Simulation in Healthcare

The Impact of Personal Protective Equipment on Speech Discrimination and Verbal Communication in the Operating Room and the role of audio-communication devices

--Manuscript Draft--

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Abstract:	Introduction Recent work has highlighted communication difficulties in Personal Protective Equipment (PPE) within operating theatres but currently there is no objective data on its effects. We assessed the impact of PPE on verbal communication in a simulation operating room and evaluated use of an audio-communication device. Methodology Frontline health professionals across specialties including surgery, anaesthetics, surgery and nursing undertook speech discrimination testing with and without standardized levels of PPE in a simulated operating-room environment. Background noise (30 dBA and 70 dBA multi-talker-babble) at two distances (2m and 4m) were selected representative of operating room environments. Bamford-Kowal-Bench (BKB) scoring (192 sentences per participant) was perfomed. A Digital Multi-channel Transceiver System (DMTS) was evaluated. Pair-wise comparison with Bonferroni correction for multiple comparisons via adjusted p-value and likert scores of participant

	experience was recorded. Results: Thirty-one healthcare professionals were tested. Without PPE in 70dBA ‘babble’, median BKB sentence scores were 90% and 76% at 2m and 4m (adjusted p <0.0005). Median BKB sentence scores dropped to 8% and 4% at 2m and 4m in PPE (adjusted p<0.0005). Improved speech discrimination was achieved with DMTS use to 70% and 76% at 2m and 4m. PPE led to a statistically significant reduction in BKB scores across all conditions compared to baseline. Overall participant confidence in PPE clinical communication was low. Conclusions Addition of PPE dramatically impairs speech discrimination and communication in high levels of background noise, which can be significantly improved using DMTS. Measures should be taken by teams through both through reduction of background noise and consideration of assistive technologies maximising patient safety. This may be further rehearsed in a simulation environment.
Suggested Reviewers:	

Dear Editorial team of Simulation in Heathcare 22/5/21

Re: 'The Impact of Personal Protective Equipment on Speech Discrimination and Verbal Communication in the Operating Room and the role of audio-communication devices

We are grateful for your consideration of the attached manuscript We believe it explores a vital issue of worldwide relevance in the face of the current COVID-19 pandemic in assessing verbal communication within PPE. We demonstrate a dramatic impact on speech discrimination in background noise in our simulated operating room environment through our objective testing. We highlight strategies that may be undertaken to improve this, evidenced with use of an audio-communication device in a simulation environment. Financial support for such technologies will need to be based on evidence and we hope this work in simulation can assist anaesthetists and theatre teams to achieve the necessary support and also better inform 'in situ' simulation.

We feel focus on this issue and potential solution tested in the simulated environment would provide benefit in highlighting within your broad international readership. We understand the journal has an additional 1000 word COVID brief report section but hoped this work may be considered as an technical report given the detail enclosed.

Kind regards and best wishes

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Abstract

Introduction

Recent work has highlighted communication difficulties in Personal Protective Equipment (PPE) within operating theatres but currently there is no objective data on its effects. We assessed the impact of PPE on verbal communication in a simulation operating room and evaluated use of an audio-communication device.

Methodology

Frontline health professionals across specialties including surgery, anaesthetics, surgery and nursing undertook speech discrimination testing with and without standardized levels of PPE in a simulated operating-room environment. Background noise (30 dBA and 70 dBA multi-talker-babble) at two distances (2m and 4m) were selected representative of operating room environments. Bamford-Kowal-Bench (BKB) scoring (192 sentences per participant) was perfomed. A Digital Multi-channel Transceiver System (DMTS) was evaluated. Pair-wise comparison with Bonferroni correction for multiple comparisons via adjusted p-value and likert scores of participant experience was recorded.

Results:

Thirty-one healthcare professionals were tested. Without PPE in 70dBA ‘babble’, median BKB sentence scores were 90% and 76% at 2m and 4m (adjusted p <0.0005). Median BKB sentence scores dropped to 8% and 4% at 2m and 4m in PPE (adjusted p<0.0005). Improved speech discrimination was achieved with DMTS use to 70% and 76% at 2m and 4m. PPE led to a statistically significant reduction in BKB scores across all conditions compared to baseline. Overall participant confidence in PPE clinical communication was low.

Conclusions

Addition of PPE dramatically impairs speech discrimination and communication in high levels of background noise, which can be significantly improved using DMTS. Measures should be taken by teams through both through reduction of background noise and consideration of assistive technologies maximising patient safety. This may be further rehearsed in a simulation environment.

Introduction

COVID-19 has made routine use of Personal Protective Equipment (PPE) a necessity to minimize healthcare worker exposure, infection and onward transmission [1,2]. Clear verbal communication between healthcare professionals is vital to provide optimal patient safety within high-risk clinical areas, minimize error and improve outcomes [3]. In the experience of clinicians, use of PPE has hindered effective communication [4–6].

Speech-in-noise testing is used to aid in audiology and auditory implantation to provide objective scoring on speech discrimination and assess effective verbal communication [7]. Obtaining this information related to PPE in clinical environments, would allow us to identify the necessity for further assistive communication methods and ultimately improve clinical care for patients undergoing treatment in COVID-19.

We hypothesize PPE use results in significant impairment in verbal communication within clinical environments. Our primary outcome measure was speech discrimination scores obtained by frontline hospital staff when wearing PPE. Assessment was undertaken at two different levels of background noise (30 dBA and 70 dBA) and two distances between the individuals communicating (2m and 4m) within a simulated operating room environment. Secondary outcome measures were assessing the effect of a Digital Multi-Channel Transceiver System (DMTS) within the identical scenarios and participant perspectives on the device and overall impact of PPE on verbal communication.

Methods

Recruitment

Local Trust research and development approval was undertaken for this service development work. Participants were recruited on a voluntary basis. Each volunteer received printed information and provided written consent for participation. All data has been anonymized.

Testing Environment

A simulated clinical setting used was expressly designed to replicate our hospital operating room. Its configuration incorporated a patient bed with a simulated patient, overhead lighting and the GE Carestation 650 anaesthesia machine providing identical levels of acoustic clutter throughout all tests. Testing occurred between the tester and each participant over the patient bed at distances of 2m and 4m apart. To minimize inter-test differences, a single individual undertook the testing of each participant.

Vocal volume and ambient noise levels were calibrated (+/-5dBA) throughout using a sound level meter (Casella CEL-24X). The background noise of medical equipment in the theatre environment was also calibrated to 30dBA. This baseline noise threshold of 30 dBA was selected following the World Health Organization recommendation that average background noise in hospitals should not exceed this level [8].

When indicated, multi-talker babble was played through Behringer MS20 digital 20-watt stereo near-field speaker calibrated to 70dBA. These values were selected in keeping with previous studies on background noise within theatre and intensive care environments (approximate 55-70dBA), with common peak levels measured over 80-90 dBA [9–12].

Identical PPE was standardized and provided to each participant. An FFP2 anti-particle respirator was used (GB2626-2006 KN95) along with a transparent face-shield visor and disposable surgical scrub cap throughout (Supplimentary **Error! Reference source not found.**). This is the minimum standard level of personal protection for health professionals recommended in dealing with a COVID-positive patient or aerosol generating procedure in a patient of unknown COVID status [13].

The assistive communication device used was the DMTS comprised of Kenwood WD-K10PSB (base unit) and individual WD-K10TR (subunits) worn by each individual. This was originally designed to assist verbal communication in a motorsport setting. It operates as a compact, hands free Digital Enhanced Cordless Telecommunications system transmitting at frequency of 1.9 gigahertz (GHz). This frequency offers suitability for use in the hospital environment minimizing the effect of interference from transmissions in the industrial, medical or scientific band (2.4GHz) or high-speed Wi-Fi (5GHz).

The DMTS base unit was located within the simulated theatre itself and individual subunits were worn by the participant, tester and scorer. The microphone was clipped to the mask under the face shield and receiver clipped to a pocket under the PPE (Supplimentary **Error! Reference source not found.**).

Testing Procedure

A screening audiogram was carried out on all participants (Otometrics Bio-logic AuDX Pro with Radioear DD45 headphones). Each ear was screened individually to 20dBHL at 0.25, 0.5, 1, 2, 4 and 8 kHz (air conduction).

The tester ‘mirrored’ the participant assessing six distinct conditions at both two and four meters.

a) ‘Full PPE’ with background machine noise (30 dBA)

b) ‘Full PPE’ with background ‘babble’ (70 dBA)

c) ‘Full PPE’ with background ‘babble’ (70 dBA) and DMTS

d) 'Full PPE' with background machine noise (30 dBA) and DMTS
e) No PPE with background machine noise (30 dBA)
f) No PPE with background 'babble' (70 dBA)

For each condition, sixteen Bamford-Kowal Bench (BKB) sentences were provided by a tester to the participant, each delivered once upon achieving eye contact [14]. Speech testing and delivery of sentences were calibrated and delivered at 60 dBA throughout by a single individual in order to minimize inter-test variation. Delivery in 'live voice' includes the potential effect of PPE on the tester as well as the recipient in a manner that could not be simulated with recorded delivery. Twelve lists of sixteen sentences (192 sentences) were used for testing each participant.

An independent 'scorer' recorded the results with a score derived from the number of correct keywords identified from a single delivery of the sentence. For example, "the SWEET SHOP was EMPTY" would score '3' if the words SWEET, SHOP and EMPTY were identified with "the" and "was" non-contributory. A final score out of fifty is obtained and this percentage is used in subsequent analysis.

Statistical analysis

A power calculation was performed to ensure adequate number of participants. *Alpha was set at 0.05 and beta at 0.8. The Minimum clinically important difference (MCID) as the effect size and standard deviation of the outcome measure (BKB sentence score) was set to 15%* [15,16].

IBM SPSS Statistics for Macintosh, (Version 25.0. Armonk, NY, USA: IBM Corp) and GraphPad Prism version 8.0.0 for Macintosh, (GraphPad Software, San Diego, California USA) were used in analysis.

Data did not follow normal distribution due to a ceiling effect of the BKB results in several testing conditions; therefore, non-parametric statistical analysis was adopted.

The Friedman test was used for analyzing these within-subject repeated-measures BKB sentence scores. Pair-wise comparison (post-hoc test) was performed with Bonferroni correction for multiple comparisons via adjusted p-value.

Sensitivity analysis was done to evaluate the potential effect of underlying hearing problems toward the BKB performance when using the communication device. Correlation and Regression models were also computed to study the effect of each testing condition factor toward the BKB test score.

A 10-point Likert scale (low to high) was used to record participants perceived confidence and listening effort in delivering both routine and emergency verbal communication. Mann-Whitney testing was performed to assess for perceived impact of DMTS use.

Results

Thirty-one individuals completed testing with varied frontline clinical roles. Seven anaesthesiologists or intensive care physicians, twelve surgeons, seven allied healthcare professionals (e.g. operating theatre practitioner) and five registered nurses took part. Median age of participants was thirty-five years old (IQR: 6 years) with the youngest participant of twenty-six and oldest at fifty.

BKB sentence scores for each condition without PPE (baseline conditions) and with PPE (testing conditions) are shown in Table 2. Preceding hearing conditions were known and confirmed in four individuals and included in analysis. It was felt these were representative of the 'real world' setting and would enhance generalizability.

Baseline conditions (without PPE or DMTS)

For baseline conditions without PPE, there were significant differences in BKB sentence scores ($\chi^2 = 74.60$, df = 3, $p < 0.0005$). Pairwise comparison showed as expected in background babble noise, BKB sentence performances were significantly lower than in background machine noise at both 2m and 4m (adjusted $p < 0.0005$ and < 0.0005 accordingly). This was most clearly shown at 4m where median BKB scores fell from 100% to 76%.

No significant difference was established between BKB sentence scores communicating at 2m compared with 4m distance in both machine and babble noise conditions (adjusted p =1.000 and 0.233 accordingly).

Testing conditions with PPE (Figure 1)

Significant yet minor differences were found between individual performance with and without PPE at both 2m and 4m in background machine noise of 30 d BA (adjusted p = 0.006 and 0.001 accordingly). The median BKB sentence scores were 98% and 98%.

In babble noise 70 dBA the median BKB sentence score was 8% and 4% for 2m and 4m respectively. (Both adjusted p <0.0005). This demonstrates a dramatic reduction in speech discrimination wearing PPE in this clinical setting.

Testing conditions with PPE + DMTS (Figure 2)

The addition of DMTS to PPE demonstrated significant differences in participant performance in comparison to PPE alone conditions at 2m and 4m in babble noise of 70 dBA (adjusted p <0.0005 and <0.0005). Median BKB scores elevated to 70% and 76% from 8% and 4% respectively on using DMTS.

Higher BKB scores were also found in PPE + DMTS device conditions at 4 m compared with PPE alone conditions at 2m among machine noise (adjusted p-value <0.0005) and babble noise (adjusted p <0.0005). This indicated that the effect of DMTS could be more robust in increasing the BKB sentence score performance than reducing the distance of 2m between talkers in PPE in background noise.

Effect of underlying hearing conditions/background noise

Sensitivity analysis was done to determine the effect of underlying hearing problems toward the BKB performance with DMTS. Even under the lowest BKB performance condition with the device (babble noise background at 4m distance), there was no significant difference between the median BKB performance score for the overall cohort and the mean BKB score after excluding 4 cases with underlying problems (p = 0.949)

Regression models were computed to determine the magnitude of background noise and PPE in BKB performance scores. Due to the likely ceiling effect of BKB performance which could not be fully overcome by data transformation. A prediction regression model could not be conducted.

Participant perspectives

Overall confidence in verbal communication of participants when wearing PPE was low and concerning given its importance to optimize patient care. Perceived confidence of participants in performing routine communication in PPE increased with use of DMTS with a median score of 8 ($p < 0.0001$) in comparison to 3 without. Perceived confidence of participants in performing urgent communication when in PPE also increased with use of DMTS with a median score of 7.5 ($p < 0.0001$) in comparison to 3/10 without. Verbal communication in PPE was perceived to require more effort with a median score of 8 in comparison to 6 with DMTS ($p < 0.01$).

Thirty of the thirty-one individuals would recommend the use of DMTS in delivering clinical care when wearing PPE (96.7%). Free-text comments by the single individual who felt that the DMTS was not beneficial included that he found ongoing difficulties hearing throughout the exercise. This individual was from the cohort with a background of hearing impairment (pre-existing intrusive tinnitus). Other free text comments repeated by participants referenced 'late pick up' of the DMTS resulting in '*missing all/part of the first word/s*'. The earpiece of the DMTS was also subject to criticism with regard to fit within the external auditory canal.

Discussion

The purpose of this study was to quantify the effect of PPE on verbal communication. We propose these results suggest potentially serious consequences for patient safety and staff welfare during the COVID-19 pandemic without provisions to overcome impaired communication. These findings also have direct relevance to simulation carried out in PPE.

Levels of background noise of 70dBA have been shown to be routinely experienced in hospital [12]. Our results confirm verbal communication is severely affected within a clinical setting even without PPE being worn in high levels of background noise. Speech discrimination scores at 4m deteriorated from a median of 100% at 30dBA to 76% at 70dBA. This is important information to be considered by all health professionals, suggesting a quarter of 'key' information is not transmitted in this level of background noise.

The addition of PPE precludes to a dramatic fall in speech discrimination in background babble of 70 dBA, the median BKB sentence score was 8% and 4% for 2m and 4m respectively (both adjusted $p < 0.0005$). The impact of the informational masking effect of background speech appears particularly disruptive to verbal communication in PPE resultant from a disorientating aspect of the underlying babble and its impact on individuals [17,18] Use of DMTS increased BKB sentence scores by 62% and 72%, at 2m and 4m respectfully (70dBa background babble). Participant opinion was very supportive of its future use in clinical care.

Our work is the first to confirm the detremental effects of PPE on verbal communication in an operating room. We provide a validated method of improving speech discrimination within this simulated setting. Previous studies have failed to find consensus whether a standard surgical mask worn in isolation impairs verbal communication [19,20]. Mask usage has however been demonstrated to result in acoustic filtering with high-frequency attenuation affecting overall audibility [21]. Vowel formants in particular are most prominent at 750-2000 Hz meaning crucial speech frequencies are predominantly affected by this acoustic filtering.

For audible speech, target speech should be at least 5-10 dBA louder than background noise. Compensatory increases in vocal intensity following noisy environment immersion is known as the ‘Lombard effect’, which can further perpetuate increasing noise within clinical environments [22]. This compensatory technique may result in vocal and auditory strain in staff [23,24]. Increases in stress secondary to prolonged periods of listening in noisy environments is well recognized [25,26].

This work was undertaken within frontline health professionals from a broad range of disciplines. There are several hearing impairments that might disproportionately disadvantage communication whilst wearing PPE. These include age-related hearing loss [27] or cochlear synaptopathy [28]. Individuals with hearing impairments find it disproportionately difficult distinguishing speech within background noise when compared to normal hearing peers [29,30]. Affected individuals may require further assistance to deliver clinical care within a working environment involving the use of PPE. Currently, there is little data is available publicly describing hearing impairment prevalence within frontline healthcare professionals compared to a random population sample [31]. Health professionals are however less likely to disclosure of any form of disability to their employer than many other careers [32].

Overall, confidence in verbal communication of participants when wearing PPE was low and concerning given its importance to optimize patient care. Strategies to improve clinical communication in PPE should involve both reduction in unnecessary background noise and improving the transmission of verbal communication (Figure 3).

Methods of reducing background noise may be targeted through human factors training and publicizing the differences PPE causes in audibility. A greater appreciation of acoustic environments may also play a role in design and modification of existing clinical settings considering increasing the acoustic absorbance of surfaces e.g. ceilings [33].

Improving transmission of verbal communication may be achieved in a variety of ways including our demonstrated use of adjunctive technology. Our methodology could allow different forms of PPE itself to be scored, and indeed designed, with optimising communication as a necessary analogous goal of the device. For example, previous work discussing the benefit of transparent surgical masks for hearing impaired may be extrapolated to a conferred advantage in normal hearing individuals in background noise with lip-visible FFP2 or FFP3 devices [20].

Verbal communication challenges in an acute clinical setting may be exacerbated further by existing hierarchies, role ambiguity and inter-personal conflict (‘*Did he hear me express my concern*?’) and are fundamental to patient safety[34]. Reinforcing good communication etiquette within teams in PPE is critical e.g. directed communication and feedback-read-back models[35].

Although DMTS was felt to require less listening effort, an overall significant listening effort was perceived by participants suggestive of potential for further optimisation. Participant comments as to the late ‘pick up’ of DMTS (missing the start of a transmitted sentance) could be improved through radio communication training. This may include routine use of ‘verbal priming of the radio device’ such as producing a noise cue prior to delivery of important clinical information or improving head orientation[36,37]. Future modifications of the existing design with ear mould customization and fitting could also be considered to help with device retention.

This current work assessed verbal communication between two individuals. Future assessment involving more complex communication between larger teams is required. Owing to global shortages of FFP3 masks and powered air-purifying respirator (PAPR) at the height of the pandemic, we chose to undertake this study using FFP2 masks; however, we can summate it likely these respirators would display at least similar effects, although further work is required. Additionally, exploring the cumulative contribution of PPE (cap, mask and visor) rather than mask use in isolation is also needed.

Use of radio communication such as DMTS is not without difficulty or potential error [38,39] we demonstrate benefits of using DMTS to significantly improve speech discrimination scores. Current costs of approximately $6000 dollars to supply a ten-person team may impact potential uptake; however, the true cost of imprecise clinical communication between health professionals in an emergency setting remains difficult to measure.

Although the personal protection of health professionals is essential for the management of patients with COVID-19, it is vital to ensure effective communication between individuals is maximised to improve teamwork and optimise patient care. This is an important consideration for all health professionals and policymakers within any pandemic setting and simulation may pay an important role in this area.

Authorship Contributions

AH Contribution: Conception/design/acquisition/analysis with draft and approval

BHS Contribution: Design/acquisition/analysis with draft and approval

WE Contribution: Design/acquisition/analysis with draft and approval

JGM Contribution: Design/acquisition/analysis with draft and approval

NU Contribution: Data analysis with draft and approval

NB Contribution: Data analysis with draft and approval

MB Contribution: Data analysis with with critical revision and approval

AP Contribution: Design/acquisition with draft with critical revision and approval

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Figure Legends

Table 1: Bamford-Kowal-Bench (BKB) sentence scores for each condition without PPE (baseline conditions) and with PPE (testing conditions)

Figure 1: Pairwise Comparisons for babble noise conditions (70 dB) to explore the effect of PPE on Bamford-Kowal-Bench (BKB) score

Figure 2: Cluster boxplot to demonstrate the effect of Digital Multi-channel Transceiver System communication device on Bamford-Kowal-Bench (BKB) score in PPE with background babble noise (70 dBA)

Figure 3: Strategies to improve Verbal Communication in PPE

Supplimentary figures

Figure 0.1 The simulated clinical setting replicating our hospital operating room. Containing a patient bed with a simulated patient, overhead lighting and an anaesthesia machine. Testing occurred between the tester and each participant over the patient bed at distances of 2m and 4m apart. Background noise in the theatre environment was also calibrated to 30 dBA. When indicated, multi-talker babble was played through Behringer MS20 digital 20-watt stereo near-field speaker calibrated to 70 dBA located behind the participant.

Figure 0.2 Picture demonstrating tester during experiment in recommended PPE (FFP2 mask, visor, disposable surgical cap and the placement of the Digital Multi-channel Transceiver System (DMTS) device whilst reading the BKB sentences from clipboard.

Supplimentary Video

1: Demonstration of BKB testing in background noise level of 30dBA

2: Demonstration of BKB testing in background noise level of 70dBA

Table 1: Bamford-Kowal-Bench (BKB) sentence scores for each condition without PPE (baseline conditions) and with PPE (testing conditions)

PPE condition	Communication	Background condition	BKB sentence scores **Median** (%) (+/- IQR) Distance between talkers 2m	4m
No PPE	No DMTS	Machine noise 30dBA	**100** (+/-0)	**100** (+/-0)
		Babble noise 70dBA	**90** (+/-14)	**76** (+/-24)
With PPE	No DMTS	Machine noise 30dBA	**98** (+/-24)	**98** (+/-34)
		Babble noise 70dBA	**8** (+/-20)	**4** (+/-10)
	Using DMTS	Machine noise 30dBA	**98** (+/-6)	**98** (+/-6)
		Babble noise 70dBA	**70** (+/-32)	**76** (+/-40)

PPE= Personal Protective Equipment
DMTS= Digital Multi-Channel Transceiver System
IQR= Inter-quartile range
dBA= A-Weighted Decibels

Figure

Click here to access/download;Figure;Figure 1.jpg

Figure 1: Pairwise Comparisons for babble noise conditions (70 dB) to explore the effect of PPE on Bamford-Kowal-Bench (BKB) score

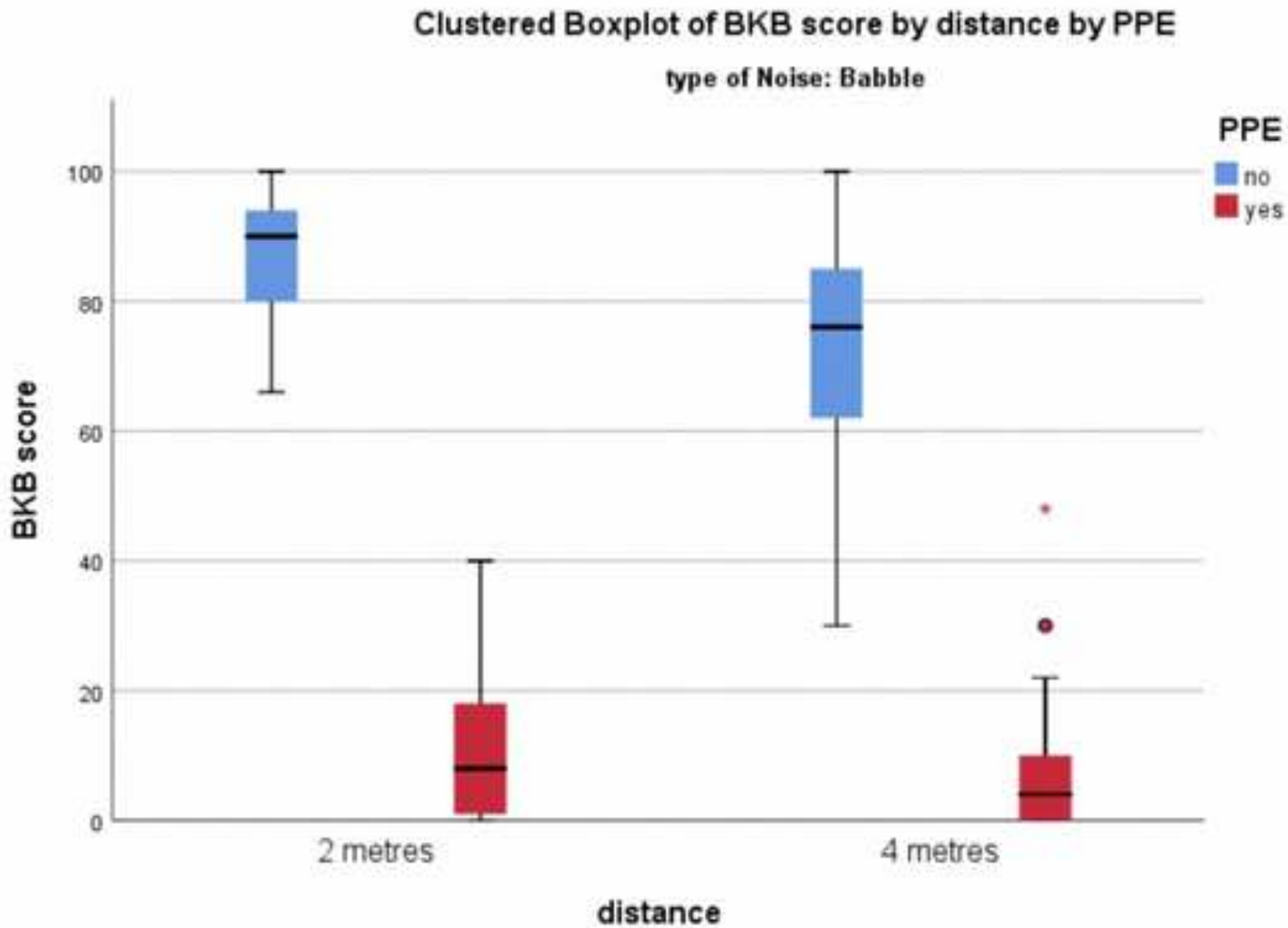

Figure 2 Cluster boxplot to demonstrate the effect of Digital Multi-channel Transceiver System communication device on Bamford-Kowal-Bench (BKB) score in PPE with background babble noise (70 dBA)

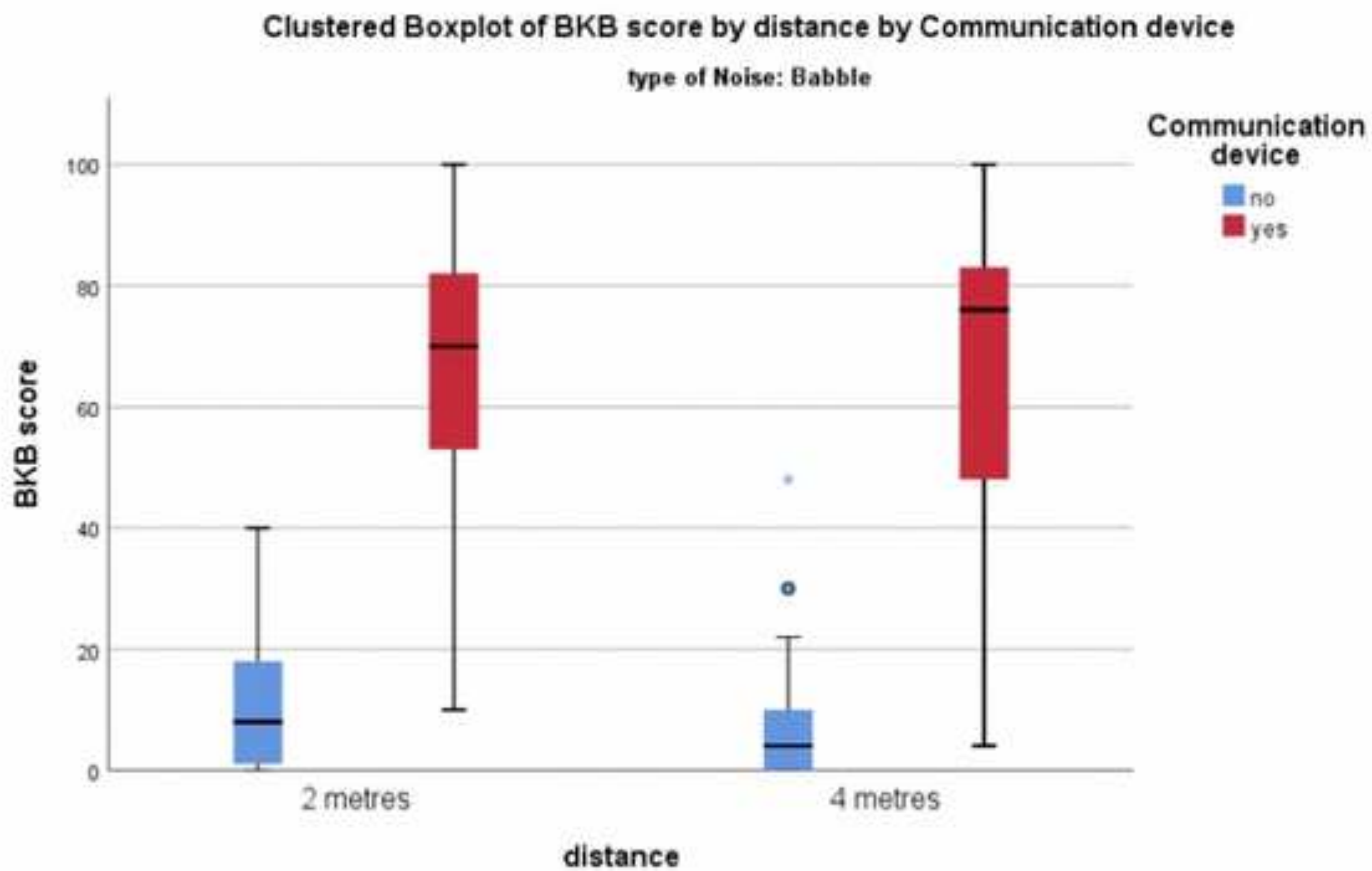

Figure 3: Strategies to improve Verbal Communication in PPE

Reduce Background Noise	**Personnel**: *Team PPE training; noise awareness* **Environmental modifications**: *Alarm setting management; non-noise mediated alarms* **Structural Considerations**: *Acoustic modifications to environment*
Improve Transmission of Verbal Communication	**Assistive Technology use**: *Adjunctive communication devices e.g. DMTS, hand signals* **PPE modifications**: *Lip-visibility; acoustic considerations of PPE materials/design* **Technique**: *Directed communication; feedback-readback*

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Supplemental Data File (doc, pdf, etc.)
supp_fig_2.jpg

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30dBA_BKB.mp4

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70_dBA_BKB.mp4