



Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Ng, I;Kave, B;Paynter, C;Bodas, C;Roberts, M;Hung, S;Williams, DL

Title:

Speech intelligibility and hearing acuity assessments of N95/P2 respirator with under-mask elastic band beard cover

Date:

2025-11-01

Citation:

Ng, I., Kave, B., Paynter, C., Bodas, C., Roberts, M., Hung, S. & Williams, D. L. (2025). Speech intelligibility and hearing acuity assessments of N95/P2 respirator with under-mask elastic band beard cover. *Infection Control and Hospital Epidemiology*, 46 (11), pp.1127-1133. <https://doi.org/10.1017/ice.2025.10297>.

Persistent Link:







<https://hdl.handle.net/11343/363006>

License:

[CC BY-NC-ND](#)

Original Article

Speech intelligibility and hearing acuity assessments of N95/P2 respirator with under-mask elastic band beard cover

Irene Ng MBBS, FANZCA, MCLinRes, GCert (CritCareEcho)^{1,2} , Benjamin Kave MBBS, FANZCA^{1,2} ,
Camille Paynter PhD, B Speech Path (Hons)^{3,4} , Charles Bodas GradDip (Health, WHS)⁵ , Megan Roberts⁵ ,
Shan Hung BNurs, GradCert(ClinNurs)^{6,1} and Daryl Lindsay Williams MBBS, FANZCA, MBA, CPI, FAPCR^{7,2} 

¹Department of Anaesthesia and Pain Management, Royal Melbourne Hospital, Parkville, VIC, Australia, ²University of Melbourne, Parkville, VIC, Australia, ³Department of Speech Pathology, Royal Melbourne Hospital, Parkville, VIC, Australia, ⁴School Health Sciences, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne, Parkville, VIC, Australia, ⁵Respiratory Protection Program, Royal Melbourne Hospital, Parkville, VIC, Australia, ⁶Anaesthetic & Recovery, Royal Melbourne Hospital, Parkville, VIC, Australia and ⁷Department of Anaesthesia and Pain Management, Royal Melbourne Hospital, Parkville, VIC, Australia

Abstract

Objective: Using the Modified Rhyme Test in accordance with the National Institute for Occupational Safety and Health (NIOSH) protocol, we assessed the communication performance for both speech intelligibility and hearing acuity in bearded healthcare workers (HCWs) wearing a N95/P2 respirator with an under-mask elastic band beard cover.

Design and setting: A prospective simulation study conducted at the respiratory fit test center of the Royal Melbourne Hospital.

Participants: Bearded HCWs who required respiratory protection and could not shave for medical, cultural, or religious reasons.

Results: The overall performance rating score was 91.3% and 99.8% for speech intelligibility and hearing acuity respectively. There was a reduction in the percentage of correct words perceived by a panel of trained listeners when bearded HCWs were speaking while wearing the N95/P2 respirator/elastic band combination compared to the uncovered beard condition (84.5% vs. 92.9%, $p = 0.011$). However, no significant difference was found in the perception of medical phrases between these two conditions. In the hearing assessment, there were no differences found in hearing correct single words or medical phrases between the two conditions.

Conclusions: This study demonstrates that when bearded HCWs wore the N95/P2 respirator/elastic band combination, their speech intelligibility and hearing acuity greatly exceeded the NIOSH standard of 70% in the Modified Rhyme Test. This finding is crucial for ensuring effective communication among bearded HCWs, thereby supporting both respiratory protection and operational efficiency in healthcare settings.

(Received 25 June 2025; accepted 15 August 2025; electronically published 2 October 2025)

Introduction

The N95/P2 respirator with under-mask elastic band beard cover is a relatively new respiratory protection method for healthcare workers (HCWs) who are unable to shave for medical, cultural, or religious reasons.¹ This technique innovatively uses a long elastic band to compress and cover the beard, wrapping tightly around the sides of the face to form an artificial skin-like surface, against which a conventional respirator can create a seal. This method has been referred to as the “Singh Thattha technique” since it was first

published in 2020.¹ Recent studies have shown that it is a safe and effective practice, which yields a high quantitative fit test pass rate and is relatively comfortable and well tolerated by bearded HCWs.^{2,3} According to the Project BREATHE recommendation by the United States National Institute for Occupational Safety and Health (NIOSH),⁴ there are other respirator characteristics, apart from safety and efficacy, that need to be evaluated when assessing respiratory protective equipment. Features such as speech intelligibility and hearing acuity are two important factors, as any reduction can interfere with daily occupational activities.

Face masks and respirators are known to negatively affect verbal communication.^{5–8} The degree of impact depends on the type of masks being worn. Radonovich Jr et al. demonstrated that the decrease in word intelligibility while wearing commonly used respirators ranged from 1% to 17% in an intensive care

Corresponding author: Irene Ng; Email: Irene.Ng@mh.org.au

Cite this article: Ng I, Kave B, Paynter C, et al. Speech intelligibility and hearing acuity assessments of N95/P2 respirator with under-mask elastic band beard cover. *Infect Control Hosp Epidemiol* 2025. 46: 1127–1133, doi: [10.1017/ice.2025.10297](https://doi.org/10.1017/ice.2025.10297)

© The Author(s), 2025. Published by Cambridge University Press on behalf of The Society for Healthcare Epidemiology of America. This is an Open Access article, distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives licence (<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided that no alterations are made and the original article is properly cited. The written permission of Cambridge University Press must be obtained prior to any commercial use and/or adaptation of the article.



environment, with the worst performing respirator being the half-face elastomeric mask.⁸ Wearing an elastic band beard cover under a N95/P2 respirator can potentially further diminish speech intelligibility because the band must form an artificial skin, cover facial hair over the chin and cheeks, cross the ears and be tied tight enough to sit flat on the chin and face.⁹ It can potentially limit jaw movement, which in turn may affect speech quality. Moreover, the elastic band covers both ears and may potentially reduce hearing acuity.

Communication difficulties may not only hinder healthcare operations, but also potentially reduce respirator user compliance, which can reduce respiratory protection effectiveness. As shown in a previous large study, half of the surveyed hospital staff found wearing masks bothersome due to communication barriers.¹⁰ Some staff discontinued respirator use sooner than planned in a prolonged respirator wear study due to diminished communication ability.¹¹ Therefore, it is crucial to identify and quantify any communication issues when using this relatively new beard cover technique, as there is currently no data available.

In this study, the aim was to assess the communication performance for both speech intelligibility and hearing acuity, of bearded HCWs when wearing a N95/P2 respirator with an under-mask elastic band beard cover (the N95/P2 respirator/elastic band combination). The assessment tool used was the Modified Rhyme Test (MRT), a widely used measure for assessing speech intelligibility of individuals wearing respirators^{6,8,12–16} and is endorsed by NIOSH.¹⁷ The primary aim was to determine whether the N95/P2 respirator/elastic band combination achieves an overall performance rating of $\geq 70\%$, which is set by NIOSH as the minimum communication performance requirement. The secondary aim was to examine whether there is a significant difference in the percentage of correct words or medical phrases perceived when the same group of bearded HCWs wear the N95/P2 respirator/elastic band combination versus having an uncovered beard (i.e. without the respirator and elastic band), both as a speaker and as a listener.

Methods

This was a controlled simulation study conducted in a large (approximately 50 m²) isolation room at the respirator fit test center of the Royal Melbourne Hospital. The room exhibited exceptionally low natural ambient noise, with a controlled background noise level of 60 ± 2 dBA, maintained using background pink noise (details provided below). The project was approved by the local ethics committee, Melbourne Health Human Research Ethics Committee under approval number QA 2023092.

Recruitment was via email invitation through our local Respiratory Protection Program to our 159 bearded HCWs, who had previously completed the elastic band beard cover training and passed the quantitative fit test with a N95/P2 respirator whilst wearing the under-mask elastic band beard cover. All participants adhered to the standard operating procedure when using the elastic band beard cover technique. Participants were instructed to position the elastic band (10–15 cm wide and 1m long) over their facial hair on the chin and cheeks, cross it over the ears, and tie it approximately 3 cm (± 2 cm) in front of the crown of the head. Details were described in our previous study.⁹ In addition to having bearded HCWs, five staff members (two females and three males without facial hair) from the Respiratory Protection Program were invited to participate in this study (details below). Participation was voluntary and consent was implied upon acceptance of the

participation invitation. All participants were required to be fluent in English and with no hearing or speech impairment.

A simple hearing test and speech assessment was performed before commencement of the study. Hearing screening was conducted by each individual independently using an online Hearing Range Test.¹⁸ Speech screening was conducted by a senior speech pathologist (C.P.) with extensive experience working with adults with acquired communication disorders.

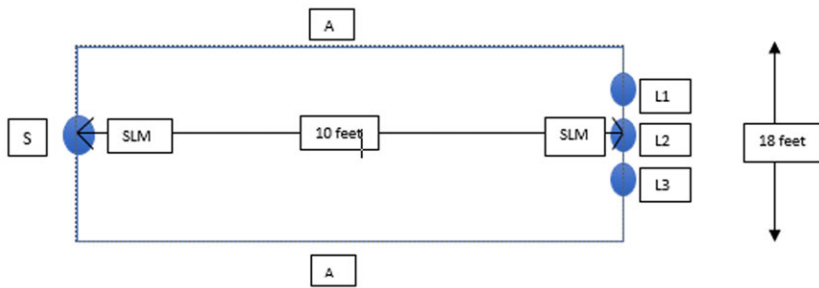
The communication performance of the N95/P2 respirator/elastic band combination was assessed by using the MRT, as outlined by NIOSH in the standard testing procedure.¹⁷ The test involved a speaker group and a listener group. The room setup is shown in Figure 1. Background pink noise in the frequency range of 20–50 kHz was transmitted through two amplifiers (SoundLink Mini II, Bose, Framingham, MA, USA, and Spark Mini, Positive Grid, Sandiego, CA, USA). Two calibrated sound level meters (Optimus, Cirrus Research plc, North Yorkshire, UK) were used to ensure the background noise was at 60 ± 2 dBA and the speaker's voice level was at 75–85 dBA. A test administrator (I.N.) recorded the decibel level during the MRT trial and provided immediate feedback if the voice level was out of the required range.

Each listener's ability to comprehend 50 random single-syllable words (Appendix 1 as an example) from each of the five speakers was evaluated. Additionally, 20 random commonly used medical phrases (Appendix 2 as an example), which are not in the NIOSH MRT protocol, were also included. We included medical phrases in this study because communication in healthcare settings often involves full sentences with medical terminology, providing essential context, which helps listeners use their linguistic knowledge and experience to fill in gaps and understand the intended message, even when some parts of the speech signal are distorted or masked.¹⁹ Each speaker read aloud 50 words, using the phrase "The word is [list word]" from the given word list (out of a total of 15 random word lists, with no repeats), followed by 20 medical phrases (randomly selected from a pool of 180 phrases). The listeners, sitting next to each other, selected the word they perceived to be spoken from six possible words on the provided answer sheet (Appendix 3 as an example), and wrote down the medical phrases as heard. A test administrator (C.P.) recorded any words spoken incorrectly.

Two sessions of the MRT trials were held with the aim of evaluating both speech intelligibility and hearing acuity of HCWs whilst using the N95/P2 respirator/elastic band combination. Both N95 and P2 respirators are tight-fitting half-mask facepiece with comparable filtration performance ($\geq 95\%$ vs $\geq 94\%$ respectively), but N95 respirators are certified by the US NIOSH under 42 CFR Part 84,²⁰ whereas P2 respirators are certified under AS/NZS 1716 in Australia/New Zealand.²¹ Similar to our previous evaluation study,³ the N95/P2 respirator used for this study was 3M 1870+ (3MTM, St. Paul, MN, USA) and the elastic band used was the green heavy THERABAND Professional Non-Latex Resistance Band (THERABAND, Akron, OH, USA).

Session one: speech intelligibility assessment

The speaker group consisted of five bearded HCWs and the listener group consisted of three recruited voluntary staff members (Figure 2). Each bearded HCW conducted two MRT trials as a speaker. In one trial, each bearded speaker wore a 3M 1870+ N95/P2 respirator with an under-mask elastic band beard cover, whereas in another trial without a respirator and elastic band (ie, uncovered beard). This gave a total of 10 MRT trials for the speech intelligibility



S = speaker
 L1 = listener 1; L2 = listener 2; L3 = listener 3
 SLM = sound level meter
 A = amplifier



Figure 1. Diagram and picture to show the room setup for the Modified Rhyme Test.



Figure 2. Picture to show participant wearing under-mask elastic band beard cover as speaker and staff members as listeners for the speech intelligibility assessment.



Figure 3. Picture to show staff member as speaker and participants wearing under-mask elastic band beard cover as listeners for the hearing acuity assessment.

session. The listener's visual attention was directed to their word lists and/or writing phrases; they therefore did not have the opportunity to lip-read during the "uncovered beard" condition.

Session two: hearing acuity assessment

Five bearded HCWs were in the listener group and five staff members were in the speaker group (Figure 3). Each staff member conducted two MRT trials wearing their routine N95/P2 respirators. However, the bearded HCWs who were the listeners wore the N95/P2 respirator/elastic band combination for one of the trials, and did not wear the respirator and the elastic band (ie, uncovered beard) for the other trial of the hearing acuity assessment. This provided a total of 10 MRT trials for the hearing acuity session.

All conditions of the MRT trials were randomly assigned, including the order of speakers, the order of whether the bearded HCWs were wearing the N95/P2 respirator/elastic band combination or having an uncovered beard, and the individual chosen word and medical phrase list.

The intelligibility of single-syllable words in both the speaking and hearing assessments was evaluated using the overall performance rating score, calculated by according to the steps outlined in the NIOSH MRT protocol.¹⁷ According to NIOSH criteria, the overall performance rating must be at least 70% for a respirator to pass NIOSH's communication requirement.¹⁷

We also directly compared the average percentage of correct words perceived from all listeners between the N95/P2 respirator/elastic band combination condition and the uncovered beard condition for both the speaking and hearing assessments.

The intelligibility of medical phrase reading was measured using two methods: the percentage of correct words perceived and the percentage of phrases in which the correct meaning was captured. Correct meaning was defined as accurately recording the key words, such as the main verb and noun in the phrase or using a synonym that preserved the original intent and context of the sentence. Minor variations in prepositions or connecting words were accepted as long as they did not change the overall meaning of the phrase. The assessor was blinded from the group allocation. Again, we compared these results between the N95/P2 respirator/elastic band combination condition and the uncovered beard condition for both the speaking and hearing assessments.

Statistical analysis

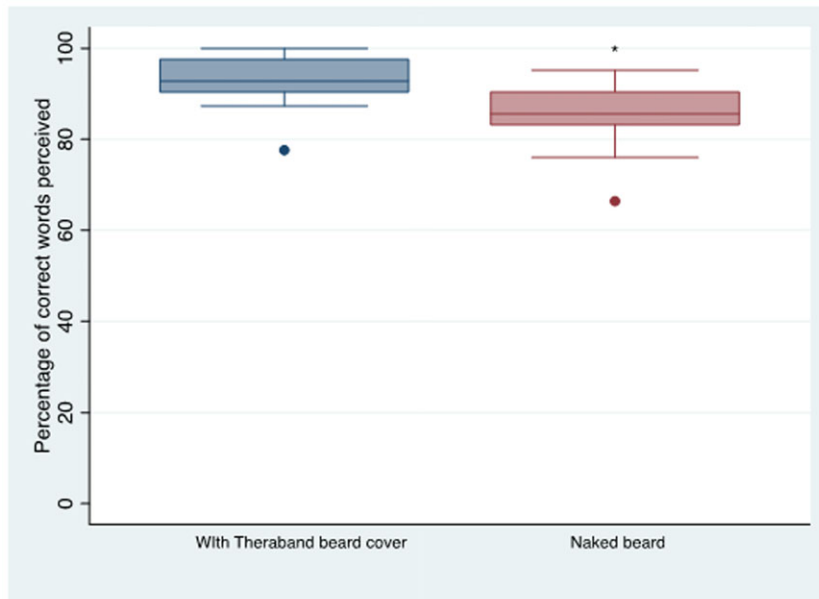
A sample size of five was chosen as according to the NIOSH protocol,¹⁷ five speakers are required to allow the calculation of the MRT results. An additional five staff members participated in this study to assist in the speaking and hearing trials as described above. Descriptive statistics were used to present the MRT outcomes. Communication performance analysis for both speaking and hearing components was performed according to the NIOSH protocol as described above.¹⁷ Wilcoxon signed-rank test was used to compare the percentage of correct words perceived (in both single-syllable words trials and medical phrases trials) and the percentage of phrases in which correct meanings were perceived between the N95/P2 respirator/elastic band combination condition and the uncovered beard conditions. A p -value of <0.05 is considered statistically significant. Statistical analysis was performed using Stata 13.0 (Statacorp, College Station, Texas, USA).

Results

A total of five bearded HCWs who were familiar with, and had previously passed a quantitative fit test using the under-mask elastic band beard cover technique with a 3M 1870+ respirator, participated in this study. The mean age of the group was 29 ± 10 years and their average work experience was 3 ± 3 years. Five additional staff members (two female and three clean-shaven males) were also recruited to assist in this study. All participants involved in the MRT trials passed the baseline hearing and speech assessments. Nine individuals scored "good range of hearing". One participant scored "fair range of hearing" (indicating they may find it hard to hear soft voices from a distance). No individual presented with a speech impairment.

Session one: speech intelligibility assessment

The overall communication performance rating of the under-mask elastic band beard cover technique as a speaker was 91.3% in the MRT. There was a statistically significant reduction in the average percentage of correct words perceived when the bearded HCWs were reading single words while wearing the N95/P2 respirator/elastic band combination compared to the uncovered beard condition ($84.5 \pm 7.4\%$ vs $92.9 \pm 5.7\%$, $p = 0.011$, Figure 4).



* $p=0.011$

Figure 4. Comparison of percentage of correct words perceived with bearded healthcare workers reading single words between wearing a N95/P2 respirator with under-mask elastic band beard cover and without a respirator and elastic band (ie, uncovered beard).

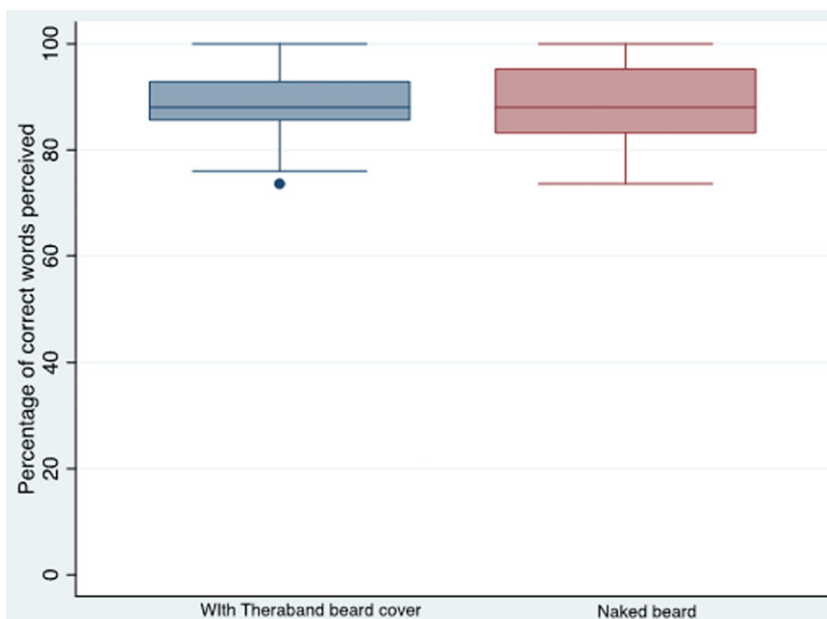


Figure 5. Comparison of percentage of correct words perceived with bearded healthcare workers hearing single words between wearing a N95/P2 respirator with under-mask elastic band beard cover and without a respirator and elastic band (ie, uncovered beard).

The speech intelligibility of random medical phrases was high with no significant difference between the two groups. Overall, $99.6 \pm 0.6\%$ of correct words and 100% of medical phrases with correct meanings were perceived when participants were wearing the N95/P2 respirator/elastic band combination, whereas for the uncovered beard group, $99.8\% \pm 0.6\%$ of correct words and 100% of medical phrases with correct meanings were perceived.

Session two: hearing acuity assessment

The overall communication performance rating score was 99.8% on the MRT when bearded HCWs acted as listeners while wearing

the N95/P2 respirator/elastic band combination. There was no statistically significant difference in the percentage of correct words perceived when the bearded HCWs were hearing single words while wearing the N95/P2 respirator/elastic band combination compared to when they had uncovered beard ($88.3 \pm 8.3\%$ vs $88.5 \pm 7.0\%$, $p = 0.979$, Figure 5).

The hearing acuity of random medical phrases was also high with no significant difference between the two groups. Overall, $99.6 \pm 0.8\%$ of correct words and $99 \pm 0.2\%$ of the medical phrases with correct meanings were perceived by HCWs wearing the N95/P2 respirator/elastic band combination, whereas for the uncovered beard group, $99.8\% \pm 0.7\%$ of correct words and $99.8 \pm 0.1\%$ of medical phrases with correct meanings were perceived.

Discussion

Facial hair in areas where a tight-fitting respirator seals against the skin is known to reduce respiratory protection.^{22,23} Bearded HCWs who are unable to shave can however achieve effective respiratory protection by wearing an under-mask elastic band beard cover combined with a N95/P2 respirator.³ Previous studies have demonstrated the basic efficacy and user-acceptability of the elastic band beard cover for respiratory protection,³ and this current study elaborates on this work through quantifying the effect of the technique on communication between HCWs.

Our findings in this study demonstrated that bearded HCWs wearing the N95/P2 respirator/elastic band combination could effectively maintain acceptable level of communication, surpassing NIOSH minimum intelligibility standard of 70%. Specifically, the communication performance measured was 91.3% for speech intelligibility and 99.8% for hearing acuity, comfortably above NIOSH threshold. These findings are significant for bearded HCWs, particularly in the context of ensuring ongoing pandemic preparedness, where the use of face masks and respirators has become ubiquitous in healthcare settings.

Despite exceeding the NIOSH standard, we noted a measurable decline in speech intelligibility when participants wore the N95/P2 respirator/elastic band combination compared to uncovered beard with no respirator. The relative impact of the N95/P2 respirator versus the elastic band beard cover is unknown, as we did not assess either component in isolation. We do not consider it necessary to separate their effects, as they function together as a single unit to provide effective respiratory protection for bearded HCWs. This finding aligns with existing literature indicating respirators inherently impose challenges to clear communication, primarily due to sound attenuation and distortion caused by the mask material and fit.^{24,25} However, this significant difference was not found in the perception of medical phrases between the two conditions. This finding aligns with the concept of top-down processing of language, where listening to phrases is a cognitively easier task than listening to isolated words. Phrases provide context, which helps listeners use their linguistic knowledge and experience to fill in gaps and understand the intended message, even when some parts of the speech signal are distorted or masked.¹⁹

Another option for respiratory protection in bearded HCWs is a powered air-purifying respirator (PAPR), but evidence shows that N95/P2 respirators with an under-mask elastic beard cover compare favorably. Communication is less affected, as PAPRs substantially reduce speech intelligibility and hearing acuity, introducing noise and attenuation equivalent to moderate hearing loss, while N95 respirators cause only minor, clinically insignificant muffling in quiet.^{26,27} PAPRs also tend to be more cumbersome to doff and are often perceived to interfere more with communication.⁷ In addition, they are far more costly and require greater maintenance,²⁸ making the N95/P2 plus beard cover a practical, effective, and communication-friendly option.

While the study provides valuable insights, there are some limitations to consider. Our sample was relatively small, limiting generalizability. Our experimental design did not include a respirator-only control condition. The reason was that respirators alone cannot provide an adequate seal for bearded HCWs, rendering them ineffective for respiratory protection. As a result, measuring speech intelligibility in bearded individuals wearing a respirator alone would be impractical and irrelevant, as they would

not wear a respirator alone for effective respiratory protection in real-world settings. Further limitations include the controlled environment of the study, which may not accurately reflect realistic clinical settings that often include background noise, urgency, and distractions typical of actual healthcare practice.

In conclusion, our findings demonstrate that bearded HCWs can achieve communication performance well above NIOSH standards when using a N95/P2 respirator combined with an under-mask elastic band beard cover. This finding is crucial for ensuring effective communication among bearded HCWs, thereby supporting both respiratory protection and operational efficiency in healthcare settings. Future research should address existing limitations by employing larger sample sizes and replicating this study in realistic, noise-filled clinical environments. Moreover, exploring other communication strategies, such as the use of clear masks or integrating technology, such as speech enhancement devices, may also help mitigate the communication challenges posed by masks and respirators.

Supplementary material. To view supplementary material for this article, please visit <https://doi.org/10.1017/ice.2025.10297>.

Data availability statement. All the individual de-identified data that support the findings of this study are available upon request from the corresponding author. Study protocol and statistical analysis are also available. Information will be available immediately following publication until five years after publication.

Acknowledgements. We would like to thank all the staff from the Royal Melbourne Hospital Respiratory Protection Program for their assistance in completing this project.

Author contribution. A/Prof Irene Ng: Obtained ethics approval, Conceptualization, Project administration, Investigation, Methodology, Formal analysis, Validation, Writing – original draft, review, and editing.

Dr Benjamin Kave: Conceptualization, Methodology, Investigation, Project administration, Resources, Validation, Writing – original draft, review, and editing.

Dr Camille Paynter: Conceptualization, Methodology, Investigation, Project administration, Validation, Writing – original draft, review, and editing.

Mr Charles Bodas: Conceptualization, Methodology, Investigation, Project administration, Resources, Supervision, Validation, Writing – review and editing.

Ms Megan Roberts: Investigation, Project administration, Resources, Supervision, Validation, Writing – review and editing.

Ms Shan Hung: Investigation, Project administration, Resources, Supervision, Validation, Formal analysis, Writing – review and editing.

Prof Daryl Williams: Obtained ethics approval, Conceptualization, Methodology, Investigation, Project administration, Resources, Supervision, Validation, Writing – review and editing.

Financial support. None to report.

Competing interests. All authors report no conflict of interest relevant to this article.

References

1. Singh R, Safri HS, Singh S, *et al.* Under-mask beard cover (Singh Thattha technique) for donning respirator masks in Covid-19 patient care. *J Hosp Infect* 2020;106:782–785.
2. Bhatia DDS, Bhatia KS, Saluja T, *et al.* Under-mask beard covers achieve an adequate seal with tight-fitting disposable respirators using quantitative fit testing. *J Hosp Infect* 2022;128:8–12.
3. Williams DL, Kave B, Bodas C, Begg F, Roberts M, Ng I. Prospective comprehensive evaluation of an elastic-band beard cover for filtering

- facepiece respirators in healthcare workers. *Infect Control Hosp Epidemiology* 2024;45:89–95.
4. Gosch ME, Shaffer R, Eagan AE, *et al.* B95: a new respirator for health care personnel. *Am J Infection Control* 2013;41:1224–1230.
 5. Grassi J, Oliveira IBD, Chiriboga LF, Maia AA, Attianezi M, Almeida ANP. Effects on communication due to face mask use: an integrative review. *Rev Bras Enferm* 2023;76:e20220674
 6. Round M, Isherwood P. Speech intelligibility in respiratory protective equipment – implications for verbal communication in critical care. *Trends Anaesth Crit Care* 2020;36:23–29.
 7. Ng I, Lee K, Kave B, *et al.* HALO CleanSpace PAPR evaluation: communication, respiratory protection, and usability. *Infect Control Hosp Epidemiol* 2023;44:295–301.
 8. Radonovich Jr LJ, Yanke R, Cheng J, Bender B. Diminished speech intelligibility associated with certain types of respirators worn by healthcare workers. *J Occup Environ Hyg* 2010;7:63–70.
 9. Williams DL, Kave B, Bodas C, Begg F, Roberts M, Ng I. Protocol of a prospective comprehensive evaluation of an elastic band beard cover for filtering facepiece respirators in healthcare. *PLoS One* 2023;18:e0281152
 10. Nickell LA, Crighton EJ, Tracy CS, *et al.* Psychosocial effects of SARS on hospital staff: survey of a large tertiary care institution. *Can Méd Assoc J* 2004;170:793–798.
 11. Radonovich Jr LJ, Cheng J, Shenal BV, Hodgson M, Bender BS. Respirator tolerance in health care workers. *JAMA* 2009;301:36–38.
 12. Johnson AT, Scott WH, Coyne KM, Koh FCS, Rebar JE. Telephone communications with several commercial respirators. *AIHAJ – Am Ind Hyg Assoc* 2001;62:685–688.
 13. Johnson AT, Scott WH, Lausted CG, *et al.* Communication using a telephone while wearing a respirator. *AIHAJ – Am Ind Hyg Assoc* 2000;61:264–267.
 14. Coyne KM, Barker DJ. Speech intelligibility while wearing full-facepiece air-purifying respirators. *J Occup Environ Hyg* 2014;11:751–756.
 15. Coyne KM, Johnson AT, Yeni-Komshian GH, Dooly CR. Respirator performance ratings for speech intelligibility. *Am Ind Hyg Assoc J* 1998;59:257–260.
 16. Caretti DM, Strickler LC. Speech intelligibility during respirator wear: influences of respirator speech diaphragm size and background noise. *AIHA* 2003;64:846–850.
 17. National Institute for Occupational Safety and Health. Determination of communication performance test for speech conveyance and intelligibility of powered air-purifying respirator (papr) series papr100 standard testing procedure. 2020. <https://www.cdc.gov/niosh/rap/stps/CVB-APR-STP-0089-508.pdf>. Accessed August 12, 2025.
 18. Connect Hearing. *Online Hearing Assessment*. 2024. <https://oab.connecthearing.com.au>. Accessed August 12, 2025.
 19. Mattys SL, Davis MH, Bradlow AR, Scott SK. Speech recognition in adverse conditions: a review. *Lang Cogn Process* 2012;27:953–978.
 20. Centers of Disease Control and Prevention. The National Personal Protective Technology Laboratory (NPPTL). 42 CFR Part 84 Respiratory Protective Devices. <https://www.cdc.gov/niosh/npptl/topics/respirators/pt84abs2.html>. Accessed August 12, 2025.
 21. 3M Science. Applied to Life. Technical Bulletin. Comparison of FFP2, KN95, and N95 Filtering Facepiece Respirator Classes. February 2021. Revision 6. <https://multimedia.3m.com/mws/media/1791500O/comparison-ffp2-95-filtering-facepiece-respirator-classes-tb.pdf>. Accessed August 12, 2025.
 22. Prince SE, Chen H, Tong H, *et al.* Assessing the effect of beard hair lengths on face masks used as personal protective equipment during the COVID-19 pandemic. *J Expo Sci Environ Epidemiol* 2021:1–8.
 23. Sandaradura I, Goeman E, Pontivivo G, *et al.* A close shave? Performance of P2/N95 respirators in healthcare workers with facial hair: results of the BEARDS (BEnchmarking Adequate Respiratory DefenceS) study. *J Hosp Infect* 2020;104:529–533.
 24. Hampton T, Crunkhorn R, Lowe N, *et al.* The negative impact of wearing personal protective equipment on communication during coronavirus disease 2019. *J Laryngol Otol* 2020;134:1–5.
 25. Corey RM, Jones U, Singer AC. Acoustic effects of medical, cloth, and transparent face masks on speech signals. *J Acoust Soc Am* 2020;148:2371–2375.
 26. Kempfle J, Panda A, Hottin M, *et al.* Effect of powered air-purifying respirators on speech recognition among health care workers. *Otol Head Neck Surg* 2020;019459982094568
 27. Weiss R, Guchlerner L, Weissgerber T, *et al.* Powered air-purifying respirators used during the SARS-CoV-2 pandemic significantly reduce speech perception. *J Occup Med Toxicol* 2021;16:43
 28. Hines SE, Brown C, Oliver M, *et al.* User acceptance of reusable respirators in health care. *Am J Infect Control* 2019;47:648–655.