening difficulty ratings for the aged increased with increasing reverberation time. The minimum listening difficulty ratings were 42, 57, and 65% for the reverberation times of 0.5, 1.0, and 2.0 s, respectively. Although these increases in listening difficulty ratings by reverberant sounds seemed to limit the effect of speech level, the listening difficulty ratings for the aged decreased with increasing speech level, and seemed to be minimized when speech level exceeded around 50 or 55 dBA for all reverberation times. However, the optimum speech levels were unclear, because the curves of listening difficulty rating as a function of speech level for all reverberation times were too shallow and rough to visually determine a local minimum point. The results of ANOVA revealed that the main effect of speech level was significant for all reverberation times ( $F(7,336)=9.9$ ,  $F(7,336)=6.5$  and  $F(7,336)=2.8$ , for reverberation times of 0.5, 1.0, and 2.0 s, respectively) at the 5% significant level. HSDs for the listening difficulty ratings for the aged were calculated to be 12.2, 13.0, and 12.4% ( $p<0.05$ ) for the reverberation times of 0.5, 1.0 and 2.0 s, respectively. The minimum listening difficulty rating was not significantly different from the listening difficulty ratings for the speech levels from 55.6 to 75.6 dBA, from 51.7 to 71.7 dBA, and from 48.2 to 78.2 dBA for the reverberation times of 0.5, 1.0, and 2.0 s, respectively.

The word intelligibility scores in the ranges of speech level described above were maximized, except for the reverberation time of 2.0 s. For the reverberation time of 2.0 s, the lower limit of the acceptable speech level that maximizes word intelligibility scores should be 58.2 dBA. In conclusion, the acceptable ranges of speech level for the aged are from 55.6 to 75.6 dBA and higher, from 51.7 to 71.7 dBA, and from 58.2 to 78.2 dBA and higher for the reverberation times of 0.5, 1.0, and 2.0 s, respectively.

## IV. ACCEPTABLE SPEECH LEVEL FOR BOTH THE YOUNG AND THE AGED

Figure 7 represents the acceptable ranges of speech level for the young and the aged for the sound fields used in the



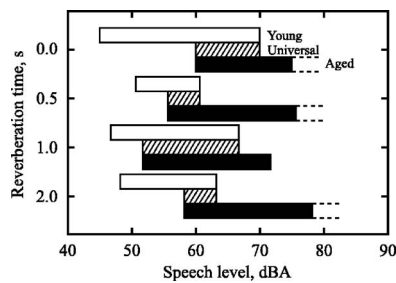


FIG. 7. The acceptable ranges of speech level for each of the sound fields. Open and closed bars represent the acceptable ranges for the young and the aged, respectively. The hatched bars represent the universally acceptable range.

present study. The acceptable ranges of speech level for the young and the aged overlap. This indicates that there is a universally acceptable range of speech level for both the young and the aged for each sound field. The universally acceptable ranges of speech level (the hatched range in Fig. 7) are from 60.0 to 70.0 dBA, from 55.6 to 60.6 dBA, from 51.7 to 66.7 dBA and from 58.2 to 63.2 dBA, for the reverberation times of 0.0, 0.5, 1.0, and 2.0 s, respectively. It is worth noting is a speech level that falls within all of the universally acceptable ranges of speech level obtained in the present study; the speech level is around 60 dBA.

Note that the acceptable speech level in the present study was obtained under quiet conditions. Considering the results reported by Heusden *et al.*<sup>7</sup> and Kobayashi *et al.*,<sup>13</sup> the acceptable speech level should be constant when the background noise level is less than 35 or 40 dBA. When the background noise level exceeds 40 dBA, the acceptable speech level increases with increasing background noise level.<sup>6,7,13</sup>

In the present study, the acceptable speech level was obtained only for three reverberant sound fields. The temporal, spectral, and spatial characteristics of reverberant sounds in public spaces are more complex than those of the three test sound fields. Further investigations are needed to clarify the effects of the characteristics of reverberant sounds on the upper and lower limits of the acceptable speech level.

The optimum speech level for the young might not be greatly affected by the characteristics of reverberant sounds. As described in the previous section, the results of the present study showed that the optimum speech level for the young was almost the same for the three test sound fields, and this might be because the speech-to-detrimental energy ratio under reverberant and quiet conditions was stable regardless of speech level. This indicates that the optimum speech level for the young might be determined by the loudness of speech sounds rather than the speech-to-detrimental energy ratio in reverberant and quiet conditions. Considering that loudness is determined solely by the sound pressures at the left and right ears,<sup>20</sup> the characteristics of reverberant sounds might not affect the optimum speech level for the young.

In the present study, single words controlled by word familiarity were used as test materials. However, the verbal information supplied by PA systems is generally in the form of sentences. It is important to discuss the difference between

the acceptable speech level for single words and that for sentences to clarify the applicability of the present study. In the present study, the acceptable speech level is determined from both intelligibility scores and listening difficulty ratings. The results of the present study indicate that intelligibility scores are related to the lower limit of the acceptable speech level. Generally speaking, sentence intelligibility scores are higher than word intelligibility scores.<sup>21</sup> This means that a lower limit determined using word intelligibility scores would be on the safe side in real situations. Meanwhile, the results of the present study indicate that listening difficulty ratings are related to both the upper and lower limits of the acceptable speech level. It is surmised that the evaluation of listening difficulty would depend on discomfort due to loudness rather than audibility when the speech level is near the limits of the acceptable speech level. Because the minimum speech level to maximize word intelligibility scores was equal to or less than the lower limit of the acceptable speech level for almost all cases in the present study. It is expected that discomfort due to loudness for sentences would be similar to that for single words, if the peak levels in the two cases are equal. In conclusion, the acceptable range of speech level obtained using single words would be practically applicable to PA systems in public spaces.

## V. CONCLUSION

The acceptable range of speech level for both the young with normal hearing level and the aged with age-appropriate hearing loss were investigated using word intelligibility scores and listening difficulty ratings in the reverberation-free and quiet sound field and three reverberant and quiet sound fields.

The acceptable ranges of speech level were obtained for each group of listeners and each sound field using ANOVA and Tukey's multiple comparison tests. The results indicated the following. (1) The acceptable ranges of speech level for the young are from 50 to 70 dBA, from 51 to 61 dBA, from 47 to 67 dBA and from 48 to 63 dBA for the test sound fields with reverberation times of 0.0 (reverberation-free), 0.5, 1.0, and 2.0 s, respectively. (2) The acceptable ranges of speech level for the aged are from 60 to 75 dBA and higher, from 56 to 76 dBA and higher, from 52 to 72 dBA and from 58 to 78 dBA and higher for the test sound fields with the reverberation times of 0.0, 0.5, 1.0, and 2.0 s, respectively.

The comparisons between the acceptable ranges of speech level for the young and the aged revealed that (1) the universally acceptable ranges of speech level are from 60 to 70 dBA, from 56 to 61 dBA, from 52 to 67 dBA and from 58 to 63 dBA for the test sound fields with the reverberation times of 0.0, 0.5, 1.0, and 2.0 s, respectively, and that (2) there is a speech level that falls within all of the universally acceptable ranges of speech level obtained in the present study; the speech level is around 60 dBA.

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