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Effect of face masks on speech understanding: A clinical perspective during speech audiometry

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ABSTRACT

The objective was to measure the effect of various face masks on speech recognition threshold and the word recognition score in the presence of varying background noise levels. 20 normal-hearing adult subjects (a total of 40 ears) participated. Pure tone audiometry followed by speech recognition threshold and word recognition score at the most comfortable level in varying signal-to-noise ratios (SNR0, SNR10, and SNR15) using surgical, pleated cloth, and N95 masks. Using surgical, cloth, and N95 masks, speech recognition thresholds increased by 1.8 dB, 4.4 dB, and 5.05 dB, respectively. Word recognition scores decreased by 32% without a mask, 43.7% in a surgical mask, 46.3% in a cloth mask, and 46.7% in N95 mask conditions, between SNR15 and SNR0. The speech recognition threshold was negatively affected with cloth and N95 masks. Surgical masks do not affect the word recognition scores at lower background noise levels. However, as the signal-to-noise ratio decreased, even the surgical, cloth, and N95 masks significantly impacted the word recognition score even in normal-hearing individuals.

1. Introduction

In the COVID-19 pandemic, the introduction of routine use of the face mask became an effective aid in reducing the onward transmission of viral contamination by asymptomatic and pre-symptomatic persons. Therefore, face masks became a potential tool to tackle the COVID-19 pandemics since the initial outbreak (Marler and Ditton, 2020). Many countries have made it essential to wear face masks for every citizen in public and private places for this concern.

Various masks have varying filter characteristics, depending on their design and material (Brosseau, 2009). Multiple studies have focused on the filtration effect of aerosol or droplet exposure of N95, surgical, and cloth masks. The N95 face mask has the most excellent filtration (95%) for droplets and aerosols. The single-layered cloth mask has the least protection; however, a three-layered cloth mask performs equally as a medical or surgical mask (Aydin et al., 2020; Konda et al., 2020). Centers for Disease Control and Prevention (CDC) recommends a NIOSH-approved respirator N95 mask and KN95 for the best protection followed by a surgical disposable mask and a cloth mask with the least protection (Geoge Alba, 2020; Lydia, 2020; Asadi et al., 2020; MacIntyre CR et al., 2015).

When all forms of messages are delivered accurately and appropriately, it is referred to as intelligible communication. Effective communication is the cornerstone for patient safety and health care professionals, where the content of information shared must be complete, accurate, timely, unambiguous, and understood between them (Peelle, 2018; Pichora-Fuller, 2016). Hence, intelligible communication is essential in personal or professional settings. Face masks can result in detrimental effects on verbal communication and speech intelligibility by occluding important visual cues from mouth and lip gestures, interfering with natural articulatory movements, and altering speech acoustic features (McGurk, 1976; Bond et al., 1989; Murthy et al., 1995; Wieczorek, 2013; Palmiero et al., 2016). Recent studies on the acoustic effect of masks on speech signals have reported that masks serve as a low-pass filter and the high-frequency range (above 1 kHz) of spoken speech is primarily attenuated by 3–4 dB with a simple medical mask and close to 12 dB with the N95 masks (Corey et al., 2020; Wolfe et al., 2020; Balamurali BT et al., 2021).

Speech perception is more difficult for hard of hearing than normal hearing, especially in circumstances of varying background

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noise levels (Wilson, 2010; Smith, 2012). Many studies have addressed the attenuation effect of masks on speech. But listening to an individual wearing a mask and recognizing words at different background noise levels can have more impact even on a normal hearing person. Thus, the current study aimed to evaluate speech recognition threshold (SRT) and word recognition score (WRS) in individuals with normal hearing at different Signal-to-Noise ratios (SNRs) with and without a mask.

2. Methodology

An observational, cross-sectional study was conducted with 20 adults (aged 18–23 years; mean = 20.3 years) with confirmed normal hearing thresholds (≤15 dBHL) for pure tone at octave frequencies from 0.25 to 8 kHz in both ears. The audiological assessment was conducted using an Interacoustics immittance audiometer AT235, and AC40 Hybrid clinical audiometer with TDH-39 supra-aural earphones. Puretone and speech audiometry were performed in a double-walled and two-chambered sound-treated room, as per the American National Standard Institute (ANSI, 2008).

To measure the attenuation effect of face masks on speech audiometry tests, the clinician wore a face mask covering the mouth and nose. Three types of masks were used in the study a) the surgical mask (double-layered), b) cloth mask (pleated single-layered), and c) N95 mask (5-layered). The modified and standardized Hindi version consists of two lists of 38-spondee words and two lists of 50-phonetically balanced words that were used (Abrol BM, 1971; De NS, 1973). SRT measurement was started at 25 dB above the pure-tone average (average of 500 Hz, 1 kHz, and 2 kHz) by presenting the spondee word through the VU meter to monitor and maintain the same intensity of the voice. Once the listener repeated the correct word, the intensity was descended by a 5 dB step. SRT was recorded where the participant could repeat 50% of the spondee words presented (Chaklin and Ventry, 1964). The WRS measurement was started at 40 dB above the SRT. The most comfortable level (MCL) was set prior to measuring the WRS. The percentage of correct responses was calculated as the word recognition score (ASHA, 1979). The presentation of both spondee and PB-words from each of the lists was randomized during recording.

Signal-to-noise ratios usually vary from 10 to 20 dB in schools and homes; however, 0–8 dB in public and cocktail party environments (Nabelek, 1985; Pearsons, 1976; Plomp, 1977). Hence, to make the test situation more representative of real-life listening we also opted following three levels of SNRs (1) SNR0: signal and noise presented at the same level; (2) SNR10: signal presented 10 dB above the level of noise; (3) SNR15: signal presented 15 dB above the level of noise. The speech-shaped noise of frequency characteristic 125–6000 Hz falling 12dB/octave above 1 KHz ± 5 dB was used.

The same clinician wore each type of mask. To avoid an order effect, the presentation of words from each spondee and PB word lists was randomized. Also, different SNRs and mask conditions were randomized to avoid the ceiling effect. Speech audiometry was conducted for all participants under the following four conditions:

- Condition 1- no mask: SRT & WRS at SNR0, SNR10, and SNR15.
- Condition 2 - surgical mask: SRT & WRS at SNR0, SNR10, and SNR15.
- Condition 3 - cloth mask: SRT & WRS at SNR0, SNR10, and SNR15.
- Condition 4 - N95 mask: SRT & WRS at SNR0, SNR10, and SNR15.

The statistical analysis was conducted using SPSS version 20.0. The ANOVA test was used to compare the levels of SRT and WRS at various SNRs. The mean differences between the groups were investigated using Tukey post-hoc multiple comparisons.

Ethical approval was obtained from the Institutional Ethics Committee (reference: INT/IEC/2021/SPL-237). A written and signed informed consent form was taken from all participants.

3. Results

Participants in the study had bilateral normal middle ear function, as evidenced by a normal tympanogram (Type-A). Fig. 1 shows the average pure-tone thresholds of both ears at tested octave frequencies from 250 Hz to 8000 Hz. The pure-tone average (PTA, average of mean threshold obtained at 500 Hz, 1000 Hz, and 2000 Hz) of 40 ears was 8.77 ± 1.02 dBHL. A student t-test was applied to compare the mean thresholds of right and left ears. The hearing sensitivity data between ears did not show a statistically significant difference ($p > 0.05$). Hence, the right and left ear data were combined for further analysis based on the results of the work conducted by Beattie RC et al., 1997 wherein it was reported that WRS are equivalent for the right and left ear and there is no right ear advantage.

Fig. 2 shows the graphical representation of the speech recognition thresholds (SRTs) obtained without a mask and with different types of masks. The average SRT without a mask was 12.5 ± 3.02dBHL however, 14.3 ± 3.22dBHL with a surgical mask, 16.8 ± 3.03dBHL with a cloth mask, and 17.55 ± 3.07 with an N95 mask (as shown in Table 1). The ANOVA test was applied to compare SRT obtained without a mask and with different masks. Results showed a statistically significant ($F(3, 156) = 22.53$; $p < 0.001$) difference between without a mask, surgical mask, cloth mask, and N95 mask conditions. Tukey multiple comparisons were performed to compare the differences between two means of SRT levels obtained without a mask and with different masks. Results revealed a statistically significant ($p < 0.05$) and highly significant ($p < 0.001$) difference for all pairs (as shown in Table 2) except between cloth and N95 masks. The mean SRT without a mask condition differed by 1.8 dB with a surgical mask, 4.40 dB with a cloth mask, and 5.05 dB with an N95 mask.

Fig. 3 shows the graphical representation of word recognition scores (WRS) obtained at different signal-to-noise ratios (SNR15, SNR10, and SNR0) without a mask and with other masks. The average WRS at SNR15 was 99.7%, 97.9%, 93.3%, and 92.8%, without the mask, with a surgical mask, cloth mask, and an N95 mask, respectively. The average WRS at SNR10 without a mask, with a surgical mask, cloth mask, and N95 mask was 96.4%, 91.8%, 86.3%, and 86.2%, respectively. However, a lower mean WRS was recorded at SNR0 without a mask, with a surgical mask, cloth mask, and N95 mask respectively as 67.8%, 54.2%, 47%, and 46.1%. The means of WRS obtained without a mask and with different masks at SNR15, SNR10, and SNR was compared using one-way ANOVA (shown in Table 3). Results revealed a statistically highly significant difference between the surgical mask, cloth mask, N95 mask, and without a mask at SNR15 [$F(2, 117) = 41.164$; $p < 0.000$], SNR10 [$F(2, 117) = 41.129$; $p < 0.000$] and SNR0 [$F(2, 117) = 38.477$; $p < 0.000$] as shown in Table 3.

Further, the Tukey post-hoc pairwise comparisons were done to observe the differences between the means of WRS obtained at different SNRs (SNR15, SNR10, SNR0) for the following pairs: without a mask–surgical mask; without a mask–cloth mask; without a mask–N95 mask; surgical mask–cloth mask; surgical mask–N95 mask; and cloth mask–N95 mask (as shown in Table 4). Results revealed a statistically highly significant difference ($p < 0.001$) between the means of WRS obtained at SNR15 for the following pairs: without a mask–cloth mask; without a mask–N95

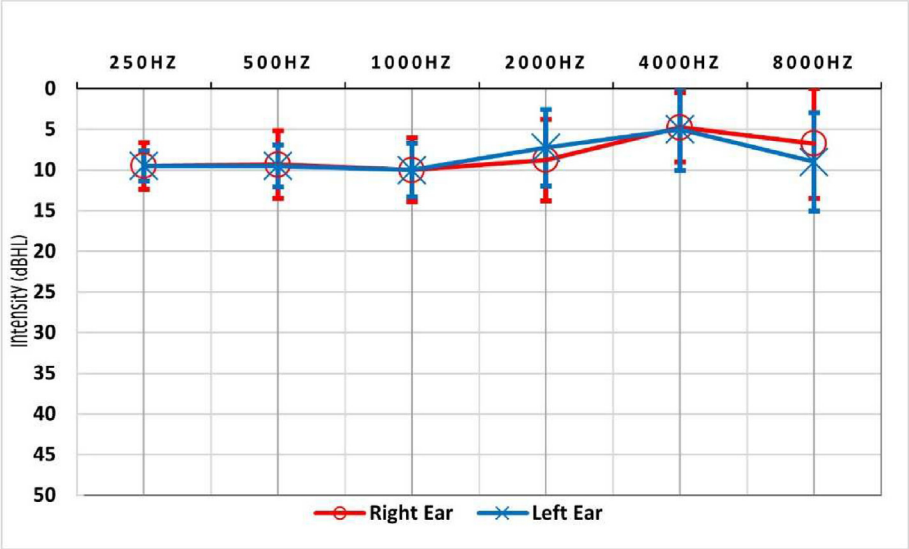

Fig. 1. Audiogram, Average Hearing Threshold at Octave frequency from 250 to 8 kHz of the subjects.

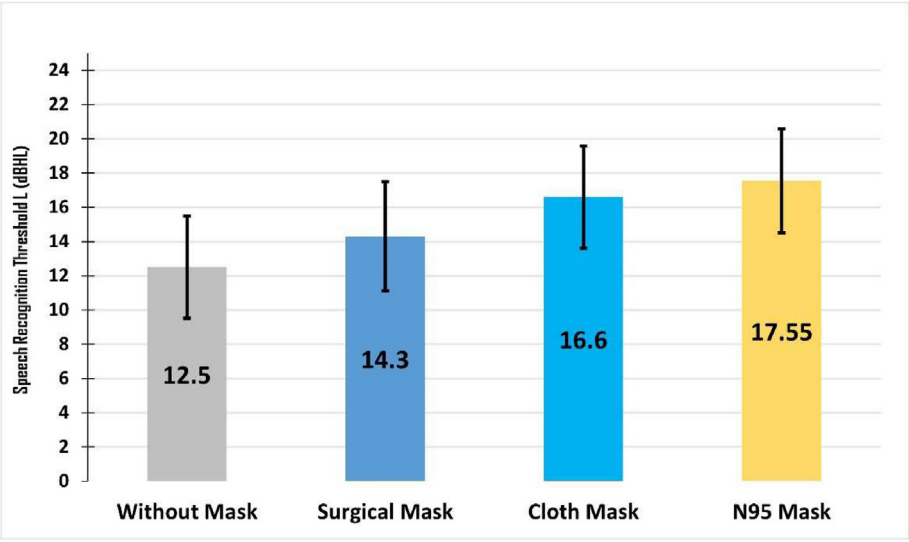

Fig. 2. Mean SRT (in dBHL) of subjects while clinician alternately wore the surgical mask, cloth mask, N95 mask, and without a mask.

Table 1
Comparison of SRT without a mask and with different masks in dBHL.

Mask Condition	SRT (mean ± SD in HL)	F-value	p-value
Without Mask	12.5 ± 3.02	22.53	0.000***
Surgical mask	14.3 ± 3.22		
Cloth mask	16.8 ± 3.03		
N95 mask	17.55 ± 3.07		

***Statistically highly significant ($p < 0.001$).

mask; surgical mask–cloth mask, and surgical mask–N95 mask. However, no significant ($p > 0.05$) difference was observed for the pairs without a mask–surgical mask and cloth mask–N95 mask. Similarly, at SNR10 and SNR0, a statistically highly significant difference ($p < 0.001$) was observed for all the above said pairs except the cloth mask–N95 mask pair ($p > 0.05$), as shown in Table 4.

We also made the Tukey post-hoc multiple comparisons between different SNRs for WRS without a mask and with varying conditions of the mask. Results (shown in Table 5) depicted a statistically highly significant ($p < 0.0001$) difference between the mean WRS obtained at different SNRs with and without a mask, except for without a mask condition at SNR15 and SNR10 ($p = 0.118$, not significant). Results also depicted that without a mask condition, the WRS reduced by 3.3% at SNR10 and 31.9% at SNR0. Similarly, in surgical mask conditions, WRS decreased by 6.1% at SNR10 and 43.7% at SNR0. With a cloth mask, WRS reduced by 7% at SNR10 and 46.3% at SNR0. Finally, with the N95 mask condition, WRS decreased by 6.6% at SNR10 and 46.7% at SNR0.

4. Discussion

We aimed to evaluate the speech recognition threshold and word recognition ability in normal-hearing individuals without masks and with different types of masks recommended during the COVID-19 pandemic. Results displayed a statistically significant difference ($p < 0.05$) between without mask and with various

Table 2
Post hoc pairwise comparisons between without mask and among masks for SRT (in dBHL).

Pairs	Mean diff.	Stand. Error	95% Confidence Interval		p-value
			Lower Bound	Upper Bound	
Without Mask - Surgical mask	1.80	0.698	0.0049	3.595	0.0118*
Without Mask - Cloth mask	4.40	0.676	2.504	6.095	0.0001***
Without Mask - N95 mask	5.05	0.681	3.254	6.845	0.0001***
Surgical mask - Cloth mask	2.50	0.699	0.704	4.295	0.0006***
Surgical mask - N95 mask	3.25	0.703	1.454	5.045	0.0001***
Cloth mask - N95 mask	0.75	0.682	−1.045	2.545	0.275ns

*Statistically significant ($p < 0.05$); *** Statistically highly significant ($p < 0.001$).

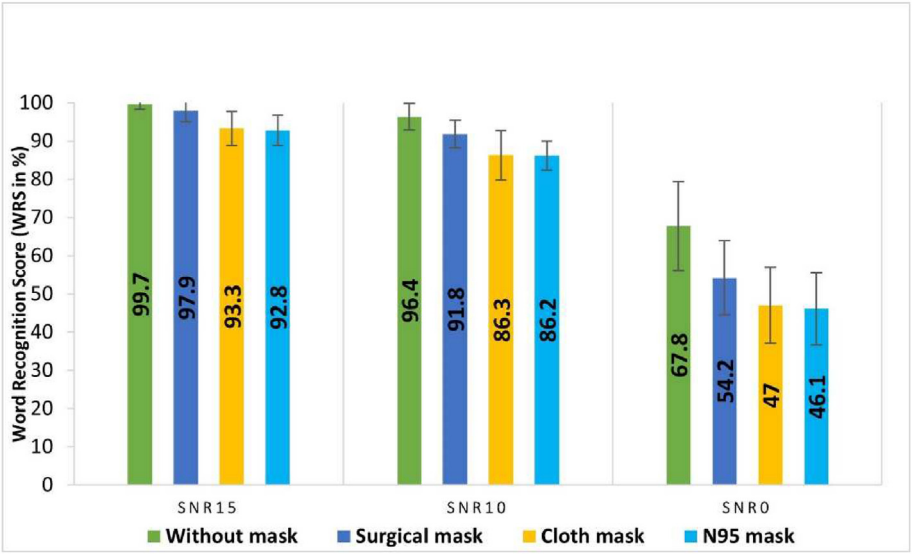

Fig. 3. Measures of WRS (in %) without a mask, with a surgical mask, cloth mask, and N95 masks at SNR15, SNR 10 and SNR0.

Table 3
Comparison of WRS with Surgical mask, Cloth mask, N95 mask, and without mask at different SNRs.

SNR Levels	WRS with Different Masks (mean ± standard deviation) in %age				F-value	p-value
	Without mask	Surgical mask	Cloth mask	N95 mask		
SNR15	99.7 ± 1.39	97.9 ± 2.86	93.3 ± 4.38	92.8 ± 3.96	41.164	0.0000***
SNR10	96.4 ± 3.48	91.8 ± 3.61	86.3 ± 6.46	86.2 ± 3.83	47.129	0.0000***
SNR0	67.8 ± 11.66	54.2 ± 9.75	47 ± 9.91	46.1 ± 9.41	38.477	0.0000***

*** Statistically highly significant ($p < 0.001$).

masks for the SRT, except between the cloth mask and N95 mask (Table 2). The frequency spectrum or formant area of most speech sounds used in speech audiometry (Spondee & PB word lists) was between 1 kHz and 6 kHz (De NS, 1973). Therefore, these differences in SRT with different masks would be due to several masks' varied acoustic effects on speech signals. Few recent studies have reported that the mask has little effect on the speech signal below 1 kHz. However, a modest and strong attenuation effect is seen between 1 and 4 kHz and above 4 kHz, respectively, with different masks (Ryan M Corey et al., 2020, Wolfe et al., 2020). The current study also manifested a maximum difference of 5.05 dBHL for the SRT between N95 and without a mask. This difference and poor speech recognition threshold with several masks may be due to attenuation in the speech spectra signal while wearing a mask. In the present study, an increase in SRT level was seen in the following order, i.e., without a mask, with surgical, pleated cloth, and N95 masks. Findings also revealed that the mean SRT level was elevated by 1.8 dB with a surgical mask, 4.4 dB with a cloth mask, and 5.5 dB with an N95 mask compared to no mask condition. In concordance, Corey et al. have also reported that an average of 3.4 dB might attenuate the speaker's speech signal with the surgical mask, 4.3 dB with the cotton mask, and 5.7 dB with the N95 mask (Ryan M Corey et al., 2020). Therefore, results revealed that the individual's speech recognition thresholds were best without a mask; however, they were poorer with pleated cloth and N95 masks than surgical masks.

WRS was measured at three varying levels of SNRs (SNR15, SNR10, and SNR0) for the test situation to identify and demonstrate the day-to-day communication difficulties faced by normal-hearing listeners wearing different kinds of face masks. The current study aimed to compare the effects of different masks on the WRS at above mentioned SNRs. The presentation of words from each list was randomized to avoid an order effect. Each type of face mask and SNR conditions were also changed when the ceiling occurred (Theunissen M, 2009). Results indicated that the surgical mask does not significantly deter the speech signal, and the verbal output can be understood almost like without mask condition at SNR15.

Table 4
Post hoc pairwise comparisons without a mask and with different masks for WRS (in %) at SNR15, SNR10 and SNR0.

SNR Levels	Pairs	Mean diff.	Stand. Error	95% Confidence Interval		p-value
				Lower Bound	Upper Bound	
SNR15	Without Mask - Surgical mask	0.20	0.503	−3.749	0.149	0.691ns
	Without Mask - Cloth mask	−4.40	0.727	−8.349	−4.450	0.0001***
	Without Mask - N95 mask	−4.9	0.664	−8.849	−4.950	0.0001***
	Surgical mask - Cloth mask	−4.60	0.827	−6.549	−2.650	0.0001***
	Surgical mask - N95 mask	−5.10	0.772	−7.049	−3.150	0.0001***
	Cloth mask - N95 mask	−0.50	0.934	−2.449	1.449	0.593ns
SNR10	Without Mask - Surgical mask	−4.60	0.793	−7.226	−1.975	0.0001***
	Without Mask - Cloth mask	−10.10	1.160	−12.724	−7.475	0.0001***
	Without Mask - N95 mask	−10.20	0.818	−12.824	−7.575	0.0001***
	Surgical mask - Cloth mask	−5.50	1.170	−8.124	−2.875	0.0001***
	Surgical mask - N95 mask	−5.60	0.832	−8.224	−2.975	0.0001***
	Cloth mask - N95 mask	−0.10	1.187	−2.724	2.524	0.933ns
SNR0	Without Mask - Surgical mask	−13.60	2.403	−19.537	−7.662	0.0001***
	Without Mask - Cloth mask	−20.80	2.420	−26.737	−14.862	0.0001***
	Without Mask - N95 mask	−21.70	2.369	−27.637	−15.762	0.0001***
	Surgical mask - Cloth mask	−7.20	2.198	−13.137	−1.262	0.0016***
	Surgical mask - N95 mask	−8.10	2.142	−14.037	−2.162	0.0003***
	Cloth mask - N95 mask	−0.90	2.161	−6.837	5.037	0.6782ns

ns = not significant ($p > 0.05$); *** Statistically highly significant ($p < 0.001$).

Table 5
Post hoc pairwise comparisons between different SNRs for WRS (in %) without a mask and different masks conditions.

Variables	Pairs	Mean diff.	95% Confidence Interval		p-value
			Lower Bound	Upper Bound	
Without Mask	SNR15 – SNR10	3.30	−7.223	0.623	0.118ns
	SNR10 – SNR0	28.6	24.676	32.523	0.0001***
	SNR15 – SNR0	31.9	27.976	35.823	0.0001***
Surgical mask	SNR15 – SNR10	6.10	2.646	9.553	0.0001***
	SNR10 – SNR0	37.6	34.146	41.053	0.0001***
	SNR15 – SNR0	43.7	40.246	47.153	0.0001***
Cloth mask	SNR15 – SNR10	7.0	2.961	11.038	0.0001***
	SNR10 – SNR0	39.3	35.261	43.338	0.0001***
	SNR15 – SNR0	46.3	42.241	50.338	0.0001***
N95 mask	SNR15 – SNR10	6.6	3.106	10.093	0.0001***
	SNR10 – SNR0	40.1	36.606	43.593	0.0001***
	SNR15 – SNR0	46.7	43.206	50.193	0.0001***

ns = not significant ($p > 0.05$); *** Statistically highly significant ($p < 0.001$).

However, the other masks markedly impacted the discrimination abilities even at SNR15. It indicates that at higher SNR, the surgical mask does not hamper the word recognition ability in normal-hearing individuals. Mendel et al. also found no significant difference in recognizing words with the surgical mask in quiet conditions (Mendel et al., 2008). The attenuation effect (ranging from 3 to 12 dB) of medical and N95 masks on the speech signal in the high-frequency region (above 1 kHz) may be the contributing factor to decreased word recognition ability (Ryan M Corey et al., 2020, Wolfe et al., 2020; Balamurali BT et al., 2021).

Under the second condition (i.e., at SNR 10), where the noise levels were slightly higher than the first, there was a significant reduction in WRS even with surgical masks. Furthermore, all three masked conditions showed a remarkable decrease in the WRS compared to the without mask condition. Lastly, when the speech and noise levels were equal, i.e., SNR0, all three mask conditions showed a distinguishable reduction in WRS than without mask conditions. Moreover, no difference was observed in WRS between mask-2 and mask-3 at all three SNRs, which means both affected the word recognition ability by the same amount (as shown in Table 4). Furthermore, results depicted that the WRS deteriorated with the decrease in signal-to-noise ratio and was worst at SNR0. The discrimination ability decreased by 31.9% when SNR was changed from 15 to 0 even in without mask conditions, and it further decreased by 43.7%, 46.3%, and 46.7% in a surgical mask, cloth mask, and N95 mask conditions, respectively (as shown in Table 5). Despite randomization of PB words, face mask, and SNR conditions, the WRS approached the ceiling with different face mask conditions at three tested SNR levels. The ceiling of the WRS can be attributed to the WRS done at the suprathreshold level and the participants perform well but when the speaker wears these masks, the effect of noise on the speech signal has a greater influence, as seen in a fall in WRS, especially at SNR0. Researchers have proposed that this remarkable deterioration in WRS between SNR15 and SNR0 among different mask conditions may attribute to various factors such as the upward spread of masking, differences in competing messages, and test stimuli during the psychophysical procedure (Beattie, 1989, 1997; Wilson, 2010; Smith, 2012).

The current study is a novel study indicating the enormous impact of various masks in day-to-day listening situations on the speech understanding of normal-hearing individuals. We must also ponder that the attenuation effect of face masks at lower SNR might further hamper the speech understanding in persons with compromised hearing abilities and substantially deteriorate their quality of life.

There are a few limitations in the current study. First, the stimuli were presented using live voice instead of recorded which can cause a lack of consistency in the presentation of the stimulus.

Further, no acoustic measurements of the masks used in this study were performed so specific conclusions regarding the acoustic effects of these masks cannot be determined. Also, ears were tested separately at a given time; however, binaural hearing can elicit better results and provide a more precise effect of the face masks in noisy situations. Therefore, future research must be carried out in free field conditions to imitate better and document the impact of face masks in real-life situations. In addition, it would be interesting to include a study group of hearing-impaired populations along with normal hearing. It would render a better and more precise understanding of the effect of face masks on speech understanding in both populations.

5. Conclusion

The conclusion drawn from the present study is that the speech recognition threshold was negatively affected with cloth and N95 masks even in normal-hearing participants. Surgical masks do not affect the word recognition scores (WRS) at lower background noise levels. However, as the background noise levels increase, even the surgical masks, cloth masks, and N95 masks significantly impact speech discrimination even in normal-hearing individuals. Hence, this potential concern can be used to compensate during audiology programs or practice.

Declaration of competing interest

No potential conflict of interest relevant to this article was reported. All authors affirm that there is no actual or potential conflict of interest. The institute also does not provide any financial or funds for the research work.

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References

Alba, Geoge, 2020. The difference between N95s, surgical masks, and cloth masks. COVID-19 Infect. Dis. Med. Popul. Health Outcomes. http://mgriblog.org/2020/04/29/the-difference-between-n95s-surgical-masks-and-cloth-masks/.

American Speech-Language-Hearing Association, 1979. Guidelines for determining the threshold level for speech. Asha 21, 353–355.

Asadi, S., Welxler, A.S., Cappa, C.D., Barreda, S., Bouvier, N.M., Ristenpart, W.D., 2019. Aerosol emission and super emissions during human speech increase with voice loudness. Sci. Rep. 9, 1–10.

Aydin, O., Emon, B., Cheng, S., Hong, L., Chamorro, L.P., Saif, M.T.A., 2020. Performance of fabrics for home-made masks against the spread of COVID-19 through droplets: a quantitative mechanistic study. Extreme Mech. Lett. 40, 100924.

Balamurali, B.T., Enyi, T., Clarke, C.J., et al., 2021. Acoustic effect of face mask design and material choice. Acoust Aust. 49, 505–512. https://doi.org/10.1007/s40857-021-00245-2.

Beattie, R.C., 1989. Word recognition functions for the CID W-22 test in multitalker noise for normally hearing and hearing-impaired subjects. JSHD (J. Speech Hear. Disord.) 54 (1), 20. https://doi.org/10.1044/jshd.5401.20.

Beattie, R.C., Barr, T., Roup, C., 1997. Normal and hearing-impaired word recognition scores for monosyllabic words in quiet and noise. Br. J. Audiol. 31 (3), 153–164. https://doi.org/10.3109/03005364000000018.

Bond, Z.S., Moore, T.J., Gable, B., 1989. Acoustic–phonetic characteristics of speech produced in noise and while wearing an oxygen mask. J. Acoust. Soc. Am. 85, 907–912. https://doi.org/10.1121/1.397563.

Brosseau, 2009. N95 Respirators and Surgical Masks. CDC, Blogs.

Chaiklin, J.B., Ventry, I.M., 1964. Spondee threshold measurement: a comparison of 2- and 5-dB steps. JSHD (J. Speech Hear. Disord.) 29, 47–59.

Corey, R.M., Jones, U., Singer, A.C., 2020. Acoustic effects of medical, cloth, and transparent face masks on speech signals. J Acoust. Soc Am. October. 148 (4), 2371–2375.

De, N.S., 1973. Hindi PB list for speech audiometry and discrimination test. Indian J. Otolaryngol. 25, 64–75.

Konda, A., Prakash, A., Moss, G.A., Schmoldt, M., Grant, G.D., Guha, S., 2020. Aerosol filtration efficiency of common fabrics used in respiratory cloth masks. ACS Nano 14 (5), 6339–6347.

Lydia, B., 2020. Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. JAMA 323 (18), 1837–1838. https://doi.org/10.1001/jama.2020.4756.

MacIntyre, C.R., et al., 2015. A cluster-randomized trial of cloth masks compared with medical masks in health care workers. BMJ Open 5, e006577. https://doi.org/10.1136/BMJopen-2014-006577.

Marler, H., Ditton, A., 2020. I'm smiling back at you": exploring the impact of mask-wearing on communication in healthcare. Int. J. Lang. Commun. Disord. https://doi.org/10.1111/1460-6984.12578.

McGurk, H., MacDonald, J., 1976. Hearing lips and seeing voices. Nature 264 (5588), 746–748.

Mendel, L.L., Gardino, J.A., Atchersin, S.R., 2008. Speech understanding using surgical masks: a problem in health care? J. Am. Acad. Audiol. 19, 686–695.

Murthy, V.S.S.N., Malhotra, S.K., Bala, I., Raghunathan, M., 1995. Detrimental effect of noise on anesthetists. Can. J. Anaesth. 42, 608–611.

Nabelek, A.K., Nabelek, I.V., 1985. Room acoustics and speech perception. In: Katz, J. (Ed.), Handbook of Clinical Audiology, third ed. Williams &Wilkins, Baltimore, pp. 834–846.

Palmiero, A.J., Symons, D., Morgan, J.W., Shaffer, R.E., 2016. Speech intelligibility assessment of protective facemasks and air-purifying respirators. J. Occup. Environ. Hyg. 13, 960–968. https://doi.org/10.1080/15459624.2016.1200723.

Pearsons, K.S., Bennett, R.L., Fidell, S., 1976. Speech Levels in Various Noise Environments. U.S. Environmental Protection Agency, Office of Health and Ecological Effects, Office of Research and Development, Washington, DC. Report No. EPA-600/1-77-025).

Peelle, J.E., 2018. Listening effort: how the cognitive consequences of acoustic challenge are reflected in brain and behavior. Ear Hear. 39 (2), 204–214.

Pichora-Fuller, M.K., 2016. How social psychological factors may modulate auditory and cognitive functioning during listening. Ear Hear. 37, 92S–100S.

Plomp, R., 1977. Acoustical aspects of cocktail parties. Acustica 38, 186–191.

Smith, S.L., Pichora-Fuller, M.K., Wilson, R.H., MacDonals, E.N., 2012. Word recognition for temporally and spectrally distorted materials: the effects of age and hearing loss. Ear Hear. 33, 349–366.

Theunissen, M., Swanepoel de, W., Hanekom, J., 2009. Sentence recognition in noise: variables in compilation and interpretation of tests. Int. J. Audiol. 48 (11), 743–757.

Wieczorek, S.S., 2013. Lipreading Difficulty during Audio-Visual Integration. Independent Studies and Capstones. Paper 657. Program in Audiology and Communication Sciences. Washington University School of Medicine, St. Louis, MO. http://digitalcommons.wustl.edu/pacs_capstones/657.

Wilson, R.H., McArdle, R., Betancourt, M.B., Herring, K., Lipton, T., Chisolm, T.H., 2010. Word recognition performance in interrupted noise by young listeners with normal hearing and older listeners with hearing loss. J. Am. Acad. Audiol. 21, 90–109.

Wolfe, J., Smith, J., Neumann, S., Miller, S., Schafer, E.C., Birath, A.L., et al., 2020. Optimizing communication in schools and other settings during COVID-19. Hear. J. 73 (9), 40–45.