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Acoustical measurements of masks and the effects on the speech intelligibility in university classrooms

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ABSTRACT

Acoustical measurements of three different masks, surgical, KF94, and N95 respirator (3 M 9210+) were performed and compared with the results obtained with no mask on a dummy head mouth simulator to understand the acoustical effects of the three different masks on speech sounds. The speech intelligibility and perceived difficulty of understanding speech sounds with and without an N95 mask were also measured using speech signals convolved with previously measured impulse responses in 12 occupied university classrooms. The acoustic attenuations with the three masks were greatest in front of the talker. The surgical, and KF94 masks resulted in 6–12 dB reductions of high frequency sounds between 2 kHz and 5 kHz, and the N95 respirator decreased sound levels by an additional 2–6 dB at these frequencies. Both surgical, and KF94 masks performed acoustically better at high frequencies between 2 kHz and 5 kHz than N95 mask did. The mean trends of the speech intelligibility test results indicate that young adult listeners at university achieve a mean score of 90% correct at a signal-to-noise ratio (SNR) value of + 8 dBA or higher for no mask conditions, which is a 4 dBA lower SNR value than for N95 mask conditions. The intelligibility scores obtained with N95 mask conditions decreased the correct scores by a maximum of 10% at a SNR of 5 dBA or lower compared to the results obtained with no mask conditions. The perceived difficulty ratings obtained in N95 mask conditions increased the ratings by a maximum of 10% at lower SNR values compared to the results obtained in no mask conditions. Achieving higher SI scores of 95% or more doesn't indicate that the listeners experience no difficulty at all in understanding speech sounds. Higher SNR values are beneficial for achieving better speech communication for both no mask and an N95 mask on a talker in classrooms.

1. Introduction

The effect of SNR (signal-to-noise ratio) is important for speech communication in classrooms for both children and adult listeners [1–3]. The mean noise levels measured both in elementary school classrooms [4] and university classrooms [5,6] during actual classroom situations can vary from 43.7 dBA to 49.1 dBA due to the noise level generated by the occupant's activity, especially for younger children. The mean noise levels during actual lectures in the two different university classrooms were not as high as those measured in the elementary school classrooms with student activities, but indicated that the received speech levels at listener's positions should exceed 59.4 dBA for obtaining a desirable SNR value of + 15 dBA [7]. The measured data during actual lecture situations in the two different university classrooms [5,6] clearly showed that achieving a received speech level of 59.4 dBA at listener's positions would not be easily accomplished.

Recently, face masks are essential for preventing the spread of the viruses indoors as well as outdoors during the pandemic. However, it can be more difficult to understand speech sounds when the talker wears a mask, because the masks greatly reduce the high frequency sounds between 2 and 8 kHz [8,9] and also obstruct visual cues that are especially important for people with hearing loss. Visual cues can help a listener with normal hearing or hearing loss more accurately understand speech signals [10]. Most of the recent studies focused on measuring the acoustic attenuation of speech sounds and showed that medical masks, such as surgical masks and N95 respirators, can reduce the high frequency sounds by 3–12 dB [8,9]. There are quite limited results reported on the effects of masks on the speech intelligibility and the perceived difficulty of understanding speech sounds or the listening effort required to perceive speech sounds [11–13], especially for speech communication in actual classroom situations with realistic ambient noises and instructor's speech voices.

Bottalico et al. [11] investigated the effects of three different types of masks (fabric, surgical, and N95 masks) on speech intelli-

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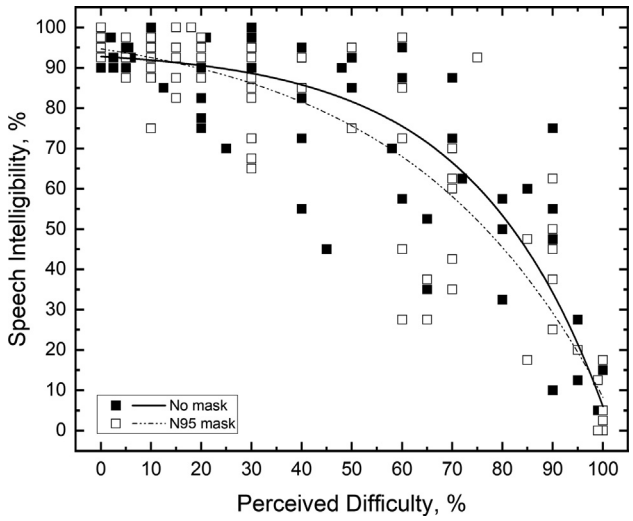

Fig. 8. 168 individual speech intelligibility scores versus perceived difficulty ratings of understanding speech sounds obtained for both no mask and N95 mask conditions.

understanding speech sounds for both no mask and the N95 mask cases. The SI and PD values for both no mask and the N95 mask cases in Fig. 8 show a good fit to the nonlinear regression line, but with large scatter in the results (R^2 = 0.841, and R^2 = 0.849). The best-fit regression lines to the data in Fig. 8 show that the young adult listeners could experience, on average, 0 ~ 20% difficulty of understanding the speech sounds for achieving SI scores of 95% or more for both no mask and the N95 mask conditions. However, with wearing an N95 mask the young adult listeners could achieve a maximum of 10% less correct scores when they perceive the same difficulty of understanding speech sounds. The present results indicate that the N95 masks influence on both speech intelligibility and perceived difficulty of understanding speech sounds in classrooms.

4. Conclusions

The present study has provided measurement and subjective test results that well describe the acoustical effects of masks on the speech intelligibility and perceived difficulty of understanding speech sounds in classrooms. The subjective tests were performed using speech signals convolved with the measured impulse responses in the university classrooms in Korea and therefore reflect conditions in real classrooms.

The surgical mask, KF94 mask, and N95 respirator reduced the sound levels by approximately 6–7 dB for frequencies between 100 Hz and 1.6 kHz, but they showed a greater reduction about 7–13 dB for high frequencies between 2 kHz and 5 kHz. The N95 respirator decreased sound levels by an additional 2–6 dB for high frequencies between 2 kHz and 5 kHz.

The young adult listeners could achieve, on average, speech intelligibility scores of 90% or more at a SNR of 8 dBA or higher for no mask cases and at a SNR of 12 dBA or higher for N95 mask cases. The speech intelligibility scores obtained in N95 mask cases decreased the correct scores by a maximum of 10% at a SNR of 5 dBA or lower compared to the results obtained in no mask cases.

The mean trends of perceived difficulty ratings for both with and without N95 masks on a talker showed that some listeners still experience about 20% difficulty of understanding speech sounds at an ideal SNR value of 15 dBA. That is, achieving higher SI scores of 95% or more doesn't mean that the listeners experience no difficulty at all in understanding speech sounds. The perceived difficulty of understanding speech sounds can only evaluate relatively and cannot indicate which values are acceptable for achieving good speech communication in classrooms. The perceived difficulty ratings obtained for wearing an N95 mask increased the ratings by a maximum of 10% at lower SNR values relative to the results obtained with no mask cases. Higher SNR values (SNR $\geq$ 15 dBA) are beneficial for achieving higher intelligibility scores for both no mask and an N95 mask on a talker in classrooms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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