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Influence of Protective Face Coverings on the Speech Recognition of Cochlear Implant Patients

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Objectives: The objectives were to characterize the effects of wearing face coverings on: 1) acoustic speech cues, and 2) speech recognition of patients with hearing loss who listen with a cochlear implant.

Methods: A prospective cohort study was performed in a tertiary referral center between July and September 2020. A female talker recorded sentences in three conditions: no face covering, N95 mask, and N95 mask plus a face shield. Spectral differences were analyzed between speech produced in each condition. The speech recognition in each condition for twenty-three adult patients with at least 6 months of cochlear implant use was assessed.

Results: Spectral analysis demonstrated preferential attenuation of high-frequency speech information with the N95 mask plus face shield condition compared to the other conditions. Speech recognition did not differ significantly between the uncovered (median 90% [IQR 89%–94%]) and N95 mask conditions (91% [IQR 86%–94%]; $P = .253$); however, speech recognition was significantly worse in the N95 mask plus face shield condition (64% [IQR 48%–75%]) compared to the uncovered ($P < .001$) or N95 mask ($P < .001$) conditions.

Conclusions: The type and combination of protective face coverings used have differential effects on attenuation of speech information, influencing speech recognition of patients with hearing loss. In the face of the COVID-19 pandemic, there is a need to protect patients and clinicians from spread of disease while maximizing patient speech recognition. The disruptive effect of wearing a face shield in conjunction with a mask may prompt clinicians to consider alternative eye protection, such as goggles, in appropriate clinical situations.

Key Words: Mask, face shield, speech perception, COVID-19, hearing loss.

Level of Evidence: 3

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INTRODUCTION

The coronavirus (COVID-19) pandemic led to many international public health-related changes to curb the spread of disease, which is transmitted primarily by aerosolized particles.[1,2] Public health measures have included extended shut-downs of non-essential businesses, medical clinic and school closures with phased re-opening, and recommendations on interpersonal interaction, including social distancing of greater than 6 feet and wearing personal protective equipment (PPE). Subsequently, various face coverings are being used to reduce disease transmission,[2] including surgical masks, cloth masks, N95 masks, transparent masks (fully transparent or paper masks with a plastic window), goggles, and face shields. Currently, the CDC recommends that people wear masks in all public settings or when around people who do not live in their households.[1] In healthcare settings, PPE practices are more stringent given higher exposure risks for patients, personnel, and clinicians. At the study institution, all personnel wear at least a surgical mask and eye protection (e.g., goggles or face shield), and patients wear a surgical mask. Specialties such as otolaryngology that perform aerosolizing procedures apply more rigorous standards, such as regular use of N95 masks plus eye protection.

Talker face coverings can limit the acoustic information available to the listener, with signal degradation varying for different face coverings. Prior studies have demonstrated that face masks act as a lowpass filter, attenuating high-frequency spectral content.[3–7] Although the most important cues for speech recognition are in the region of 0.5 to 3 kHz, higher frequencies also contribute to speech recognition, particularly with respect to fricative consonants such as /s/, /f/, and /t/.[8] Normal-hearing listeners demonstrate similar speech recognition when listening to a talker who is either unmasked or wearing a surgical mask when the conversation occurs in a quiet environment,[4] such as a clinic exam room. However,

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significantly poorer speech recognition is observed when listening to a talker who is wearing an N95 mask plus a face shield, as compared to unmasked, when the conversation occurs in a noisy environment.[9]

Acoustic degradation of speech created by different face coverings may have a larger negative effect on speech recognition for listeners with hearing loss compared to normal-hearing listeners. The majority of listeners with hearing loss experience poorer hearing detection thresholds in the high-frequency region,[10] resulting in difficulty understanding consonant information due to reduced audibility and spectral resolution.[11] Reduced high-frequency sensitivity could be exacerbated by high-frequency attenuation. Listeners with hearing loss can compensate for reduced audibility by using visual cues (e.g., lip reading). These visual cues are largely obscured by the most commonly used masks, including cloth, surgical, and N95 masks. Previous work has demonstrated listeners with severe-to-profound hearing loss experience significantly poorer speech recognition when the talker is wearing a conventional or transparent surgical mask as compared to unmasked conversations.[5] Taken together, patients with hearing loss likely experience difficulty understanding a clinician wearing a face covering—even in a quiet exam room.

The attenuation of high-frequency information caused by face coverings may have a significant negative impact on speech recognition even when the listener is using hearing technology, such as a cochlear implant (CI) or a hearing aid. Cochlear implantation is recommended for patients with severe-to-profound high-frequency hearing loss. The CI is a two-part device consisting of an internal receiver/stimulator and electrode array that is surgically implanted into the patient's cochlea and an external processor that translates acoustic auditory information into an electric signal that the patient uses to recognize sounds. The majority of CI patients experience significant improvements in speech recognition as compared to preoperative performance with hearing aids, though speech recognition remains poorer than normal-hearing listeners.[12,13] One reason for this discrepancy is the limited spectral information available to CI users, due to a discrete number of electrode contacts and current spread in the cochlea. In the case of hearing aid users, both hearing loss and amplification are associated with reduced frequency selectivity.[14,15] The combination of limited spectral information and reduced high-frequency energy for speech produced with a face covering is likely to have a significant negative effect on the speech recognition of patients with hearing loss, even when using hearing technology.

There is limited information on the effect of currently recommended face coverings for clinicians, including N95 masks and face coverings with a plastic component (e.g., face shields) on the acoustic properties of speech. For clinicians working with patients with hearing loss, there is a need to understand how different face coverings influence the patient's speech recognition and whether performance on routinely-performed speech recognition measures predicts decrements in recognition. This study aimed to characterize the effects of face coverings on: 1) the availability of acoustic speech cues, and 2) the speech recognition of CI patients. A second aim was to determine whether sentence recognition with face coverings is predicted by word recognition in quiet, an outcome that is routinely assessed clinically for CI patients.

MATERIALS AND METHODS

This prospective investigation was approved by the study site IRB. Subjects provided informed consent prior to participation.

Subjects

Adult patients implanted at the University of North Carolina at Chapel Hill (UNC) were recruited during follow-up encounters between July and September 2020. Subjects were recipients of either an Advanced Bionics Corporation (Los Angeles, CA, U.S.A.), Cochlear Corporation (Sydney, Australia), or MED-EL Corporation (Innsbruck, Austria) device; these subjects listened with either electric stimulation alone (CI-alone) or ipsilateral combination of electric and acoustic stimulation (EAS). Inclusion criteria were as follows: post-lingual onset of hearing loss, ≥18 years of age at time of testing, ≥6 months of device use, and >20% sentence recognition score in quiet on the AzBio sentences test.[16] The 6 months of device use criterion was selected since device settings and speech recognition have been shown to stabilize by approximately 6 months post-activation.[17,18]

Recording of Experimental Stimuli

Speech stimuli were AzBio sentences.[16] This test was selected due to its reputation for better reflecting listeners' performance in real life,[16] and its inclusion of contextual information as compared to word-based test batteries. Each list contains 20 sentences, with variable numbers of words per sentence and per list. Seven lists from the corpus of extended lists were selected for recording; these materials have been shown to be equivalent in terms of performance[19] and were unfamiliar to the subjects. The same lists were recorded for each of the three experimental conditions: 1) no mask or shield (referred to as "uncovered"), 2) N95 mask (referred to as "N95"), and 3) N95 mask plus face shield (referred to as "N95 + shield"). A commercially available plastic face shield (CKFS-100), with forehead contact and a free inferior edge, was used. The present test methods assessed speech recognition with auditory-only cues. Additional recordings were made using a paper mask with transparent plastic window (Communicator™ Mask, Safe'N' Clear, Davidson, NC, U.S.A.) and a fully transparent mask (ClearMask™, ClearMask LLC, Baltimore, MD, U.S.A.). Recordings with the transparent masks were made as a comparison for the acoustic analysis.

Stimuli were recorded by a female native English speaker in a double-walled sound-isolated booth with an omnidirectional microphone (Shure KSM42) suspended in a shock mount. The microphone was positioned six inches from the talker's mouth. Microphone output was routed to a soundcard (M-audio M-Track 2 × 2) that was connected to a computer. Recordings were made at a 44.1-kHz sampling rate in all three experimental conditions (i.e., uncovered, N95, or N95 + shield). The talker listened to the commercially-available recording of each sentence prior to producing that sentence. This procedure was intended to elicit productions with uniform speaking rate and prosody across conditions. Resulting recordings were similar across the three conditions with respect to median sentence duration (2.2–2.3 sec), fundamental frequency (205–209 Hz), and range of F0 (25th to 75th percentiles: 57–60 Hz).

Speech Recognition Procedures

Subjects were seated in a double-walled sound booth, facing a soundfield speaker (SP90, RadioEar, Denmark) approximately one meter away. The frequency response of this speaker is flat within ±6 dB between 0.125 and 8 kHz. Subjects were tested in a monaural condition, listening with their familiar CI-alone or EAS settings. Masking was presented to the contralateral ear via an insert for subjects with moderate or better acoustic hearing thresholds to isolate the input to the test ear. For bilateral CI recipients, the ear with better baseline sentence recognition (see below) was selected and the contralateral device was removed.

Baseline performance was evaluated with the test battery used clinically to assess the performance of adult CI patients, known as the Minimum Speech Test Battery (MSTB).[20] The MSTB includes the consonant nucleus consonant (CNC) monosyllabic words test and AzBio sentences test. Next, speech recognition was assessed with the recordings of the experimental conditions (i.e., uncovered, N95, and N95 + shield). Subjects were presented with two lists per experimental condition. The order of the lists and the experimental condition were randomized. Test materials were presented at 60 dB SPL (sound pressure level) after root mean square level normalization. Subjects were instructed to repeat the presented word or sentence and encouraged to guess if unsure. Performance on each test was scored as the percent of words correctly repeated and the average percent correct between the two lists per experimental condition was calculated.

Data Analysis

The long-term average speech spectrum (LTASS) of speech in each of the face covering conditions was computed in MATLAB (MathWorks) using a 512-point Hanning window. Speech recognition was evaluated using a repeated-measures analysis of variance (ANOVA; SPSS, version 26) with post-hoc Bonferroni analysis. A Bivariate Pearson correlation assessed the relationship between CNC scores and AzBio scores in the N95 + shield condition to evaluate whether performance on the routine clinical test battery correlated with performance in the most challenging experimental condition. Significance was defined as $\alpha < 0.05$, and scores of percent correct were transformed to rationalized arcsine units (RAUs) prior to analysis to normalize error variance.[21]

RESULTS

Twenty-three patients (14 female, 61%) were selected for inclusion. Demographic data are listed in Table 1. The age at time of cochlear implantation ranged from 17 to 84 years (mean: 57 years, SD: 16 years). Duration of device use ranged from 6 months to 16 years (mean: 4 years, SD: 4 years). Subjects were recipients of devices from Advanced Bionics (n = 2), Cochlear (n = 1), or MED-EL (n = 20). Eighteen subjects were CI-alone users, and five were EAS users. Thirteen subjects used contralateral hearing technology, either CI (n = 9) or hearing aid (n = 4); seven subjects had unilateral hearing loss (UHL).

TABLE I.
Demographics of the Study Sample.

Category	(n = 23)
Age at implantation	
Range	17 to 84 yr
Mean (SD)	57 yr (16 yr)
Gender	
Female	n = 14 (61%)
Male	n = 9 (39%)
Duration of device use	
Range	6 mo to 16 yr
Mean (SD)	4 yr (4 yr)
Device manufacturer	
Advanced bionics	n = 2 (9%)
Cochlear	n = 1 (4%)
Med-El	n = 20 (87%)
External processor	
CI-alone	n = 18 (78%)
EAS	n = 5 (22%)
Contralateral hearing	
CI	n = 9
Hearing aid	n = 4
Normal hearing (UHL)	n = 7

CI = cochlear implant, EAS = electric-acoustic stimulation, UHL = unilateral hearing loss.

Spectral Analysis

Figure 1 plots the LTASS for one list of AzBio sentences produced in each of the face covering conditions, including those used in speech recognition testing (left panel) and those omitted from behavioral assessment (right panel). As predicted, there was little or no attenuation for any of the face coverings at low frequencies. However, there was attenuation at the higher frequencies in all face covering conditions. Relative to the uncovered condition, attenuation at 5 kHz was modest for the N95 mask (4.3 dB), more substantial for the Communicator™ mask and ClearMask™ (8.4 and 10.9 dB), and substantial for the N95 + shield (17.3 dB).

Speech Recognition

Figure 2 plots the percent correct performance in each of the experimental conditions. Panel A shows data for each subject, with lines connecting individual results across conditions. Panel B shows the distribution of data in each condition, with median values of: uncovered 90% (interquartile range (IQR): 89%–94%), N95 91% (IQR: 86%–94%), and N95 + shield 64% (IQR: 48%–76%). There was a significant main effect of experimental condition ($F_{(1.34,29.55)} = 105.27$, $P < .001$), indicating differences in speech recognition across the three conditions. Post-hoc analyses revealed speech recognition was significantly different between the uncovered and N95 + shield conditions ($P < .001$) and between the N95 and N95

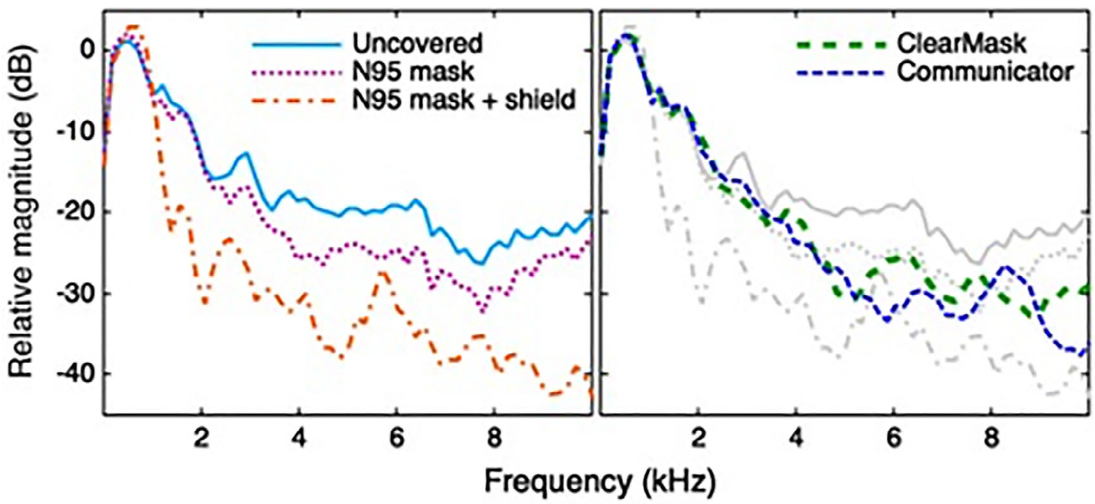

Fig. 1. Long-term average speech spectrum for one list of AzBio sentences produced with and without face coverings. The left panel shows results for conditions tested behaviorally: 1) uncovered, 2) N95 mask, and 3) N95 mask plus face shield. The right panel shows two additional conditions: 4) ClearMask™, and 5) Communicator™ mask. Line style indicates stimulus condition, as defined in the legends. Gray lines in the right panel are reproduced from the left panel, for reference.

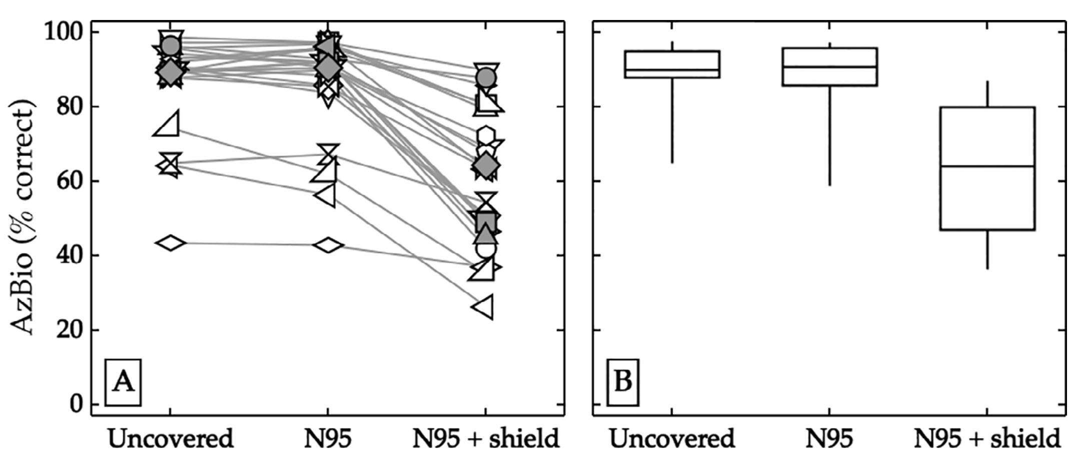

Fig. 2. Speech recognition of subjects for each of the three stimulus conditions: 1) uncovered, 2) N95, and 3) N95 + shield. Results are plotted in percent correct. A) Individual subject results, with open symbols indicating CI-alone users and filled symbols indicating EAS users. B) Distribution of group data for each condition. Horizontal lines indicates the median, boxes span the 25th and 75th percentiles, and whiskers span the 10th and 90th percentiles.

+ shield conditions ($P < .001$). Speech recognition was not significantly different between the uncovered and N95 conditions ($P = 1.000$).

Figure 3 plots the performance in the most challenging experimental condition (i.e., N95 + shield) by the performance on the CNC word test. Symbols indicating individual results are the same as in Figure 2A. There was a significant positive correlation between sentence recognition in the N95 + shield condition and word recognition ($r = 0.501$, $P = .015$). This indicates that CI patients with worse performance on routine clinical speech recognition testing also tend to perform poorly when the talker is wearing an N95 mask plus a face shield.

DISCUSSION

In the era of the COVID-19 pandemic there is a need to protect patients and medical personnel from spread of disease, including the use of face coverings. The various face covering options may have differential effects on attenuation of speech information and speech recognition for patients with hearing loss. The present study findings demonstrate preferential attenuation of high-frequency speech content with face coverings, with more significant attenuation with addition of plastic barriers. These findings are consistent with those of previous studies,[3–5] and further demonstrate increased attenuation of high-frequency acoustic signals with the addition of a plastic face barrier.

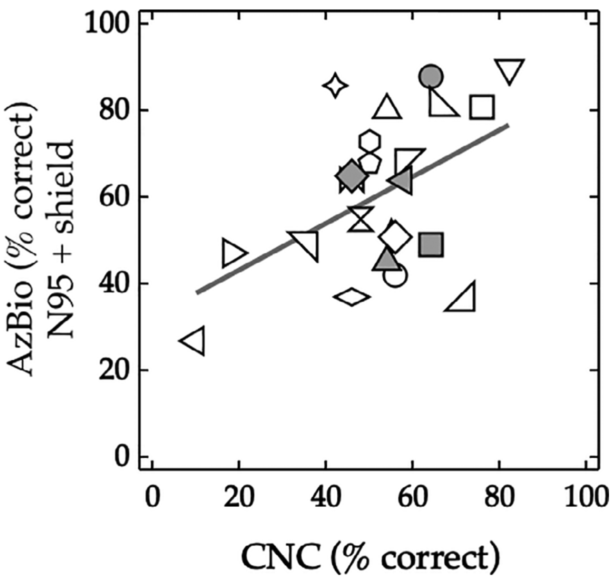

Fig. 3. Correlation between the CNC word recognition score and AzBio sentence recognition score in the most challenging experimental condition (N95 mask plus face shield) for each subject. Symbol shape and fill is consistent with the plotting contentions in Figure 2.

The present study demonstrates that an N95 alone did not significantly affect speech recognition of CI patients, but that the addition of a face shield led to a significant reduction in speech recognition. These findings corroborate previous investigations of speech recognition for listeners with normal hearing or mild hearing loss, which demonstrated no significant difference in speech recognition with a surgical mask; however, they contradict the findings of impaired speech recognition for listeners with severe to profound hearing loss listening to speech produced with a surgical mask.[4,5] Direct comparisons between the present study and previous investigations are limited because previous investigations used a paper surgical mask and a small number of data-points on patients using hearing technologies.[4,5] In addition, previous studies have evaluated performance using word recognition tests,[4,5,9] which do not provide contextual information. Sentence recognition, as evaluated in the present study, is more reflective of the experience of a patient listening to a clinician.

The present study demonstrates CI patients experience a significant decrement in speech understanding with the addition of a plastic barrier. As a plastic barrier may be warranted for eye protection during clinical encounters, goggles may be an appropriate alternative to a face shield to provide eye protection while limiting the amount of attenuation. Goggles plus a mask configuration may not be appropriate for encounters requiring more rigorous PPE. Clinicians may also support patient speech understanding by using augmentative communication tools (e.g., written or typed messages, voice-to-text applications, or remote microphones) and using effective communication strategies, such as rephrasing concepts in lieu of repeating, asking questions to assess patient understanding, ensuring appropriate positioning relative to the patient, using gestures, limiting background distractions, and providing written supplements.[22–24]

Of note, the present study found that subject performance in the most challenging experimental condition (i.e., N95 + shield) was positively correlated with performance on a test included in the routine clinical test battery (i.e., CNC word recognition). This correlation suggests that CI patients who perform poorly on the routinely-performed MSTB would be anticipated to demonstrate worse speech recognition with clinicians wearing an N95 mask plus face shield. Word recognition in quiet scores could be useful to consider when selecting PPE or deciding whether to use adjunct communication strategies.

During the COVID-19 pandemic, there has been an increase in the utilization of PPE with a transparent plastic component, including paper masks with plastic windows and fully transparent surgical masks. Acoustic analysis of two such alternatives demonstrated increased high-frequency attenuation compared to an N95 mask. The addition of visual cues to auditory information has been shown to improve speech recognition under some conditions.[25,26] It is unclear whether the availability of visual cues offsets the reduction in speech understanding resulting from the attenuation of high-frequency speech information for masks with a transparent plastic component. The present report reviewed speech recognition with auditory-only stimuli to characterize the amount of attenuation and understand the influence on speech recognition for different face coverings. There is a need to investigate the benefit of visual cues in the presence of attenuated auditory information. Findings will have important implications not only for clinicians who treat patients with hearing loss, but also for teachers and providers who work with children with hearing loss. However, otolaryngologists frequently must wear N95 masks in clinical encounters, which do not incorporate visual cues.

The present study demonstrates the significant influence of face coverings on the speech recognition of CI patients, though there are limitations worthy of consideration. The recordings were of a single female talker, and findings may not generalize across talkers, including male talkers. In addition, the present study included a heterogeneous sample of CI patients, including CI-alone and EAS users. While the intent was to observe trends in a sample representative of the clinical CI population, it is possible that use of different technologies could introduce bias. Performance was assessed in a monaural condition to control for the variability in audibility in the contralateral ear across subjects (e.g., UHL). Finally, speech recognition was evaluated in a soundproof booth to simulate a clinic encounter in a quiet exam room. However, medical encounters can also occur in background noise, such as noise from background talkers and medical equipment. Ongoing work is assessing the influence of face coverings on speech recognition in noise. Importantly, this study does not address the effect of different PPE configurations on disease transmission. At the study institution, clinicians wear a surgical mask and eye protection (e.g., face shield or goggles) in routine clinical encounters, and an N95 mask and eye protection when airborne precautions are required. Further research addressing both disease transmission and speech recognition are needed prior to making recommendations in situations where more rigorous PPE is required.

CONCLUSION

This study demonstrated that CI patients experience significantly impaired recognition of speech produced with an N95 mask and face shield compared to an N95 alone or no face covering. Plastic barriers resulted in greater high-frequency attenuation than with an N95 mask. While these results were obtained on CI patients, we hypothesize similar outcomes for other patient groups with significant hearing loss, and more pronounced effects in background noise. Clinicians may consider the use of goggles versus a face shield as eye protection for clinical encounters that do not require more rigorous PPE, in addition to communication tools and strategies to maximize patient speech understanding.

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