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# Influence of face surgical and N95 face masks on speech perception and listening effort in noise

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## ABSTRACT

Daily life conversation relies on speech perception in quiet and noise. Due to the COVID-19 pandemic, the usage of face masks has become mandatory in many situations. Acoustic attenuation of sound pressure by the mask tissue reduces speech perception ability especially in noisy situations. Mask also impede the process of speech information from sight of the moving mouth (lip reading).

In a prospective exploratory experimental study including 17 normal hearing participants, speech perception in noise and listening effort were measured with and without a surgical mask or an N95 mask between the speech signal and the listener. Additionally, the influence of the masks on the acoustic frequency spectrum was measured.

Averaged over all noise signals, speech perception threshold in noise was significantly reduced by 1.6 dB (95% CI[1.0, 2.1]) by a surgical mask and by 2.7 dB (95% CI[2.2, 3.2]) using an N95 mask. The 50%-listening effort signal-to-noise ratio was not significantly increased by 0.58 dB (95% CI[0.4, 1.5]) by a surgical mask but significantly increased by 2.2 dB (95% CI[1.2, 3.1]) using an N95 mask. In acoustic measures the amplitudes were reduced by the mask tissue by up to 8 dB at frequencies above 1 kHz while no reduction was observed below 1 kHz.

We conclude that face masks reduce speech perception and increase listening effort in different noise signals. Together with an additional interference by missing lip reading the compound effect of face masks would have a relevant impact on daily life communication already in normal hearing subjects.

## KEYWORDS

Covid19, Matrix test, Face masks, Dummy head, Listening effort, Speech perception in noise

# 1 INTRODUCTION

Coronavirus disease 2019 (COVID-19) is an infectious disease that can occur because of infection with the novel coronavirus SARS-CoV-2. The disease, which primarily affects the respiratory tract, was first described at the end of 2019 in Wuhan, China. It developed into an epidemic in the People's Republic of China in January 2020 and spread worldwide into the COVID-19 pandemic. There is high evidence that the spread occurs through superspreading [1,2]. The infection usually takes place through the transmission of droplets. Transmission via aerosols is also possible, particularly in closed, poorly ventilated rooms [3,4].

In many countries, including Germany and the USA, regulatory bodies as the Robert Koch Institute (RKI) or the Centers for Disease Control and Prevention (CDC) require that mouth and nose protection or even a medical face mask [5] should be worn to reduce the risk of infection. For many situations in social life, this is even mandatory.

Medical face mask or mouth and nose protection masks can become a challenge that impairs communication [6]. On the one hand, masks cover the mouth, which impedes the use of information from the lips and face supporting aural comprehension. Lip reading is especially important for hearing in noisy situations since lip movements provide temporal clues and increase awareness of the language elements. Particularly, information about spoken consonants is provided [7]. Access to lip reading cues has a very positive effect on speech understanding in background noise, especially for the hearing impaired [8]. The speech reception threshold (SRT) in background noise can be improved by 3-5 dB by adding the face image [9,10].

On the other hand, masks can affect the acoustic properties of the speech signal itself with negative implications on speech perception. Simple medical masks as used in operating rooms reduce the signal level of spoken language by 3-4 dB in the high-frequency range of 2000-7000 Hz, N95 masks by about 12 dB [11]. In another study, a level decrease of 12 dB was measured for surgical masks [12]. Although speaking through face masks alters the speech signal, some specific voice quality features (e.g., harmonic-to-noise ratio, temporal pattern) remain largely unaffected [13]. The sound pressure level of spoken language is reduced mainly in frequencies above 2000 Hz. Thus, the resulting signal would be similar to listeners having a slight high frequency hearing loss [14]. In a recent study on health workers the speech perception threshold was increased by 12.4 dB, if the speaker used an N95 mask and a face shield [15].

In normal hearing listeners, speech intelligibility in noise is not significantly affected by face masks [6,16,17]. However, speech perception thresholds in noise were not yet performed in those conditions. In hearing impaired listeners, speech perception in noise would be more affected by reduced sound pressure levels caused by face masks [6,8,18,19].

To compensate for such “pseudo hearing impairment”, hearing amplifiers that compensate for these deficits are required, especially for vulnerable occupational groups and social groups [20]. Specific recommendations for the school situation also aim to compensate for the negative aspects of mouth and nose protection [21].

Active listening requires cognitive resources as focus and attention. Decreased speech level in quiet or signal-to-noise ratio (SNR) in noisy situations increase stress of cognitive resources [22]. It is expected that the use of mouth and nose protection will also increase the listening effort, which in turn has consequences for many daily life situations with a high communication load. With the Adaptive CAtegorical Listening Effort Scaling Test (ACALES), a clinical procedure has recently become available that enables the measurement of the listening effort when listening to background noise [23]. Therewith, listening effort can be assessed on a 14-point subjective scale [24].

The aim of this research project was to measure the influence of medical face masks (mouth and nose protection) according to EN 14683 and N95 masks according to EN 1149 (EN 14683) on speech recognition and the listening effort in various types of background noise in normal hearing listeners. Results were be correlated to the acoustic effects of face masks on recorded speech signals.

# 2 METHODS

A prospective exploratory experimental study was conducted on normal hearing volunteers. Normal hearing was confirmed if the bilateral pure-tone thresholds for air-conduction were ≤ 15 dB hearing level (HL) at both ears at the frequencies 0.5, 1, 2 and 4 kHz. Audiological assessments were conducted using an AT900 audiometer (Auritec, Hamburg, Germany). Informed consent was obtained from all participants for being included in the study. The study was approved by the ethical committee of the Medical Faculty of the Martin Luther University Halle-Wittenberg (approval number 2017-103) and conducted in accordance with the Declaration of Helsinki.

Influence of face masks on speech perception in noise was measured using Foliodress LOOP TYPE IIR surgical face masks (CMC Medical Devices & Drugs, Malaga, Spain) according to European standard EN 14683 (‘Surgical mask’) and RSN95B FFP2 NR particle filtering half masks (Rysam Medical Equipment Manufacturing, Donguan City, China) (‘N95 mask’).

To measure the effects of the masks on the acoustic features of the speech test signals, the masks were placed directly before the grid of a loudspeaker (CD 1020, Canton, Weilrod, Germany) which was positioned in a distance of 1 m in front of a “Dummy Head” (KU 100, Neumann, Berlin, Germany). Using the Oldenburger Measurement Application 2.2 R&D software (Hörtech, Oldenburg, Germany), a Gigaport eX audio interface (ESI Audiotechnik, Leonberg, Germany), and a PLMRA400 amplifier (Pyle, Brooklyn, NY, USA), the olnoise speech simulation noise for a male speaker (‘Olnoise male’), a female speaker (‘Olnoise female’), and the International Speech Test Signal (ISTS) [25] were presented for 30 s at a sound pressure level of 65 dB. White noise was also presented for comparison. Sound signals were recorded by the microphones of the dummy head and amplified by a Fireface 400 audio interface (RME, Haimhausen, Germany). Recorded signals of the two channels were averaged. The root-mean-square (RMS) of the recording and the 1/3-ocatave amplitude spectrum were computed for every experimental condition by using Python scripts. Differences between recordings with and without masks were computed.

In normal hearing listeners, speech recognition in noise was measured using the German Matrix Sentence Test OLSA (Hörtech, Oldenburg, Germany) using the same setup. Noise signals were continuously presented at a sound pressure level of 60 dB from behind. After two training runs, lists of 20 sentences were superposed and presented frontally ($S_0N_{180}$). The sound pressure level of every sentence was adjusted based on the subject’s response to the previous sentence to measure the open-set SRT for 50% correct recognition ($SRT_{50}$) as the primary endpoint. ACALES v2.2 software (Hörtech, Oldenburg, Germany) was used to measure listening effort. After two training runs, series of two consecutive sentences with various SNR from the OLSA in a 60 dB SPL background noise from a rear loudspeaker ($S_0N_{180}$) were frontally presented to the participants. Listening effort was measured in 14 effort categorical units (ecu). The speech level changed adaptively between –40 dB SNR and +20 dB SNR, based on the previous assessment of the subjectively perceived listening effort. Secondary endpoints were the $SNR_{cut}$, i.e., the SNR at 7 ecu, and the slopes of the SNR-effort function for SNR with listening effort > 7 ecu ($m_{low}$) and < 7 ecu ($m_{high}$).

All participants were seated while the head was fixated using a Papillon head fixation system (Focal Meditech, Tilburg, The Netherlands). After two OLSA and two ACALES training runs all participants completed the test runs while the noise signals (Olnoise female, Olnoise male, ISTS) and mask conditions (w/o mask, surgical mask, N95 mask) were applied in pseudorandomized order.

Primary and secondary endpoints were descriptively analyzed and tested for normality using the Shapiro-Wilk-Test. Then, the distributions of $SRT_{50}$ and $SNR_{cut}$ were compared with an analysis of variance (ANOVA) for repeated measures using the within-subject factors of noise type (Olnoise female, Olnoise male, ISTS) and mask type (w/o mask, surgical mask, N95 mask). The assumption of sphericity was tested using Mauchly’s test. Degrees of freedom were adjusted using Bonferroni correction for all post-hoc comparisons. SPSS software version 25 (IBM, Ehningen, Germany) was used for statistical analyses.

# 3 RESULTS

Seventeen normal hearing participants (14 female, 3 male) were included in the study. The average age of the participants was 28 years (*SD* = 5.4). The average pure-tone thresholds across participants and frequencies ($4PTA_{0.5\text{-}4kHz}$) were 7.0 dB HL (*SD* = 2.8) for the left ear and 6.3 dB HL (*SD* = 3.2) for the right ear.

**Table 1: Speech perception in noise and listening effort results.**

| | Speech perception in noise | | | Listening effort | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Olnoise male | Olnoise female | ISTS | Olnoise male | | | ISTS | | |
| Mask type | Mean $SRT_{50}$ (SD) [dB SNR] | Mean $SRT_{50}$ (SD) [dB SNR] | Mean $SRT_{50}$ (SD) [dB SNR] | Mean $SNR_{cut}$ (SD) [escu] | Mean $Slope_{low\ SNR}$ (SD) [escu/dB] | Mean $Slope_{high\ SNR}$ (SD) [escu/dB] | Mean $SNR_{cut}$ (SD) [escu] | Mean $Slope_{low\ SNR}$ (SD) [escu/dB] | Mean $Slope_{high\ SNR}$ (SD) [escu/dB] |
| Without mask | -11.0 (1.6) | -13.2 (1.8) | -23.3 (2.9) | -6.3 (3.5) | -1.5 (1.0) | -1.1 (0.33) | -13.5 (6.0) | -0.83 (0.36) | -0.58 (0.16) |
| Surgical mask | -9.7 (1.6) | -11.6 (1.7) | -21.4 (3.4) | -5.4 (3.3) | -1.7 (1.2) | -1.1 (0.36) | -13.3 (5.2) | -0.91 (0.50) | -0.55 (0.12) |
| N95 mask | -8.3 (1.5) | -10.3 (1.2) | -20.7 (3.2) | -4.5 (3.5) | -1.7 (1.2) | -1.1 (0.27) | -11.1 (6.5) | -0.90 (0.78) | -0.68 (0.25) |

SD: standard deviation; SNR: signal-to-noise ratio; $SRT_{50}$: 50% speech reception threshold

Table 1 shows the descriptive data for the OLSA hearing-in-noise test and the ACALES listening effort test. Figure 1 shows the $SRT_{50}$ distributions for all applied mask type conditions and noise signals. Mauchly's test indicated that the assumption of sphericity had been violated for the $SRT_{50}$ (noise type: $\chi^2(2) = 20.1$, $p < 0.001$; mask type x noise type interaction: $\chi^2(9) = 19.6$, $p < 0.05$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. An ANOVA with noise type and mask type as within-subjects factors revealed main effects of mask type ($F(1.9, 29.8) = 74.9$, $p < 0.001$) and of noise type ($F(1.2, 18.4) = 459.9$, $p < 0.001$). No interaction between mask type and noise type was revealed ($F(2.7, 42.5) = 1.2$, $p > 0.1$). Post-hoc comparisons show that a surgical mask increased the $SRT_{50}$ significantly by 1.6 dB (*SE* = 0.21, *CI* = 1.0, 2.1) on average. A further significant increase of 1.1 dB (*SE* = 0.25, *CI* = 0.5, 1.8) was measured if a N95 mask was applied, resulting in a total increase of 2.7 dB (*SE* = 0.20, *CI* = 2.2, 3.2) across all noise signals. $SRT_{50}$ was lowest for the ISTS (*M* = -21.8 dB, *SE* = 0.74), followed by the Olnoise female (*M* = -11.7 dB, *SE* = 0.35) and the Olnoise male (*M* = -9.7 dB, *SE* = 0.74) across all mask types.

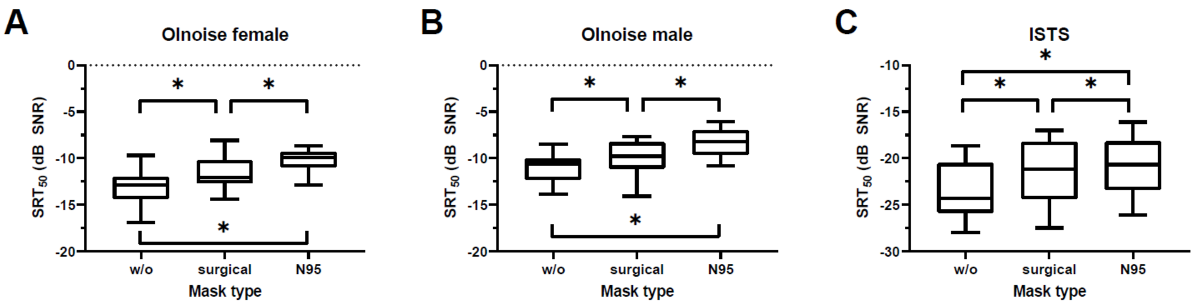

**Figure 1**: Distributions of speech perception in noise $SRT_{50}$ for the Oldenburg Sentence Test (OLSA) presenting speech and noise signals from female (**A**), a male (**B**) speaker, or a female speaker in International Speech Test Signal (ISTS), (**C**). Putting a surgical face mask or an N95 mask between the speaker and the listener reduced the performance as reflected by an increased $SRT_{50}$. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles.  Asterisks (*) mark significant differences ($p < 0.05$).

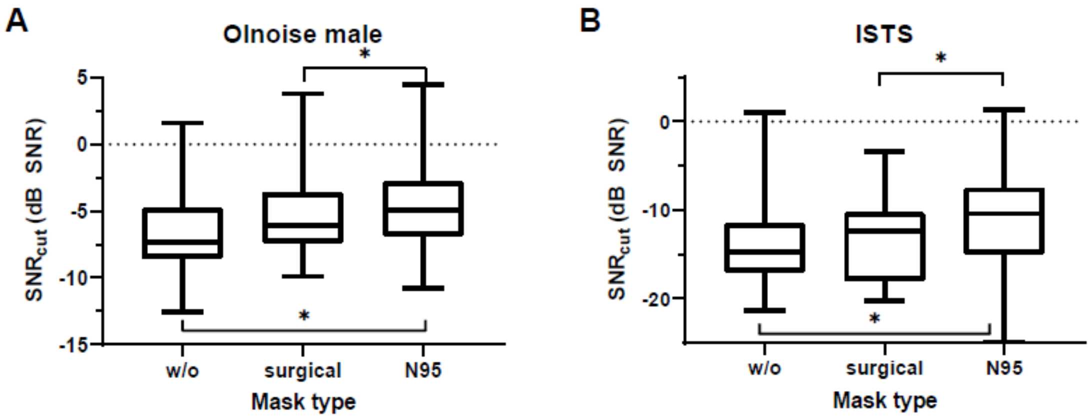

**Figure 2**: Distributions of listening effort in noise $SNR_{cut}$ for the ACALES presenting speech and noise signals from a male speaker (**A**) or a male speaker in International Speech Test Signal (ISTS), (**B**). Placing a surgical face mask or an N95 face mask between the speaker and the listener did not change the listening effort significantly. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles. Asterisks (*) mark significant differences ($p < 0.05$).

Figure 2 shows the $SRT_{cut}$ distributions for all mask type conditions and noise signals.  Mauchly's test indicated that the assumption of sphericity had not been violated for the $SNR_{cut}$ ($p > 0.1$). An ANOVA with noise type and mask type as within-subjects factors revealed no main effects of mask type ($F(2, 32) = 16.3$, $p < 0.001$) and noise type ($F(1, 16) = 132.5$, $p < 0.001$). No interaction between mask type and noise type was revealed (*F*(2, 32) = 1.5, *p* > 0.1). Post-hoc comparisons show that a surgical mask did not increased the $\mathrm{SRT}_{\mathrm{cut}}$ not significantly, by 0.58 dB (*SE* = 0.35, *CI* = 0.4, 1.5) on average. A further significant increase of 1.6 dB (*SE* = 0.46, *CI* = 0.4, 2.8) was measured if a N95 mask was applied, resulting in a significant total increase of 2.2 dB (*SE* = 0.37, *CI* = 1.2, 3.1) across both noise signals. $\mathrm{SRT}_{\mathrm{cut}}$ was lower for the ISTS (*M* = -12.6 dB, *SE* = 1.4), compared to the Olnoise male (*M* = -5.4 dB, *SE* = 0.81) across all mask types.

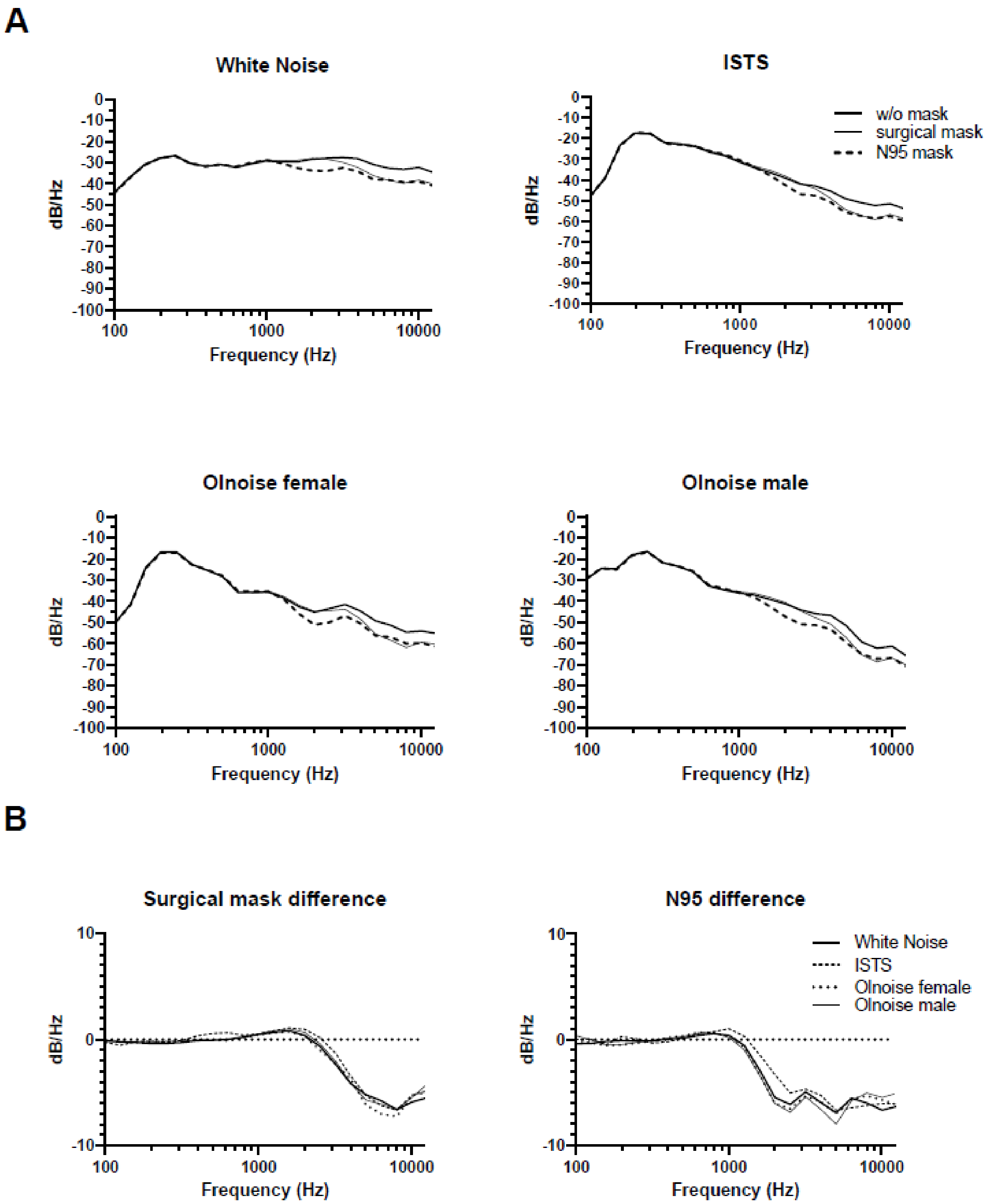

**Figure 3**: **A**. 1/3-octave amplitude spectra of the dummy head recording for white noise, ISTS, Olnoise female, and Olnoise male noise signals presented without a mask (thin line), a surgical mask (bold line), or an N95 mask (dashed line). At frequencies above 1 kHz, the amplitudes were reduced by the mask tissue by up to 8 dB. **B**. Differences between recording without mask and a surgical mask (left) or an N95 mask (right) for all noise signals. The amplitude reduction was comparable between all noise signals. While a surgical mask reduced the amplitudes at frequencies above 2 kHz, the effect was measured at frequencies already above 1 kHz for the N95 mask.

Figure 3 A shows the 1/3-octave amplitude spectra of the dummy head recording for white noise, ISTS, Olnoise female, and Olnoise male noise signals presented without a mask, a surgical mask, or a N95 mask. At low frequencies below 1 kHz, no reduction was observed. At frequencies above 1 kHz, the amplitudes were reduced by the mask tissue by up to 8 dB. Figure 3B shows the differences between recordings without mask and a surgical mask and an N95 mask for all used noise signals. The amplitude reduction was comparable between all noise signals. While a surgical mask reduced the amplitudes at frequencies above 2 kHz, a reduction was already measured at frequencies above 1 kHz for the N95 mask. Maximum amplitude reduction was observed at 8 kHz for the surgical mask. Amplitude reduction by using an N95 mask showed two local maxima in 1/3-octave frequency bands at 2.520 Hz and at 5.040 Hz.

The RMS of the white noise dummy head recordings was reduced by a surgical mask by 2.6 dB and by 4.0 dB by an N95 mask. Only little RMS reduction (< 0.2 dB) was measured for all speech-noise signals.

# 4 DISCUSSION

Speech perception in noise was significantly reduced, if a medical face mask was placed between the speech source and the listeners. Reduction was larger, if an N95 mask was used. The observed effect is comparable to the reduction observed by Goldin et al. [11], Branda [12] and Bandaru et al. [15]. While those studies used live, studies using audio only recordings made with medical masks did not show significant effects on speech intelligibility [6,16,17].

The results show that face mask induced SRT reductions consistently across three different noise types. Without a mask between the speaker and the listener, the measured SRT were better than the normative range of the used speech-in-noise test for signal and noise both presented from the front ($S_0N_0$) [26]. Use of masks still resulted in SRTs being within that reference value range. In daily life situations, the noise source is not fixed and would potentially be in front of the listener in many situations. Then, already the baseline SRT would be worse as compared to the used configuration with noise from behind ($S_0N_{180}$). Since only the speech signals would be affected by a face mask in those situations, speech in noise perception SRTs would be even lower, i.e., worse, than measured in the present study.

Acoustic transmission of sound was attenuated by the surgical and N95 masks. Dummy-head recordings showed an RMS reduction by the speech noise signals in the same low magnitude as previously reported [6,8]. For white noise, however, our result showed a larger RMS reduction for both used mask types. A more detailed analysis of the amplitude spectrum showed no relevant amplitude reduction for low frequencies but a pronounced reduction for higher frequencies. Both mask types modified sound transmission like a low-pass filter with cut-off frequencies of 2 kHz for the surgical mask and 1 kHz for the N95 mask. The measured magnitude of the attenuation, however, is comparable for the surgical and N95 mask and in the same range [11] or larger as previously measured [14]. Our results strengthens previous findings by providing attenuation data for currently used medical mask types. For the first time, acoustic attenuation data were gathered for sex-related speech shaped noise and the ISTS in comparison to a white noise signal.

The observed increase of the speech perception in noise threshold is below the measured attenuation of sound pressure by the masks. Since the SRT measure is based on the difference between speech and noise sound pressure levels, an attenuation of the speech signal alone would potentially increase the SRT by the same amount. The acoustic attenuation, however, was not equal across the frequency spectrum. As low, middle and high frequencies contribute differently to speech perception, the observed discrepancy between acoustical sound attenuation and SRT increase is plausible.

Acoustic attenuation and reduced speech perception in noise have possible implications for communications in daily life situations. Since normative reference data are available for the used speech-in-noise tests, the present results allow a quantification of the effect. In normal hearing listeners, the slope of the speech intelligibility function at the SRT is 17.1%/dB [26]. If the observed SRT shift of 1.58 dB (surgical mask) or 2.69 dB (N95 mask) would only be caused by a speech level reduction by the masks, the estimated speech intelligibility reduction would be 27 percent points for the surgical mask and 46 percent points when an N95 mask is used in that specific constant signal-to-noise ratio.

Low-pass filtering as caused by face masks would reduce the audibility of high-frequency portions of spoken speech as consonants and sibilants or at least increase the listening effort. The observed effect of the masks on listening effort was in the same magnitude as the speech perception threshold in noise. The absolute threshold ($SNR_{cut}$) of the hearing effort function was increased by the face masks which reflects increased listening effort. It is also known that face masks additionally increase the effort for the speaker themselvesf with symptoms of vocal fatigue, discomfort and coordination of speech and breathing [27]. To the listener, an increased communication effort would therefore be expected due to the face masks and changed interpersonal components of communication.

In hearing impaired individuals speech perception in noise is reduced additionally to an increased pure-tone threshold in quiet [28,29] and is mainly attributed to a reduced cochlear amplifier function. Other than in conductive hearing loss, hearing aids can only partially compensate impaired hair cell function. Therefore, reduced speech level in noise would particularly affect daily life communication in hearing impaired listeners.

In the present study, the used face mask type was visible for the patients which could have biased the subjects' speech perception performance. The reported acoustic measurements, however, showed a clear modification of speech signals, which can explain the observed subjective results. Influence of habituation and training on the SRT of the used matrix test was reduced by randomizing experimental conditions and starting with training lists. In daily life, the sight of a speaker that uses a face mask could potentially increase the subjective perceived listening effort due to missing lip reading and other visual, e.g. emotional cues of face to face communication. The results, however, did not show evidence for an increased listening effort by the masks alone.

We conclude that face masks modify acoustic features of speech signals and significantly reduce speech perception in different noise signals. In combination with an additionally reduction by missing lip reading in the same magnitude, the combined effect of face masks would have an relevant impact on daily life communication.

# 5 FIGURE LEGENDS

**Figure 1**: Distributions of speech perception in noise $SRT_{50}$ for the Oldenburg Sentence Test (OLSA) presenting speech and noise signals from female (**A**) or a male (**B**) speaker, or a female speaker in International Speech Test Signal (ISTS), (**C**). Putting a surgical face mask or an N95 mask between the speaker and the listener reduced the performance as reflected by an increased $SRT_{50}$. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles.

**Figure 2**: Distributions listening effort in noise $SNR_{cut}$ for the ACALES presenting speech and noise signals from a male speaker (**A**) or a male speaker in International Speech Test Signal (ISTS), (**B**). Putting a surgical face mask or an N95 mask between the speaker and the listener did not change the listening

effort significantly. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles.

**Figure 3**: **A**. 1/3-octave amplitude spectra of the dummy head recording for white noise, ISTS, Olnoise female, and Olnoise male noise signals presented without a mask (thin line), a surgical mask (bold line), or a N95 mask (dashed line). At frequencies above 1 kHz the amplitudes were reduced by the mask tissue by up to 8 dB. **B**. Differences between recording without mask and using a surgical mask (left) or an N95 mask (right) for all used noise signals. The amplitude reduction is comparable between all noise signals. While a surgical mask reduced the amplitudes at frequencies above 2 kHz, the effect was measured at frequencies already above 1 kHz for the N95 mask.

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TR: Conceptualization, Methodology, Data acquisition, Investigation, Formal Analysis, Writing - Original Draft, Visualization, Project administration

SP: Validation, Resources, Writing - Review & Editing, Supervision

LF: Data acquisition, Investigation, Validation, Writing - Review & Editing

LW: Data acquisition, Investigation, Validation, Writing - Review & Editing