REVIEW ARTICLE

# Method for Measuring Speech Enhancement of Electronic Hearing Protection Device: A Systematic Review

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## ABSTRACT

The usage of electronic hearing protection devices (e-HPDs) among industrial workers has been introduced among others, to allow more effective communication in noisy environments. The effectiveness of the speech enhancement element of e-HPDs thus needs to be assessed. To date, no standardized speech enhancement assessment method is available. This systematic review aimed to compile and synthesize available information in the literature on speech perception test method of e-HPDs while also assessing the quality of the selected studies. The Cochrane methodology was used, with the findings documented using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and checklist. The International Prospective Register of Systematic Reviews (PROSPERO) was utilized to register this systematic review, with the CRD number assigned as CRD42024526086. Five electronic databases were explored: PubMed, ProQuest, IEEE, Scopus, and ScienceDirect. The quality appraisal was conducted based on Effective Public Health Practice Project (EPHPP) tool. In total ten studies were reviewed, utilizing several speech tests including Hearing in Noise Test (HINT), Speech Recognition in Noise Test (SPRINT), Callsign Acquisition Test (CAT), Modified Rhyme Test (MRT), Quick Speech in Noise Test (QuickSIN), Dutch Monosyllabic Speech Test and Mandarin Disyllabic Word Discrimination Test (WDT) to evaluate speech enhancement capabilities in e-HPDs. In conclusion, speech tests are essential for assessing how well e-HPDs perform enhancing speech in noisy environments. HINT has the strongest quality compared to other speech test for e-HPDs assessment. HINT or its modifications can subsequently be considered in the anticipated standardized speech perception test method of e-HPDs tests worldwide.

**Keywords**
Speech Assessment, Speech Test, Electronic Hearing Protection Device, Noise, Worker

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## INTRODUCTION

Speech intelligibility assessment is a crucial aspect of assessing communication, serving to demonstrate the clinical benefits or outcomes of hearing interventions such as cochlear implants[1] and hearing aids.[2] It is also important in occupational audiology, aiding in the quantification of noise-induced hearing loss's impact on speech perception. Several studies have highlighted how speech intelligibility assessment can reveal the unmet needs associated with passive hearing protection devices (HPDs). These studies found that workers wearing passive HPDs often exhibit poor speech perception compared to those without protection.[3,4]

This was also proved in one study which stated that the passive mode in hearing protection device led to a decrease in speech recognition performance by 25-30 percent compared to unprotected listening.[3] This was affirmed by a similar study that revealed how two passive HPDs (Peltor & Nacre) reduced speech recognition performance by 27–29 percent and 17–25 percent respectively compared to unprotected listening.[5] Passive hearing protection device is defined as a hearing protection device without the use of dynamic, mechanical elements such as valves or reactive ports or electronic circuitry such as active noise cancellation or electronically modulated signal pass-through technology.[6]

This reduction may cause workers to remove their HPDs to hear speech; a common occurrence proved by a study done in Malaysia which documented 25 percent of sawmill workers felt that HPDs created a barrier during communication,[7] thus forcing them to remove the HPDs temporarily which potentially results in noise-induced hearing loss (NIHL). To address these challenges, electronic hearing protection devices (e-HPDs) were introduced to mitigate communication barriers by allowing workers to hear speech while protecting their hearing. e-HPD is defined as devices that involved electronics components and digital signal processing that aimed to maintain good situational awareness while protecting against hazardous or loud noise.[8] Typically, the feature that is mostly incorporated in an e-HPDs is automatic noise reduction (ANR), which increases protection through the reduction of high noise levels, or phase-cancellation technology, which introduces antiphase noise. In contrast, speech is amplified and filtered at spectrum frequencies between 125 Hz and 8000 Hz by means of a level-dependent function, which continuously monitors the surrounding noise level to determine how much sound can pass through.[8]

Despite the gazettement of hearing protector implementation in laws and legislation[9], reluctance among workers to wear hearing protectors continuously persists due to various reasons, including attenuation of conversational signals, discomfort, and communication difficulties. Such reluctance can jeopardize critical communications, particularly in hazardous environments, where workers may need to respond to warning signals or interact with colleagues or supervisors.[10]

To alleviate these challenges, e-HPDs offer a promising solution. They facilitate more effective communication in noisy environments and help reduce instances where HPDs are removed. However, the suitability of existing speech intelligibility assessment methods for evaluating e-HPDs performance in industrial settings remains unclear because there are various types of speech test methods used to assess the e-HPD depending on their needs and interests. The wide variety of industrial noises also contribute to the none availability of a uniform standard to properly evaluate the speech enhancement component of an e-HPD due to the scarcity of assessing method. The authors thus felt that a systematic review looking into all previous methods that has been utilized to assess e-HPDs particularly those which also include not just the attenuation of noise but also the speech enhancement component was timely and much needed to ensure that workers that needed this type of protection gets what is expected. This is especially true in workers that need to hear speech conversation well during work as one study states that the passive protection led to a decrease in speech recognition performance by 25-30 percent compared to unprotected listening.[3]

This systematic review was retrospective in nature, conducted according to the Cochrane methodology13 where it involves defining the objectives through population, intervention, comparison, outcome (PICO), searching, screening, appraisal, analysis and reporting.

### Registration

The International Prospective Register of Systematic Reviews (PROSPERO)14 of Cochrane Collaboration was used where the review was reported. The PROSPERO registration number was CRD42024526086.

### Literature Searching

PubMed, ProQuest, IEEE, Scopus, and ScienceDirect were used to look for relevant papers published in December 2022. The above databases were chosen to cover all disciplines of biomedicine, biological sciences, medicine, general, engineering, computer & communication technology, and human sciences. The search was limited to the earlier fifteen years [2008-2023]. The search key consisted of ("active hearing protection device" OR "active hearing protector" OR "active personal hearing protection device" OR "active personal hearing protection" OR "active personal hearing protector" OR "active level-dependent hearing protection" OR "active level-dependent hearing protector" OR "electronic hearing protection device" OR "electronic hearing protection" OR "electronic hearing protector" OR "electronic personal hearing protection device" OR "electronic personal hearing protection" OR "electronic personal hearing protector" OR "electronic level-dependent hearing protection” OR “electronic level-dependent hearing protector”) AND (“speech intelligibility” OR “speech enhancement” OR “speech perception” OR “speech recognition” OR “speech test”).

The process applied the inclusion criteria of articles for systematic review and meta-analysis combined a strategy using population, intervention, control, and outcomes measures (PICO). The PICO details are displayed in Table I. Publications were accepted for inclusion if they included the keywords and phrases, as well as a general description of the speech test procedures used to evaluate electronic hearing protection devices. All quantitative and qualitative research were included. Only publications in the English language will be selected and only research that utilized electronic hearing protection devices were included. Papers with conventional hearing protection devices alone were excluded.

**Table I:** Inclusion criteria using Population, Intervention, Control, Outcomes (PICO) Strategy

| PARAMETER | INCLUSION CRITERIA |
|---|---|
| Population | Adults 18 years or older with and without hearing loss |
| Intervention | Use of e-HPDs equipped with speech perception test methods |
| Control | Non e-HPDs or no hearing protection |
| Outcomes | Speech test used with the speech perception percentage (i.e., signal to noise ratio, speech recognition, percent correct) |

## Citation Management

All citations were imported into the Mendeley software, and all the duplicates of duplications were removed before the title and abstract relevance screening.

## Screening

The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) 2020 statement[15] is applied for the screening process. Two levels of screening was conducted with two reviewers audiological knowledge with certified from accredited university. The first level of screening is based on the title and the abstracts of the articles while the second level of screening was based on the full articles. The following eligibility criteria were utilized to screen the articles. This process was recorded in an excel workbook.

## Title and Abstract Relevance Screening

Only the title and abstract of citations were examined at the first level to ensure effective time management in situations when resources may be squandered by getting articles that did not match the minimum inclusion criteria. For relevance screening, the researchers used spreadsheets to create the title and abstract. The researchers separately reviewed the title and abstract of each citation. Any disagreements were resolved among the researchers through regular discussion. The principal author then read the full texts of the remaining articles and summarised them for discussion with the team later. The full-text journal articles were discussed among the researchers before the data was extracted.

## Quality Assessment

The study quality was evaluated using the Effective Public Health Practice Project (EPHPP) critical appraisal tool. This process includes grading each article as strong, moderate or weak based on the following components: (1) Selection bias, (2) Study design. (3) Confounders, (4) Blinding, (5) Data collection methods, and (6) Withdrawal and drop-outs. A score of 1 applied if the study was "strong", a score of 2 for "moderate", and 3 for "weak". According to the following acceptance criteria, the decision to grade the global score for each paper was strong if it had no weak attributes, moderate if one weak attribute and weak if two or more weak attributes.[16,17]

## Data synthesis

The data contained in the selected articles were extracted and synthesized based on PICO: (1) population (number, age, sex, hearing threshold); (2) interventions and control (types and brands of personal hearing protector used); (3) outcomes (type of speech test used with the speech perception percentage (i.e., signal to noise ratio, speech recognition, percent correct).

## RESULTS

### Article Selection

A total number of 166 articles and abstracts were initially selected from the search. Figure I shows the number of articles that were screened and assessed for eligibility. Then, 46 duplicate articles were eliminated. In the next stage 75 of the remaining 120 papers were rejected because they did not match the inclusion requirements. The writers reviewed the remaining 45 publications for eligibility, and 35 were found unfit based on certain criteria. Six papers were further excluded because they did not utilize electronic personal hearing protector device in their studies, while 22 papers were removed as the speech assessment test method of e-HPDs were not discussed in those studies. Additionally, three papers that were not in full articles and three old publications that were more than 15 years earlier were excluded respectively. One publication that was not in English language, but in German in 1994 was removed from the final review. The attempt to translate the paper was not successful because it was an old publication. Finally, the remaining ten articles were deemed relevant for this final systematic review.

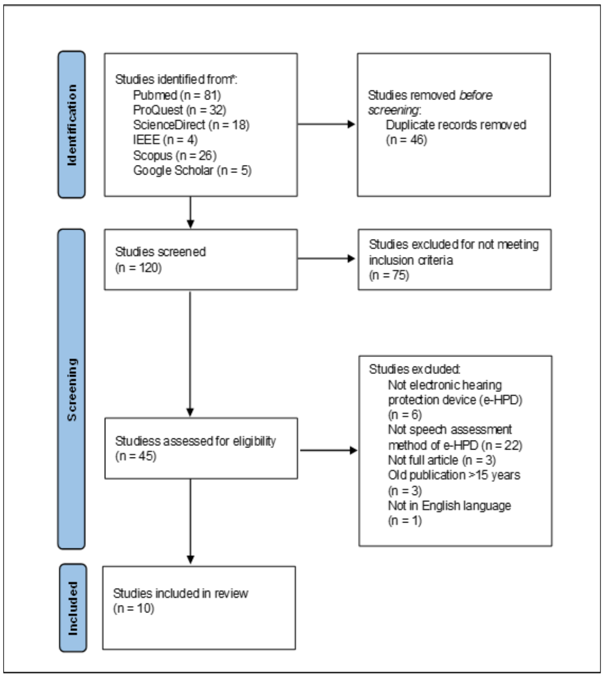


**Figure 1.** PRISMA flow chart of the article search and selection

### Study Quality Scores

Table II shows the quality appraisal scores for the ten selected studies. Two studies were scored as strong as they did not have any weak scores across the quality appraisal criteria and two studies were scored as weak and both had poor quality due to the withdrawals and double blinding were not described in the articles. Meanwhile the rest of the articles were scored as moderate as they had 1 weak criterion in which the double blinding process was not described in those articles.

**Table II**: Quality appraisal scores for the ten articles included in the review.

| Articles | Quality Appraisal Criteria | | | | | | Global Score |
|---|---|---|---|---|---|---|---|
| | Participant Selection Bias | Study Design | Confounding variables | Double blinding | Data collection | Withdrawals | |
| Giguère, Laroche, and Vaillancourt (2015)[12] | 2 | 1 | 2 | 2 | 1 | 1 | 1 |
| Byrne and Palmer, (2012)[21] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Giguère, Laroche, and Vaillancourt, (2012)[3] | 2 | 1 | 2 | 2 | 1 | 1 | 1 |
| Brown et al., (2015)[19] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Brammer, Yu and Tufts, (2014)[22] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Smalt et al., (2019)[23] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Hung Lin et al., (2006)[24] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Nakashima and McDavid, (2018)[18] | 2 | 1 | 2 | 3 | 1 | 1 | 2 |
| Bockstael, Coensel and Bottekdooren, (2011)[20] | 2 | 1 | 2 | 3 | 1 | 3 | 3 |
| Hiselius, Edvall and Reimers, (2015)[4] | 2 | 1 | 2 | 3 | 1 | 3 | 3 |

*1 is strong, 2 is moderate and 3 is weak

### The Findings Based on PICO on the Speech Perception Test Method of Electronic Hearing Protection Devices

#### *Population*

The summarized results of the reviewed studies according to the PICO criteria are displayed in Table III. Six studies adopted normal hearing subjects and the other four studies recruited both normal hearing and hearing loss participants. Only one study classified the participants into 4 categories of hearing status (1) normal,

(2) slight-to-mild, (3) mild-to-moderate, and (4) moderate -to-severe.[5]

### Intervention and Controls

All the studies included electronic hearing protection devices or protection devices with electronic elements in their speech test. Four studies utilized only electronic HPD in their research in which two studies combined electronic earmuffs and earplugs[5,18], one study utilized electronic earmuffs only[3], and one study did not state the type of e-HPD used.[4] Four other studies adopted both electronic and conventional HPDs (work as passive only) in their speech test in which two studies used earplugs category only[19,20], one study used earmuffs category only[21] and one study did not state both types of HPD or e-HPD used.[23] The remaining two studies utilized proof-of-concept devices and headsets with electronic features.[22,24]

### Outcomes

#### *Speech Test Methods for e-HPD*

In the final reviewed articles, varieties of the speech perception test methods for electronic hearing protection devices (e-HPD) were adopted in their studies. The most utilized method is Hearing-in-Noise Test (HINT) (3 articles, 30%)[3,5,21], followed by Modified Ryhme Test (MRT) (2 studies, 20%).[22,23] The remaining five articles[4,19,20,24] individually utilized different methods which are Callsign Acquisition Test (CAT), Modified QuickSIN test, Dutch monosyllabic speech test, Mandarin Disyllabic Word Discrimination Test (WDT), and Speech Recognition in Noise Test (SPRINT) respectively. The details of the speech perception test methods of e-HPD were classified as shown in Table III.

#### *The Outcome Measure of the Speech Test*

Most of the studies measured percent word recognition score (WRS) in their speech test outcome.[3,5,22,24] Two studies considered speech recognition scores in absolute as their outcome measure.[18,20] The remaining four studies assessed different outcome measures based on the type of speech test used in which speech recognition threshold[4], mean QuickSIN score[19], MRT percent correct[16] and lastly, correct percentage of HINT test score.[21]

## DISCUSSION

### Meta Analyses

The researcher actually intended to conduct the meta-analyses; however, this was not possible as there are insufficient studies related to the speech perception test method of e-HPDs in the body of knowledge. Only ten studies were available for discussion. Additionally, all the studies included had different methodologies like different sample sizes recruited, type of speech tests used some using HINT, MRT, CAT, SPRINT, and more. There was also unstandardized type of e-HPDs used as well as the outcome measures etc that made it impossible to proceed with the meta-analyses. The alternative syntheses used is narrative synthesis.

### Speech Test

From the included studies in this review, most of the researchers used Hearing-in-Noise Test (HINT) for the speech perception test of the e-HPDs. It is mostly used due to the nature of the HINT test that can be developed and adapted to other languages to provide comparable measurements of speech intelligibility in noise for each language.[25] Various HINT test has already been developed for other languages such as Malay[26], Mandarin27, Danish28, American English[29], Brazilian Portuguese[30], Cantonese[31], Korean[32], Spanish[33], Norwegian[34], Turkish[35], Castilian[36], Canadian French[37], Japanese[38], Bulgarian[39] and many others. Based on the location of the studies conducted, it is preferable to use the language of the speech test respective to the mother language of the local population as the ability to perceive speech in noisy environments is affected by the level of proficiency in a non-native language. This is also to make sure the reliability of the speech test itself.[40] Apart from that, HINT was claimed to adopt phonetically balance elements in its wordlists that is commonly used in intelligibility testing.

**Table III:** The Findings of The Systematic Review on the E-HPD Speech Test Methods Based On PICO

| Author(s); date; study location | Participants | Type and brand of e-HPD used | Mode of testing | Speech test used | Outcome measures | Main Findings |
|---|---|---|---|---|---|---|
| Giguère, Laroche, and Vaillancourt, 2015[5], Canada | Forty-five adults aged from age 23 to 81 years old (24 males and 21 females). Participants were divided into four groups: normal hearing (n=12), minor to mild hearing loss (n=12), mild to moderate hearing loss (n=12), and moderate to severe hearing loss (n=9). | [1] One level-dependent earmuff: Peltor® PowerCom Plus™ (muffs)<br>*Active SR1-SR5<br>*NRR 25dB<br><br>[2] One level dependent earplug: Nacre QuietPro (earplugs)<br>*Active (TT2-TT11)<br>*Passive (TT1- 29dB NRR) | [1] Unprotected<br>[2] Passive attenuation<br>[3] Active (low gain)<br>[4] Active (high gain)<br><br>Low and high gain quantitatively measured using manikin" | Hearing-in-Noise Test (HINT). | Speech recognition (% word recognition). | Participants with normal hearing exhibited minimal effect, however those with the most hearing loss showed significant reductions in scores as compared to unprotected listening. At both low and high gain pass-through levels, activating the devices' level-dependent mode produced significant speech recognition gains over the passive mode. |
| Byrne and Palmer, 2012[21], United Stated | 15 adults with normal hearing (aged 21 to 60 years) | [1] One electronic earmuff: MineEars electronic earmuffs. (ProEars, Westcliffe, CO, USA).<br><br>[2] One passive earmuff: Bilsom model 847 (Sperian Hearing Protection, San Diego, CA, USA). | [1] Passive muff<br>[2] Active off, low gain, and high gain | Hearing-in-Noise Test (HINT). | Correct percentage of HINT test score (%) | The repeated-measures ANOVA findings revealed a significant main effect for the SNR condition [F (2,28)=1014.50, p 0.0001]. The highest scores were obtained when the SNR was +5 dB, while the lowest values were obtained when the SNR was -5 dB. The earmuff condition also had a significant main effect [F (3,42) = 57.19, p 0.0001]. The interaction effect was also significant [F (6,84) = 6.94, p 0.0001]. |
| Giguère, Laroche, and Vaillancourt, 2012[3], Canada | Twenty-two subjects (combination of hearing status) | One electronic earmuff: Peltor Powercom Plus (muff)<br>*NRR 25dB<br>*At full gain, limit at 87dBA | [1] Unprotected<br>[2] Passive attenuation<br>[3] Active (low gain)<br>[4] Active (high gain) | Hearing-in-Noise Test (HINT). | Speech recognition (% word recognition). | The passive mode with surround off led to a decrease in performance by 25-30% compared to unprotected listening, while the active modes yielded a benefit of 11-15% and 23-24% at surround setting 1 (low gain) and surround setting 4 (high gain) respectively. |
| Brown et al., 2015[19], United States | Ten normal hearing male adults (mean age: 29.5 years) | A proof-of-concept device | [1] Conventional passive HPD<br><br>[2] Active HPD with subband ANC and no communication signal processing<br><br>[3] Active HPD with subband ANC and communication channel gain processing. | Modified Rhyme Test (MRT). | Word recognition score (%) | Follow-up pair-wise tests revealed that Combat Arms (t9 = 3.00, p=0.015) and Hybrid (t9 = 3.53, p=0.006) performance was significantly worse than Control (p=0.595), while EB15 performance was very similar to Control (p=0.595) and better than Combat Arms (t9 = 2.41, p= 0.039) or Hybrid (t9 = 3.17, p=0.011). Thus, the EB15 performed the best voice recognition among the three HPDs tested in the speech-in-noise task, despite the fact that mean scores for all conditions were higher than 25, with more than 80% correct. |
| Brammer, Yu and Tufts, 2014[22], United States | Six subjects normal hearing (4 male and 2 female) with mean age of 29.5 ± 8.5 yrs. Subjects are Native American English | [1] Two actives electronic<br>[2] Two passive<br><br>Brands were not stated | [1] Open ear<br>[2] Passive A<br>[3] Passive B<br>[4] Active A<br>[5] Active B | Modified Rhyme Test (MRT). | MRT percent correct score (%) | For the environmental noises used in this work, subband speech SNR control paired with subband ANC enhanced word scores more than subband ANC alone and improved word score consistency among participants. |
| Smalt et al., 2019[23], United States | Thirteen adults with normal hearing (excluding one) with an average age of 31 years. | Four earplugs:<br>[1] Etymotic EB15 (active)<br>[2] Active prototype<br>[3] 3M Combat arms (passive)<br>[4] ShotShields passive prototype | [1] Control (open)<br>[2] Active hpd<br>[3] Active prototype<br>[4] Passive hpd<br>[5] Passive prototype | Modified version of QuickSIN test. | Mean QuickSIN score (out of 30 words) | There was an effect of HPD (F [4,48] = 3.716; p = 0.010) and a noise level effect (F [2,24] = 1737; p=2 1016). There was no effect of HPD or noise level on MRT performance. A pairwise T-test with Bonferroni-Holm correction for multiple comparisons revealed that Active A and Active B were the only HPD pairs with significant differences in MRT performance (p = 0.017). |
| Hung Lin et al., 2006[24], Taiwan | Thirty normal hearing subjects aged of 19-30 years old (15 men and 15 women) | Feedback Adaptive Active Noise Cancellation (FBAANC) headset | 1) With headsets<br>2) without headsets | Mandarin Disyllabic word discriminatio n test (WDT). | Word recognition score | The mean WDT score is the average of the first six lists on the same SNR. When the SNR was more than -10dB, the mean WDT score was greater than 80%. However, the score with the FbAANC headset was 6 to 8% lower than the score without the FbAANC headset on the SNR of -5 and 0 dB. However, when the SNR was less than -10dB, the score with the FbAANC headset was 13 to 32% higher than without the FbAANC headset. |
| Nakashima and McDavid, 2018[18], Canada | Eighteen participants ages 20-54 yrs old (15 males and 3 females). 16 normal hearing and 2 have hearing loss at 40dBHL at 6/8kHz | [1] One electronic earmuff 3M Peltor Tactical 6-S (muff)<br>*max level of 82 dBSPL<br><br>[2] One electronic earplug (Invisio V60 and X5 headsets) | 1) Unprotected<br>2) Active earmuff<br>3) Active earplug | Speech Recognition in Noise Test (SPRINT). | Number of correctly repeated words (out of 50 numbers) | The conventional SPRINT settings yielded average scores ranging from 41 to 44 out of 50, while the SHL SPRINT conditions yielded scores ranging from 20 to 34 out of 50. A two-way ANOVA on the results revealed significance for the ear condition (F=34.7, p 0.001) and SPRINT condition (F =1077, p 0.001), mas well as their interaction (F=27.3, p 0.001). Unprotected ear and earplug (EP) and unprotected and earmuff (EM) pairwise comparisons were significant (p 0.001 for both). There was no discernible difference between EP and EM circumstances. |
| Bockstael, Coensel and Botteldooren, 2011[20], Belgium | 60 normal-hearing subjects (30 males and 30 females) with average age of 27.6 years old. They are native Dutch speakers. | [1] One acrylic passive earplug (25NRR)<br>[2] One active custom-made earplug<br>[3] One active form earplug | [1] Unoccluded<br>[2] Active min<br>[3] Active max<br>[4] Active foam<br>[5] Passive earplug | Dutch monosyllabic speech test. | Speech recognition score (absolute) | The interaction effects between sound environment and subject [F (236, 647) =1.2; p=0.032], listening condition and subject [F (162, 647) =1.3; p=0.009], and sound environment and listening condition [F (12, 647) =77.7; p0.0001] are all significant (=0.05). If the amplification is set low enough, active custom-made protectors look to be a better option. |
| Hiselius, Edvall and Reimers, 2015[4], Sweden | Thirty-one normal hearing subjects | Three electronic HPDs. Brand not stated | Three e-HPDs in 2 noises each (3x2) | Callsign Acquisition Test (CAT) | Speech Recognition Threshold (SRT) | Passive HPDs with low attenuation are expected to have a negligible effect on speech intelligibility in noise, whereas an electronic HPD with a level-dependent function has the potential to improve intelligibility. |

### The Quality Score of the Study

#### *Tool Utilized*

Effective Public Health Practice Project Quality Assessment Tool was utilised for this study instead of other quality assessment tool specifically the Cochrane Collaboration Risk of Bias Tool (CCRBT). EPHPP was selected as this is a more generic tool that can be used to assess various types of study designs, including RCTs, observational studies, and before-and-after studies compared to CCRBT that specifically designed for assessing randomized controlled trials (RCTs). It evaluates risks of bias in depth across several domains. As this study is interested in a holistic view of study quality, the EPHPP was chosen to assess broader methodological quality, which includes but is not limited to bias meanwhile CCRBT focuses specifically on the risk of bias. More importantly, EPHPP can be scored based on objective guideline meanwhile CCRBT was scored subjectively. Thus, EPHPP is easier to be used and applied across different types of studies with less intensive training compared to CCRBT. The latter may require more training and expertise to apply effectively, as it requires detailed judgments about bias that are often not straightforward. In addition, EPHPP is flexible and has better inter-rater reliability compared to CCRBT.[17]

#### *Quality Scores*

Among ten available speech tests for e-HPD assessment, the articles that utilized HINT in their speech perception test have the strongest quality, as six aspects of elements in which participant selection, study design, confounding variables, double blinding, data collection, and withdrawals information have been clearly stated in those studies. The high-quality appraisal scores indicate that studies using HINT typically adhere to rigorous methodological standards, which enhances the reliability and validity of their findings. Additionally, because HINT was already adapted to multiple languages, it is widely used around the world. Both the reliability of the studies and the test's adaptability contribute to its popularity and acceptance as a preferred method for assessing speech perception. Two articles that were categorized as weak due to the unclear description on the blinding and withdrawal elements were still be included in this study as the researcher just wanted to explore all the available speech test method for e-HPDs.

## CONCLUSION

In summary, speech tests play a crucial role in evaluating the performance of e-HPDs in ensuring their effectiveness in enhancing speech perception in noisy environments. Each speech test for e-HPD assessment has its advantages and disadvantages. The choice of tests used depends on factors such as language compatibility, ease of administration, reliability, and validity, with researchers selecting the most appropriate test for their specific study objectives. This review found that studies using HINT showed the strongest quality scores compared to other speech tests and should thus be utilized and adopted in future standardized speech perception test method of e-HPDs worldwide. Based on this review, the authors would also like to suggest future studies that compare and assess speech tests to determine the most appropriate speech test in e-HPDs assessment, as currently, no such experiments have been conducted. This will surely expedite the development of a much-anticipated standardized assessment of speech-enhancing element of e-HPDs specifically and hearing protection devices in general.

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## CONFLICT OF INTEREST

There are no known conflicting financial or non-financial interests among the authors that could have influenced the conclusions presented in this study.

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