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Research Paper

Effect of Curvature Shape of Transparent COVID-19 Protective Face Shields on the Speech Signal

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Recent papers and studies over the course of last three years have shown that COVID-19 has a negative impact on the speech communication quality between people. This paper presents an influence analysis of the curvature shape of protective transparent shields on the speech signal. Five shields made of the same material and dimensions but with different curvatures were analyzed, from a completely flat to a very curved shield which has the same shape of curvature at its top and bottom and covers the entire face. The influence of the shield is analyzed with two types of experiments – one using dummy head with integrated artificial voice device, and the other using real speakers (female and male actors). It has been shown that usage of protective shields results in a relative increase in the speech signal level, in the frequency range of around 1000 Hz, compared to the situation when protective shields are not used. The relative increase in speech signal levels for large-curvature shields can be up to 8 dB. The possible causes of this phenomenon have been analyzed and examined.

Keywords: acoustic effects; COVID-19; curvature; face shield; pandemic; protection; speech.

1. Introduction

The COVID-19 pandemic has affected lives of people worldwide by introducing social distance, hand sanitizers, and the mandatory wearing of face protectors such as protective masks and shields. Protective equipment was used to prevent the spread of the virus but also negatively impacted communication between people. Masks as a visual barrier affected verbal communication, readability of emotional facial expressions, and lip-reading. In everyday communication, lip-reading is extremely useful for people (Dalka *et al.*, 2006).

Transmission of speech signal through the physical channel leads to reduced speech intelligibility, especially in the situation when parasitic signals overlay parts of smaller speech signal amplitudes. Overlaying quieter parts of the speech signal can occur as time-uniform noise coverage or time-limited coverage by reflections in the room (Nábělek *et al.*, 1989). It has been shown that speech intelligibility can be reduced by more than 15% in rooms with a long reverberation time (Liu *et al.*, 2020). Also, in the literature has been shown that at low signal-to-noise ratios in rooms, typically less than 5 dB, speech intelligibility can be below 75% (Liu *et al.*, 2020; Kociński, Sęk, 2005; Choi, 2020; 2021).

Face protective equipment degrades speech intelligibility and many researchers in acoustics have focused on examining the impact of protective masks on speech communication (Nobrega *et al.*, 2020; Caniato *et al*, 2021; Pörschmann *et al*, 2020; Corey *et al.*, 2020; Atcherson *et al.*, 2017; 2020; Magee *et al.*, 2020; Bottalico *et al.*, 2020; Wolfe *et al.*, 2020; Rudge *et al.*, 2020; Kopechek, 2020). Several groups of authors examined speech intelligibility with the use of face protective equipment in rooms, such as school classrooms (Choi, 2021; Caniato *et al.*, 2021; Bottalico, 2020; Wolfe *et al.*, 2020; Rudge *et al.*, 2020). The results of these studies have shown that speech intelligibility with protective masks is less than 25%. Some research analyzed the effects of masks through the forms of long-term speech spectrum as an objective measure of the impact of protective equipment (Choi, 2021; Corey *et al.*, 2020; Atcherson *et al.*, 2021).

These studies show that the attenuation introduced by protective masks can be up to 20 dB at high frequencies. In addition to objective methods for testing some of the hypotheses related to protective masks, subjective tests were also used (Magee *et al.*, 2020; Rudge *et al.*, 2020). The influence of the material from which the protective equipment was made on the speech signal has been investigated in several studies (Corey *et al.*, 2020; Atcherson *et al.*, 2021). Choosing the design and material of the face mask, the boundary conditions of acoustic radiation at the mouth opening of the speaker are changing, so it is necessary to make articulatory adjustments to maintain speech quality (Vojnović *et al.*, 2018). Research has dealt with the direct impact of poor intelligibility due to the usage of protective equipment. Studies have shown that a protective mask affects listener fatigue during prolonged listening due to reduced intelligibility (Choi, 2020; Nobrega *et al.*, 2020).

Research conducted by two groups of scientists has shown that the usage of protective masks reduces speech intelligibility in people with hearing impairments because they do not have lip reading possibility (Dalka *et al.*, 2006; Atcherson *et al.*, 2017). It has been shown that speech intelligibility improves when transparent protective equipment is used in their case. Therefore, some research focuses on examining the impact of transparent protective shields on speech communication (Caniato *et al.*, 2021; Corey *et al.*, 2020; Atcherson *et al.*, 2021). The influences of protective shields of various sizes, primarily on the shape of the speech signal spectrum, were considered. In the first approximation, the shield effect on the speech signal can be described as low-pass filtering. By comparing the difference in the speech signal spectrum in cases with and without the use of a protective shield, it was noticed that in certain areas, typically around 1000 Hz, there is an increase in these differences (Corey *et al.*, 2020; Atcherson *et al.*, 2021). When varying recording microphone positions, it was concluded that the highest levels of the speech signal occur when the microphone is in the space between the mouth and the transparent shield. Explanations for the causes of these increases, can be found related to resonant phenomena in the literature (Atcherson *et al.*, 2021). This indicates that protective shields have some other effects on the speech signal, apart from the weakening that occurs with protective masks.

The value of the energy, between the shields and the face increase of the speech signal, in case of the use of different transparent shields varies (Corey *et al.*, 2020; Atcherson *et al.*, 2021). Therefore, it was hypothesized that the shape of the protective shield, primarily its curvature, may affect the energy increase of the speech signal in a certain frequency range. The stated hypothesis was the motivation for the research presented in this paper. The studies aimed primarily at examining and describing possible reasons for the increase in the speech signal level in determining spectrum parts when protective shields were used. In the literature, different shields were compared. However, they were of different dimensions and made of different materials, so the influence of the shield curvature on the speech signal could not be clearly seen (Atcherson *et al.*, 2021). This article examines the change in the shape of the long term spectrum of the speech signal when protective shields of the same shape were made of the same material but with different curvatures. The realized experiments aimed at quantifying the curvature influence of the transparent shield on the long-term speech spectrum. The comparing approach of the long-term speech spectrum in the case without the shield's usage and in cases where shields of different curvature sizes were used, from a completely flat shield to a shield of large curvature, was used. Experiments were conducted with real speakers reading text in Serbian and also by another method, using a dummy head to enable the repeatability of the experiment.

2. Methods

2.1. Shields of different curvatures

In order to examine and quantify the curvature influence of protective shields on the speech signal, several shields made of the same transparent material with the same dimensions were analyzed. Figure 1a shows the shape of the transparent plastic foil used for protective shields in this paper. The width and height of the foil are 24 cm each, and the thickness is 0.5 mm. The used foil was not purposely made but used plastic foil from shields commercially available in stores and pharmacies. For achieving different curvatures, appropriate plastic supports were used which were produced with a 3D printer. The plastic support was always present on the upper side of the plastic foil so that the transparent foil could be attached to the head. In a situation where it was necessary, the plastic support was placed on the lower end of the plastic foil in order to obtain the appropriate shield curvature.

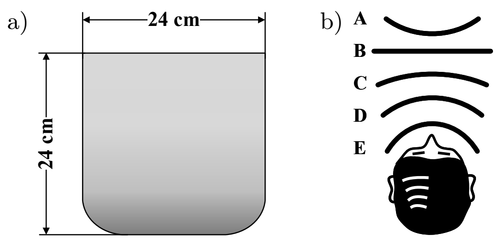

Fig. 1. a) Transparent plastic foil for shields; b) curvature shapes of protection shields.

Figure 1b shows a sketch with the curvature shapes of the protective shields used in this paper. The shields are arranged according to the degree of curvature and marked with letters from A to E. The distances of the middle of all types of shields from the surface of the face are approximately the same, but due to the need to compare the curvature in one place, the sketch is given with shields placed in front of each other. In order to better perceive the shape of the used shields, Fig. 2 shows all the used shields and their position on the human head, frontally and from the profile. Figure 2a shows the protective shield case A, which is not a protective shield in the sense that it is used as a protective device. This shield is the reverse version of the standard shield, i.e., the curve is turned away from the face and not towards it. To analyse the shield curvature influence on the speaking signal, this shield was chosen as the antipode to the shield that has the greatest curvature.

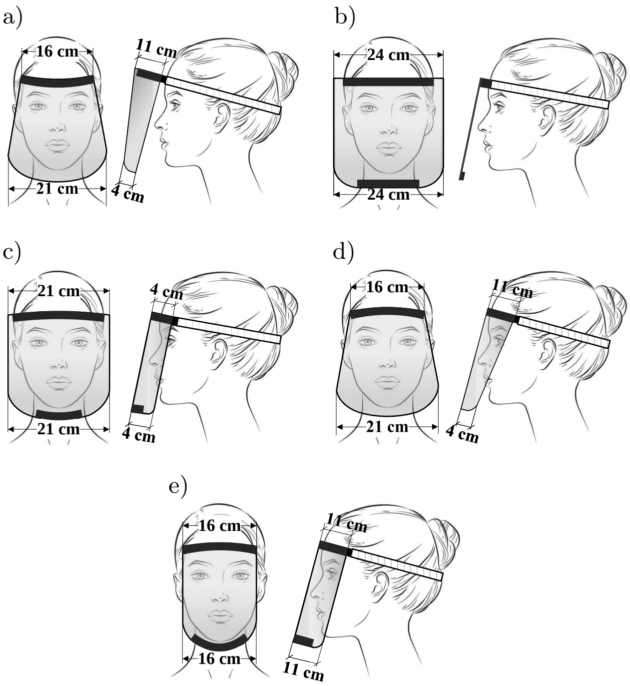

Fig. 2. Shield dimensions and position on the head: a) case A; b) case B; c) case C; d) case D; e) case E.

Figure 2b shows a flat shield (case B), i.e., a shield with no curvature. Special plastic supports were constructed on the upper and lower sides of the shield, which ensured that the transparent foil from Fig. 1a was flat over its entire surface. The case B shield represents a case where the shield has no curvature. In Fig. 2c, a shield with a slight curvature (case C) is shown. Its width protects the face from the outer environment and such shields can be found on the market as protective equipment. Plastic supports on the lower and upper sides were used to form this shield. The case C shield in this paper represents the mean curviness. The shield showed in Fig. 2d is a shield of greater curvature compared to the shields shown in the previous figures. It has been formed by placing the plastic support on the upper side of the transparent foil, which enables the shield placement on the head. The formed shield is 5 cm wider on the lower side compared to the upper side. This type of shield can also be found on the market as a protective device during the COVID-19 pandemic. In the experiments, the case D shield was used to obtain the case A shield so that it is turned away from the face and attached to the head using a special bracket. The last type of shield presented in this paper is shown in Fig. 1e. This shield has the greatest curvature compared to all other used types of shields. Its width on the lower and upper sides is the same and it is 16 cm. This was achieved by adding a plastic bracket on the underside of the case D shield. Observed in relation to the human head, this type of shield leaves the smallest air space to the face, seen from the profile, i.e., it protects the face from outer influences the most. When all the types of shields shown are compared, it can be said that the case A represents the shield with the lowest curviness (inversely curved). In contrast, the type E shield represents the shield with the highest positive curviness.

2.2. *Experimental setup*

The experiments were performed in anechoic chamber with a volume of 50 m^3. The level of ambient noise in the room was around 20 dB(A), and the reverberation time of the anechoic chamber is around 0.1 s. Two groups of experiments have been performed:

– the first group – with real speakers reading a text (without the shield, and with five shields of different curvatures);
– the second group – with a dummy head reproducing speech signals (without the shield, and with five shields of different curvatures).

In Fig. 3a one of the speakers is presented with the case D shield. As a source of the speech signal in

a) b)

Fig. 3. Experimental setting in anechoic conditions: a) one of the speakers with protective shield (case D); b) artificial head with protective shield (case D).

Table 1. Statistical distribution of letters in the used text.

Type	Vowels	Semivowels	Plosives	Fricatives	Affricates	Nasals
Part of text [%]	45.3	10.6	17.6	13.1	2.6	10.8

the second group of experiments, a dummy head with an integrated artificial voice device is used (*Technical documentations of the manufacturer*, 1971). In Fig. 3b the dummy head with the case D shield is presented. At the distance of 20 cm from the middle of the dummy head (or speaker head), a measurement microphone is placed (*Technical documentations of the manufacturer*, 2010). The recording of the signal emitted by the dummy head is performed using an audio interface (*Technical documentations of the manufacturer*, 2012) with a sampling rate of 48 kHz.

In the first group of experiments, real speakers were reading a literary text in Serbian. The literary text is composed of 436 words (1021 letters) which corresponded to average reading time of 2 min. Statistical distribution of letters of this text per articulation is given in Table 1.

The letter distribution of this text is in accordance with general distribution for the Serbian, obtained on a large sample of literary texts (Jovičić, 1999). Ten speakers, five male and five female, participated in the first group of experiments, with the age range between 20 to 27 years old. In this paper, the speakers were professional actors, final year students of the Faculty of Dramatic Arts, without speech defects or vocal tract diseases. To conduct the experiments, reading the same text as much repeatability as possible was required, in order to eliminate the influence of the speaker on the results of the shield tests. Each speaker had to read the same text 6 times, once without a shield and 5 times with shields of different curvature. This is why actors were chosen because they have good control over intonation, rhythm and dynamics of speech. Each of the speakers was recorded reading the text not wearing the shield, and then the recordings were made of speakers reading the text when wearing each type of shield (five types with different curvatures). Therefore, 60 recordings were made with real speakers.

In the second group of experiments speech signals were reproduced using a dummy head. Experiments were performed with a dummy head in order to examine whether, in addition to the influence of the shield, there is also an influence of the speaker's articulation. The reproduced speech signals (ten signals) were taken from the first group of experiments and correspond to the case when real speakers are not wearing a protective shield. The microphone records a speech signal emitted by the dummy head (ten recordings). Afterwards, shields of different curvatures are placed on the dummy head and recordings are made (50 recordings). In such a way, 60 recordings of speech emitted by the dummy head were made.

2.3. Long term speech spectrum

For speech analysis in this paper, a spectrum in 1/3 octave bands is used, obtained with 1/3 octave filter bank (ANSI, 2004). In Fig. 4, a block diagram is shown for obtaining the long term spectrum of the speech signal, used in this paper. The speech signal (of real speakers or from dummy head) is at the input of the 1/3 octave filter bank, which is composed of filters numerated from 1 to m. In this paper, the frequency range of interest is 125 Hz to 16 kHz. The filtering is performed for all speech signals of the same category (e.g., for speech signals of all ten speakers without the protective shield).

Next, for all filtered signals, a square of RMS values is calculated which is a value proportional to the power of the speech signal in the observed frequency range. For each frequency range (defined by the corresponding filter), averaging is performed of the RMS values obtained for all speakers. This procedure is repeated for all frequency ranges of interest (1 to m). After averaging, m values are obtained which represent the long-term spectrum in 1/3 frequency bands.

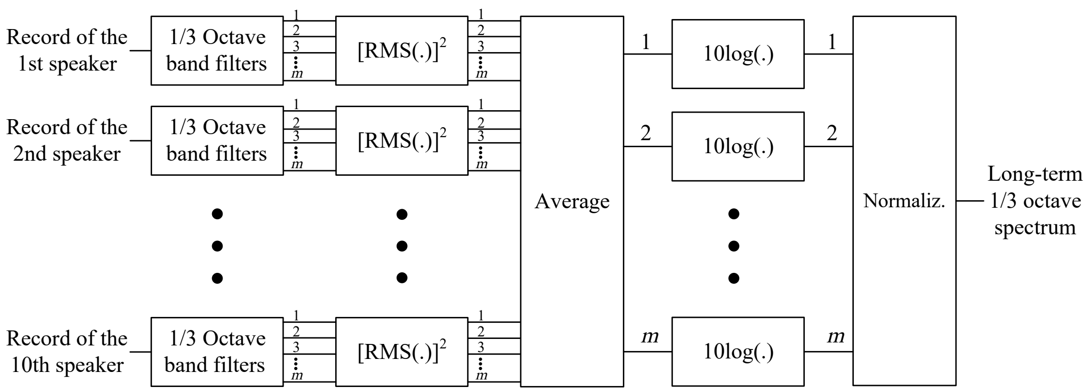

Fig. 4. Diagram for obtaining long term speech spectrum.

The values are then converted to dB and normalized so that the total level in the entire frequency range of interest equals 0 dB.

The presented procedure obtains the 1/3 octave long term spectrum for one group of recordings (e.g., speech signals of ten speakers without shield). This procedure is performed for all groups of recordings, which include all types of shields. In such a way, six long term spectrums are obtained (one without shield, and five with shields of different curvatures), in the case of real speakers. In the same way, six long term spectrums are obtained for the dummy head experiments as well.

3. Results and discussion

3.1. Speech signal without the shield

Figure 5 shows the 1/3 octave band long term spectrum of speech in the case of real speakers reading a text, not wearing the protective shield. The maximum level value of the normalized long-term speech spectrum corresponds to the 1/3 octave range with a center frequency of 500 Hz. In the range from 200 to 500 Hz, the spectrum decreases by 3 dB per octave, in the area below 200 Hz by 8 dB per octave, and in the range up to 3.1 kHz, the speech spectrum decreases 6 dB per octave. In the frequency range between 3.1 and 10 kHz, the spectrum is approximately flat, and after 10 kHz, it can be considered that there are no significant components in the long-term speech spectrum. The obtained spectrum coincides with the Serbian speech spectrum data from the literature (Vojnović, Mijić, 1997; Byrne *et al.* 1994). This shows that the selected group of speakers is relevant. The standard deviation of the averaged speech spectrum for the frequency range of interest belongs to the interval (2.4 ± 1.5 dB). The highest standard deviation value of 3.9 dB was obtained for the frequency range of 1250 Hz.

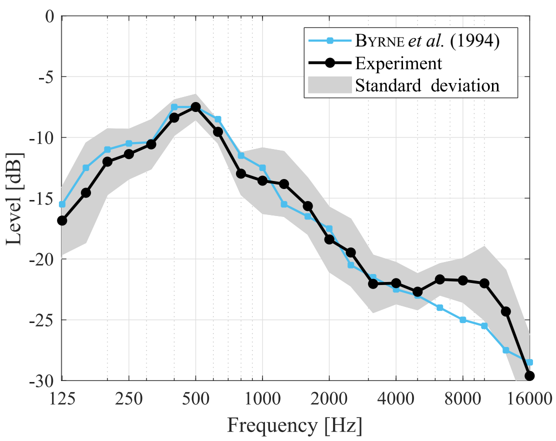

Fig. 5. Average speech spectrum of 10 speakers without a shield, standard deviation and speech spectrum from the literature.

3.2. Dummy head results

In order to see the influence of the shield curvature on the speech signal, differences in the spectrum of broadcasted speech were calculated for cases with and without protective shields. Long-term spectrum differences over 1/3 octave frequency bands averaged for 10 recorded signals for each of the shields. The calculated differences represent the insertion losses introduced by the shields in frequency bands. In this way, five frequency dependent insertion loss curves were calculated (five protective shields, case A to case E), which are shown in Fig. 6. The figure also depicts a symbolic representation of the different shield curvatures and their label for easier tracking of the results.

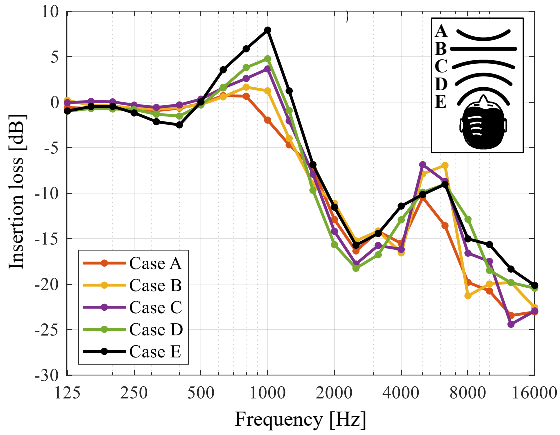

Fig. 6. Insertion loss introduced by the shields of different curvature – dummy head experiments.

In the frequency range up to 250 Hz, the differences shown in Fig. 6 are less than 0.5 dB, i.e., there are no significant differences between the speech signal spectrum with and without protective shields. In this frequency range, the sound wavelengths are up to several meters. Hence, the protective shield with dimensions of several tens of centimeters and a millimeter thickness is not a significant obstacle (Pierce, 2019). In the range from 250 to 500 Hz, the differences are slightly larger for all types of shields (for example in the case E – 2 dB). For all shields except the case A shield, the maximum difference with regard to the case without the usage of a protective shield is occurring for the 1/3 octave range with a center frequency of 1000 Hz. In the case of the shield with the largest curvature (case E), the difference is even 8 dB. The differences are 5, 4, and 2 dB (cases D, C, and B, respectively). It can be concluded that the level difference increases too at 1000 Hz with an increasing shield curvature. In case when the case A shield was used (reverse shield), there is no local maximum as with other shield types.

From Fig. 6, it could be seen that only negative differences occur in the range above 1250 Hz, i.e., that all shield types bring attenuation into the speech signal.

In addition to the local maximum another local maximum can be observed. The position of this maximum for different types of shields corresponds to the 1/3 frequency bands with central frequencies of 5000 and 6300 Hz. From Fig. 6, it can be seen that there is no dependence of the numerical values of the differences on the shield curvature. The connection between curvature and this local maximum does not exist because the obtained local maximum is a consequence of the resonance in the space (chamber) in front of the face on the shortest side, i.e., the resonance corresponding to the distance between the face and the shield. For all shield types, the distance between the speaker's mouth and the protective shield is approximately the same, about 3 cm, which can be seen in Fig. 2. Therefore, the differences in this frequency range for different shields are relatively small. In the band above 10 kHz, there are no significant components of the speech signal.

3.3. Real speaker results

As in the dummy head case, the differences of spectrums (insertion loss) were calculated for the cases of real speakers wearing shields of different curvature and the case when real speakers were without any protective shield. Insertion losses were averaged over all 10 speakers. The results are shown in Fig. 7. For all shields except the case A shield, the maximum difference with regard to the case without the usage of a protective shield is occurring for the 1/3 octave range with a center frequency of 1000 Hz. In the case of the shield with the largest curvature (case E), the difference is even 6.6 dB. Table 2 shows the averaged insertion loss values and standard deviations for the 1/3 octave range with a central frequency of 1000 Hz, for all speakers who participated in the experiment.

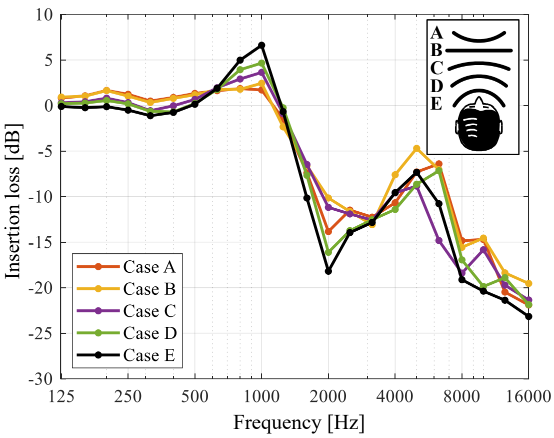

Fig. 7. Insertion losses introduced by the shields of different curvature – real speaker experiments.

As in the dummy head experiment, it can be concluded that the level difference increases at 1000 Hz with increasing shield curvature. In case when the case A shield was used (reverse shield), there is no local maximum as with other shield types. The values of differences for the frequency band at 1000 Hz in the case of real speaker experiments are somewhat lower compared to the dummy head experiments. Certain differences in the results are due to the different structure of surfaces of the face. In the real speaker experiment case it is human skin, whereas in the case of the dummy head experiment the surface is hard rubber. The absorption characteristics of these two surfaces are different, predominantly in the mid and high frequency range, where the result differences occur in the presented two groups of experiments. In studies involved in examining the influence of protective devices which use the dummy head and human head as signal sources, it was shown that certain differences occur (Pörschmann *et al.*, 2020; Corey, 2020; Atcherson *et al.*, 2021) which is in accordance with the results presented in this paper. Furthermore, the cause of differences in results obtained by two experiment methods can partially be due to differences in reading of the text when wearing protective mask. The dummy head is used in order to enable the repeatability of results, i.e., to eliminate the possible human influence because of different manner of text reading. In the case of experiments with real loudspeakers, another local maximum is present, in the frequency range of 5000 and 6300 Hz. The numerical values of the differences in these bands are within 4 dB, and are somewhat larger than in the case of the dummy head experiment. The connection between the curvatures and these local maximums is not present, which was also the case in the dummy head experiments.

Table 2. Insertion loss and standard deviation of insertion loss for all speakers for 1/3 octave range 1000 Hz.

	Insertion loss [dB]	Standard deviation [dB]
Case A	1.7	1.2
Case B	2.5	1.1
Case C	3.7	1.3
Case D	4.6	1.8
Case E	6.6	1.5

Based on the results presented in Figs. 6 and 7, it is concluded that the phenomena of pronounced maximum in the 1/3 frequency band at 1000 Hz is present regardless of the experiment type, i.e., whether the speech signal is reproduced with a dummy head or real speakers. The numerical values are different in two cases of experiments due to differences in surface characteristics of the human head and dummy head.

3.4. Analysis of the pronounced maximum in the spectrum

The obtained form of differences in the speech spectrum with and without a protective shield also appears in experiments conducted in the literature (Corey, 2020; Atcherson *et al.*, 2021). However, the causes of the relative increase in the long-term spectrum in the region around 1000 Hz have not been considered. The spectrum shape is similar to the situation when experiments were carried through on both human and artificial heads (Corey, 2020). There are claims that the appearance of the maximum difference in speech signal spectrum with and without the usage of a protective shield is a consequence of resonance in the protective shield foil (Atcherson *et al.*, 2020). In order to examine this claim, the vibrations on the shield were analyzed. For this experiment, the dummy head is used. An accelerometer recorded a transparent shield (case D) response to the impulse excitation (by the impact of a stick on the shield). In this way, the system impulse response was recorded.

Figure 8a shows the position of the accelerometer on the shield. An accelerometer weighing 0.635 grams was used (*Technical documentations of the manufacturer*, 2018) so that its mass would not affect the response of shields whose mass is not large. Several measurements were performed for different accelerometer positions and different excitation positions. The results are averaged, and Fig. 8b shows the 1/3 octave spectrum of the recorded vibrations (the frequency response of the shield). The biggest 1/3 octave value was set to 0 dB. Based on Fig. 8b, it could be seen that the maximum frequency response of the shield is positioned in the frequency range around 250 Hz and that it decreases towards higher frequencies. The maximum positive value of the differences in the speech signal spectrum with and without using a protective shield occurs in the range of about 1000 Hz. Since the positions of the maximums of the vibration spectrum on the shield (Fig. 8) and the positions of the maximum differences of the speech spectrum (Figs. 6 and 7) do not coincide, this means that vibrations generated in the transparent foil of the shield are not responsible for the local maximum in 1000 Hz.

a)

b)

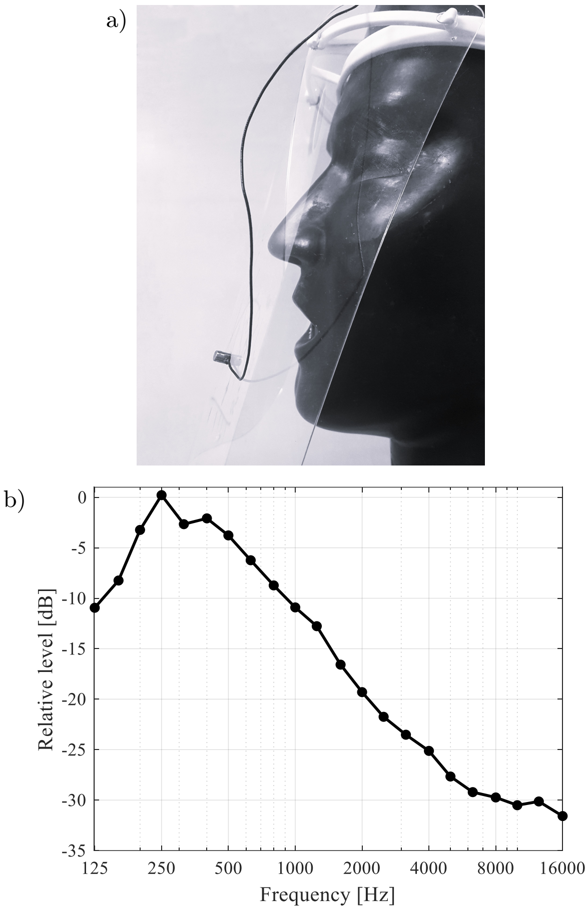

Fig. 8. a) Accelerometer on protective shield; b) shield's response.

A new hypothesis was introduced, given the proof that the shield material has no influence that could be perceived in the long-term speech spectrum. The maximum positive differences are due to the resonance that occurs in the space between the face and the shield. This narrow space (chamber) is determined by the surface of the face on the back, the shield surface on the front, the plastic shield holder on the upper side, while there is air on the other three sides of the chamber. Part of the speech signal energy (at lower frequencies, in the range up to 500 Hz) passes through the protective shield, so the protective shield does not affect this frequency range, as seen in Figs. 6 and 7. For the frequency range in which the transparent material represents an obstacle (medium and high frequencies), the speech signal excites the space (chamber) in front of the face in which the sound field is established. The chamber width is 24 cm, height 24 cm, and thickness is about 3 cm (a distance of the face from the shield). Due to the small thickness, for the frequency range of the speech signal above 500 Hz, this space could be considered a sound pipeline that is open at the ends. Based on the given shield dimensions (width and height), it is possible to determine the frequency corresponding to the surface resonance in this sound pipeline, approximately 1000 Hz (that resonance covers a band around 1000 Hz, not just a discrete frequency). For this frequency range in the space between the face and the shield, there is an increase in sound energy, which is also sustained in the increase in the value of sound pressure recorded by the microphone placed in front of the shield. Consequently, the differences shown in Figs. 6 and 7 have a maximum positive value for the 1/3 octave frequency range with a center frequency of 1000 Hz. The increase in the difference value with increasing shield curvature is a consequence of the fact that in the case of greater curvature, the air space at the ends of the chamber becomes smaller, i.e., the chamber behaves more like a sound pipe. The losses from the sides top and bottom are less allowing for stronger resonances. The smallest opening exists in the case of the case E shield, and in that case the space between the face and the shield most closely resembles a sound pipe, so the value of the difference shown in Fig. 5 is the largest and amounts to 8 dB. In contrast, for the case A shield, the largest opening is at the end of the chamber (practically a funnel), so in this case we cannot talk about the space in front of the face as a sound pipeline. Therefore, there is no increase in the difference for this type of shield at 1000 Hz. Other shield types due to the shape of the space they define, are between these two extreme cases, as shown by the results obtained.

4. Conclusion

This paper examines the influence of protective shields' curvature on the speech signal. In literature, results show that using transparent protective shields increases the level of speech signal in certain frequency ranges. However, detailed explanations for these phenomena are not found. This paper analyses and explains the reasons for the level increase in the long-term speech spectrum. The experiments were performed using an artificial head emitting recorded speech signals of real-life speakers. Furthermore, another set of experiments was performed with real speakers to test whether the speaker's articulation affects the end result. Five shields were examined, having the same overall dimensions, made of the same material, but with different curvature. The curvature of the shields is varied in order to examine whether there exists an influence of the level of curvature on the speech signal. It was shown that the resonant processes do not occur within the transparent material of the shield. Rather, they occur in the air space between the face of the speaker and the transparent material. Protective shields form a sound pipeline between the face of the speaker and the transparent material of the shield. Therefore, in this space, resonant processes occur which result in the level increase of the speech spectrum in certain frequency ranges. It has been concluded that increasing the curvature of the protective shield increases the relative difference in long-term speech spectrums, when comparing the long-term spectrum of the speech signal recorded with and without shield. This phenomenon is explained by the fact that increasing curvature reduces the volume of the air space between the face of the speaker and the shield, which means that the air space has the characteristics of a sound pipeline. This is the reason for the level increase in the long-term speech spectrum, when compared to the shields with lower curvature. The dummy head experiments show that in the frequency range around 1000 Hz, the level of speech signal when using protective shield with large curvature can be higher up to 8 dB compared to the speech signal when no shield is used. In the case of real speaker experiments this difference is 6.6 dB. Since the phenomenon is observed in both types of experiments, it is concluded that articulation has no influence and that the increase in the level of speech signal in this frequency range is a consequence of the curvature of the shield. Increase in speech level was also observed in the frequency range around 5000 Hz, and it is concluded that this phenomenon is a consequence of the resonance which corresponds to the distance between the shield and the face of the speaker. The increase in level in this frequency range is not dependent on the shield curvature, because the distance from the mouth of the speaker to the shield is approximately the same for all tested shields.

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