Acoustic Attenuation of Face Masks Defined by Pure Tone and Audio Book Sampling

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INTRODUCTION

The COVID-19 pandemic has brought unprecedented communication challenges to the deaf and hearing communities alike. Through the use of Audacity audio samples and excel data analysis, it has become clear that masks have a tangible impact on verbal communication and cause measurable amounts of acoustic attenuation. Most recently, scientists have found that face coverings with an impermeable surface have more acoustic attenuation than face coverings with a permeable surface (Saeidi, et. al 2016). However, it should be noted that there isn't any current research on the acoustic properties of face masks as they relate to the COVID-19 pandemic. In this study, disposable surgical masks, pleated fabric masks, shaped fabric masks, furnace-filter hospital masks, ClearMasks, face shields, N95s, KN95s, N95 coupled with a face shield, clear-view fabric masks, and Dublin face shield (face shield with fabric on the sides) were compared with a no-mask reading in an audio booth at The Ohio State University Eye and Ear institute. Through the use of a pure-tone sweep and audio book recording in Audacity, we were able to empirically compare the audio qualities of these masks.

EXPERIMENTAL SET-UP

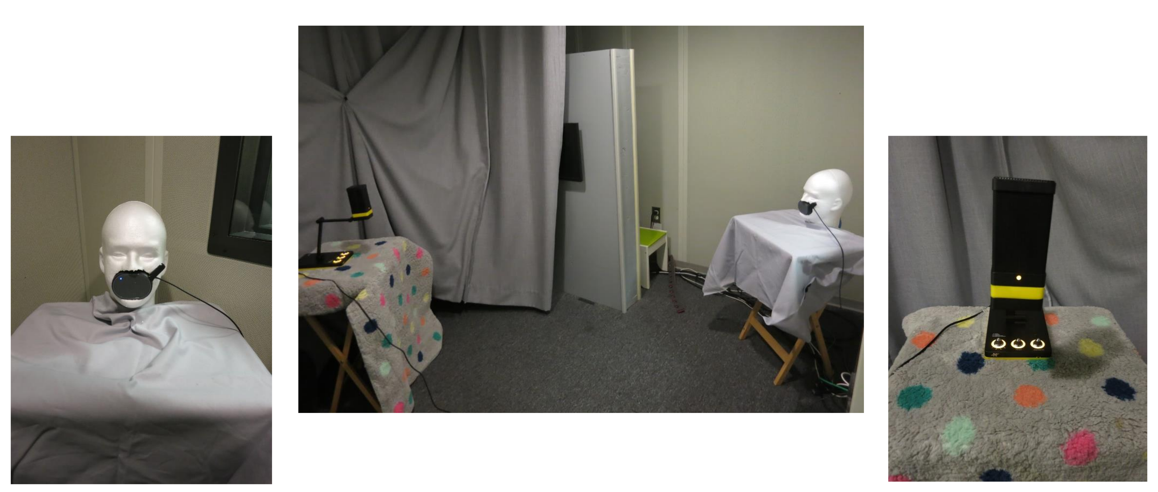

Figure 1. **Sound booth set-up**. All hard surfaces were covered with fabric to help absorb sound reflections that could impact my results. The hardware used was a Sony SRS-XB01 Extra Bass Bluetooth speaker and a Beecaster microphone. Both cover a frequency range of 20Hz to 20 kHz.

Figure 2. **Model of masks on the foam head mannequin.** The masks are attached above the ear using an embedded paperclip and cover the entirety of the speaker, which is carved into the foam head. Fig. 1.1 shows the control with no mask. Fig. 1.2 shows the surgical masks, layered up to 3 surgical masks. Fig. 1.3 shows the KN95. Fig. 1.4 shows the N95, sealed with modeling clay to get a more accurate fit. Fig. 1.5 shows the face shield. Fig. 1.6 shows the N95 combined with a face shield. Fig. 1.7 shows the furnace filter hospital mask. Fig. 1.8 shows the pleated fabric mask. Fig. 1.9 shows the shaped fabric mask. Fig. 1.10 shows the clear-view mask. Fig. 1.11 shows the ClearMask. Fig. 1.12 shows the Dublin face shield, with the fabric attached to the side of the face shield..

EXPERIMENTAL APPROACH

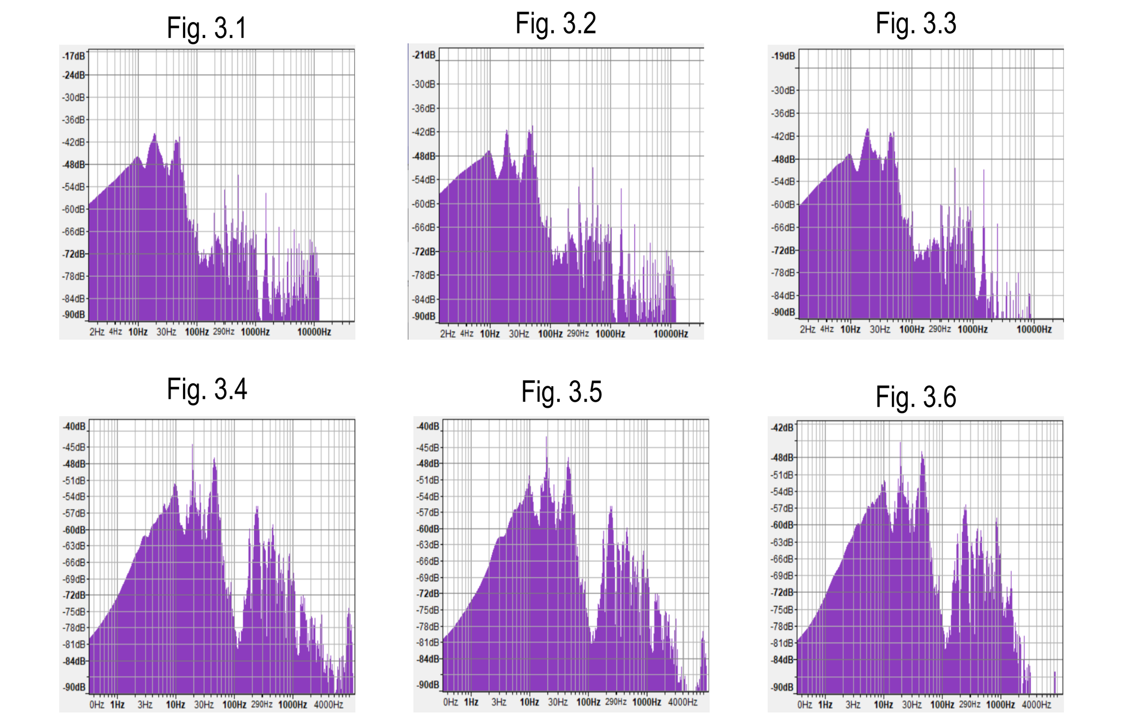

Figure 3. **Pure tone spectrum**. Fig. 3.1 is the control (no mask), Fig. 3.2 is the pure tone 1 surgical mask, Fig. 3.3 is the pure tone face shield, Fig. 3.4 is the audio book control (no mask), Fig. 3.5 is the audio book 1 surgical mask, and Fig. 3.6 is the audio book face shield. This is depicted through a Hann log frequency graph

Results

Mask type	Average attenuation pure-tone (dB)	Average attenuation audio book (dB)	Maximum attenuation in the audiobook data set (dB)	Frequency with maximum attenuation in the audiobook data set (Hz)
1 surgical mask	2.72	2.98	7	9700
2 surgical masks	6.40	6.13	14	9600
3 surgical masks	9.29	8.32	20	9600
KN95	3.58	4.11	9	2800
N95	5.91	6.18	14	4100
N95+face shield	16.51	12.38	28	9600
Face shield	10.75	9.65	28	9300
Furnace filter hospital fabric mask	3.69	3.97	9	10400
Pleated fabric mask	3.19	3.01	10	7400
Shaped fabric mask	2.47	2.44	5	4700
Clear-view fabric mask	10.41	9.25	24	8600
ClearMask	8.80	7.38	25	2300
Dublin engineered face shield	11.42	10.64	29	8600

Table 1. **Cumulative quantitative analysis**. Averages were calculated across all recorded frequencies and without weight in relation to one another. The decimals of attenuation displayed are recorded to the one's place, as the biggest change a human can detect is 3 decibels (Hawkins, 2014). With this in mind, the averages are rounded to the hundredth's place for clarity and a more accurate picture of the average attenuation recorded.

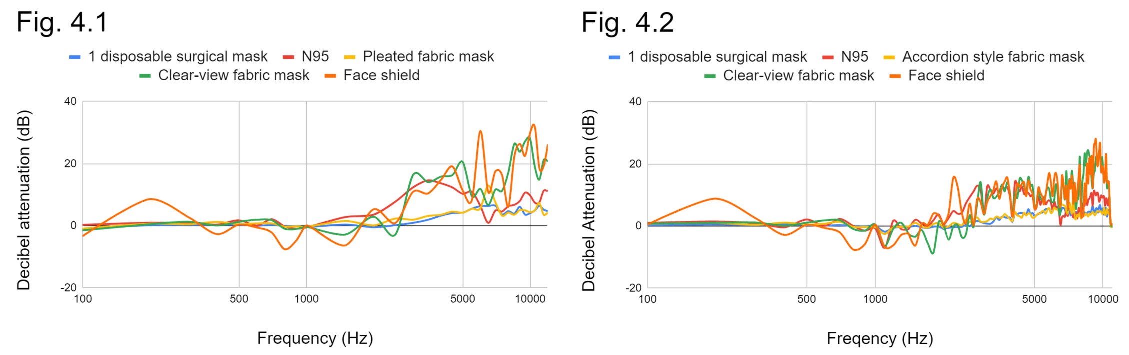

Figure 4. **High interest masks compared to the normalized control**. Masks included in this figure are the disposable surgical mask, N95, pleated fabric mask, clear-view mask, and face shield. These results are consistent through both the pure-tone (Fig. 4.1) and audio book (Fig. 4.2) tests.

COMPARISON GRAPHS

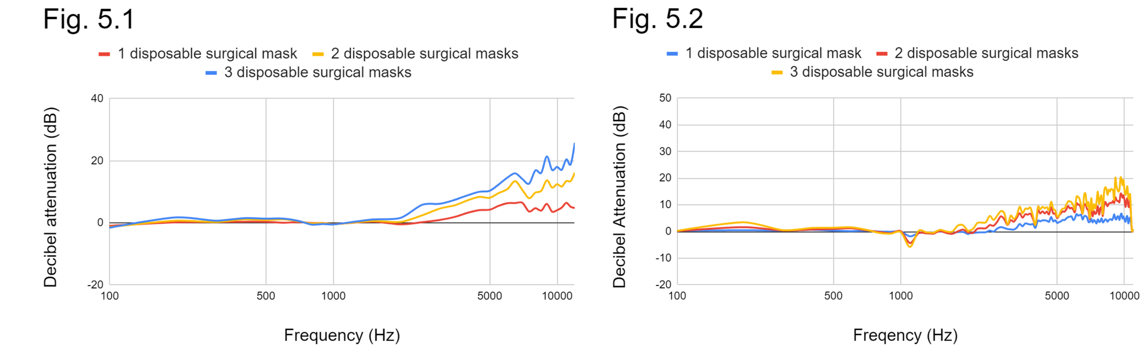

Figure 5. **Layered surgical masks compared to the normalized control**. In this figure, there are 3 different layers of surgical masks, 1 surgical mask, 2 surgical masks, and 3 surgical masks. As demonstrated in both the pure-tone (Fig. 5.1) and audio book (Fig. 5.2), increasing the number of layers of surgical masks decreases the rate of increase of attenuation. It should be noted that this is a current avenue of research, how layering masks provides additional protection against COVID-19.

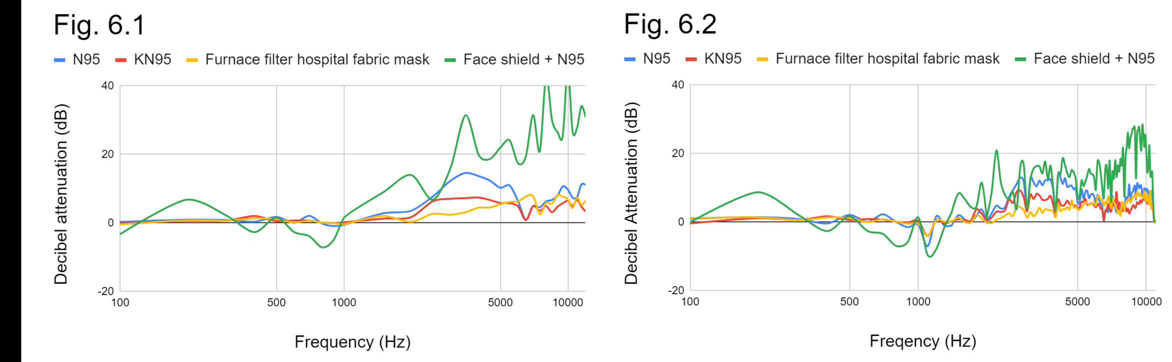

Figure 6. **N95 equivalent comparison**. This figure shows the attenuation of the N95 (blue), KN95 (red), Furnace filter hospital fabric mask (yellow), and Face shield + N95 combination (green). These variables were grouped as they are among FFP3 masks typically worn for personal safety (Kähler et. al. 2020).

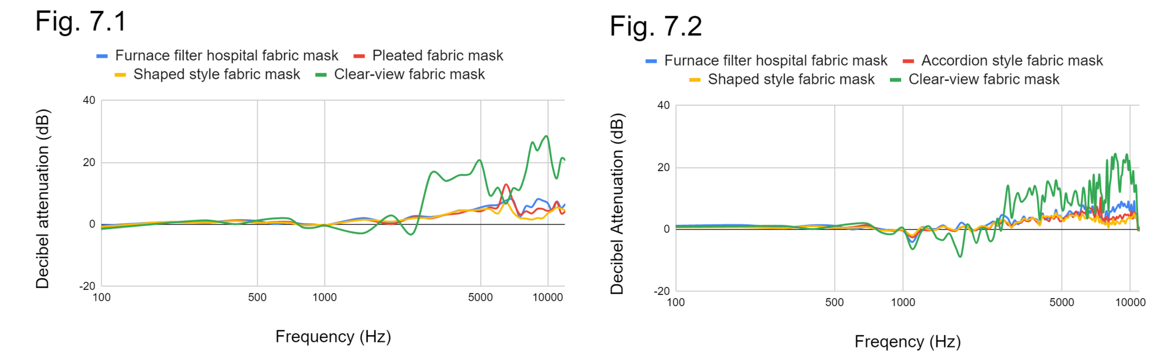

Figure 7. **Fabric mask comparison**. Masks in this section are organized as reusable alternatives of face masks, including the clear-view fabric mask (green), furnace filter hospital fabric mask (blue), pleated fabric mask (red), and shaped style fabric mask (yellow). It is notable that although the shaped fabric mask and pleated fabric mask are made of the same fabric, the shaped fabric mask induces less attenuation.

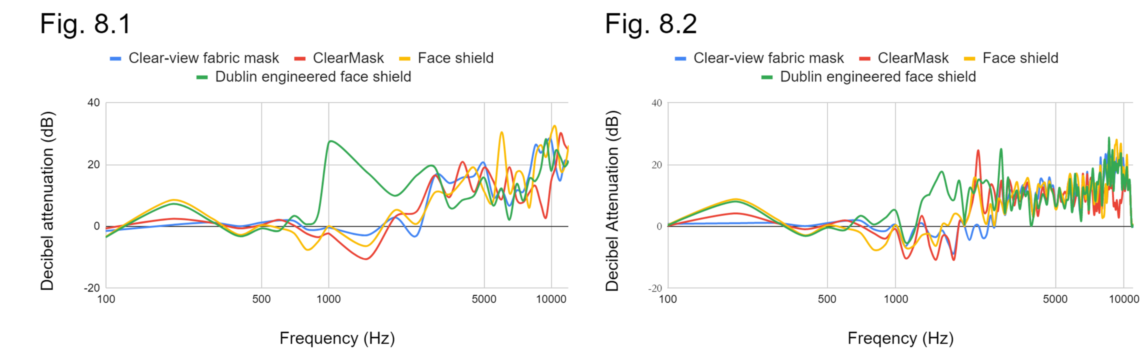

Figure 8. **Visual access solution comparison.** This graph details the Dublin engineered face shield, face shield, ClearMask, and clear-view fabric mask. It should be noted that the acoustic resonance effect can throw off some of these values.

CONCLUSION

There are several major trends that stand out among the data sets. To begin, masks that offer visual access with a hard plastic or vinyl surface have very poor attenuation and high acoustic attenuation. This is best visible through figure 4, which compares the most common masks used during the COVID-19 pandemic, anecdotally speaking. Evidently, the disposable mask and pleated fabric mask had the lowest attenuation when compared with the N95, clear-view fabric mask, and face shield. This is the most readily applied to the real world and an easy reference for which common mask induces the most attenuation.

Second, masks that have a smooth surface have less attenuation than masks with a pleated surface, despite being made with the same material and same number of fabric layers. Shown through figure 7, even though the pleated fabric mask and shaped fabric mask have the same number of layers of fabric and threads-per-inch, the average attenuation of the pleated mask was 3.0125 dB for the audiobook test, while the average attenuation of the shaped mask was 2.4414 dB, also for the audiobook test. This shows how the pleats add to acoustic attenuation marginally. However, it should be noted that the human ear can only detect differences in increments of 3 decibels. Thus, masks with the same fabric composition with or without pleats can be used interchangeably.

Finally, when layering masks, the general trend is that the difference between the first and second layer is higher than the second and third layer. This could be the result of "tamping down" the material to provide a smoother and smoother surface with each additional layer. As shown in figure 5, the difference between 1 surgical mask and 2 surgical masks is, on average, 3.1495 dB, while the difference between 2 surgical masks and 3 surgical masks is 2.1980 dB on average in terms of the pure-tone data. This demonstrates how each new mask added increases the attenuation, however, this increase is less and less notable as each mask is added. As the CDC is exploring new avenues to prevent the spread of COVID-19, layering masks is an avenue of research.

DISCUSSION

Assuming that 1-4 kHz are the most meaningful frequencies for English, it is evident that some masks would be less muffled than others. For example, it is evident that the face shield + N95 induces the most attenuation in this range, while the shaped fabric mask induces the least, but what does this mean for speech? Likely that speech would be less muffled and clearest through the shaped fabric mask, and less understandable through the face shield + N95 combination. This would be a very relevant future course for research going forward.

Looking to the future, there are many questions left unanswered by this project. For example, visual access masks have poor sound quality, but would this be overshadowed by the use of lipreading by deaf individuals? And how would the results change if a male voice had been used for the audiobook sample?

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