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Relating speech intelligibility to useful-to-detrimental sound ratios (L)

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This letter corrects typographical errors in two previously published regression equations relating measured speech intelligibility scores and useful-to-detrimental sound ratios. The implications of one of these corrections on a more recent paper are shown to be small. A new and more generally applicable relationship is presented that was derived from a larger data set. This new relationship is presented as a better means of estimating expected speech intelligibility from useful-to-detrimental sound ratios in a wide range of rooms.

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I. INTRODUCTION

Two earlier publications related speech intelligibility test scores in rooms to measured useful-to-detrimental sound ratios. The first study¹ considered a range of larger rooms. The second study² was based on measured values in school classrooms. One of the relationships from the classroom study was used in a more recent publication³ that compared the implications of various speech intelligibility metrics when applied to classrooms. It has been brought to our attention that there were typographical errors in the original documents^{1,2} that have also influenced the analyses of the more recent publication.³

More generally applicable relationships between speech intelligibility scores and useful-to-detrimental sound ratios can be derived by combining the data from both of the earlier studies. This was done previously to a limited extent but not widely publicized.⁴

This letter therefore has three objectives. The first is to correct the errors in the published regression coefficients of the equations relating speech intelligibility scores and useful-to-detrimental sound ratios. The second is to consider the implications of the corrected relationship on the comparisons with other speech metrics. The third objective is to make available a more broadly applicable relationship based on the results of both earlier measurement studies.

II. CORRECTIONS TO PREVIOUS ERRORS

The initial measurement study included a regression equation [Eq. (9) in Ref. 1] relating measured speech intelligibility scores (SI) using a Fairbanks rhyme test to measured U_{95} values. The U_{95} values were obtained according to the original useful-to-detrimental sound ratio concept proposed by Lochner and Burger.⁵ Useful-to-detrimental sound ratios are the ratio of the sum of the direct and early reflections of the speech sounds to the combination of the later-arriving speech sounds and ambient noise. They have been shown to be good predictors of speech intelligibility scores

in rooms because they combine the effects of signal-to-noise ratio and room acoustics. Lochner and Burger's original formulation included a somewhat complicated weighting of the importance of each early arriving reflection in the calculation of the useful component of the ratio. The obtained relationship [Eq. (9) in Ref. 1] should have been given as

$$SI = +0.7348U_{95} - 0.09943U_{95}^2 - 0.0005457U_{95}^3 + 97.39. \quad (1)$$

The final constant was incorrect as previously published.

Equation (2) in Ref. 2 also included a typographical error. It related measured speech intelligibility scores (SI) to measured U_{50} values. U_{50} is a useful-to-detrimental ratio where the early energy is an unweighted sum of the direct sound and early reflections arriving within 50 ms after the direct sound. This equation should have been printed as follows:

$$SI = +1.027U_{50} - 0.0838U_{50}^2 + 99.42. \quad (2)$$

A zero was missing from the coefficient of the squared term in the original publication.

III. IMPLICATIONS OF THE CORRECTIONS

The incorrect version of Eq. (2) above was used in the recent comparison of various speech metrics and was repeated (incorrectly) as Eq. (27) in Ref. 3. When this is corrected, Fig. 6 from Ref. 3 is changed, along with some small details derived from this form of graph for various room volumes that were included in Table II (of Ref. 3). The re-calculated version of the former Fig. 6 is included here as Fig. 1. It shows calculated speech intelligibility scores (SI) versus reverberation time (T) for various combinations of $L_n - L_{splm}$. Here L_n is the ambient noise level and L_{splm} is the speech level at 1 m in a free field.

FIG. 1. Speech intelligibility given by the Fairbank's rhyme test, calculated using Eq. (2) with U_{50} obtained from Eq. (12) (of Ref. 3) as a function of the reverberation time T , for a 300-m^3 classroom and for $L_n - L_{splm}$ equal to -10 dB ($\circ$), -20 dB ($\triangle$), and -30 dB ($\square$). Indicated in this figure is the "minimum optimum" value of 100% speech intelligibility recommended by Bradley (Ref. 4).

The new figure shows that predicted SI values decrease less rapidly than in the original figure for very small or very large reverberation times. Similar to the original, the figure shows that 100% speech intelligibility scores are found over a range of reverberation times from about 0.1 to 0.9 s for $L_n - L_{splm}$ values of -20 and -30 dB. Table II (of Ref. 3) indicated that, according to U_{50} , 100% speech intelligibility would occur over a range of reverberation times from 0.1 to 1.0 s for most of the combinations of $L_n - L_{splm}$ and room volumes. The corrected calculations indicate that these would change to a range of 0.1 to approximately 0.9 s. Because this is a very small change, a corrected version of the previous Table II is not included here and the discussion and conclusions that were previously made, based on Table II of Ref. 3, would not change.

IV. MORE BROADLY APPLICABLE RELATIONSHIP

A more generally applicable regression equation relating speech intelligibility and useful-to-detrimental ratios can be derived by combining the data from both of the earlier measurement studies.^{1,2} This provides a total of 320 sets of average speech intelligibility scores and measured U_{50} values. The resulting regression equation is

$$SI = +0.861U_{50} - 0.0863U_{50}^2 + 98.24. \quad (3)$$

The associated $R^2 = 0.737$ with $p < 0.0001$.

This new equation is compared with Eq. (2) and the combined original measurement data in Fig. 2. The two equations are seen to be very similar. This is partly because both data sets extended over the range of 1-kHz U_{50} values from -20 to $+2$ dB. Because Eq. (3) is based on a larger number of measurements and a larger range of room sizes, it is preferred for estimating speech intelligibility from U_{50} values.

Figure 2 shows that Eq. (3) indicates that 100% speech intelligibility is reached for a 1-kHz U_{50} value of approximately $+2$ dB. Although Eq. (3) is a good fit to the mean trend, one should use it with some caution. First, the standard deviation about the regression line is $\pm 8.7\%$, indicating some uncertainty to the estimate of the mean trend. Second, because intelligibility scores cannot exceed 100%, this regression line should probably be a little higher for U_{50} values approximately ≥ 0 dB. Thus it is a conservative estimate of when the mean trend reaches 100% speech intelligibility. For these results, 100% speech intelligibility was concluded to indicate near-optimum conditions for speech communication. A goal of 100% speech intelligibility may seem unnecessarily high, but in practice it represents the result of subjects concentrating very hard to do well on a very simple rhyme test. It would not correspond to 100% intelligibility with

FIG. 2. Comparison of regression equations (2) and (3) and the combined data sets from the two earlier studies (Refs. 1 and 2).

more difficult material or in more relaxed listening conditions that would be more representative of everyday situations.

V. CONCLUSIONS

Corrections to two previously published regression equations have been presented. The changes implied by one of these to the analyses of a more recent publication have been demonstrated to be relatively small.

A new regression equation is presented that is thought to be a better indication of the general relationship between 1-kHz U_{50} values and mean speech intelligibility scores. It indicates that a 1-kHz U_{50} value of +2 dB is a reasonable goal for conditions that would permit very good speech communication in rooms.

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