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The Noise Exposure Structured Interview (NESI): An Instrument for the Comprehensive Estimation of Lifetime Noise Exposure

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Abstract

Lifetime noise exposure is generally quantified by self report. The accuracy of retrospective self report is limited by respondent recall, but is also bound to be influenced by reporting procedures. Such procedures are of variable quality in current measures of lifetime noise exposure, and off-the-shelf instruments are not readily available. The Noise Exposure Structured Interview (NESI) represents an attempt to draw together some of the stronger elements of existing procedures and to provide solutions to their outstanding limitations. Reporting is not restricted to pre-specified exposure activities, and instead encompasses all activities that the respondent has experienced as noisy (defined based on sound level estimated from vocal effort). Changing exposure habits over time are reported by dividing the lifespan into discrete periods in which exposure habits were approximately stable, with life milestones used to aid recall. Exposure duration, sound level, and use of hearing protection are reported for each life period separately. Simple-to-follow methods are provided for the estimation of free-field sound level, the sound level emitted by personal listening devices, and the attenuation provided by hearing protective equipment. An energy-based means of combining the resulting data is supplied, along with a primarily energy-based method for incorporating firearm-noise exposure. Finally, the NESI acknowledges the need of some users to tailor the procedures; this flexibility is afforded and reasonable modifications are described. Competency needs of new users are addressed through detailed interview instructions (including troubleshooting tips) and a demonstration video. Limited evaluation data are available and future efforts at evaluation are proposed.

Keywords

Noise-induced hearing loss; Self report; Occupational noise; Risk; Public health

Background

Research into noise-induced hearing damage has proliferated in recent years. In part, this is attributable to endeavours to determine human physiological and functional correlates of noise-induced cochlear synaptopathy, as demonstrated in animal models (Liberman and Kujawa, 2017). Unlike this animal work, human research predominantly relies on retrospective self-report estimates of cumulative noise exposure. Accuracy of quantification is undoubtedly limited by respondent recall, but also by data capture procedures. Numerous methods have been developed independently by different research teams, each to solve the same objective. The first research gap is therefore the lack of standardisation of procedure. The second research gap is the comprehensiveness of the estimation procedure itself. Existing procedures tend not to fully consider all of the factors that are important for eliciting an estimate of noise exposure over the lifespan (e.g. Bramhall et al., 2017; Carter et al., 2016; Dalton et al., 2001; Johnson et al., 2017; Jokitulppo et al., 2006; Liberman et al., 2016; Neitzel et al., 2004; Moore et al. 2017; Spankovich et al., 2017; Yeend et al., 2017). Figure 1 reports on these factors and summarises the performance of existing methods. While some of the procedures appear more comprehensive than others, few allow public access to the instrument *per se*. This identifies the third research gap, which is lack of publication of the administrator instructions, record forms, checklists, and calculations of noise units, at least as an 'off-the-shelf' solution that can readily be used, in a consistent manner, by researchers elsewhere.

[Insert Figure 1 approximately here. The image is 17.6 cm wide and should occupy two columns.]

The Noise Exposure Structured Interview (NESI) represents the first effort to go beyond simply describing a procedure for estimating lifetime noise exposure based on self report, by offering a comprehensive and ready-made solution that we intend as a common standard for the field. This article presents the complete instrument, including a description of the procedure and all supporting materials for self-directed 'training' and for administration. The NESI does not claim to contain completely novel elements; indeed, some of its elements are adopted from existing procedures, notably the Noise Exposure and Rating Questionnaire published in a Health and Safety Executive report (Lutman et al., 2008), which was originally developed for the UK National Study of Hearing (Davis, 1995; Lutman & Spencer, 1991), and utilised in a number of other projects (e.g. Browning, 1986; Smith et al., 2000). Rather, the innovation and scientific value lie in the way the procedures are packaged together and integrated with novel elements, yielding an instrument that is comprehensive, clear, and not unduly time-consuming for the administrator.

Methods have been developed in an iterative manner using insights from at least seven co-authors and external colleagues who conducted 'beta' testing of preliminary versions. Of the various preliminary versions (see e.g. Prendergast et al., 2017; Prendergast et al., 2018), those bearing closest resemblance to the current NESI are the versions reported by Guest et al. (2017) and Dewey et al. (2018), which differ from the NESI in terms of interview instructions and aspects of the supporting documents, but would be unlikely to produce markedly different results. We define the current instrument as 'NESI version 1', in order to explicitly acknowledge the potential for subsequent refinement and revision, as deemed necessary. However, for brevity, the remainder of this article refers to the instrument simply as 'the NESI'.

Concept

The structured interview aims to elicit data on the level and duration of noise exposures over the lifespan, along with usage and attenuation of hearing protective devices (HPDs). The great challenge when collecting such data is that exposure activities and patterns of exposure are unique to the individual and change over time. In addressing these problems, the NESI adopts an approach which is flexible but also highly structured.

Reporting is not restricted to pre-specified exposure activities, and instead encompasses all activities that the respondent has experienced as noisy (defined based on sound level estimated from vocal effort). Changing exposure habits over time are reported by dividing the lifespan into discrete periods in which exposure habits were approximately stable, with life milestones used to aid recall. Within each life period, standardised methods are used in the estimation of sound level, duration, and attenuation of HPDs. A suggested means of combining these data is provided, based on total energy of exposure, along with a primarily energy-based method for incorporating firearm-noise exposure.

Methods

Structure and Documentation

Practical administration of the NESI requires three documents, supplied as supplementary material:

- The NESI Worksheets (for recording recreational, occupational/educational, and firearm noise exposure; SM1).
- The NESI Guidance (overview, instructions, recreational noise examples, speech communication table, personal listening device table, and hearing protection guide; SM2).
- The NESI Example Calculations (a spreadsheet demonstrating calculation of units of noise exposure; SM3).

Additional background materials are also supplied:

- Further information on the methods for estimating free-field sound level based on vocal effort (SM4)
- Further information on the methods for estimating attenuation of HPDs (SM5)
- Further information on the methods for quantifying firearm noise exposure (SM6)
- A video demonstrating NESI procedures for training and familiarisation purposes (available at https://youtu.be/bqgz7-_wmYA)

The methods by which noise exposure data are obtained and combined fall into seven basic categories: (a) identification of exposure activities, (b) segmentation of the lifespan, (c) estimation of exposure duration, (d) estimation of exposure level, (e) consideration of hearing protection, (f) quantification of firearm noise exposure, and (g) calculation of noise exposure units.

Identification of Exposure Activities

Restricting reporting to pre-specified activities is common in measures of noise exposure, but risks underestimating the exposure of respondents who engage in activities that are less common, or less commonly associated with high sound levels. An additional risk is the over-reporting of activities which *can* involve high sound levels, but do not always do so (e.g. quieter bars and concerts). The NESI follows Lutman et al. (2008) in allowing the respondent to report all noisy (>80 dBA) activities that they have experienced (see also Smith et al., 2000). A ‘noisy’ environment is defined as one in which the respondent would need to raise his/her voice to communicate (at a distance of 4 feet, communicating with a listening partner with normal hearing, with gestures and facial cues available to aid communication).

Though identification of exposure activities is ultimately determined by the respondent’s report, we have elected to provide prompts to expedite this process. Recreational Noise Examples (on page 8 of SM2) are provided to the respondent early in the interview. These examples were derived from preliminary data from respondents with varying ages, backgrounds, and noise exposures, obtained using measures closely related to the NESI. Listed activities were those reported by four or more out of ~250 respondents. Crucially, this list of examples is not exhaustive, and respondents are explicitly instructed to also report any other activities they perceived as noisy (i.e. requiring a raised voice to communicate). Similarly, they are instructed to ignore any activities that appear on the list but which they did not perceive as noisy.

Segmentation of the Lifespan

Exposure habits vary across the lifespan. This can be true of not only choice of exposure activities, but also frequency of occurrence, sound level, usage of hearing protection, and so on. Reporting of current habits is likely to be unrepresentative of lifetime exposure patterns, especially in older respondents. One solution, utilised by Yeend et al. (2017) and Moore et al. (2017), is to segment the lifespan into decades and assess noise exposure habits in each. However, this framework is likely to compromise accuracy where exposure habits have changed markedly mid-decade, e.g. if a respondent attended nightclubs from 18 to 22 (incurring two years of exposure in the second decade of life, and two in the third).

A more accurate approach is to segment the lifespan *on the basis of exposure habits*. Hence, the NESI prompts respondents to divide their life into periods in which exposure habits were approximately stable (e.g. time spent as a university student). Patterns of exposure are then recorded for each life period separately, until reporting across the lifespan is complete. Since exposure habits may change for one activity but not others, life periods are identified for each activity separately.

The authors have observed an additional benefit of this approach: life events can be used as points of reference to improve quality of recall, as in the Noise History Calendar (Welch et al., 2011). Hence, the NESI provides fields for recording the timing of each exposure period, and advises that any contemporaneous life milestones (e.g. graduation or change of workplace) be noted to assist recall (see step 5 of the NESI instructions in SM2).

Estimation of Exposure Duration

In order to estimate total exposure duration within each life period, the interviewer requires information on typical duration and frequency of occurrence of exposures. Following Lutman et al. (2008), we have elected to express exposure frequency in weeks per year and days per week. Broader subdivisions (e.g. days per month and months per year) are inappropriate for some purposes, such as the reporting of occupational exposure patterns that remain constant from week to week.

However, recording of data in this format is not always straightforward. For example, a respondent might report engaging in an activity “twice a month”. In these cases, it falls to the interviewer to convert these data to fit the NESI framework (e.g. “twice a month” = 24 weeks per year × one day per week). The need to perform such conversions is highlighted in step 7 of the NESI instructions (SM2).

Estimation of Exposure Level

Three basic approaches to the quantification of sound level are employed in existing self-report measures of noise exposure:

(a) No consideration of sound level; all exposure activities are weighted equally (e.g. Liberman et al., 2016; Moore et al., 2017).

(b) Sound level is estimated for each exposure activity using databases of sound level measurements (e.g. Bramhall et al., 2017; Johnson et al., 2017; Yeend et al., 2017).

(c) Sound level is estimated by the participant, based on communication difficulty (e.g. Guest et al., 2017; Jokitulppo et al., 2006; Keppler et al., 2015; Lutman et al., 2008).

Method (b) has some advantages, principally in reducing the time taken to complete the measure and in circumventing concerns about the accuracy of respondent estimates. However, we propose that the method (c) may be preferable, for the following reasons:

- For some exposure activities, especially those associated with less commonplace occupations, no sound level measurements may be available.
- For activities that *are* included, the listed sound levels may not reflect the full range of levels possible for that activity, and may therefore be misleading. For example, sound levels associated with sailing, listed at 45 dBA in the Noise Navigator^{TM} database (Berger et al., 2015), were estimated to exceed 80 dBA by several preliminary NESI respondents.

- Within a single activity, a very wide range of sound levels is often listed, e.g. 67-88 dBA for restaurants in the NOISE database (Beach et al., 2013). A means of choosing among them, guided by the respondent, is required.
- Respondents are capable of estimating noise levels with reasonable accuracy, given a loudness rating scale based on communication difficulty (Beach et al., 2012; Ferguson et al., 2018).

Hence, the NESI procedure incorporates respondent-estimated sound level. The Speech Communication Table (Ferguson et al., 2018; Lutman et al., 2008) prompts the respondent to estimate the vocal effort that (s)he would require to communicate in a given environment, at a distance of four feet, assuming that the listener is not hearing-impaired, is not wearing hearing protective equipment, and may be assisted by gestures and facial cues (see page 9 of SM2). Note that only the hypothetical listener in this scenario is required to have normal hearing, not the talker (the NESI respondent), who may be hearing-impaired. The present version of the table was adapted from that reported by Lutman and colleagues (see SM4). Evaluation data have been obtained for the use of this procedure in estimating occupational noise levels (Ferguson et al., 2018), though not for recreational exposures and not for exposures in the distant past (see "Evaluation" section of the present article). We recognise that some NESI users may wish to adopt an alternative approach, such as using respondent estimates for only those activities omitted from databases of sound-level measurements. To facilitate this approach, the NESI Worksheets (SM1) include extra fields for recording estimates from an alternative source.

Finally, for earphones or headphones used with Personal Listening Devices (PLDs), we have developed the Personal Listening Device Table (page 10 of SM2): a tool for estimating free-field equivalent output level based on typical volume control setting. Conversion values are based on approximate mean levels measured by Portnuff and Fligor (2011), using a range of devices coupled to stock earphones. These values are also consistent with EU standards governing maximum sound levels of PLDs (British Standards Institution, 2017). Note that the Personal Listening Device Table applies only to PLDs, not to earphones used with other devices (e.g. stereos or personal computers). For such exposures, sound level may be estimated by eliciting comparisons to other activities previously reported by the participant (e.g. "louder than", "similar loudness to", or "quieter than" an activity whose sound level has already been estimated).

It is important to note that, although we have attempted to provide sound-level estimation methods for most common noisy activities, omissions remain. For example, for musicians performing at amplified live-music events, sound from in-ear monitors contributes to personal exposure (Federman and Ricketts, 2008), yet levels could not be easily estimated using the NESI (nor, indeed, using any of the procedures reported in Table 1). Hence, caution and common sense must be employed when attempting to quantify the exposure of some music-industry professionals and students.

Consideration of Hearing Protection

HPDs reduce sound levels in the ear canal, but may be worn inconsistently. Hence, to quantify its effects, the NESI examines the approximate proportion of time that HPDs were used, as well as their estimated attenuation. The former is estimated by the respondent. The latter is derived from attenuation ratings published by HPD manufacturers.

To assist the user in estimating the attenuation of HPDs, we have developed the NESI Hearing Protection Guide (pages 11-12 of SM2). Several possible routes to an estimate are provided, since, in our experience, respondents vary greatly in their recollection of protector type, from vague descriptions of shape through to precise reports of make and model. Pictorial representations of protector types are provided, along with attenuation values for several popular HPDs, and guidance on estimating attenuation based on the product's Single Number Rating (SNR) or Noise Reduction Rating (NRR).

SM5 provides detailed information on the quantitative methods by which our attenuation estimates are derived from SNR and NRR, and the reasoning behind these methods.

Quantification of Firearm Noise Exposure

Over the decades, damage risk criteria have employed a variety of methods for quantifying firearm noise exposure. Early metrics based on peak level and duration have been succeeded by metrics based on the entire temporal waveform (Davis and Clavier, 2017). Prominent among the latter is A-weighted equivalent continuous 8-hour level (L_{Aeq8hr}), which has been recommended by the National Institute for Occupational Safety and Health (Murphy and Kardous, 2012), the American Institute of Biological Sciences (Wightman et al., 2010), and Defence Research and Development Canada (Nakashima, 2015). One clear benefit of this metric is that it can be easily integrated with energy-based measures of continuous-type noise exposure (Nakashima, 2015).

However, a significant body of research indicates that impulsive noise is more damaging to the auditory system than continuous-type noise of equal energy (e.g. Dunn et al., 1991; Hamernik and Qiu, 2001). In the context of damage risk criteria, there is growing support for energy-based metrics that are adjusted for the greater kurtosis (peakedness) of impulsive noise (e.g. Murphy and Kardous, 2012; Davis and Clavier, 2017). Sounds with greater kurtosis cause greater permanent threshold shift than Gaussian noise of equal energy (Hamernik and Qiu, 2001; Hamernik et al., 2007; Davis et al., 2012). Adjusting noise metrics for kurtosis improves their capacity to predict permanent threshold shift in humans (Zhao et al., 2010; Goley et al., 2011; Xie et al., 2016). The NESI has adopted the kurtosis-corrected metric of Goley et al. (2011):

$$L'_{Aeq} = L_{Aeq} + 4.02 * \log_{10} (\beta / \beta_G)$$

where L'_{Aeq} is kurtosis-corrected A-weighted equivalent continuous level, L_{Aeq} is uncorrected A-weighted equivalent continuous level, 4.02 is a constant derived from dose-response data in chinchillas, β is the kurtosis statistic of the noise, and β_G is the kurtosis statistic for Gaussian noise ($\beta_G = 3$).

Incorporation of firearm noise into the NESI can therefore be achieved by combining L_{Aeq} and β, as measured at the shooter's ear. Flamme et al. (2009b) and Meinke et al. (2014) have reported these data for a variety of firearms. More specifically, Flamme and colleagues report A-weighted equivalent continuous *8-hour* level (L_{Aeq8hr}): the A-weighted noise level that, if present over an 8-hour period, would contain the same sound energy as the firearm impulse. Due to a markedly bimodal distribution of L_{Aeq8hr}, we have elected to dichotomize these weapons into low-calibre (.22 and .17) rifles and all other hand-held firearms (with the exception of air guns, see below). Mean L_{Aeq8hr} for each category has been combined with a kurtosis correction term, yielding kurtosis-corrected A-weighted exposure energy for each category. These values are presented for the NESI user as fractions of a NESI unit of noise exposure, which should be multiplied by the total number of rounds fired.

Exposures to air guns and exposures while wearing hearing protection are disregarded, due to their very low exposure energy. Quantitative justification for this decision is provided in SM6, as are details of all calculations outlined above. Exposure to impulsive noise from sources other than civilian firearms (e.g. artillery and blast noise) is beyond the scope of the NESI.

Finally, it is worth noting that, for the sake of simplicity, NESI procedures for quantification of firearm noise are more rudimentary than those for continuous-type noise in recreational or occupational settings. The Firearm Noise worksheet (SM1) allows the respondent to estimate the total number of rounds fired in whatever manner they choose. (The field labelled "Additional information to assist recall" may be used to note number of rounds per session, sessions per year, etc.) This contrasts with the more prescriptive approach adopted in the other worksheets. Additionally, as stated above, firearms are dichotomised, and exposures while wearing hearing protection disregarded. Though preliminary NESI respondents (who were generally UK residents) reported relatively little firearm exposure, we appreciate that other populations may be more highly exposed. SM6 provides guidance on implementing a more fine-grained approach, if required.

Calculation of Noise Units

The NESI is primarily a procedure for collecting noise exposure data. However, a suggested means of *combining* these data is also provided, based on that of Lutman et al. (2008).

For exposure activities where no hearing protection was worn:

$$Units\ of\ noise\ exposure = \frac{Y \times W \times D \times H}{2080} \times 10^{\frac{L-90}{10}}$$

For exposure activities where hearing protection was worn and reduced sound levels to ≤80 dBA:

$$Units\ of\ noise\ exposure = \frac{Y \times W \times D \times H}{2080} \times (1-P) \times 10^{\frac{L-90}{10}}$$

For exposure activities where hearing protection was worn and did not reduce sound levels to ≤80 dBA:

$$Units\ of\ noise\ exposure = \frac{Y \times W \times D \times H}{2080} \times \left(P \times 10^{\frac{L-A-90}{10}} + (1-P) \times 10^{\frac{L-90}{10}}\right)$$

where *Y* = years of exposure
W = weeks per year of exposure
D = days per week of exposure
H = hours per day of exposure
P = proportion of time that hearing protection was worn (from 0 to 1)
L = sound level (dBA)
A = attenuation of hearing protection

The resulting measure is linearly related to the total energy of exposure above 80 dBA. One unit is equivalent to one working year (2080 hours) of exposure to 90 dBA (hence "*L*-90" in the above equations). The reasons for focusing on one working year and 90 dBA are largely historical: the equations were originally devised for the assessment of *occupational* noise exposure, at a time when 90 dBA represented an important legal limit. We have elected not to alter the calculations, so that NESI data may be comparable with data obtained using precursor measures. Firearm noise exposure is incorporated using a primarily energy-based metric (see step 16 of SM2, and further details in SM6).

To aid investigators new to the NESI, an Excel spreadsheet with example calculations is provided (SM3). It is possible to remove the example data and replace with data from verum NESI respondents, and some users may opt for this approach. However, users are advised to carefully consider alternative ways to store and analyse the data.

Application and Training

The NESI was developed for use in auditory research, but may have wider application, for example in non-auditory research fields and for clinical purposes. Piloting suggests that completion of the interview takes 10-25 minutes for most respondents, excepting those with extremely extensive or complex noise exposure histories. The instructions (SM2) and demonstration video (https://youtu.be/bqgz7-_wmYA) provide guidance on maintaining interview duration within reasonable limits.

Competency in conducting the NESI requires thorough training and practice, due to the potential for interviewer behaviour to influence reporting. To maximise both inter- and intra-rater reliability, the user must develop a consistent "script" for each stage of the interview. The precise wording of the script may be chosen by the user, but must express the points set out in the NESI instructions and be consistent across participants. We recommend that new users carefully study the Worksheets, Guidance, and additional background materials (SM1-6 and video), and also conduct several mock interviews before embarking upon data collection.

We recognise that some users may wish to modify the NESI in order to address specific research questions (e.g. quantifying total duration of exposure above a given level, or examining exposure at specific stages of the lifespan). The instructions provide guidance on some reasonable modifications and how they might be implemented (page 7 of SM2). It would be good practice to disclose any deviations from the principal NESI methods when reporting the resulting data.

Evaluation

The advent of smart-watches and other technologies may soon allow for continuous, long-term, objective measurement of an individual's noise exposure. For now, the absence of a gold-standard measure of lifetime noise exposure means that self-report metrics must be evaluated piecemeal.

A component of the NESI, the Speech Communication Table, has been evaluated via dosimetry in 15 workplace settings in which noise levels were greater than or equal to 85 dBA (Ferguson et al., 2018). In this study, 168 participants aged 16-25 years estimated noise exposure using a version of the Speech Communication Table, and wore personal noise dosimetry badges to objectively measure the noise level in the same nominated occupational tasks. In terms of estimation, methods agreed to within ±3 dB in 56% of cases and within ±6 dB in 91% of cases (Ferguson et al., 2018). Lutman and colleagues (2008) therefore concluded that, "for group comparisons, noise level estimation from self-reported communication difficulty is appropriate" (pp. 57). Note, however, that a limitation of this study is that exposures were purely occupational; recreational exposures might pose different challenges.

Feedback from NESI pilot users indicates interviewer confidence in the capacity of the procedures to enhance respondent recall. In preliminary data, exposure to a single activity was often recorded across multiple life periods, suggesting that this framework is of value in capturing changing exposure habits across the lifespan. Preliminary data also demonstrate the NESI's capacity to distinguish those in noisy professions from other respondents (Figure 2).

[Insert Figure 2 approximately here. The image is 7.5 cm wide.]

Since recreational noise exposure is a major contributor to the lifetime noise dose, a priority for future research should be evaluation of the Speech Communication Table in recreational settings. Additionally, evaluation of this procedure for sporadic and/or erstwhile exposures may be important, since accuracy of recall may diminish over time. It may also be valuable to determine both the intra- and inter-rater reliability of the NESI.

Conclusion

Development of the NESI represents an attempt to draw together some of the stronger elements of existing self-report procedures for estimating lifetime noise exposure, and to supply novel solutions to their outstanding limitations. Its structure allows the report of an unrestricted range of noisy activities and of changing noise exposure habits over the lifetime, strengthened by a mnemonic approach. Methods are provided for estimating the sound levels of all exposure activities, not only those that are adequately represented in databases of sound-level measurements. Straightforward methods allow the effects of hearing protection to be quantified. An energy-based means of combining the resulting data – including exposure to firearm noise – is supplied. Since some users may wish to deviate according to research needs, the NESI affords the flexibility for reasonable modifications. Training of new users is aided by detailed instructions and a demonstration video. Of course, further evaluation of the NESI instrument is required, and suggestions as to useful modifications in future versions of NESI are welcome. Finally, the authors call for the open sharing of data obtained using the NESI, so that the power of large data sets might be harnessed.

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Figure Captions

Figure 1: Performance of existing self-report measures of noise exposure

Figure 2: Noise exposure data from a cohort of 62 preliminary NESI respondents, obtained using a beta version of the NESI (Dewey et al., 2018). Nineteen were classed as music-industry workers, the remaining 43 were not. Music-industry workers encompassed professionals, teachers, trainees, and experienced amateurs in the following: musical performance, sound engineering, music production engineering, and disk jockeying. Density plots illustrate the distributions of (A) recreational noise exposure, (B) occupational noise exposure, and (C) total lifetime noise exposure. Note that, to allow plotting on a logarithmic scale, NESI scores of 0 have been adjusted to 0.001.

Supplementary Material

SM1: Worksheets
Three sheets, for recording recreational, occupational/educational, and firearm noise exposure

SM2: Guidance
Twelve pages, composed of an overview, instructions, recreational noise examples, speech communication table, personal listening device table, and hearing protection guide

SM3: Example Calculations
A spreadsheet demonstrating how NESI noise units are calculated

SM4: Adoption of the Speech Communication Table
Further information on the methods used to estimate free-field sound levels based on vocal effort

SM5: Estimating Attenuation of HPDs
Further information on the methods used to estimate the attenuation of HPDs

SM6: Quantifying Firearm Noise Exposure
Further information on the energy-based methods used to quantify firearm noise exposure

Demonstration video
A 12-minute video demonstrating interview techniques and troubleshooting tips, available online at https://youtu.be/bqgz7-_wmYA

Thorough consideration

Unclear or limited consideration

Absent or very limited consideration

	Lifetime Exposure to Noise and Solvents (Bramhall *et al*, 2017)	Leisure Noise Table (Carter *et al*, 2016)	Epidemiology of Hearing Loss Study Questionnaire (Dalton et al, 2001)	Noise Exposure Questionnaire (Johnson et al, 2017)	Exposed Noise & Hearing Disorders of Conscripts (Jokitulppo et al, 2006)	Questionnaire 1 (Liberman et al, 2016)	Questions Concerning Music Exposure (Moore et al, 2017)	First Annual Study Questionnaire (Neitzel et al, 2004)	Adolescents' Habits & Hearing Protection Use (Spankovich et al, 2017)	General Noise History (Spankovich et al, 2017)	NAL Online Noise Survey (Yeend et al, 2017)
Examines *lifetime* exposure?	Yes	Yes	In part [2]	No	Yes	Yes	Yes	No	Un-clear [1]	No	Yes
Considers duration of each exposure?	No [3]	Yes	Yes	Yes	Yes	No	No	In part [4]	No	Yes	Yes
Considers duration of overall exposure period?	Yes	Yes	In part [2]	No	Yes	Yes	Yes	No	No	Yes	Yes
Considers frequency of occurrence of exposures?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Allows for changing exposure habits over time?	No	No	No	In part [5]	No	No	In part [6]	No	No	No	In part [6]
Considers sound level?	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
Includes all potential exposure activities?	No (>10)	Yes	No (>10)	No (>10)	Yes	Un-clear [7]	No (<10)	No (>10)	No (>10)	No (>10)	No (>10)
Considers ear protection?	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Incorporates ear protection into exposure calculation?	Yes	Un-clear	Yes	No	Un-clear	Un-clear	No	No	No	Un-clear	Yes
Considers firearm exposure?	Yes [3]	Yes [8]	Yes [9]	Yes [9]	Yes [10]	Yes [8]	No	No	Yes	Yes [8]	Yes [8]
Specifies quantitative method for combining the data?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes

[1] Described as a measure of lifetime exposure, but interrogates current habits (*'How often do you ...?'*)

[2] Seeks information on number of years of exposure, but does not incorporate this information into the overall measure

[3] Treats firearm peak sound level as if it were continuous sound level, causing the measure to be overwhelmingly dominated by firearm noise

[4] Assumes a 4-hour duration for most activities

[5] For occupational noise only, the respondent may report different exposure habits in term time than in the summer vacation period

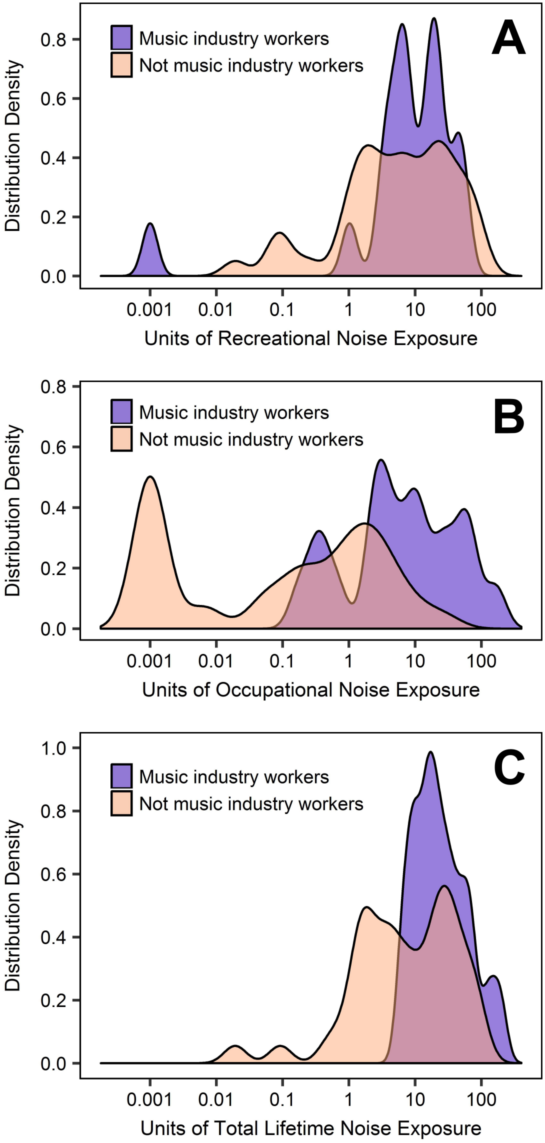
[6] Allows changing exposure habits to be reported, but requires that the lifespan be divided by decade, reducing accuracy where habits have changed mid-decade

[7] Asks about noisy "hobby(s)" and "job(s)", but provides a single field for each response, making it unclear how to report data for multiple activities

[8] Gathers data on firearm noise, but does not state how these data are incorporated into the measure

[9] Gathers data on firearm noise, but does not incorporate these data into the measure

[10] Attempts to quantify firearm noise using the same methods as for continuous-type noise (combining estimated level and duration)



A
Music industry workers
Not music industry workers
Distribution Density
0.0
0.2
0.4
0.6
0.8
0.001
0.01
0.1
1
10
100
Units of Recreational Noise Exposure
B
Music industry workers
Not music industry workers
Distribution Density
0.0
0.2
0.4
0.6
0.8
0.001
0.01
0.1
1
10
100
Units of Occupational Noise Exposure
C
Music industry workers
Not music industry workers
Distribution Density
0.0
0.2
0.4
0.6
0.8
1.0
0.001
0.01
0.1
1
10
100
Units of Total Lifetime Noise Exposure

NESI THE NOISE EXPOSURE STRUCTURED INTERVIEW

Category A: Recreational noise exposure

ID: **Date:**

Exposure activity									
Timing of exposure period (e.g. age at start and age at end)									
Exposure duration	Years								
	Weeks per year								
	Days per week								
	Hours per day								
Exposure level	Basis for estimate								
	Estimated level (dBA)								
Optional: Exposure level (alternate estimation method)	Basis for estimate								
	Estimated level (dBA)								
Use of hearing protection	Proportion of time worn (between 0 and 1)								
	Notes on type and attenuation of protector								
	Estimated attenuation (dB)								

NESI THE NOISE EXPOSURE STRUCTURED INTERVIEW

Category B: Occupational and educational noise exposure

ID: **Date:**

Exposure activity										
Timing of exposure period (e.g. age at start and age at end)										
Exposure duration	Years									
	Weeks per year									
	Days per week									
	Hours per day									
Exposure level	Basis for estimate									
	Estimated level (dBA)									
Optional: Exposure level (alternate estimation method)	Basis for estimate									
	Estimated level (dBA)									
Use of hearing protection	Proportion of time worn (between 0 and 1)									
	Notes on type and attenuation of protector									
	Estimated attenuation (dB)									

NESI THE NOISE EXPOSURE STRUCTURED INTERVIEW

Category C: Firearm noise exposure

ID: **Date:**

Type of firearm								
Additional information to assist recall								
Total number of rounds fired without hearing protection								

Summary information

	Category A: Recreational noise	Category B: Occupational and educational noise	Category C: Firearm noise	Total
Number of worksheets used				
Person conducting interview				

NESI THE NOISE EXPOSURE STRUCTURED INTERVIEW

Introduction	Outline how the NESI works Explain which activities should be reported
Recreational noise exposure	Identify exposure activities For each activity, identify life periods in which exposure habits were approximately stable For each life period… • Estimate ***duration of exposure*** • Estimate ***level of exposure*** • Record use and type of ***hearing protection***
Occupational and educational noise exposure	Identify exposure activities For each activity, identify life periods in which exposure habits were approximately stable For each life period… • Estimate ***duration of exposure*** • Estimate ***level of exposure*** • Record use and type of ***hearing protection***
Firearm noise exposure	For any exposures without hearing protection... • Record ***type of firearm*** • Estimate ***number of rounds fired***
Analysis	For each activity and life period, combine the above data into units of noise exposure Add them together, yielding ***total units of lifetime noise exposure***

Use the **recreational noise examples** (page 8) to aid identification of noisy recreational activities

Use the **speech communication table** (page 9) to estimate the sound level of free-field exposures

Use the **personal listening device table** (page 10) to estimate the sound level from earphones/headphones

Use the **hearing protection guide** (pages 11-12) to estimate the attenuation of hearing protectors

Use the **worksheets** to record the respondent's noise exposure information

Steps 1 to 2: Introducing the NESI

1. Outline the purpose of the interview: to identify activities involving high sound levels and estimate the duration and level of exposure for each.

Suggested script:
The purpose of this interview is to estimate your lifetime noise exposure. We will identify activites that have caused you to be in noisy situations, then estimate how long you spent in those situations and how noisy they were.

2. Define the activities that should be reported: those with an estimated sound level exceeding 80 dBA.

For free-field exposures, this is based on estimated vocal effort required to communicate (see **Speech Communication Table**). Instruct the respondent to report situations requiring a "raised voice" at a communication distance of 4 feet (1.2 m).

For personal listening devices, instruct the respondent to report listening at volume control settings above 70% of maximum volume (see **Personal Listening Device Table**).

Suggested script:
I'll explain what I mean by a "noisy" situation: It's the kind of situation where, if you and I were 4 feet apart, you would have to raise your voice to communicate with me. [Interviewer gestures to indicate a distance of 4 feet.] *Assume that I have normal hearing, that I am not wearing ear plugs or ear muffs, and that we are able to see each other's faces and gestures clearly.*

Situations that are at least this noisy are the ones you should report. Quieter situations, which don't cause you to raise you voice, can be ignored.

Finally, there's one other kind of noisy activity we'll look at, and that's listening through earphones or headphones with the volume control set quite high, above 70% of maximum volume.

Tip:

It is sometimes necessary to emphasise that the communication scenario used to estimate free-field noise levels is *hypothetical*.

The respondent should imagine attempting to communicate with a listener without hearing protection, even if this scenario would be unlikely to occur in the environment in question.

Steps 3 to 11: Estimating recreational, occupational, and educational noise exposure

Record recreational exposures (Category A) first, followed by occupational and educational exposures (Category B). Interview methods are similar for the two categories.

3. Prompt the respondent to identify exposure activities. For Category A, these should be noisy activities that occurred recreationally; for Category B, noisy activities that occurred in the course of work or study.

Provide pen and paper and allow the respondent a few minutes alone to note exposure activities. For Category A, also provide the **Recreational Noise Examples**.

The respondent should use these notes later, to aid their recollection. The notes will not be analysed. They may add to the notes at any time.

Tip:

In Category A, what appears initially to be a single "activity" may be divisible into more specific activities with differing sound levels and/or use of hearing protection (e.g. "metal bands" and "folk bands"). If the respondent is able to recall information about these exposures separately, then record them as separate activities.

Similarly, in Category B, make sure to distinguish between a job and an activity. One job may involve multiple activities, only some of which may be noisy.

4. Next, you will examine the identified exposure activities, one after another, estimating sound level, duration, and use of hearing protection for each one.

Encourage the respondent to report their most significant sources of noise exposure early in the interview.

Suggested script:

Now let's look at one activity in detail. Which do you think has contributed most to your overall noise exposure?

5. Outline the process for recording exposure habits across time: dividing the lifespan into periods in which exposure habits were approximately stable.

Make clear that a single activity may be reported over multiple life periods if habits or duties have altered.

Suggested script:

Now we need to estimate how long you have spent [engaging in the activity].

As a first step, I'll ask you to think of a period of your life when your habits were fairly stable: a number of years where there weren't major changes in how often you [engaged in the activity], or how noisy it was, or how long the noise lasted. You might need to divide your life into a several periods. For example, if you [engaged in the activity] very frequently from 16 to 22 and less frequently from 22 to 30, we would look at each period separately.

6. Prompt the respondent to identify a life period. Note the timing (e.g. "age 22 to 30") in the second row of the worksheet. This information may be useful later in the interview, when checking for "gaps" in the exposure record (life periods which involved exposure, but haven't yet been recorded).

Record the duration of this period in years. (This doesn't have to be a whole number.)

Suggested script:

So, when it comes to [the present activity], which period of your life should we look at first?

Tip:

Encourage the participant to make use of relevant life milestones to structure their recollection (e.g. change of workplace, graduation from university).

7. For the activity and life period identified above, prompt the respondent to estimate weeks per year and days per week of exposure. (These don't have to be whole numbers.)

Tip:

Participants sometimes find it easier to express this information in alternative terms (e.g. days per month or days per year). The interviewer should allow this, then convert the information into weeks per year and days per week.

Example: "Twice a month for 3 years"= 3 years × 24 weeks/year × 1 day/week

8. Prompt the respondent to estimate average hours per day of exposure. (This doesn't have to be a whole number.)

9. Prompt the respondent to estimate the typical sound level associated with the activity.

Standard NESI procedure is to use the **Speech Communication Table** (for free-field exposures) or **Personal Listening Device Table** (for headphones/earphones attached to personal listening devices).

Record the estimated sound level. Also record the information that provided the basis for this estimate (e.g. "shout from 2 feet" from the Speech Communication Table).

It is possible to obtain sound-level estimates from alternative sources. (See "Departing from NESI standard procedure" on page 7 of this guide.) Such estimates may be recorded in the grey-shaded fields on the NESI worksheets, which should otherwise be left blank.

Suggested script for free-field exposures:

I'd like you to estimate how noisy it was when you [engaged in the activity] by answering this question: If you and I were 4 feet apart in that situation, which of the following would you need to do to communicate with me? [The interviewer presents the six options from the **Speech Communication Table**.] *Assume that I have normal hearing, that I am not wearing ear plugs or ear muffs, and that we can see one another's faces and gestures clearly.*

Tip:

The **Personal Listening Device Table** applies only to portable devices such as personal music players and phones, not to stereos, PCs, or sound recording equipment. For such exposures, sound level may be estimated by drawing comparisons to other activities previously reported by the participant (e.g. "louder than", "similar loudness to", or "quieter than" an activity whose sound level has already been estimated).

10. For free-field exposures, obtain information on use of hearing protection: protector type, estimated attenuation, and proportion of time worn (ranging from 0 to 1).

Use the **Hearing Protection Guide** to help identify protector type and estimate attenuation.

Tip:

The participant may express the proportion of time that hearing protection was worn as a percentage. Convert from percentage to proportion by dividing by 100 (e.g. 70% ⟶ 0.7).

If hearing protection was never worn, record proportion of time worn as 0.

11. One worksheet column is now complete. Repeat steps 7 to 10 for each additional period of the respondent's life which involved the present activity. Then repeat for each additional exposure activity.

If you run out of columns, attach extra worksheets as needed.

Tip:

Be prepared to split the content of a column into multiple columns, if necessary. A respondent may initially report consistent exposure habits for a given activity, only for further questioning to reveal otherwise (e.g. changes in frequency of exposure, level of exposure, or use of hearing protection).

Steps 12 to 13: Estimating firearm noise exposure

12. Determine whether the respondent has ever used a rifle, shotgun, or handgun ***without hearing protection***. (Exposures while wearing hearing protection should be ignored. Exposure to air guns should be ignored.)

It is possible to implement a modified version of the NESI which incorporates firearm exposure while wearing hearing protection. (See “Departing from NESI standard procedure” on page 7 of this guide.)

Tip:

The NESI quantifies exposure to civilian firearms only. Exposure to heavier weapons and blast noise is beyond the scope of the measure.

13. For exposures ***without hearing protection***, record type of firearm and approximate number of rounds fired on the Category C worksheet. Low-calibre (.22 and .17) rifles are assigned fewer units of noise exposure than other firearms, so make sure to establish whether this type of firearm was used.

Tip:

Complete as many columns as are needed to capture the respondent's exposure history. More than one column may be completed per firearm type. Notes may be made in the “Additional information...” field to assist in estimating the total number of rounds fired (e.g. rounds per session and sessions per year). The contents of this field will not be analysed.

Steps 14 to 17: Recording and analysis

14. Complete at least one worksheet for each of the three categories. Even if the respondent reports no noise exposure in a given category, fill in the fields at the top right corner and retain the worksheet with the others.

If a respondent requires more than one worksheet for a given category, attach extra worksheets as required.

Tip:

Completion of the NESI takes 10-25 minutes for most respondents, excepting those with extensive or complex noise histories.

If an interview risks overrunning the available time, reinstruct the respondent to reduce the precision of their reporting. For example, rather than describing three life periods with slightly differing exposure habits, the respondent may report average exposure habits over one long period.

Do not adopt this approach with the ***earlier*** exposure activities in each category (i.e. those that contributed most to overall exposure). Instead, reserve this approach for later in the interview, when dealing with more minor sources of noise exposure.

The priority is to ensure that the interview is not cut off, and that all activities are reported across the full lifespan.

15. Calculate units of recreational, occupational, and educational noise exposure.

Use the following formulae to generate noise units for each completed column on worksheets A and B.

The **NESI example calculations** spreadsheet shows how these formula are applied, using example NESI data.

Calculation of noise units in Categories A and B:

If hearing protection was not worn...

$$\textit{Units of noise exposure} = \frac{Y \times W \times D \times H}{2080} \times 10^{\frac{L-90}{10}}$$

If hearing protection was worn, and reduced the sound level to <80 dBA...

$$\textit{Units of noise exposure} = \frac{Y \times W \times D \times H}{2080} \times (1-P) \times 10^{\frac{L-90}{10}}$$

If hearing protection was worn, but did not reduce the sound level to <80 dBA...

$$\textit{Units of noise exposure} = \frac{Y \times W \times D \times H}{2080} \times \left(P \times 10^{\frac{L-A-90}{10}} + (1-P) \times 10^{\frac{L-90}{10}} \right)$$

where *Y = years of exposure*
W = weeks per year of exposure
D = days per week of exposure
H = hours per day of exposure
L = level (dBA)
A = attenuation of hearing protection (dB)
P = proportion of time that hearing protection was worn (0 to 1)

16. Calculate units of firearm noise exposure.

Use the following formula to generate noise units for each of the completed columns on worksheet C.

The **NESI example calculations** spreadsheet shows how this formula is applied, using example NESI data.

Calculation of noise units in Category C:

$$\textit{Units of noise exposure} = \frac{R}{500} + \frac{R_{low}}{16000}$$

where *R = number of rounds fired from shotguns, handguns, and rifles, excluding low-calibre (.22 and .17) rifles and air guns*
R_{low} *= number of rounds fired from low-calibre (.22 and .17) rifles*

17. Add the units from all columns to yield total units of lifetime noise exposure, a measure linearly related to total energy of exposure above 80 dBA. One unit equates to one working year (2080 hours) of exposure to 90 dBA.

Alternate units may be generated. See “Departing from NESI standard procedure” on page 7 of this guide.

Departing from NESI standard procedure

Recommended procedure for administering the NESI is fully specified by:

- Steps 1 to 17 of the above guide
- The Recreational Noise Examples
- The Speech Communication Table
- The Personal Listening Device Table
- The Hearing Protection Guide

However, it is recognised that some users of the NESI may wish to modify elements of the procedure. **Any such modifications must be disclosed when reporting data obtained using the NESI**. Some anticipated modifications are outlined below, along with guidance on their implementation.

Modification 1: Estimating exposure level

NESI standard procedure involves estimating sound level using the Speech Communication Table and the Personal Listening Device Table.

It is possible to obtain sound-level estimates from other sources, e.g. databases of sound level measurements. The NESI worksheets include fields for recording an alternative estimate, so that either may be used in analysis.

Modification 2: Altering the criterion sound level for exposure activities

The NESI records all exposures with an estimated sound level >80 dBA, and the standard analysis generates noise units linearly related to total energy of exposure above this level. Some NESI users may wish to apply a higher criterion level in the course of analysis (e.g. analysing only exposures >100 dBA). Such users should implement this modification by amending the structure in which they store and process NESI data, so that inclusion of an activity in the overall NESI score is conditional upon sound level.

Modification 3: Generating units of firearm noise exposure

Standard NESI procedure assigns 1/16000 noise units to each round from a .22 or .17 rifle and 1/500 units to a round from any other handheld firearm, considering only those exposures incurred without hearing protection. These values are based principally on the approximate energy of such exposures, with an adjustment for the kurtosis of the sound waveform.

Alternate analysis methods are possible, e.g. assigning different values to different types of firearm, and/or incorporating exposures incurred with hearing protection. Users considering such modifications should refer to the NESI dissemination paper, which details the basis for the standard NESI weighting of firearm noise and suggests some possible modifications.

Modification 4: Generating total units of lifetime noise exposure

Standard NESI units of lifetime noise exposure are linearly related to the total energy of exposure above 80 dBA. One unit is equivalent to one working year (2080 hours) of exposure at 90 dBA.

Some NESI users may wish to generate an alternative measure, e.g. log energy of exposure, or total duration of exposure exceeding a criterion sound level, or total units of occupational noise exposure. Such users should implement this modification by amending the structure in which they store and process NESI data.

Modification 5: Examining noise exposure during specific periods

Standard NESI output is a measure of cumulative lifetime noise exposure.

Some users may wish instead to examine the timing of exposures (e.g. focusing on exposures during childhood, or exposures preceding the development of hearing deficits). In this case, the interviewer must ensure that the “Timing of exposure period” field is always completed, and should amend the structure in which they store and process NESI data, so that inclusion of an exposure in the overall NESI score is conditional upon timing.

- Your interviewer has asked you to note any noisy activities you have experienced. Listed below are some common noisy activities, which may help to prompt your memory.
- **Remember what is meant by "noisy"**: situations causing you to **raise your voice** to communicate at a distance of 4 feet.
- **Do not restrict yourself to the activities on this list**. Also note any other noisy activities you have experienced.
- **Only note activities that you have found to be noisy**. If you have experienced an activity on this list but did not find it noisy, then **ignore it**.

Live music

Examples:
- Concerts
- Festivals

Nightlife

Examples:
- Nightclubs
- Bars
- Pubs

Making music

Examples:
- Playing/singing in a group
- Playing/DJing/singing solo

Listening though earphones and headphones

DIY noise

Examples:
- Power tools
- Powered gardening tools

Engine noise

Examples:
- Motorbikes
- Motorsports
- Motorboats

Sport-related noise

Examples:
- Sports matches
- Sailing

Cinema

Vocal effort required	*Estimated level*
Talk normally from 4 feet	≤80 dBA
Raise voice from 4 feet	87 dBA
Talk loudly from 4 feet	90 dBA
Talk very loudly from 4 feet	93 dBA
Shout from 4 feet	99 dBA
Shout from 2 feet	105 dBA
Shout in listener's ear	110 dBA

A guide for estimating unknown noise levels (of a continuous type) based on speech communication difficulty.

Approximate communication-limiting noise levels are based on the scenario of one person communicating with another in an environment that they are both used to, assuming that the listener is not hearing impaired, is not wearing hearing protection, and may be assisted to some extent by gestures and facial cues.

A guide for estimating the free-field equivalent output levels of earphones or headphones coupled to personal listening devices (e.g. phones and music players), based on the respondent's typical volume control setting.

Volume control setting	Estimated level
<70% of maximum	<80 dBA
70% of maximum	82 dBA
80% of maximum	88 dBA
90% of maximum	94 dBA
Maximum volume	100 dBA

Output-level warning messages in European devices

Many personal listening devices sold in the European Union from February 2013 have settings designed to limit listening levels below 85 dBA*. When sound levels reach 85 dBA, the listener is presented with a visual or audible warning message which they must acknowledge in order to access the upper portion of the volume control range.

Note that "maximum volume" in the above table does ***not*** refer to the sound level that elicits this warning message. "Maximum volume" refers to the true upper limit of the volume control range, accessed by acknowledging the message and further increasing the sound level.

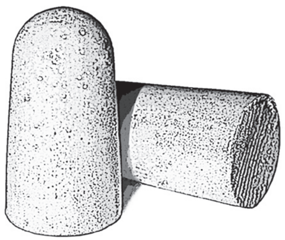
If a respondent has encountered such warning messages, then their recollection of this phenomenon can sometimes assist in estimating sound level (for example, if they consistently chose not to exceed the 85 dB warning level).

**BS EN 60065:2014+A11:2017: Audio, video and similar electronic apparatus – Safety requirements.*

A tool for estimating the attenuation of hearing protectors.

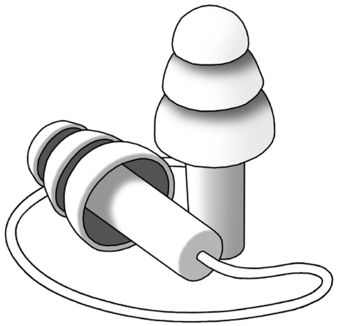
NESI "estimated attenuation" is derived from attenuation ratings reported by manufacturers: either the **Single Number Rating (SNR)**, used primarily in Europe, or the **Noise Reduction Rating (NRR)**, used in the US and elsewhere.

- **If the specific model of protector is listed in this guide**, simply read its estimated attenuation from the table
- **If the specific model is not listed, but its SNR or NRR is known**, calculate its estimated attenuation using the final table
- **For all other hearing protectors**, estimate attenuation based on the ***type*** of hearing protector



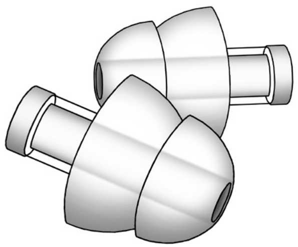
Formable ear plugs

	Estimated attenuation
3M E-A-R Classic (SNR 28)	24 dB
Howard Leight Laser Lite (SNR 35)	31 dB
Moldex SparkPlugs (SNR 35)	31 dB
Hearos Xtreme Protection (NRR 33)	32 dB
3M 1000/1100 (SNR 37)	33 dB
Typical ear plug of this type	**31 dB**



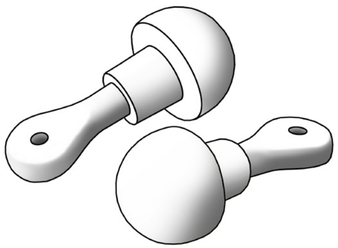
Flanged ear plugs

	Estimated attenuation
3M E-A-R Tri-Flange (SNR 29)	25 dB
Howard Leight Airsoft (SNR 30)	26 dB
Howard Leight Smartfit (SNR 30)	26 dB
3M E-A-R Ultrafit (SNR 32)	28 dB
3M E-A-R Tracer (SNR 32)	28 dB
Typical ear plug of this type	**26 dB**



High-fidelity ear plugs

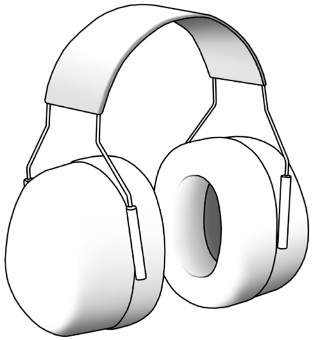
	Estimated attenuation
Etymotic ETY-Plugs (NRR 12)	11 dB
Alpine MusicSafe, gold filter (SNR 18)	14 dB
EarPeace, red filter (SNR 20)	16 dB
Alpine PartyPlug Pro (SNR 21)	17 dB
Eargasm (SNR 21)	17 dB
Typical ear plug of this type	**16 dB**



Push-in ear plugs

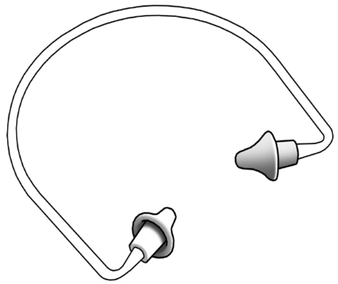
	Estimated attenuation
3M E-A-R Express Pod Plugs (SNR 28)	24 dB
3M E-A-R Skull Screw (SNR 32)	28 dB
3M No-Touch foam (SNR 35)	31 dB
Howard Leight TrustFit Pod (SNR 36)	32 dB
3M E-A-R Push-Ins (SNR 38)	34 dB
Typical ear plug of this type	**31 dB**

High-attenuation earmuffs



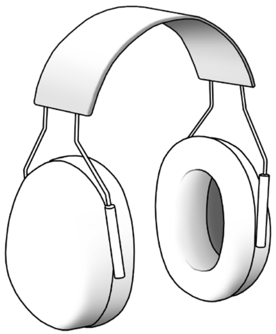
	Estimated attenuation
Mpow (SNR 34)	30 dB
3M Peltor Optime III/105 (SNR 35)	31 dB
3M Peltor X-Series X5 (SNR 37)	33 dB
Fnova 34 dB (NRR 34)	33 dB
Pro For Sho (NRR 34)	33 dB
Typical earmuffs of this type	**33 dB**

Banded ear plugs



	Estimated attenuation
Moldex 6700 Jazz-Band 2 (SNR 23)	19 dB
Howard Leight QB2HYG (SNR 24)	20 dB
Howard Leight QB1HYG (SNR 26)	22 dB
3M E-A-R Reflex, foam tips (SNR 26)	22 dB
Radians RB2120 RadBand 2 (NRR 25)	24 dB
Typical ear plugs of this type	**22 dB**

Low-attenuation earmuffs



	Estimated attenuation
Howard Leight Impact Sport (NRR 22)	21 dB
3M Peltor Optime I (SNR 26)	22 dB
Silverline 633815 (SNR 27)	23 dB
Neiko 53925A (NRR 26)	25 dB
Silverline 633816 (SNR 30)	26 dB
Typical earmuffs of this type	**23 dB**

Other protectors with known SNR or NRR

Hearing protectors with known SNR	Estimated attenuation = **SNR - 4**
Hearing protectors with known NRR	Estimated attenuation = **NRR - 1**

		Category A: Recreational noise expo				
		R1	**R2**	**R3**	**R4**	**R5**
Level	**Estimated sound level (dBA)**	**93**	**105**	**93**	**93**	**99**
Duration	**Years**	4	4	12	18	18
	Weeks per year	40	12	24	1	6
	Days per week	1	1	1	3	1
	Hours per day	5	3	4	10	3
	Total hours	800	144	1152	540	324
	Hours / 2080	0.385	0.069	0.554	0.260	0.156
Hearing protection	**Estimated attenuation (dB)**				18	18
	Proportion of time worn (0 to 1)				0.25	0.5
Units of noise exposure		0.767	2.189	1.105	0.389	0.628

		Category B: Occupational and educa				
		O&E1	**O&E2**	**O&E3**	**O&E4**	**O&E5**
Level	**Estimated sound level (dBA)**	99	87			
Duration	**Years**	4	4			
	Weeks per year	10	10			
	Days per week	5	5			
	Hours per day	4	2			
	Total hours	800	400	0	0	0
	Hours / 2080	0.385	0.192	0.000	0.000	0.000
Hearing protection	**Estimated attenuation (dB)**					
	Proportion of time worn (0 to 1)					
Units of noise exposure		3.055	0.096	0.000	0.000	0.000

	Category C: Firearm noise exposure				
	F1	**F2**	**F3**	**F4**	**F5**
Low calibre (.22 or .17) rifle?	☐ FALSE	☑ TRUE	☐ FALSE	☐ FALSE	☐ FALSE
Total number of rounds	100	100			
Units of noise exposure	0.200	0.006	0.000	0.000	0.000

Recreational units:	6.080
Occupational and educational units:	3.151
Firearm units:	0.206
TOTAL UNITS OF NOISE EXPOSURE:	9.438

The example data above may
prevent accidental editing dur

However, we advise NESI use

For example, some users may
must be added to generate th
cases, so that alternate units c

osure

R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
105	**88**								
8	18								
8	52								
1	5								
1.5	0.5								
96	2340	0	0	0	0	0	0	0	0
0.046	1.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28									
0.8									
0.292	0.710	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

ational noise exposure

O&E6	O&E7	O&E8	O&E9	O&E10	O&E11	O&E12	O&E13	O&E14	O&E15
0	0	0	0	0	0	0	0	0	0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

be removed and replaced with data from NESI respondents. (By default, cells required for data entry are
ring data entry.)

rs to consider carefully whether they require an alternative structure for the storage and analysis of NI

wish to generate alternative units of noise exposure (e.g. energy of exposure >90 dBA, or total duration
ese units, conditional upon the sound level of each exposure. Storage of all respondents' data in a single
of noise exposure may be generated for all respondents at once.

R16	**R17**	**R18**	**R19**	**R20**
0	0	0	0	0
0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000

O&E16	**O&E17**	**O&E18**	**O&E19**	**O&E20**
0	0	0	0	0
0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000

F16	**F17**	**F18**	**F19**	**F20**
☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE	☐ FALSE
0.000	0.000	0.000	0.000	0.000

editable, but the remainder are locked, to

ESI data.

of exposure >100 dBA). In these cases, formulae
data structure would also be preferable in these

NESI Supplementary Material:
Adoption of the Speech Communication Table (SM4)

Source Version of the Speech Communication Table

The basis for the NESI Speech Communication Table is the version reported by Lutman et al. (2008), which has been lightly modified to suit the needs of the NESI (modifications are described below). Ferguson et al. (2018) have since reported evaluation data for a version closely resembling that of Lutman and colleagues, though it specifies six levels of vocal effort, rather than seven, and differs at the highest level of vocal effort. (For Lutman and colleagues, “shouting close to the listener’s ear” corresponds to “>110 dBA”, whereas for Ferguson and colleagues, “>110 dBA” corresponds to the level at which communication “close to the listener’s ear” is “impossible”.)

Modifications to the Speech Communication Table

The layout and wording have been altered, so that the expression of communication distance is more straightforward (expressed in words, rather than the use of multiple columns). Dotted lines emphasise the divisions.

Vocal effort is now expressed using verb-adverb phrases (e.g. “talk loudly”), rather than adjective-noun phrases (e.g. “loud voice”), which allows easier expression of the vocal-effort options by the interviewer.

The description of the communication scenario has been altered so that only the listener is free of hearing impairment, not the talker. (The talker in the scenario is the NESI respondent, who might be hearing-impaired, whereas the listener is a *hypothetical* listener with normal hearing.)

The very highest level of vocal effort (shouting into the listener’s ear) is now ascribed a sound level of 110 dBA, not >110 dBA as in Lutman et al. (2008). This slightly more conservative estimate more closely resembles that of Ferguson et al. (2018), but was chosen largely for pragmatic reasons. Since exposures at sound levels >110 dBA are rare (Berger et al., 2015), we consider some imprecision in these estimates acceptable.

Evaluation of the Speech Communication Table

Ferguson and colleagues conducted a large-scale evaluation of their version of the Speech Communication Table, using personal dosimetry measurements from 168 employees in 15 workplaces. A summary of results is given in the main NESI paper (see section on Evaluation).

References

Berger, E.H., Neitzel, R., & Kladden, C. (2015). Noise Navigator™ sound level database with over 1700 measurement values (version 1.8). Available at: https://multimedia.3m.com/mws/media/888553O/noise-navigator-sound-level-hearing-protection-database.pdf (accessed 30 April 2018)

Ferguson, M. A., Tomlinson, K. B., Davis, A. C., & Lutman, M. E. (2018). A simple method to estimate noise levels in the workplace based on self-reported speech communication effort in noise. *Submitted for publication*.

Lutman, M.E., Davis, A.C., & Ferguson, M.A. (2008). *Epidemiological evidence for the effectiveness of the noise at work regulations*. Research report, No. RR669. Sudbury, UK: Health and Safety Executive.

NESI Supplementary Material: Estimating Attenuation of Hearing Protection Devices (SM5)

Various types of hearing protection devices (HPDs) are available, differing widely in the attenuation they offer. Those with low-to-moderate attenuation do not guarantee residual sound levels <80 dBA in the ear canal when worn in high-noise environments. Hence, the type of HPD worn by the respondent should be taken into account when quantifying noise exposure.

Since attenuation ratings reported by HPD manufacturers are publicly available, we have sought to derive attenuation estimates from these values. Consequently, attenuation should be easily estimated for protectors reported by future NESI respondents. The table below outlines the basic characteristics of two widely used attenuation ratings and the means by which they are converted into NESI “estimated attenuation”.

	Single Number Rating (SNR)	**Noise Reduction Rating (NRR)**
Region of use	The European Union	The United States and elsewhere
Defining standard	ISO 4869-2:1994	ANSI S3.19-1974
Basis for determining the attenuation rating	Mean and standard deviation of real-ear attenuation at threshold, measured for devices fitted by non-expert users	Mean and standard deviation of real-ear attenuation at threshold, measured for devices fitted by expert users
Simplified explanation of the rating calculation	Mean attenuation minus 0.84 standard deviations (i.e. the attenuation achieved by ~80% of users)	Mean attenuation minus two standard deviations (i.e. the attenuation achieved by ~98% of users) minus a 3 dB safety factor
Conversion to NESI “estimated attenuation”	Estimated attenuation = SNR – 4 dB	Estimated attenuation = NRR + 3 dB – 4 dB = NRR – 1 dB

Both conversions above involve subtraction of a 4 dB “derating” value, to account for real-world factors that reduce that reduce the attenuation of HPDs, as recommended by the UK Health and Safety Executive (Brueck, 2009).

The conversion from NRR also involves re-addition of the 3 dB “safety factor” already incorporated in the NRR, to bring the estimate closer in line with that obtained from the SNR. This approach may still be expected to yield a more conservative estimate of attenuation than the SNR, since it reflects the attenuation likely to be achieved by 98% of users, c.f. 80% for the SNR. However, the NRR measurement employs expert rather than naïve users, potentially ameliorating this disparity. In practice, we find that the estimates derived from SNR and NRR seldom differ by more than a few dB. Each is likely sufficiently accurate for the purposes of the NESI, since noise exposure incurred with HPDs contributed relatively little to the overall sound energy of pilot NESI respondents.

References

Brueck, L. (2009). *Real world use and performance of hearing protection*. Research Report RR720. Sudbury, UK: Health and Safety Executive.

NESI Supplementary Material: Quantifying Firearm Noise Exposure (SM6)

To account for the greater auditory hazard posed by impulsive sound, NESI has adopted the kurtosis-corrected noise metric of Goley et al. (2011):

$L'_{Aeq} = L_{Aeq} + 4.02 * \log_{10} (\beta / \beta_G)$

where L'_{Aeq} is kurtosis-corrected A-weighted equivalent continuous level, L_{Aeq} is uncorrected A-weighted equivalent continuous level, 4.02 is a constant derived from dose-response data in chinchillas, β is the kurtosis statistic of the noise, and β_G is the kurtosis statistic for Gaussian noise ($\beta_G = 3$).

For impulses whose acoustic energy expressed as A-weighted equivalent continuous *8-hour* level (L_{Aeq8hr}), the equation becomes:

$L'_{Aeq8hr} = L_{Aeq8hr} + 4.02 * \log_{10} (\beta / \beta_G)$

Incorporation of firearm noise into the NESI can therefore be achieved by combining L_{Aeq8hr} and β for firearm impulses measured at the shooter's ear. Flamme et al. (2009) and Meinke et al. (2014) have reported these data for a wide variety of firearms. Due to a markedly bimodal distribution of L_{Aeq8hr}, we have elected to dichotomize these weapons into low-calibre (.22 and .17) rifles and all other hand-held firearms (excepting air guns). A single kurtosis correction factor has been applied to both categories, since this factor was found to differ little between firearms:

	Low-calibre (.22 and .17) rifles	**Other hand-held firearms (except air guns)**
Energy of a round, expressed as L_{Aeq8hr}	Mean = **66.7 dBA**, SD = 2.5, n = 5 (Meinke et al., 2014)	Mean = **81.8 dBA**, SD = 3.5, n = 21 (Meinke et al., 2014)
Kurtosis statistic	Median = 78.5, range = 20 to 220, n = 10 (Flamme et al., 2009)	
Kurtosis correction factor	Kurtosis correction factor = $4.02 * \log_{10} (\beta / \beta_G)$ For the firearms reported by Flamme et al. (2009), mean kurtosis correction factor = **5.4 dBA** (SD = 1.2)	
Kurtosis-corrected A-weighted equivalent continuous 8-hour level (L'_{Aeq8hr})	L'_{Aeq8hr} $= L_{Aeq8hr} + 4.02 * \log_{10} (\beta / \beta_G)$ = 66.7 + 5.4 = **72.1 dBA**	L'_{Aeq8hr} $= L_{Aeq8hr} + 4.02 * \log_{10} (\beta / \beta_G)$ = 81.8 + 5.4 = **87.2 dBA**
Conversion to NESI units of noise exposure	NESI units of noise exposure $= 10^{(\text{level} - 90)/10}$ x hours / 2080 $= 10^{(72.1 - 90)/10}$ x 8 / 2080 = 0.000062 ≈ **1 / 16000**	NESI units of noise exposure $= 10^{(\text{level} - 90)/10}$ x hours / 2080 $= 10^{(87.2 - 90)/10}$ x 8 / 2080 = 0.002213 ≈ **1 / 500**

Note that correcting for kurtosis in the above calculations involves adding 5.4 dB to the equivalent continuous level. Interestingly, Murphy and Kardous (2012) remark that "for occupational noise exposures with impulsive content, the rule of thumb is to add 5 dB to the continuous dose estimate to compensate for the increased risk" – an adjustment similar to that obtained via Goley and Kim's kurtosis statistic.

Exceptions

We recommend that exposures incurred while wearing hearing protection be disregarded, due to their very low sound energy. Assuming protector attenuation of 30 dB, exposure to ~500000 such rounds would be required to accrue a single NESI noise unit.

Exposures to air rifles should also be disregarded, since all rifles tested by Lankford et al. (2016) were associated with a shooter-ear L_{Aeq8hr} below 54 dBA, yielding less than a billionth of a NESI noise unit.

Exposure to impulse noise from sources other than hand-held firearms (e.g. artillery and blast noise) is beyond the scope of the NESI.

Potential Limitations and Alternative Methods

It is important to note that our energy-based metric represents a single approach to the quantification of firearm noise exposure, which may not agree with other measures of auditory hazard. For example, in UK law, the threshold beyond which employers must provide hearing protection is a peak level of 135 dBC ***or*** a daily average level of 80 dBA (Health and Safety Executive, 2005). A low-powered Remington 514 rifle produces a peak sound level of 139.6 dBA, but its energy, expressed as L_{Aeq8hr}, is only 63.8 dBA (Meinke et al., 2014). Even after adding a 5.4 dB correction for kurtosis, as in the NESI, 12 rounds could be fired from the Remington before the corrected L_{Aeq8hr} exceeded 80 dBA. Hence, it is plausible that our energy-based approach might under-weight firearm noise. At present, all that can be confidently stated is that energy-based metrics of impulsive noise are increasingly advocated as a basis for firearm-noise damage risk criteria (e.g. Murphy and Kardous, 2012), and that correcting energy-based metrics of impulsive noise for kurtosis improves their ability to predict noise-induced auditory damage (e.g. Zhao et al., 2010). In short, kurtosis-corrected energy appears a plausible metric, but would surely benefit from further evaluation.

Future NESI users may wish to distinguish between different types of hand-held firearm when quantifying exposure, rather than accepting the dichotomous categorisation used here. Such users should obtain the equivalent continuous level of a round fired from the weapon in question, as measured at the shooter’s ear. They may then combine it with the 5.4 dB kurtosis correction factor and convert into NESI units of noise exposure, as demonstrated in the above calculations.

Another potential limitation is our exclusion of exposures incurred while wearing hearing protection. If HPDs worn during firearm exposure provide substantially less than 30 dB of attenuation, then such exposures might make a meaningful contribution to lifetime noise exposure. If users wish to incorporate these exposures into the NESI, they may obtain an estimate of the attenuation provided by the equipment and use it to modify the equivalent continuous level, before combining this value with the kurtosis correction factor and converting to NESI units of noise exposure.

References

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