# EFFECT OF EARLY REFLECTIONS ON DIFFICULTY OF LISTENING TO SPEECH IN NOISE AND REVERBERATION

**Hiroshi Sato[1], John S. Bradley[1], and Masayuki Morimoto[2]**

[1]M27-IRC, NRC, 1200 Montreal Rd. Ottawa, ON, Canada, K1A 0R6 Hiroshi.Sato@nrc.ca, John.Bradley@nrc.ca

[2]Faculty of Engineering, Kobe University, Rokko, Nada, Kobe , Japan, 657-8501 mrmt@kobe-u.ac.jp

## 1. INTRODUCTION

When word recognition tests are used as a subjective index for speech intelligibility, it is difficult to describe the differences among sound fields with signal-to-noise ratios above 0dBA because the scores are all very high and usually above 90% in these sound fields[1]. It is necessary to consider another subjective rating to evaluate these sound fields for speech.

Two of listening tests assessed word intelligibility and perceived difficulty of listening to speech in simulated sound fields. The first part was in sound fields including either only direct sound or direct sound with early reflections and under two constant levels of ambient noise. The second part used three types of sound fields: only direct sound, direct sound with reverberation and direct sound with early reflections and reverberation, all with a constant level of ambient noise. Additionally, paired comparison tests were used for some of sound fields in the second part to confirm the significance of some differences.

The purposes of this study are 1) to compare listening difficulty with word intelligibility scores, 2) to show clear evidence that early reflections improve subjective ratings of speech transmission.

## 2. METHOD

2.1 Sound field simulation procedures

All simulated sound fields used a 7-channel electro acoustic system with loudspeakers arranged around the listener in anechoic room. The loudspeaker located directly in front of the listener produced the simulated direct sound and in some experiments also produced reverberant sound. The other six loudspeakers each produced one early reflection and in some experiments reverberant sound. The early reflections arrived at the listener within the first 50 ms after the direct sound. Each loudspeaker also reproduced simulated ambient noise with a spectrum shape corresponding to that of an NC 40 contour and with measured overall level at the listener of 48dBA. The noise signals to each loudspeaker were not coherent. A noise level of 45dBA was used in the first experiment with the same frequency characteristics as the 48 dBA noise.

2.2 Subjects, speech intelligibility tests and listening difficulty rating

Subjects varied from 22 to 58 years of age and they didn't report any hearing disabilities. More than 11 subjects were used in each experiment.

1st and 2nd experiment: Speech intelligibility scores were obtained using a modified rhyme test[2]. The test words were embedded in the sentence "Word number__ is , write that down" and were spoken by a male talker. Subjects were also asked to rate listening difficulty of each test sentence using the four categories: (1) Not difficult, (2) Slightly difficult, (3) Moderately difficult, (4) Very difficult. Sound fields were presented in random order for each sentence and ten responses were collected per person per condition.

3rd experiment: Psychological scales of listening difficulty were obtained to assess the significance of differences among conditions with Sheffe's paired comparison test [3]. After listening to a pair of sentences presented in different conditions, subjects rated the differences in 1 of 5 categories.

## 3. RESULTS & DISCUSSION

1st experiment : The first comparisons were based on the results of tests in which subjects performed speech intelligibility tests and listening difficulty ratings for sound fields with varied speech signal-to-noise ratio (S/N) and for two types of reflection conditions. In one series of tests the sound fields consisted of only a direct sound and varied S/N was obtained by varying the amplitude of the direct speech sound with 45dBA and 48dBA of constant noise. In other series of tests three levels of direct speech sound were used and S/N was varied by adding 3dBA and 6dBA of increased levels of early reflections in combination with the same constant noise levels. Figure 1 shows the relations between S/N and listening difficulty rating and word recognition score. Both subjective ratings show good relations with S/N. Although word recognition score reaches 90% above a S/N of 0dBA, listening difficulty is 90% and just starts to decrease its value. Listening difficulty linearly decreases for S/N from −2.5dBA to 15dBA. Listening difficulty better evaluates these conditions than word recognition scores. Comparing the cases with early reflections and those without early reflection, early reflection energy has the same effect on speech intelligibility and listening difficulty ratings as increased direct sound level.

2nd experiment : The second series of conditions was created to confirm that the effect of early reflections also exist in cases including later arriving speech sounds (reverberation). Both word recognition tests and listening difficulty measurements were done as in the 1st experiment. There were 3 series of conditions. In one series the sound

fields consisted of only a direct sound and varied S/N was obtained by varying the amplitude of the direct speech sound with 48dBA of constant noise. In the second series the sound fields consisted of a direct sound and two levels of reverberation. Reverberation time was 1.2 second and the reverberant speech level was 53.0dBA for the more reverberant case called "A" and 51.6dBA for the less reverberant case called "B". There were four levels of direct sound (3dBA steps from 49dBA) for each reverberant case. In the third series, two levels of early reflections, which increased the effective signal level by 3dBA and 6dBA, were added to the 49dBA of direct sound condition of each of "A" and "B" and were compared with cases which have the same effective signal level. Word recognition scores reached above 90% in all cases except the lowest S/N case and one cannot differentiate between conditions. On the other hand, listening difficulty ratings vary from 100% to 1.5% as shown in Figure 2. Reverberation effects on listening difficulty as determinant factor for both "A" and "B" case without early reflections. The lowest direct sound case in "B" deviates from the main trend and showed lower intelligibility for its S/N value than expected. In all other cases adding early reflections increased the effective S/N and decreased the resulting difficulty rating. This was thought to be due to the large scatter in listening difficulty scores and this was verified in 3rd experiment using a paired comparison test.

3rd experiment : Two only direct sound with noise cases, three cases with "B" reverberant condition and two cases with "B" reverberant conditions and early reflections were selected from the experimental conditions in 2nd experiment to confirm the effect of early reflections more precisely. 42 pairs of speech were presented twice to 11 subjects. The results in Figure 2 describe that the effect of early reflections are more than the effect of increasing direct sound energy and the difference between the condition with early reflections and without them is significant at the $p<0.05$ level. The results confirmed that the lowest S/N condition with late arrival energy is the most difficult in conditions with late reflections and not the same as the results in the 2nd experiment which included larger scatter.

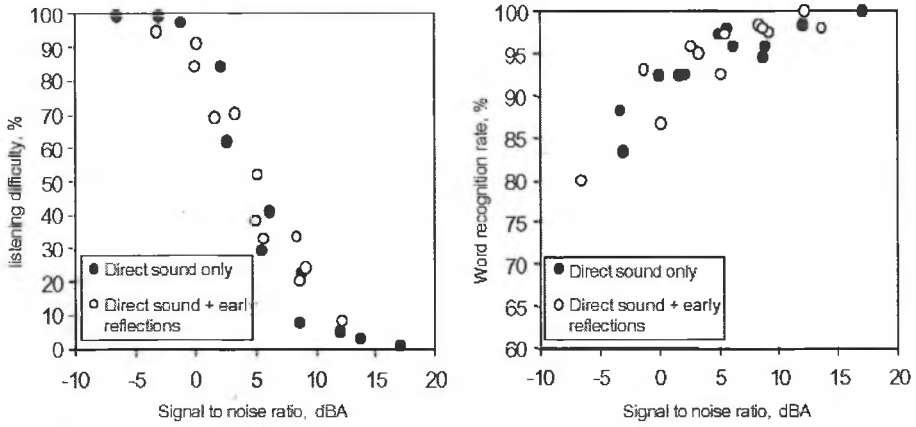


Figure1. Relation between S/N(A) and listening difficulty (left panel) and word recognition rate (right panel).

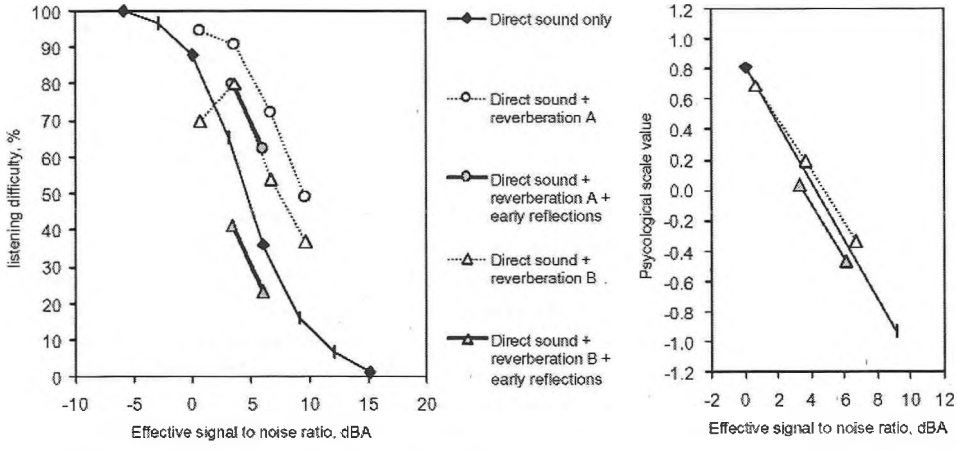


Figure2. Relation between Effective S/N(A) and listening difficulty (left panel) and psychological scale of listening difficulty obtained by paired comparison method (right panel). In calculating Effective S/N(A) values, the reverberant speech sound was excluded from the signal level.

## 4. CONCLUSION

The results demonstrate that: 1) difficulty starts to decrease for conditions in which word intelligibility scores are above 90%, and difficulty scores decrease to 5% around a 15dB signal-to-noise ratio as in the first experiment; 2) added early reflections increase the effective signal-to-noise ratio much more than in the conditions with reverberation. The second result suggests that the effective benefit of early reflections on listening difficulty ratings is greater than expected from the simple increase in early arriving speech energy.

## REFERENCES

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