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The effect of mask wearing on speech intelligibility in various architectural environments in schools

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Abstract

In this paper, the influence of mask wearing on the speech intelligibility in classrooms was investigated. The covid-19 pandemic required thousands of teachers to wear various types of masks all around the world. The impact on speech intelligibility in this context has not been widely studied. The measured transfer function of various types of masks (incl. surgical masks, N-95, etc.) was used as input for a geometrical model in Odeon. Different types of classrooms with various amounts of average sound absorption coefficients were compared in terms of reverberation time and other speech intelligibility parameters such as $D50$, $U50$ and STI. It was found that classrooms that were not acoustically treated to meet DIN18041 standards were less suited for teaching with masks than classrooms that did not comply with this widely acknowledged standard. A higher background noise exacerbated this difference.

Keywords: room acoustics, architecture, COVID-19, pandemic, mask, classroom, atrium, school, ETFE.

1 Introduction

For classrooms or atria in schools, acoustic comfort plays a vital role in not only the students' health, but also their speech intelligibility needs. According to Bradley and Sato [1], a signal-to-noise ratio (SNR) of up to 20 dB is recommended for speech intelligibility. However, a common practice, confirmed by a study in 41 schools [2], is that the SNR during teaching is usually around 11 dB (background noise sound pressure level ca. 49 dB).

Moreover, considerable attention has been paid to acoustic comfort in educational spaces due to the newly emerging covid-19 pandemic. Covid-19 is a highly transmittable and pathogenic viral infection caused by severe acute respiratory syndrome (SARS-CoV-2), resulting in a dramatic loss of human life worldwide [3]. In recent experimental work by Asadi et al. [4], they concluded that both aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to several days.

To reduce aerosol transmission to the utmost degree, many authorities demand the wearing of a face mask. However, it can be difficult to understand speech when the talker is wearing a mask, especially for listeners with hearing loss that partially rely on lip-reading to compensate for reverberation and noise [5][6]. Some governments also suggest moving classes to larger gathering halls, like atria, in order to increase the distance between people. Speech intelligibility in classrooms and atria has become even more important in this context.

In recent years, buildings with ethylene tetrafluoroethylene (ETFE) foils have attracted attention due to their excellent material properties, good architectural and structural performance compared to glass structures [7]. It has the potential to affect larger spaces positively, such as atria in schools.

Based on the context above, in the thesis on which this article is based we aim to investigate how masks can influence the speech intelligibility of teachers in a small classroom, big classroom, and an atrium with both a glass and ETFE roof, by comparing their T_{30}, D_{50}, U_{50} and STI values in acoustically optimized and unoptimized conditions. Previous work has shown that different types of masks can affect the sound and the speech signal to various degrees, depending on the talker and the level of background noise [8]. Based on this premise, we have simulated 3 types of masks for every model with 3 different levels of background noise in order to find out how the speech intelligibility of the teacher is affected by the different masks under the different levels of background noise. It is worth noting that we focus specifically on teachers talking one-sided to pupils and not on interactive learning situations.

2 Case study

Typical small classroom: 10m x 6m x 2.8m (L x W x H) with 10 people inside (9 students and 1 teacher speaking in front of the blackboard) to simulate the space during the pandemic_(Fig. 2.1). The classroom consists of concrete and timber cladding walls, a blackboard in front, two windows, a polished concrete floor, and a ceiling. No other absorption was added.

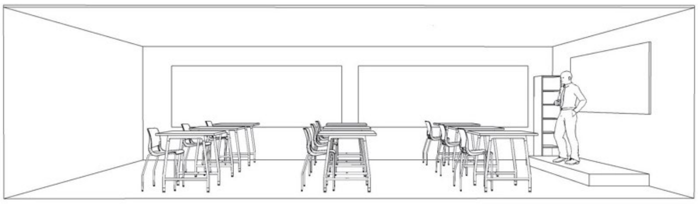

Fig. 2.1 *Small classroom - Spatial acoustic model created in Sketchup, simulated in Odeon*

Typical big classroom: 12m x 9m x 2.8m (L x W x H) with a similar interior like the small classroom (concrete and timber cladding walls, a blackboard, windows, polished concrete floor, and ceiling). In the context of COVID-19, there will be 12 students and a teacher sharing this big classroom (Fig. 2.2).

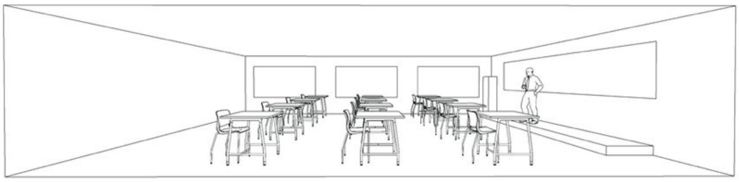

Fig. 2.2 *Big classroom - Spatial acoustic model created in Sketchup, simulated in Odeon*

The third simulated space was the atrium. The total area of the interior surfaces of this atrium (Fig. 2.3) is around 800 m^2 and the volume of the atrium is about 6500 m^3. Covered with an 8-meter high ETFE roof and glazed facade, it allows extensive natural daylighting to penetrate into this large courtyard. The whole space is surrounded by historical facades made of red clay bricks combined with modern plaster works, while the floor is refurbished with PVC tile flooring. Considering the teaching situation during the COVID-19 pandemic, if the number of students per class is the same as before, schools would usually suggest having the class in a larger space in order to maintain social distancing. In this case, the atrium can be used by two classes on different sides of the staircase at the same time, with 25 students and a teacher per class.

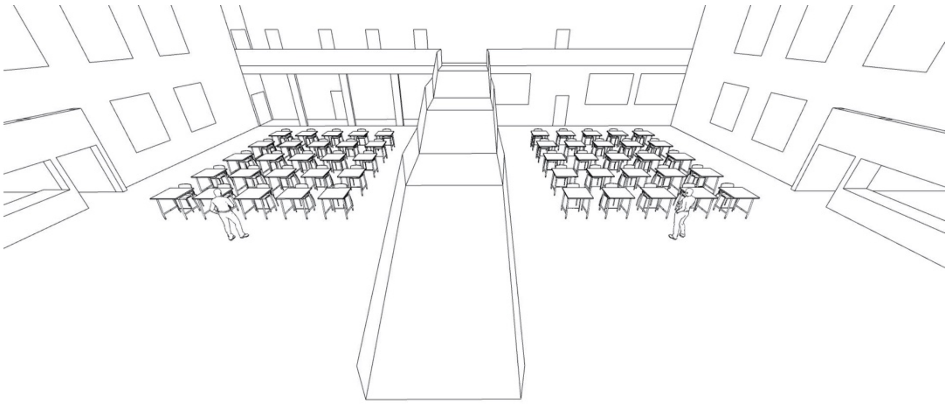

Fig. 2.3 *Atrium - Spatial acoustic model created in Sketchup, simulated in Odeon*

Ethylene tetrafluoroethylene (ETFE) foils have become popular in the last few years for large-scale buildings, such as for atria, stadia, and greenhouses, because of their excellent architectural performance, material properties and structural behavior compared to glass structures [7]. Recent research [32] has also confirmed that the use of ETFE can enhance the room's acoustic comfort due to its acoustic properties. A room covered by ETFE has a shorter reverberation time at low and middle frequencies, which indicates a depression of the noise level in the space and better speech intelligibility.

To further distinguish the differences in speech intelligibility caused by ETFE and glass roofing, 4 various acoustic conditions in this gathering place (used as teaching space in our scenario) will be simulated and discussed. First of all, the atrium with existing materials on the interior surfaces and ETFE roofing. Secondly, the optimized atrium with certain acoustic treatment to reach the German technical requirements for room acoustics. Thirdly, the untreated atrium would be covered by a glass roof and eventually, the optimized atrium with a glass roof.

Every model is put in the simulation under two conditions, the first one is to simulate a teacher talking to students in an environment without background noise; while the second situation is to simulate a teacher talking to students when there is background noise. 3 different ranges of background noise - 40, 45, 50 dB – are considered in the second situation.

A teacher both with and without a mask is simulated in both situations. In every case, a certain type of mask - N95 was simulated to see if there is a noticeable difference on STI. If the difference is noticeable, the simulations of other types of masks were further carried out; if not, other parameters were examined, such as D50 and U50.

3 Results

The average STI in the treated small classroom is generally greater than in the untreated small classroom; a shield mask has the greatest impact on STI compared to other masks and no mask. (see Fig. 3.1) We can see the negative effect of increasing background noise on speech intelligibility in every situation.

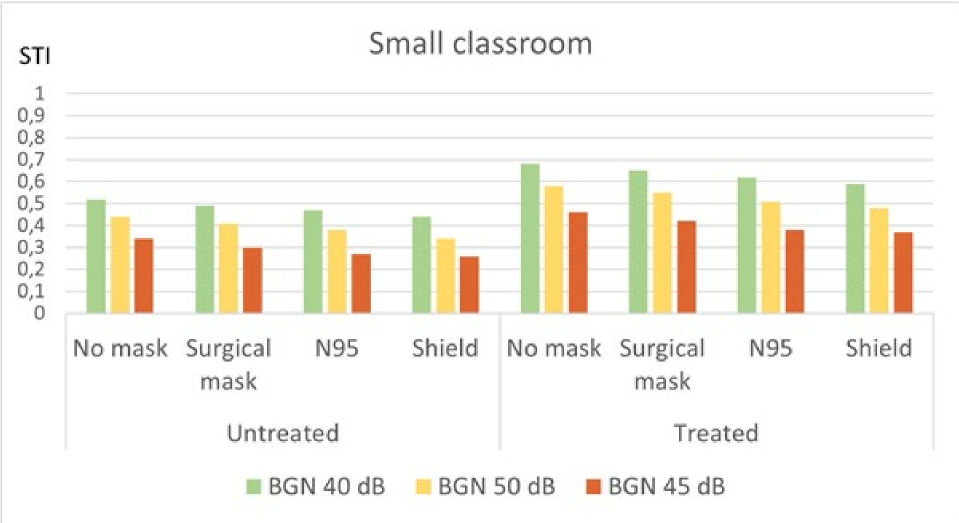

Fig. 3.1 STI average in the untreated/treated small classroom BGN: 40, 45, 50 dB

Generally speaking, the average STI in the treated big classroom is higher than the STI in the untreated classroom; a shield mask has the greatest impact on STI in all 4 situations. (see Fig. 3.2) We can see that STI decreases as the background noise level increases from 40, 45 to 50 dB.

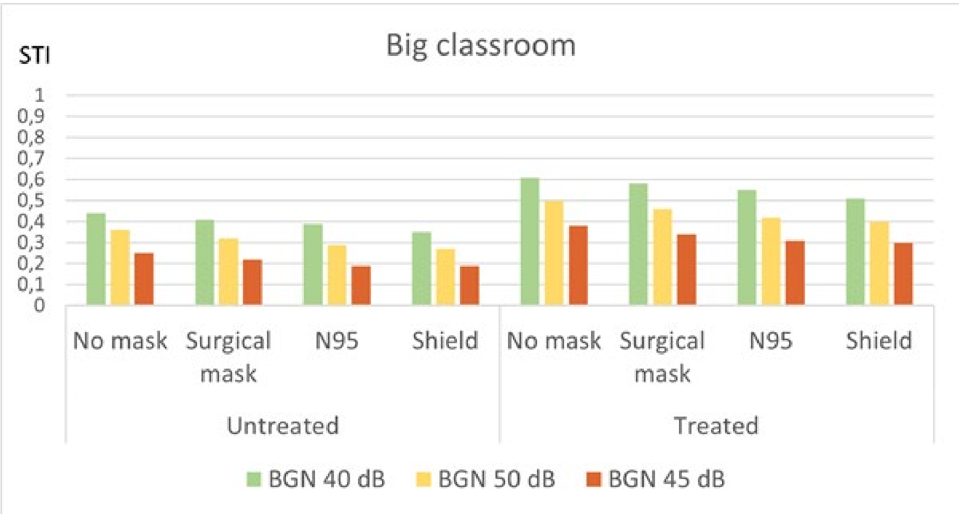

Fig. 3.2 STI average in the untreated/treated big classroom BGN: 40, 45, 50 dB

The average STI (Fig. 3.3; 3.4) in the treated atrium is higher than the STI in the untreated environment, regardless of the material of the roof. A shield mask has the greatest impact on STI across the 4 situations. We can see that STI decreases when background noise increases in all 4 models. However, in general the STI values are relatively low for teaching purposes. For teaching purposes, an STI value of 0.75 and up is required [37].

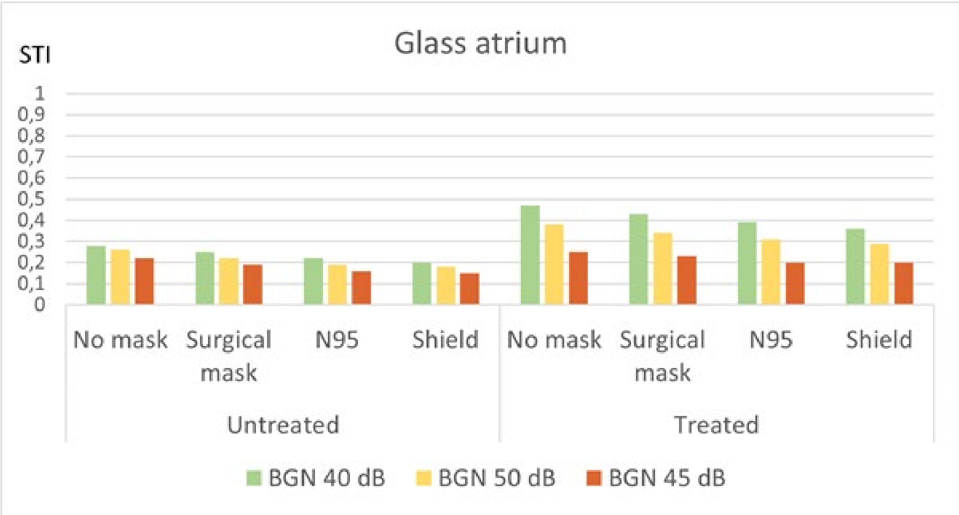

Fig. 3.3 STI average in the untreated/treated atrium, Glass roof BGN: 40, 45, 50 dB

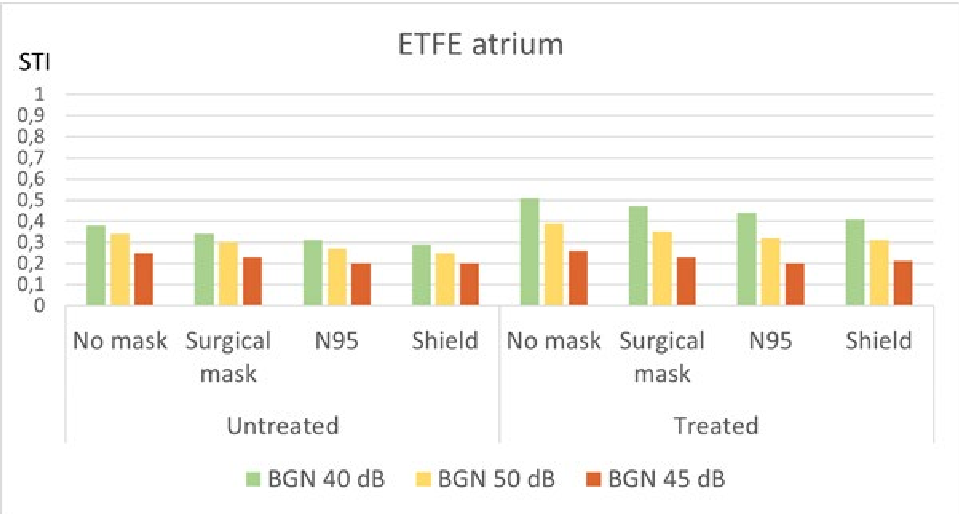

Fig. 3.4 STI average in the untreated/treated atrium, ETFE roof BGN: 40, 45, 50 dB

4 Conclusions

Simulations have shown that teaching a class with or without a mask in quiet spaces (without background noise) will not affect D_{50}, U_{50} and STI, which verifies the conclusion of recent research (C. Toscano and M. Toscano, 2021), stating that face masks have only small effects compared to speech produced without a mask in areas with low levels of background noise. In the case of classrooms without background noise, the examined parameters (D_{50}, STI, U_{50}, T_{30}) in the treated environment show significant improvements compared to the untreated classroom due to the application of wood-wool on the ceiling and the panels with mineral wool on the back wall. The same result can be found in atria without background noise. However, background levels of 35 dB and up are not uncommon in classrooms (Knecht et al., 2002).

When background noise is present, simulations of classrooms have shown that STI can be greatly affected by the teacher wearing various types of masks (Fig. 4.1). Most of these variations are more than or equal to 1 JND (JND of STI is 0.03) (Fig. 4.1), which means they are non-negligible. While in the treated glass atrium and the untreated ETFE atrium, JND of surgical masks is lower than 1 under background levels of 50 dB (Fig. 4.1). In general, the worst impact is caused by a shield and the smallest impact is caused by a surgical mask. The changing of the average STI between mask and no-mask conditions has no regular pattern regardless of the types of masks and the level of background noise.

In case of atria with background noise, both untreated and treated models with a glass roof show worse STI in comparison with the ETFE atria (Fig. 3.3 - 3.4). In particular, simulations have shown that the difference of STI between glass and ETFE atria (Fig. 4.2) is higher in untreated acoustical environments compared to treated spaces; and the disparity will reduce as the level of background noise increases. Furthermore, the STI difference of wearing a shield in glass and ETFE atria will exceed no-mask conditions with 50 dB of background noise (Fig. 4.2).

Therefore, we can conclude that the replacement of the glass roof with ETFE will have a greater impact in an untreated atrium compared to an acoustically treated atrium. In terms of practical applications, if there is a large gathering hall with a glass roof, that has inferior speech intelligibility because of poor acoustical treatment, the installation of a sufficiently large area of ETFE will likely have a beneficial impact on the quality of speech. However, if the area is already acoustically treated but still disturbed by high levels of background noise, retrofitting an ETFE roof will not help much.

It is important to note that this research only focuses on the classic teaching situation, which is when a teacher speaks to his/her students and does not include the active learning (multiple students talk to each other and the teacher). The results have confirmed that wearing the shield has the worst impact on speech intelligibility under the different levels of background noise. However, the effect of visual cues is not taken into consideration in this thesis. According to Sumby and Pollack (1954), the absolute visual contribution must, necessarily, be small at high speech-to-noise ratios, because intelligibility is high under conditions of auditory presentation alone. It might be interesting to do more research about the effect of talking with a shield to speech intelligibility relative to its audiovisual benefits over a type of mask that hides the lower part of a face.

Fig. 4.1 *Difference of STI / JDN of STI between Masked & No mask*
BGN: 40, 45, 50 dB

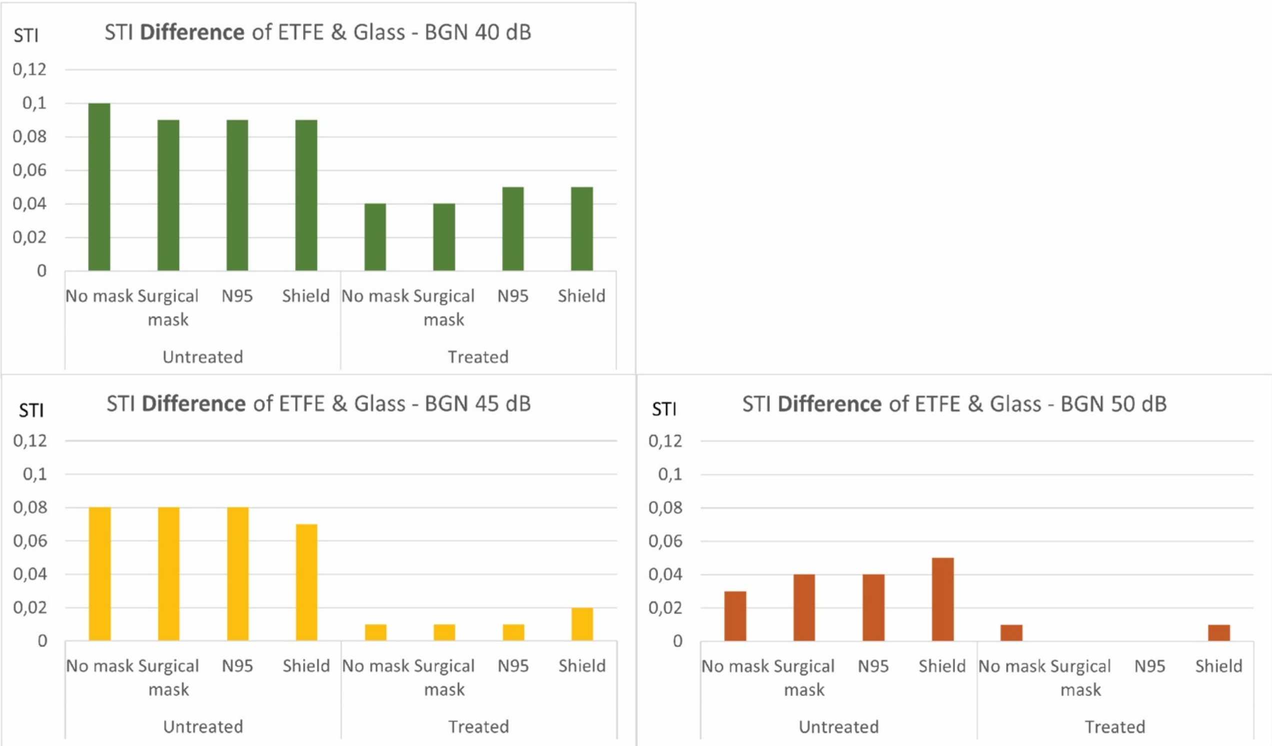

Fig. 4.2 *Difference of STI between Masked & No mask*
BGN: 40, 45, 50 dB

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