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# Firefighter hearing health: An informatics approach to screening, measurement, and research

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## Abstract

*Objective:* The purpose of this study was to evaluate the use of a standardized interface terminology, the Omaha System, with respect to noise-induced hearing loss (NIHL). *Design:* A descriptive, correlational design was employed for this secondary analysis with the data from an ongoing hearing protection intervention study. *Study sample:* A total of 346 firefighters were included. *Results:* First, an evidence-based standardized care plan (EB-SCP) for hearing screening was developed and validated by clinical experts. Second, occupational health records were used to compute Omaha System Knowledge, Behavior, and Status outcomes. Third, research data were mapped to Omaha System rating scales. For Knowledge, the mean score was close to 'adequate' (3.7). For Behavior, the mean score was close to 'rarely appropriate' (2.2). For Status, the mean score was close to 'minimal sign/symptom' (4.4). Significant positive relationships were found between Knowledge and Behavior (Spearman's rho = .13, $p = .01$), and between Behavior and hearing Status (Spearman's rho = .12, $p = .02$). *Conclusions:* Findings support the validity of the new Knowledge, Behavior, and hearing Status. Informatics methods such as the standardized NIHL EB-SCP and outcome data sets will create opportunities for clinical decision support and data exchange across various health care settings, thus supporting population-based hearing health assessments and outcomes.

**Key Words:** Informatics; Omaha System; firefighters; hearing

Noise-induced hearing loss (NIHL) is an irreversible condition caused by exposure to loud noise that damages sensory hair cells in the inner ear (National Institutes of Health, 1990; American College of Occupational and Environmental Medicine (ACOEM) Noise and Hearing Conservation Committee, 2003). NIHL is a significant public health problem for the general population and the workforce worldwide (Concha-Barrientos et al, 2004; Nelson et al, 2005). In the United States, approximately 10% (22 million) of adults between 20 and 69 years old have permanent hearing loss due to exposure to loud noise at work or during leisure activities (National Institute on Deafness and Other Communication Disorders (NIDCD), 2011).

There are many serious negative consequences of NIHL, including communication interference that can substantially affect social integration, functional ability, self-image, and quality of life. Hearing loss affects not only those individuals who have lost their hearing, but also their fellow workers, family members, and society as a whole (National Institutes of Health, 1990). Occupational Safety and Health Administration (OSHA) rules (29 CFR 1910.95) in the United States require periodic noise exposure monitoring, engineering and administrative noise controls, personal hearing protection, annual hearing tests, and worker training (U.S. Department of Labor (USDL) & Occupational Safety and Health Administration (OSHA), 1983). However, this requirement currently does not apply to firefighters.

Exposure to high levels of intermittent noise is commonplace for firefighters, particularly during emergency responses when sirens, air-horns, and vehicle engines are running (Tubbs, 1995; Kales et al, 2001; Bogucki & Rabinowtz, 2005; Hong et al, 2008; Neitzel et al, 2012). NIHL is one of the most prevalent occupational injuries that create enormous economic burden and human suffering among over one million firefighters in the USA. (National Fire Protection Association (NFPA), 2005). Data on the hearing ability of firefighters are needed to describe the extent of NIHL and measure outcomes of hearing loss prevention programs. Data standards and electronic health record (EHR) systems offer technology solutions to address the NIHL information gap.

The Omaha System is a research-based, comprehensive practice and documentation standardized taxonomy or classification designed to enhance practice, documentation, and information management (Martin, 2005; Monsen et al, 2011; Monsen et al, in press). The Omaha System provides necessary terms for describing the evidence-based intervention, as well as generating structured data that is useful in research. It includes terms related to hearing and prevention, and thus is suitable for hearing assessments within the context of comprehensive, holistic, patient care (see methods section for a further description of the Omaha System). The purpose of this study is to evaluate the use of a standardized interface terminology, the

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## Abbreviations

| | |
|---|---|
| dB | Decibel |
| EB-SCP | Evidence-based standardized care plan |
| EHR | Electronic health record |
| HPD | Hearing protection device |
| KBS | Knowledge, Behavior, and Status |
| NIHL | Noise-induced hearing loss |
| PHR | Personal health record |

Omaha System with respect to NIHL. The study has three aims: (1) Dissemination of evidence-based standardized hearing screening interventions in the EHR; (2) Transformation of clinical and research data into standardized variables; and (3) Use of standardized variables in research.

## Methods

*Study design, data, and participants*

This descriptive, correlational study was a secondary analysis of existing hearing assessment and pre-intervention survey data from an ongoing randomized controlled trial of hearing protection intervention for firefighters (Grant #: EMW-2007-FP-00785). The original project incorporated the use of internet technology for data collection of the survey, and provision of individualized intervention content aimed at increasing firefighters' use of hearing protection devices (HPDs) to prevent NIHL. The survey data include demographic and work-related characteristics, behavioral theory-based predictors of HPD use, knowledge on NIHL and prevention, and percentage of time (0%–100%) of HPD use when exposed to high noise levels. More detailed information on the survey questionnaire items can be found in our earlier publication (Hong et al, 2011). Audiometric data include hearing threshold levels measured using a microprocessor pure-tone audiometer, for both ears at frequencies 0.5, 1, 2, 3, 4, 6, and 8 kHz.

The processes of data collection and aggregation in the original study are depicted in Figure 1. Firefighters were recruited to participate in the study from occupational health clinics, fire departments, or a hearing test clinic, in three states (California, Illinois, and Indiana) in the USA. The present study included the data of 346 firefighters who completed the internet-based pre-intervention survey and audiometric tests between March 2010 and September 2011.

### Institutional Review Board approval on human subjects

The original study was approved by the Committee on Human Research of the University of California, San Francisco (UCSF) and the Institutional Review Board of North Shore University Health Systems in Evanston, Illinois. Informed consent was obtained from all interested volunteers before completing the pretest survey and audiometric tests.

*Instrument: The Omaha System*

The Omaha System is a standardized interface terminology and measure that holistically and comprehensively describes health, including hearing (Martin, 2005). It enables users to document assessments and interventions, and disseminate evidence-based practice within the EHR. In addition, it is a systematic architecture for organizing clinical data. During the development of the Omaha System (1975–1993), researchers tested and retested the three components' reliability and validity with test agencies in different geographic locations and settings. In testing reliability, they gave attention to measures of stability or consistency, homogeneity, and equivalence. In testing validity, they gave attention to content, concurrent, construct, and predictive issues. The Omaha System exists in the public domain, and is integrated into the National Library of Medicine's Metathesaurus; Logical Observation Identifiers, Names, and Codes (LOINC®); and SNOMED CT®. It is registered (recognized) by Health Level Seven (HL7®) (Martin, 2005; Omaha System, 2012). The Omaha System has three components: the Problem Classification Scheme, the Intervention Scheme, and the Problem Rating Scale for Outcomes (Martin, 2005; Omaha System, 2012).

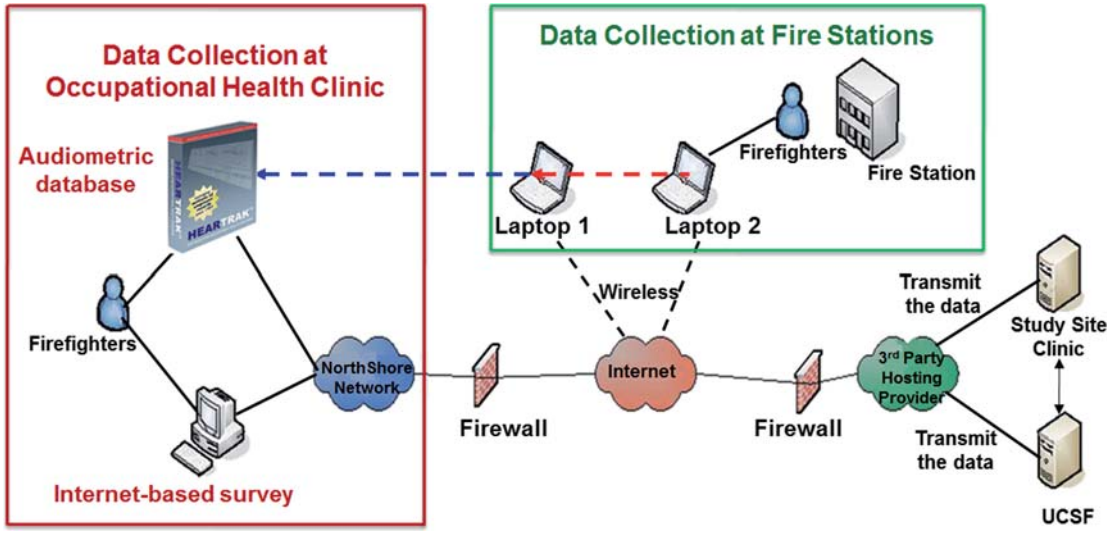


**Figure 1.** Internet data collection. Existing clinical and research data from firefighters were transformed using the algorithms. The figure shows the sources of the electronic data. On the left, clinical data from audiometric measurements provided the data for the Status variable. On the right, research data from questionnaires completed by firefighters provided the Knowledge and Behavior variables.

The Problem Classification Scheme logically classifies health information into 42 non-overlapping concepts (problems) each of which is identified by a unique definition and set of binary signs/symptoms. The problems are central to the organizing framework of the Omaha System (Martin, 2005).

The Intervention Scheme describes actions related to the 42 problems in a structured format: problem, category, target, and care description (problems are defined in the Problem Classification Scheme). In the Intervention Scheme, there are four categories or action terms: Teaching, Guidance, and Counseling (TGC); Treatments and Procedures (TP); Case Management (CM); and Surveillance (S); and 75 defined terms that serve to further define the intervention action or client need. Finally, the care description terms can be customized to capture specific program or client characteristics. Problem, category, and target terms can be used together in any problem-category-target combination, for a total of 12 600 possible interventions; each of which is further customizable at the care description level (Martin, 2005).

The Problem Rating Scale is a standardized instrument for comparison of assessments and outcomes for any health problem. It consists of three standardized variables; Likert-type ordinal rating scales for Knowledge, Behavior, and Status (KBS). Ratings range from 1 (most negative) to 5 (most positive) (Martin, 2005, p. 457). Knowledge is defined as 'the ability of the client to remember and interpret information' (1 = no knowledge, to 5 = superior knowledge) (Martin, 2005, p. 457). Behavior is defined as 'observable responses, actions, or activities of the client fitting the occasion or purpose' (1 = not appropriate behavior, to 5 = consistently appropriate behavior) (Martin, 2005, p. 457). Status is defined as 'the condition of the client in relation to objective and subjective defining characteristics' (1 = extreme sign/symptom, to 5 = no sign/symptom) (Martin, 2005, p. 457).

### *Procedure*

For clarity, procedure is organized by aim.

For aim 1, two Omaha System problems are especially relevant to NIHL: Hearing and neighborhood-workplace safety. The NIHL evidence-based standardized care plan (EB-SCP) was developed based on methods used for home care and primary care (Monsen et al, 2011). Three perspectives informed development of EB-SCPs: (1) NIHL scholarly experts, (2) Omaha System scholarly experts, and (3) occupational health clinicians. A four-step iterative process was used. First, a literature review was conducted to identify the evidence-based hearing screening guideline. NIHL experts evaluated and selected the guideline used for the EB-SCP. Second, Omaha System experts encoded the guideline into EB-SCP format, reaching consensus on linguistic validity. Third, occupational health professionals evaluated the EB-SCP for content validity. Finally, NIHL experts, Omaha System experts, and occupational health professionals reached consensus on the granularity of the EB-SCP for evidence dissemination and clinical documentation (Monsen et al, 2011).

For aim 2, algorithms were developed for mapping selected items in the research data set to create variables for Knowledge, Behavior, and Status ratings, based on definitions of Omaha System KBS ratings (see Table 1). Algorithms for Knowledge and Behavior were based on survey responses of the firefighters for selected items. The algorithm for Status was based on audiometric measurement. Audiometric measurement was conducted in the original study as follows: The audiometer was calibrated according to the American National Standards Institute (ANSI) S3.6-1969-2004 standard (American National Standards Institute (ANSI), 1969–2004). Audiometric tests were administered by CAOHC- (Council for Accreditation in Occupational Hearing Conservation) certified audiometric technicians in the occupational health clinic, audiologist's office, or fire departments. To minimize contamination of hearing loss by temporary exposure to loud noise, firefighters were instructed to have a period of at least 14 quiet hours without noise exposure, or to wear the hearing protective devices at least on the day of the audiometric test. Hearing threshold levels were measured in decibels (dB). A higher threshold level indicates poorer hearing status.

For aim 3, all data were analysed with SPSS 18. Demographic characteristics and KBS rating variables were analysed using descriptive statistics. Means, standard deviations (SDs), and ranges

**Table 1.** KBS* questionnaire scoring using S.I.R.E.N** data (N = 346).

| *Category* | *Score* | *Definition* | *N (%)* | *Mean (SD)* |
|---|---|---|---|---|
| *K* *Four items on noise-induced hearing loss and its prevention* | | | | 3.7 (0.5) |
| | 1 | None | 0 (0.0) | |
| | 2 | One correct answer | 1 (0.3) | |
| | 3 | Two correct answers | 7 (2.0) | |
| | 4 | Three correct answers | 79 (22.8) | |
| | 5 | Four correct answers | 259 (74.9) | |
| *B* *Mean use of hearing protection (average of 2 use items)* | | | | 2.2 (1.5) |
| | 1 | Not appropriate (0–20%) | 172 (49.7) | |
| | 2 | Rarely appropriate (21–40%) | 49 (14.2) | |
| | 3 | Inconsistently appropriate (41–60%) | 44 (12.7) | |
| | 4 | Usually appropriate (61–80%) | 40 (11.6) | |
| | 5 | Consistently appropriate (81–100%) | 41 (11.8) | |
| *S* *Objective hearing status*[#] | | | | 4.4 (0.8) |
| | 1 | > 80 dB | 1 (0.3) | |
| | 2 | 61–80 dB | 9 (2.6) | |
| | 3 | 41–60 dB | 40 (11.6) | |
| | 4 | 25–40 dB | 101 (29.2) | |
| | 5 | < 25 dB | 195 (56.4) | |

*KBS: Knowledge (K): 1 = no knowledge, to 5 = superior knowledge; Behavior (B): 1 = not appropriate behavior, to 5 = consistently appropriate behavior; Status (S): 1 = extreme signs/symptoms, to 5 = no signs/symptoms. **S.I.R.E.N.: Safety Instruction to Reduce Exposure to Noise and hearing loss (internet-based survey and hearing protection intervention program). [#]Determined by the mean of hearing threshold levels at 4 and 6 kHz in the worst ear.

were reported for continuous variables. Frequencies and percentages were reported for categorical variables. Considering the KBS ratings are categorical with skewed distributions, nonparametric Spearman rho correlations were used to assess their level of associations.

## Results

### *Characteristics of the participants*

As summarized in Table 2, the participants were middle-aged (mean age = 45years), white (81%), and male (94%), with many years (mean = 17years) of work experience in fire services. Over 80% of the participants reported daily/weekly loud noise exposures when working as a firefighter.

### *Dissemination of evidence-based standardized hearing screening interventions in the EHR (Aim 1)*

Using Omaha System terminology, noise-induced hearing loss EB-SCP is developed and presented in Table 3. This can be incorporated into any EHR that supports structured documentation.

### *Transformation of clinical and research data into standardized variables (Aim 2)*

Knowledge was operationalized by four questionnaire items on NIHL and its prevention (1 = no correct answers; 2 = one correct answer; 3 = two correct answers; 4 = three correct answers; and 5 = four correct answers). The four true/false questions were: (1) Long or repeated exposure to noise levels greater than 85 decibels can cause hearing loss; (2) Hearing loss from exposure to loud noise is permanent and cannot be recovered; (3) You need to use hearing protection if the noise around you is loud enough so you have to raise your voice to be heard by someone an arm's length away; and (4) Regular hearing tests help with the early detection of hearing loss.

Behavior was operationalized by frequency of self-reported percentage of time of HPD use (0%–100%) when exposed to high noise levels. The two questions were (1) HPD use during the participant's most recent emergency situation/run; and (2) HPD use in the past three months. Due to strong correlations between these two questions ($r = .74$, $p < .001$), the average score of the two items was used. Then percentage of HPD use was categorized into five levels of use (1 = 0–20%; 2 = 21–40%; 3 = 41–60%; 4 = 61–80%; and 5 = 81–100%).

Status was operationalized by classifying hearing levels using the grading system proposed by the World Health Organization (WHO) (1986) (1 = above 80 dB; 2 = 61–80 dB; 3 = 41–60 dB; 4 = 25–40 dB; and 5 = less than 25dB).

**Table 2.** Characteristics of the participants (N = 346).

| *Characteristics* | *n* | *%* |
|---|---|---|
| Gender | | |
| Male | 325 | 94.2 |
| Female | 20 | 5.8 |
| Ethnicity | | |
| Asian/Pacific Islanders | 19 | 5.5 |
| African-American or Black | 17 | 4.9 |
| Caucasian or White | 279 | 80.9 |
| Hispanic or Latino/a | 25 | 7.2 |
| Native American or American Indian | 1 | 0.3 |
| Other | 4 | 1.2 |
| Noise exposure on job site | | |
| Daily | 167 | 48.3 |
| Weekly | 124 | 35.8 |
| Monthly | 37 | 10.7 |
| Yearly | 7 | 2.0 |
| Rarely or never | 11 | 3.2 |
| | *Mean* | *SD* |
| Age (25–70 years) | 44.9 | 8.0 |
| Years worked in the fire service (0–38) | 17.5 | 8.2 |

Totals do not add up to the same number due to missing data.

### *Use of standardized variables in research (Aim 3)*

The mean KBS scores were 3.7 for Knowledge, 2.2 for Behavior, and 4.4 for Status. The analysis of bivariate correlations among three KBS variables showed significant positive relationship between Knowledge and Behavior (Spearman's rho = .13, $p = .01$). Behavior and Status were significantly associated (Spearman's rho = .12, $p = .02$). There was no significant relationship between Knowledge and Status.

## Discussion

The feasibility of using the Omaha System to describe and evaluate NIHL interventions was demonstrated by a team of experts from health informatics, hearing conservation, and occupational health nursing, using existing firefighter hearing research data. Existing firefighter hearing research data were transformed into standardized variables using the Omaha System problem rating scale for outcomes.

Dissemination of evidence-based standardized hearing screening interventions in the EHR for clinical decision support is made possible by the new EB-SCP guideline using Omaha System terminology (Table 3). This innovation provides support for delivering quality NIHL prevention during routine health care encounters. Interventions represent not only the audiologic assessment, but also counseling about the screening results, referral for audiologic evaluation, and teaching about healthy hearing practices such as use of HPDs when in loud noise. Intervention actions of Surveillance, Case Management, and Teaching, Guidance, and Counseling in column one are further described by the targets and care descriptions in columns two and three. Further detail to describe interventions is available nested in the care description when needed. For example, in order to accomplish audiologic screening, surveillance of durable medical equipment is needed, specifically a functional check of the audiometer before each use. Similarly, nested interventions are provided for Teaching, Guidance, and Counseling on Behavior Modification for use of HPDs to reflect interventions to decrease barriers, increase benefits, improve self-efficacy, and improve social norms regarding use of HPDs. Use of the EB-SCP will generate standardized intervention data that can be used to evaluate care quality.

The expert team developed and applied algorithms based on definitions of clinical measures and KBS ratings. This study demonstrated that KBS ratings based on clinical assessments can be produced using research and clinical hearing data, and is the first study to generate Omaha System KBS ratings using a clinical health data set. This is important for several reasons. Until now, KBS ratings have been strictly observation measures, with limitations inherent in the observation process. Client self-report and gold standard measures are considered more reliable data sources than observation measures. As use of the Omaha System continues to grow in EHRs, personal health records (PHRs) and surveys, calculated KBS ratings will become increasingly available for comparison

**Table 3.** NIHL prevention EB-SCP using Omaha System terminology.

| | *Problem: Hearing* | | | |
|---|---|---|---|---|
| *Category* | *Target* | *Care description* | | |
| *S* | Screening | Audiologic screening | | |
| | | *S* | Durable medical equipment | Functional check of audiometer before each use, regular calibrations. |
| *S* | Behavior modification | Self-reported use of hearing protection | | |
| *CM* | Medical/dental care | Interpretation of hearing test and referral to provider (e.g. audiologist or physician) | | |
| *TGC* | Safety | Long or repeated exposure to noise levels > 85 dBA, without proper protection, causes hearing loss | | |
| *TGC* | Signs and symptoms physical | Hearing loss from exposure to loud noise is permanent and cannot be recovered. Tinnitus (ringing in the ear) is an early sign of hearing damage. | | |
| *TGC* | Signs and symptoms physical | If you have to raise your voice to be heard by someone an arm's length away, you need hearing protection | | |
| *TGC* | Screening procedures | Regular hearing tests help with early detection of hearing loss | | |
| *TGC* | Supplies | Selecting, fitting, and use of hearing protection equipment | | |
| *TGC* | Behavior modification | Use of hearing protection behavior | | |
| | | TGC | Signs and symptoms mental/emotional | Decreasing barriers to using hearing protection |
| | | TGC | Signs and symptoms mental/emotional | Increasing benefits of using hearing protection |
| | | TGC | Signs and symptoms mental/emotional | Improving self-efficacy/confidence in using hearing protection |
| | | TGC | Signs and symptoms mental/emotional | Improving social norms for using hearing protection |

S = Surveillance; CM = Case management; TGC = Teaching, guidance & counseling.

across populations, health problems, and health care settings. Such PHR, EHR, and survey data have potential to become a primary source of population health data.

Using the standardized (KBS) outcomes, hearing assessments can be compared across the spectrum of all health outcomes in a standardized way. Thus holistic assessments of populations could be analysed and presented as population health profiles. These standardized outcome measures can also provide opportunity for comparison of benchmark attainment (e.g. Status > 4) or comparison to other organizations and their populations. The resulting data will create opportunities for data exchange across occupational health and other care settings at the individual, employer, or regional level. Future studies will (1) compare baseline and the current hearing assessments of firefighters, and (2) compare firefighters hearing KBS scores to other populations of interest for the hearing problem such as newborns (early hearing detection and intervention) and community dwelling elders.

Firefighters in this study demonstrated relatively high Knowledge scores (mean = 3.7 out of 5). However, their Behavior scores (use of HPDs) were relatively low (mean = 2.2 out of 5). Only 12% of the participants used HPDs more than 80% of the time that they were needed. Ideally all of the participants should use HPDs all the time when they work in noisy environments or work with noisy tools. The rate of 12% falls far short of the 100% use needed to prevent NIHL, indicating the need for further behavior change in firefighters. The high Status scores (mean = 4.39 out of 5), indicated that NIHL prevention strategies can be implemented successfully with this population to prevent hearing loss due to occupational noise exposure.

Using the Omaha System Knowledge, Behavior and Status framework, previously unknown relationships were discovered. The present study found a significant positive relationship between Knowledge and Behavior, demonstrating firefighters with higher level knowledge on NIHL used HPDs more. The intervention strategy for firefighters should include ways to increase their knowledge about the harmful effect of noise on hearing and prevention of hearing loss, thus, to promote their use of HPDs.

This study demonstrated a protective effect of using HPDs as shown in a positive association (Spearman's rho = .12, $p = .020$) between the Behavior (use of HPDs) and hearing Status; firefighters who reported frequent use of HPDs demonstrated significantly better hearing. This finding corroborates earlier studies (Hessel, 2000; Hong, 2005).

This study also demonstrated a successful collaboration between NIHL occupational health researchers and health informatics experts, who tested the Omaha System for applicability in the field of hearing health. Future international collaboration is planned using the Omaha System to advance use of informatics methods in occupational health in countries such as Brazil and Turkey, through the Omaha System Partnership for Knowledge Discovery and Health Care Quality.

The study included predominantly non-Hispanic white male workers, so the results may not be generalizable to other ethnicities or female workers. The data used in this study is cross-sectional, thus it is not possible to determine a definitive causal relationship for correlations among Knowledge, Behavior, and Status scores.

## Conclusion

This study demonstrated that the Omaha System was useful to describe evidence-based hearing screening interventions (1) for use in the EHR; (2) to transform firefighter hearing data into standardized variables; and (3) to use standardized variables in research. Use of the protocol will provide clinical decision support for delivering quality NIHL prevention during routine health care encounters, and generate standardized data that can be used to evaluate care quality and outcomes. Findings support the validity of the new Knowledge, Behavior, and Status hearing health outcomes. Standardized hearing health outcomes will create opportunities for data exchange across occupational health and other care settings thus supporting population-based hearing health assessments and outcomes. Together these elements facilitate meaningful use of electronic hearing health data for outcome evaluation at the individual and program level.

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***Declaration of interest:*** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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