

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

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1 ARTICLE

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24 **ABSTRACT**

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

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

33 Averaged over all noise signals, speech perception threshold in noise was significantly reduced by 1.6
34 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%-
35 listening effort signal-to-noise ratio was not significantly increased by 0.58 dB (95% CI[0.4, 1.5]) by a
36 surgical mask but significantly increased by 2.2 dB (95% CI[1.2, 3.1]) using an N95 mask. In acoustic
37 measures the amplitudes were reduced by the mask tissue by up to 8 dB at frequencies above 1 kHz
38 while no reduction was observed below 1 kHz.

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

42

43 **KEYWORDS**

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

45 1 INTRODUCTION

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

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

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

65 On the other hand, masks can affect the acoustic properties of the speech signal itself with negative
66 implications on speech perception. Simple medical masks as used in operating rooms reduce the signal
67 level of spoken language by 3-4 dB in the high-frequency range of 2000-7000 Hz, N95 masks by about
68 12 dB ¹¹. In another study, a level decrease of 12 dB was measured for surgical masks ¹². Although
69 speaking through face masks alters the speech signal, some specific voice quality features (e.g.,
70 harmonic-to-noise ratio, temporal pattern) remain largely unaffected ¹³. The sound pressure level of
71 spoken language is reduced mainly in frequencies above 2000 Hz. Thus, the resulting signal would be
72 similar to listeners having a slight high frequency hearing loss ¹⁴. In a recent study on health workers
73 the speech perception threshold was increased by 12.4 dB, if the speaker used an N95 mask and a face
74 shield ¹⁵.

75 In normal hearing listeners, speech intelligibility in noise is not significantly affected by face masks
76 ^{6,16,17}. However, speech perception thresholds in noise were not yet performed in those conditions. In

77 hearing impaired listeners, speech perception in noise would be more affected by reduced sound
78 pressure levels caused by face masks^{6,8,18,19}.

79 To compensate for such “pseudo hearing impairment”, hearing amplifiers that compensate for these
80 deficits are required, especially for vulnerable occupational groups and social groups²⁰. Specific
81 recommendations for the school situation also aim to compensate for the negative aspects of mouth
82 and nose protection²¹.

83 Active listening requires cognitive resources as focus and attention. Decreased speech level in quiet or
84 signal-to-noise ratio (SNR) in noisy situations increase stress of cognitive resources²². It is expected
85 that the use of mouth and nose protection will also increase the listening effort, which in turn has
86 consequences for many daily life situations with a high communication load. With the Adaptive
87 CAtegorical Listening Effort Scaling Test (ACALES), a clinical procedure has recently become available
88 that enables the measurement of the listening effort when listening to background noise²³. Therewith,
89 listening effort can be assessed on a 14-point subjective scale²⁴.

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

94 2 METHODS

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

102 Influence of face masks on speech perception in noise was measured using Foliadress LOOP TYPE IIR
103 surgical face masks (CMC Medical Devices & Drugs, Malaga, Spain) according to European standard EN
104 14683 (‘Surgical mask’) and RSN95B FFP2 NR particle filtering half masks (Rysam Medical Equipment
105 Manufacturing, Donguan City, China) (‘N95 mask’).

106 To measure the effects of the masks on the acoustic features of the speech test signals, the masks
107 were placed directly before the grid of a loudspeaker (CD 1020, Canton, Weilrod, Germany) which was

108 positioned in a distance of 1 m in front of a “Dummy Head” (KU 100, Neumann, Berlin, Germany). Using
109 the Oldenburger Measurement Application 2.2 R&D software (Hörtech, Oldenburg, Germany), a
110 Gigaport eX audio interface (ESI Audiotechnik, Leonberg, Germany), and a PLMRA400 amplifier (Pyle,
111 Brooklyn, NY, USA), the olnoise speech simulation noise for a male speaker (‘Olnoise male’), a female
112 speaker (‘Olnoise female’), and the International Speech Test Signal (ISTS) ²⁵ were presented for 30 s
113 at a sound pressure level of 65 dB. White noise was also presented for comparison. Sound signals were
114 recorded by the microphones of the dummy head and amplified by a Fireface 400 audio interface
115 (RME, Haimhausen, Germany). Recorded signals of the two channels were averaged. The root-mean-
116 square (RMS) of the recording and the 1/3-octave amplitude spectrum were computed for every
117 experimental condition by using Python scripts. Differences between recordings with and without
118 masks were computed.

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

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

136 Primary and secondary endpoints were descriptively analyzed and tested for normality using the
137 Shapiro-Wilk-Test. Then, the distributions of SRT_{50} and SNR_{cut} were compared with an analysis of
138 variance (ANOVA) for repeated measures using the within-subject factors of noise type (Olnoise
139 female, Olnoise male, ISTS) and mask type (w/o mask, surgical mask, N95 mask). The assumption of
140 sphericity was tested using Mauchly’s test. Degrees of freedom were adjusted using Bonferroni

141 correction for all post-hoc comparisons. SPSS software version 25 (IBM, Ehningen, Germany) was used
 142 for statistical analyses.

143 3 RESULTS

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

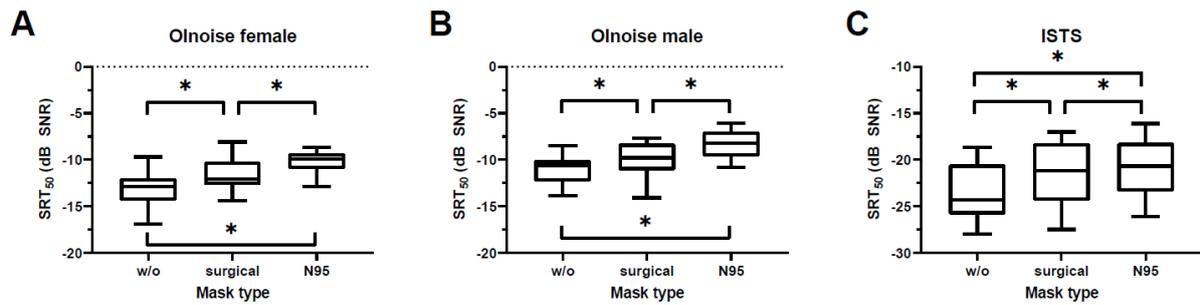
Table 1: Speech perception in noise and listening effort results.

Mask type	Speech perception in noise			Listening effort					
	Olnoise male		Olnoise female	Olnoise male			ISTS		
	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; SRT₅₀: 50% speech reception threshold

148
 149 Table 1 shows the descriptive data for the OLSA hearing-in-noise test and the ACALES listening effort
 150 test. Figure 1 shows the SRT₅₀ distributions for all applied mask type conditions and noise signals.
 151 Mauchly's test indicated that the assumption of sphericity had been violated for the SRT₅₀ (noise type:
 152 $\chi^2(2) = 20.1, p < 0.001$; mask type x noise type interaction: $\chi^2(9) = 19.6, p < 0.05$), therefore degrees of
 153 freedom were corrected using Greenhouse-Geisser estimates of sphericity. An ANOVA with noise type
 154 and mask type as within-subjects factors revealed main effects of mask type ($F(1.9, 29.8) = 74.9, p <$
 155 0.001) and of noise type ($F(1.2, 18.4) = 459.9, p < 0.001$). No interaction between mask type and noise
 156 type was revealed ($F(2.7, 42.5) = 1.2, p > 0.1$). Post-hoc comparisons show that a surgical mask
 157 increased the SRT₅₀ significantly by 1.6 dB ($SE = 0.21, CI = 1.0, 2.1$) on average. A further significant
 158 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
 159 increase of 2.7 dB ($SE = 0.20, CI = 2.2, 3.2$) across all noise signals. SRT₅₀ was lowest for the ISTS ($M = -$
 160 21.8 dB, $SE = 0.74$), followed by the Olnoise female ($M = -11.7$ dB, $SE = 0.35$) and the Olnoise male ($M = -$
 161 9.7 dB, $SE = 0.74$) across all mask types.

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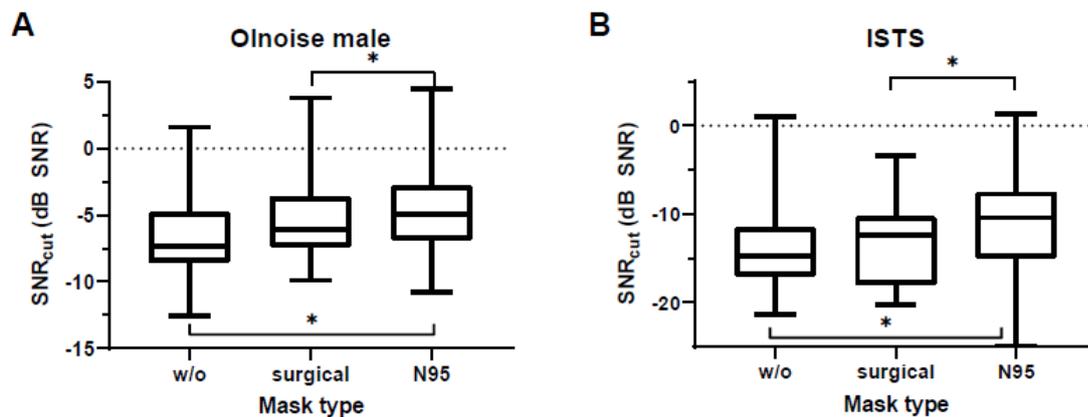
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Figure 1: Distributions of speech perception in noise SRT₅₀ for the Oldenburg Sentence Test (OLSA) presenting speech and noise signals from female (A), a male (B) speaker, or a female speaker in International Speech Test Signal (ISTS), (C). Putting a surgical face mask or an N95 mask between the speaker and the listener reduced the performance as reflected by an increased SRT₅₀. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles. Asterisks (*) mark significant differences ($p < 0.05$).



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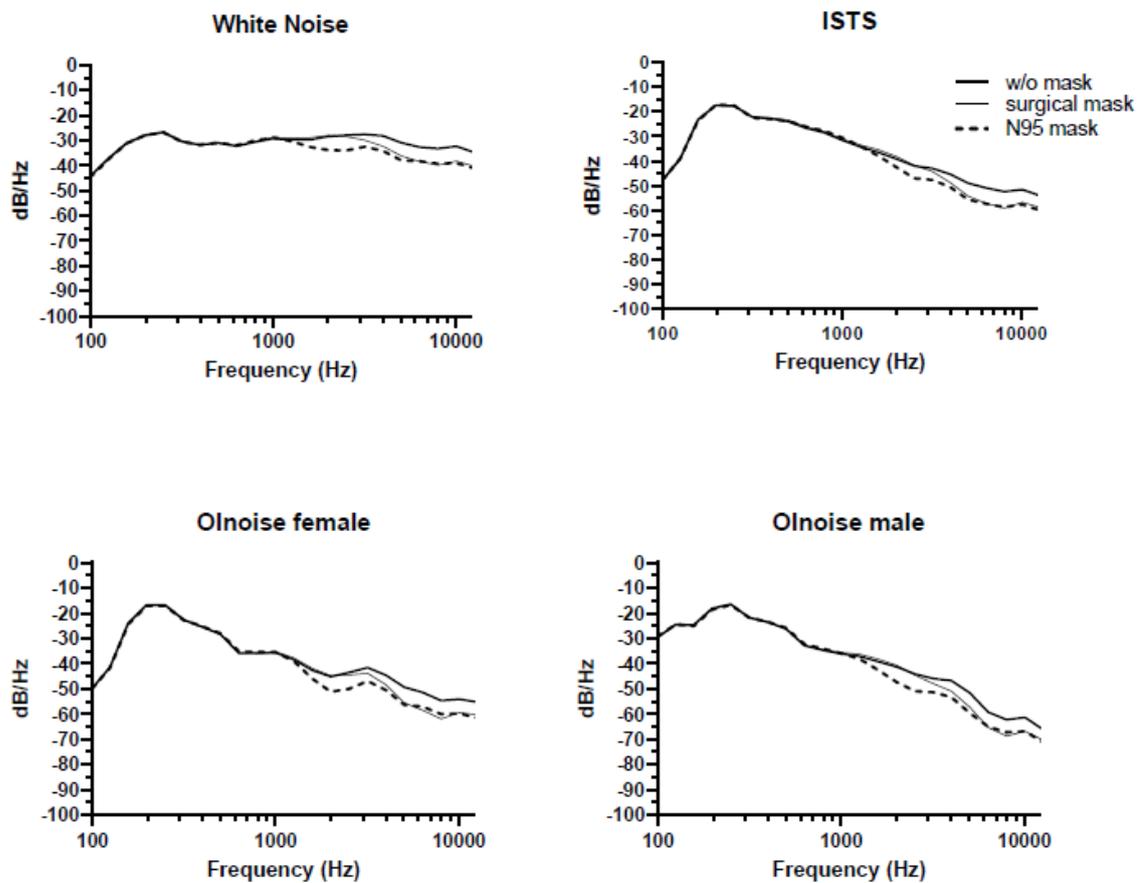
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Figure 2: Distributions of listening effort in noise SNR_{cut} for the ACALES presenting speech and noise signals from a male speaker (A) or a male speaker in International Speech Test Signal (ISTS), (B). Placing a surgical face mask or an N95 face 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 ($p < 0.05$).

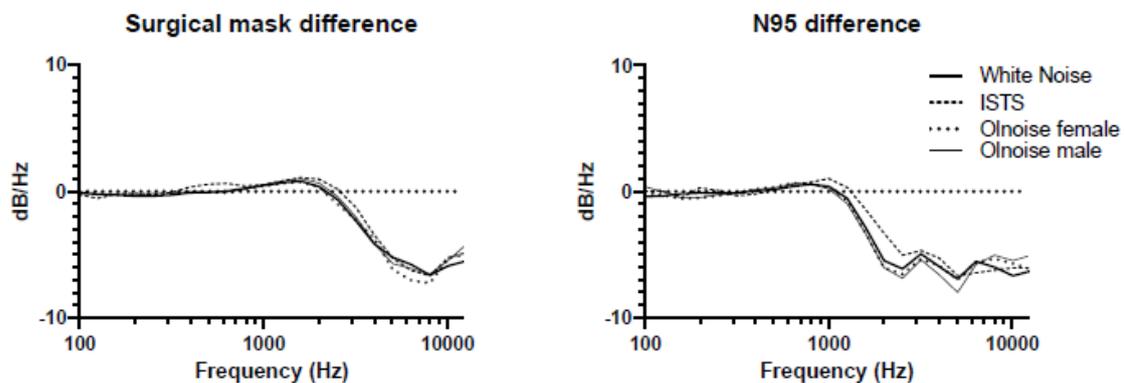
Figure 2 shows the SRT_{cut} distributions for all mask type conditions and noise signals. Mauchly's test indicated that the assumption of sphericity had not been violated for the SNR_{cut} ($p > 0.1$). An ANOVA with noise type and mask type as within-subjects factors revealed no main effects of mask 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

183 and noise type was revealed ($F(2, 32) = 1.5, p > 0.1$). Post-hoc comparisons show that a surgical mask
 184 did not increased the SRT_{cut} not significantly, by 0.58 dB ($SE = 0.35, CI = 0.4, 1.5$) on average. A further
 185 significant increase of 1.6 dB ($SE = 0.46, CI = 0.4, 2.8$) was measured if a N95 mask was applied, resulting
 186 in a significant total increase of 2.2 dB ($SE = 0.37, CI = 1.2, 3.1$) across both noise signals. SRT_{cut} was
 187 lower for the ISTS ($M = -12.6$ dB, $SE = 1.4$), compared to the Olnoise male ($M = -5.4$ dB, $SE = 0.81$) across
 188 all mask types.

A



B



189

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

198
199 Figure 3 A shows the 1/3-octave amplitude spectra of the dummy head recording for white noise, ISTS,
200 Olnoise female, and Olnoise male noise signals presented without a mask, a surgical mask, or a N95
201 mask. At low frequencies below 1 kHz, no reduction was observed. At frequencies above 1 kHz, the
202 amplitudes were reduced by the mask tissue by up to 8 dB. Figure 3B shows the differences between
203 recordings without mask and a surgical mask and an N95 mask for all used noise signals. The amplitude
204 reduction was comparable between all noise signals. While a surgical mask reduced the amplitudes at
205 frequencies above 2 kHz, a reduction was already measured at frequencies above 1 kHz for the N95
206 mask. Maximum amplitude reduction was observed at 8 kHz for the surgical mask. Amplitude
207 reduction by using an N95 mask showed two local maxima in 1/3-octave frequency bands at 2.520 Hz
208 and at 5.040 Hz.

209 The RMS of the white noise dummy head recordings was reduced by a surgical mask by 2.6 dB and by
210 4.0 dB by an N95 mask. Only little RMS reduction (< 0.2 dB) was measured for all speech-noise signals.

211 4 DISCUSSION

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

217 The results show that face mask induced SRT reductions consistently across three different noise types.
218 Without a mask between the speaker and the listener, the measured SRT were better than the
219 normative range of the used speech-in-noise test for signal and noise both presented from the front
220 (S_0N_0) ²⁶. Use of masks still resulted in SRTs being within that reference value range. In daily life
221 situations, the noise source is not fixed and would potentially be in front of the listener in many

222 situations. Then, already the baseline SRT would be worse as compared to the used configuration with
223 noise from behind (S_0N_{180}). Since only the speech signals would be affected by a face mask in those
224 situations, speech in noise perception SRTs would be even lower, i.e., worse, than measured in the
225 present study.

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

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

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

250 Low-pass filtering as caused by face masks would reduce the audibility of high-frequency portions of
251 spoken speech as consonants and sibilants or at least increase the listening effort. The observed effect
252 of the masks on listening effort was in the same magnitude as the speech perception threshold in
253 noise. The absolute threshold (SNR_{cut}) of the hearing effort function was increased by the face masks
254 which reflects increased listening effort. It is also known that face masks additionally increase the effort

255 for the speaker themselves with symptoms of vocal fatigue, discomfort and coordination of speech
256 and breathing²⁷. To the listener, an increased communication effort would therefore be expected due
257 to the face masks and changed interpersonal components of communication.

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

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

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

275

276 5 FIGURE LEGENDS

277 **Figure 1:** Distributions of speech perception in noise SRT_{50} for the Oldenburg Sentence Test (OLSA)
278 presenting speech and noise signals from female (A) or a male (B) speaker, or a female speaker in
279 International Speech Test Signal (ISTS), (C). Putting a surgical face mask or an N95 mask between the
280 speaker and the listener reduced the performance as reflected by an increased SRT_{50} . Boxes show the
281 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles.

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

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

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

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372 **7 AUTHOR CONTRIBUTIONS**

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

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

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

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

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Figures

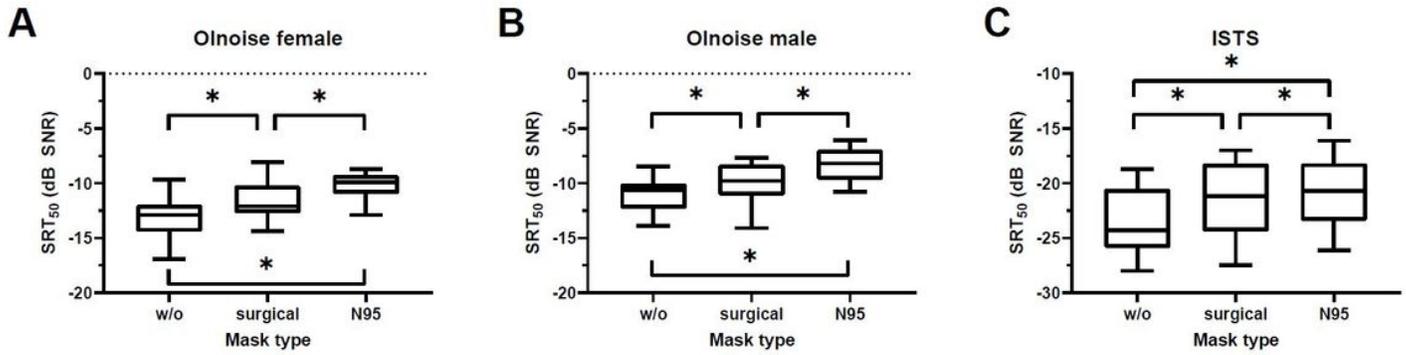


Figure 1

Distributions of speech perception in noise SRT₅₀ 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 SRT₅₀. Boxes show the 25, 50 and 75 percentiles while whiskers mark the 5 and 95 percentiles. Asterisks (*) mark significant differences (p < 0.05).

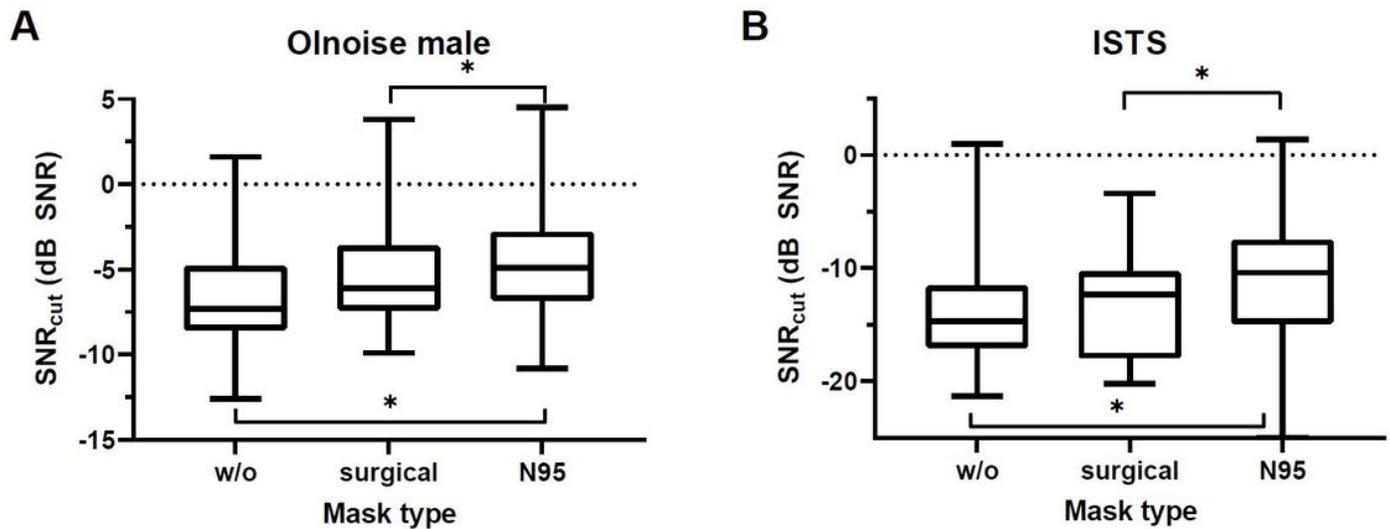


Figure 2

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).

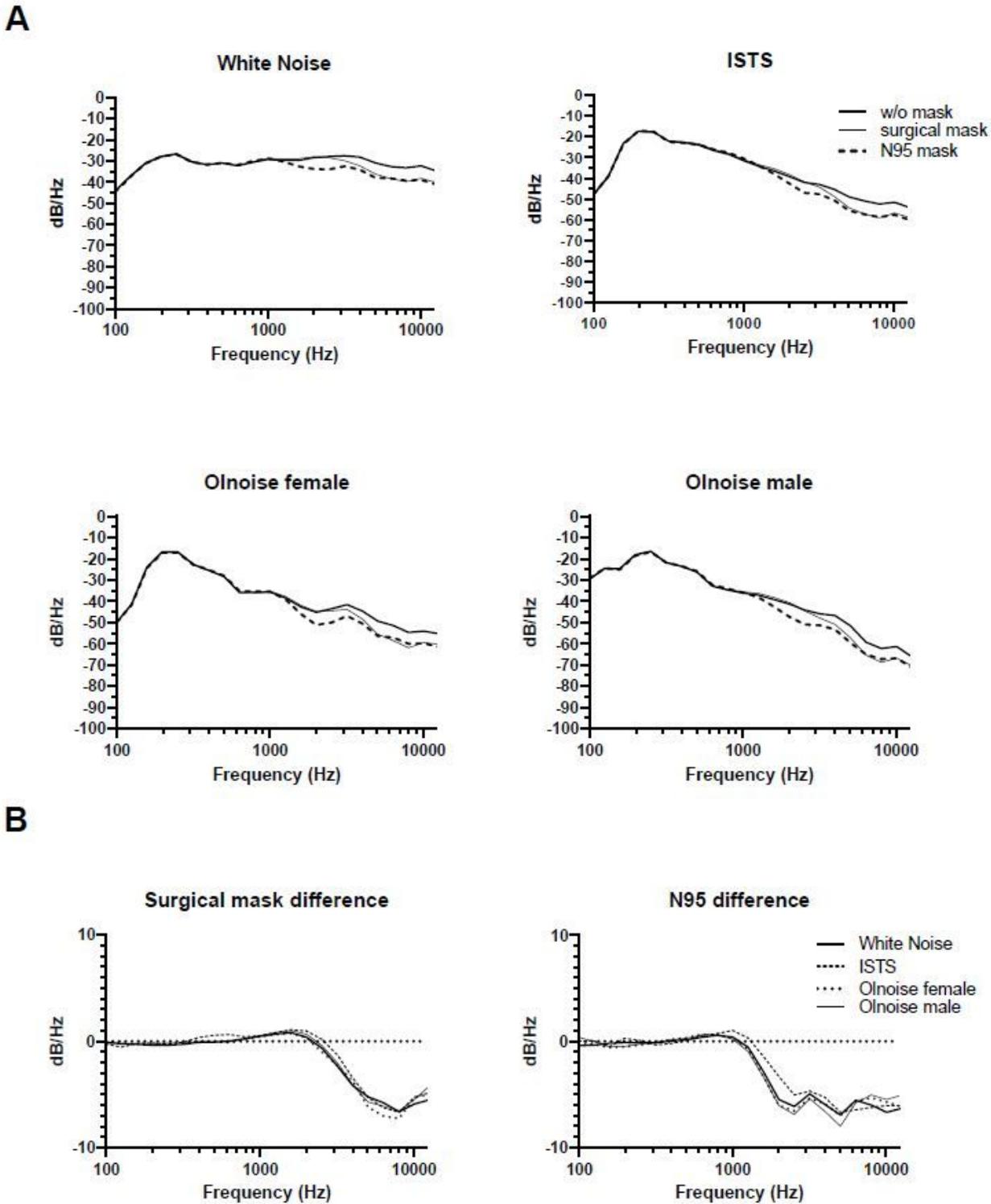


Figure 3

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 195 frequencies above 2 kHz, the effect was measured at frequencies already above 1 kHz for the N95 mask.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Table1.xlsx](#)