Predicting impact of loud incidents on individual hearing for public health policy in the framework of EVOTION

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Summary

Exposure to excessive sound pressure levels may result in temporary or permanent deterioration of hearing. Avoiding situations where inordinate noise levels are apparent, increases the protection of the hearing system from damage. The monitoring of sound and noise exposure allows to recognize the circumstances under which potentially harmful sound levels may occur. With the EVOTION platform (www.h2020evotion.eu) recognition of loud sound incidents will be monitored in patients with hearing loss during usage of the hearing aids. Depending on the outcomes of the evaluation of such episodes, appropriate preventive actions should be taken, e.g. informing users about environment conditions or activities that may be a source of harmful exposure to noise.

Sharing the sound/noise exposure data with health care professionals allows to counsel the user about their hearing habits. Moreover, combining the sound exposure data from many users enables public authorities to investigate health policy actions for noise exposure.

During the first stage of the EVOTION project, a demonstrator program was developed, which relied on sound exposure data measured at outside situations, combined with available static clinical data (i.e. audiograms). These data undergone pre-processing techniques so as to be encapsulated into data coming from a real-time recording performed by EVOTION hearing aids during a rock concert. The simulated pool of rock concert attendees with hearing loss problems was fed to a public health policy decision model.

1. Introduction

Hearing loss (HL) is the most frequent sensory deficit and one of the most prevalent chronic disease reported by the elderly. According to the World Health Organisation (WHO), it affects approximately one-third of people over the age of 65 and over 5% of the world's population [1]. In 2014, WHO estimated that in 2012 more than 360 million people had disabling HL, increased from 120 million in 1995, and 278 million in 2005. These figures do not take into account mild HL or unilateral HL. HL ranks as the 5th leading cause of Years Lived with Disability (YLD), a component of the Disability-Adjusted Life Year (DALY), used to measure the global burden of disease. This ranking is higher than diabetes and conditions causing visual impairment [2]. It is also a disease with increasing prevalence and, as the percentage of people suffering from HL will increase dramatically due to increasing exposure to workplace and social noise. In the UK, for example, the percentage of people suffering from HL is expected to exceed 20% of the overall population by 2031 [3].

Currently, the pre-eminent management strategy for HL is the provision of Hearing Aids (HA). Despite technological advancements, however, the currently available HA can only partially overcome the deficits associated with HL while the HA user is faced with several challenges [4].

One of the complication for HL patients is that they are vulnerable to deterioration of their hearing ability due to noise exposure.

Noise exposure is the main preventable cause of progression of hearing loss in the aging population. As WHO estimates, 10% of the world population is exposed to sound pressure levels that could potentially cause noise-induced hearing loss (NIHL). This is increasingly due to exposure to social noise (e.g., noise in leisure places, noise in transport) rather than exposure to occupational noise (i.e., work space noise). In about half of these people, there is a risk of sudden auditory damage (threshold shifts) that can be attributed to exposure to intense noise [5]. Hearing threshold shift is occasionally temporary in its initial stages and is manifested as Temporary Threshold Shift (TTS). TTS, however, may become permanent (Permanent Threshold Shift – PTS), due to repeated, chronic noise exposure and/or due to a single exposure to intense noise. This has been identified by since the early '60s [6], [7]) and confirmed by recent ones [8], [9].

Avoiding situations where inordinate noise levels are apparent, increases the protection of the hearing system from damage. With the EVOTION platform (www.h2020evotion.eu) recognition of loud sound incidents will be monitored during usage of the hearing aids to develop the public health policy (PHP).

1.2 Prognosis of PTS/TTS episodes

The monitoring of sound and noise exposure allows to recognize the circumstances under which potentially harmful sound levels may occur. Generally, exposure to excessive sound or noise might result in temporary or permanent deterioration of hearing.

One of the EVOTION platform objectives is the prognosis and prevention of NIHL in the HAs' users. It will be based on monitoring noise (sound) exposure and recognition sound pressure levels high enough to cause the permanent threshold shift (PTS) episodes and/or temporary threshold shift (TTS) episodes.

TTS and PTS episodes, named after the effect they have on hearing. TTS means that the threshold returns to the level it had right before the loud sound usually over 24 hours. However, even if the threshold shift is temporary it may still cause hearing problems, especially for repeated TTS episodes [10].

In the EVOTION platform these episodes are identified by noise/sound exposure levels high enough to cause temporary or permanent hearing changes.

The evidence required in a public health policy decision model (PHPDM) may rely on an existing, known computational models for population with normal or impaired hearing. For the PHPDM purpose, in the EVOTION platform two models were applied to detect PTS and TTS events.

For the recognition of PTS events the international standard ISO 1999 [11] was applied which is routinely used to estimate the risk of noise-induced hearing loss (NIHL). It provides a verified mathematical model for calculating permanent threshold shift (PTS) in adult populations following exposure to noise based on four parameters: age, gender, noise exposure level and duration of noise exposure in years. According to the aforesaid standard the lowest daily (16-hour) noise exposure level ($L_{EX,\,16h}$) that might cause NIHL is greater than 77 dBA.

For predicting TTS, it is possible to use a validated predictive computational model developed by Mills et al. [12], Melnick [13] or later by Czyzewski et al. [14] with improvement by Mazur and Voix [15].

In particular, according to the simplest model by Mills et al. [12], the temporary threshold shift resulting from exposure to a wideband noise can be calculated using following equation:

$$TTS = 17 \cdot \log\left[\frac{\left(10^{\frac{L_{Aeq,T}}{10}} + 10^{\frac{L_C}{10}}\right)}{10^{\frac{L_C}{10}}}\right] \cdot \left(1 - e^{\frac{t}{t_0}}\right) \qquad (1)$$

where $L_{Aeq,T}$ is the A-weighted equivalent-continuous sound pressure level, L_c is a critical level, i.e., the lowest noise level that will produce a TTS ≥ 5dB (L_C=78 dBA), t is time of exposure and t_o is the value of the time constant (t_o=2 h).

The aforementioned model of TTS was developed and validated in young subjects with normal hearing. For populations such as HA users with pre-existing sensorineural HL, a specific model has been proposed, that is hereby presented.

It has been shown that TTS produced by a given noise exposure decreases as a function of the degree of pre-existing hearing loss. Thus, the amount of TTS in HA users, could be predicted from the in-ear noise levels and the subject's hearing levels, by means of a mathematical model consisting of the Modified Power Law (MPL) of Humes and Jesteadt [16] combined with equations for predicting TTS in listeners with normal hearing published by Mills et al. [12].

According to Macrae [17] TTS (at a particular audiometric frequency (n) produced by noise) in HA users with sensorineural hearing impairment can be predicted form the equation:

$$TTS_{HL} = 10log\left\{\left[\left(10^{\frac{HL}{10}}\right)^{P} + \left(10^{\frac{TTS}{10}}\right)^{P} - 1\right]^{-\frac{1}{P}}\right\} - HL \quad (2)$$

where TTS_{HL} is the predicted temporary threshold shift in the impaired ear, HL is the initial hearing level of the impaired ear, TTS is the temporary threshold shift that would be produced by the noise exposure in normal subjects and P is a constant equal to 0.2.

Models are applied to the time series of recorded noise levels to predict the temporary threshold shift that it causes, and subsequently alert the individual if the current noise level may affect hearing. In first (initial) stage of EVOTION platform, the aforesaid models are used to determine the expected PTS/TTS episodes due to specific noise outside the ear canal of HA user. This will allow a more successful NIHL risk management, and eventually the HA adjustment.

In fact, this modelling could lead to two types of policies one for the individual and, if combined with location data, one on a societal level.

1.3 Decision criteria

- PTS/TTS episodes associated with high external sound levels require intervention for training in the usage of HA in a noisy environment.
- PTS episode is related to occurrence of sound exposure high enough to cause permanent threshold shift after long-term exposure.
- TTS episode is related to occurrence of sound exposure high enough to cause temporary threshold shift after short-term exposure (up to 16 hours of daily activity) and it is not unambiguous with occurrence of actual TTS in HA user.
- The PTS/TTS episodes associated with sound pressure levels at the tympanic membrane require an intervention action to verify the fit and usage of the HA.

Figure 1 presents the idea of PTS episode detection while Figure 2 shows how to find TTS episodes (for details see caption to figures).

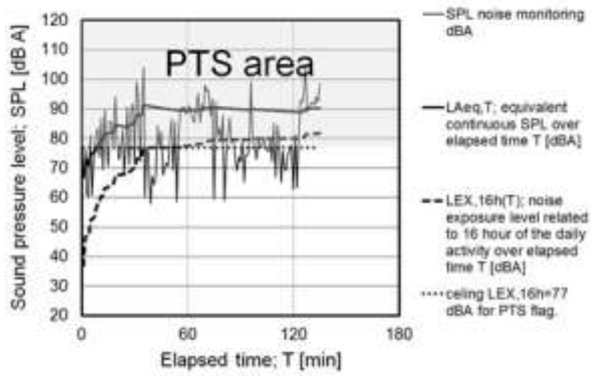

Figure 1. Recognitions of PTS episodes – warning appears when $L_{EX,16h}$(t) crosses the boundary of the PTS area marked witch DOTTED line. Lines mark the time history of: a) A-weighted sound pressure level (SPL) L_A(t) (THIN), b) A-weighted equivalent-continues SPL $L_{Aeq,T}$ since the beginning of using HA on a given day (THICK), and c) noise exposure level normalized to a nominal 16 hour daily activity (DASHED)

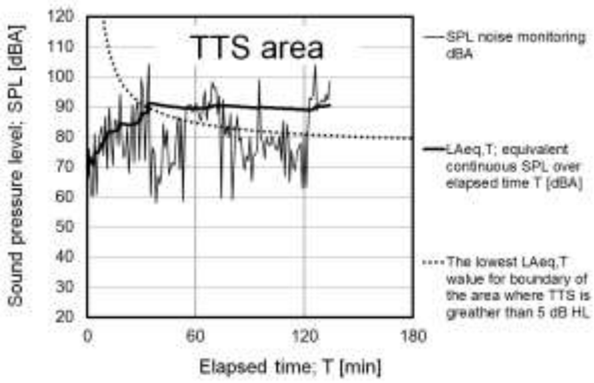

Figure 2. Recognitions of TTS episodes – warning appears when $L_{Aeq,T}$ achieves TTS area marked with DOTTED line. Lines mark the time history of: a) A-weighted sound pressure level (SPL) L_A(t) (THIN), b) A-weighted equivalent-continues SPL $L_{Aeq,T}$ since the beginning of using HA on a given day (THICK)

The monitoring of sound/noise exposure allows to recognize the circumstances under which potentially harmful sound levels may occur. With the EVOTION platform this is accomplished by determining potential PTS/TTS episodes during usage of the HA device.

There are three combinations of possible outcomes for predicting PTS / TTS episodes, i.e.:

- excessive SPL values outside the HA user's ear might cause PTS and TTS episodes
- high SPLs outside the HA user's ear are likely to cause TTS episodes
- low SPLs outside the HA user's ear are unlikely to cause any hearing changes.

1.4 Expected results

Proposed PTS and TTS predictive models enabled to improve self-control of sound exposure of HA users and will allow for early clinical intervention. The external noise might prove to be hazardous to the hearing condition of HA users to a greater extent than that of the general population. Assessing the public health impact of NIHL involves consideration of both its prevalence in a particular population, as well as the severity of impact of the condition on affected individuals and populations as a whole [18].

Depending on the outcomes of the evaluation of PTS / TTS episodes, appropriate preventive actions should be taken, e.g. informing the HA user about environment conditions or activities that may be a source of harmful exposure to noise. Sharing the sound exposure data with health care professionals allow them to counsel the user about their hearing habits, and finally combining the sound exposure data from many users enables public authorities to investigate health policy actions for noise exposure. In particular, it allows to:

- detect NIHL as early as possible.
- establish effects of daily noise type and duration on trend of NIHL developing in patients.
- recognise dangerous sources and situations during users' activities and application of restrictions/warnings to such places for avoidance of potential patients in the general population.
- register the effectiveness of interventions designed to reduce or prevent workplace injuries and illnesses due to occupational NIHL.
- register the effectiveness of the intervention

2. EVOTION demonstrator

During the first stage of EVOTION, demonstrators rely on sound exposure from pilot users combined with available static clinical data. Later in EVOTION this will be transformed into predicting the noise exposure and PTS/TTS episodes for individuals using the EVOTION platform.

The first stage of the project concerns only the environmental sounds/noise measured at outside situations. Over the next steps of the work, as well as sound/noise monitoring will also refine the modelling and improve the prediction of SPLs at ear drum. This will allow individualized prediction of PTS/TTS episodes due to the ambient sounds processed by the HA device.

In this demonstrator, the goal is to generate a PTS/TTS alert in the EVOTION platform, to undertake appropriate intervention actions related to the aforementioned events. For this purpose, static clinical data (i.e. audiograms) from NIOSH Dataset SD-1001-2014-0, Prevalence of Hearing Loss in the United States by Industry, developed by NIOSH Occupational Hearing Loss Surveillance Project, Division of Surveillance, Hazard Evaluations and Field Studies, will be used. For more information, readers are referred to [19] to download the dataset frim the NIOSH website. The NIOSH dataset contains more than one million audiograms collected between 2000 and 2008 from individuals working in industries in US with higher occupational noise exposures than the general population [19].

3. Demonstration scenario

Let us assume that we want to check the possibility of TTS episodes for attendees with HL at a rock concert placed in the middle of the auditorium. Let us also assume that one is interested in finding out on whether such an event has an effect on the PTS/TTS episodes on the users of HA.

In our case, the goal is prevention and decrease of PTS/TTS episodes with developed model for PTS and TTS prediction based on cumulative individuals' activities data.

The data are to be used are taken from the HA noise monitoring logger. The example presented below is relatively simple but it has to be pointed out that in real life more sophisticated and the daily time HA usage pattern might be the factor affecting the PTS/TTS episodes finding by model.

Since the static data taken from the NIOSH dataset are not available in the EVOTION dataspace, they need to undergo pre-processing to be in a format fitting the concept of EVOTION.

These are further processed, being encapsulated into data coming from a real-time recording performed by EVOTION HA during a rock concert. The goal of the aforementioned procedure is to create a simulated pool of rock concert attendees with HL problems to evaluate the performance of the PTS/TTS episodes' model.

The static clinical data from the NIOSH dataset are split into positions at the venue (see Figure 3):

- front row group (quarter distance from the recording site)

- front group (half distance from the recording site)
- middle group (close to the recording site)
- rear group (double distance from the recording site)

The simulation assumes an outdoor venue and with public addresses and loudspeakers positioned at the front of the stage.

For individual static clinical data the modelling of the HA amplification is half gain with compression that reduces amplification for loud sounds, that determine an outcome (TTS episodes in our case).

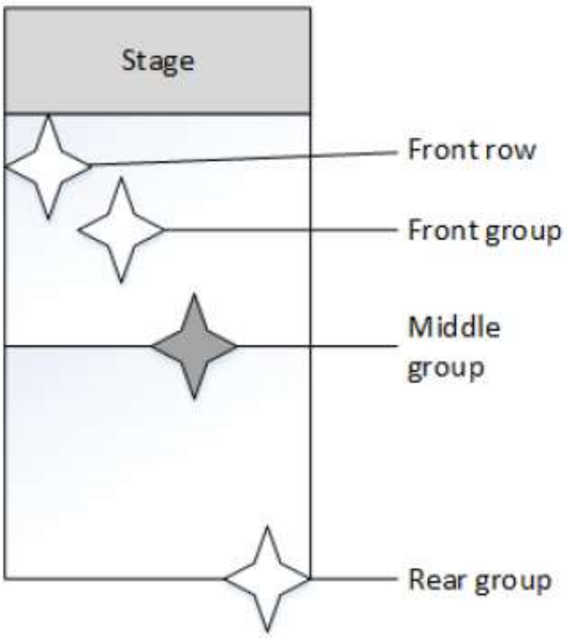

Figure 3: Concert venue

Simulating the TTSs for a large population of individual HLs from the NIOSH data set produces shown in Figure 4 and Figure 5.

The simulation output in Figure 4 shows the TTS for all the attendees as function of the HL. One overall trend is that the amount of TTS decreases as function of the HL – this is due to the output limiting of the amplification that ensures that loud sounds are not amplified as much as weak sounds. However, there seems to be a large variation in the TTS outcome for the Rear group, and in fact decreasing variation in TTS outcome as the positioning moves towards the stage.

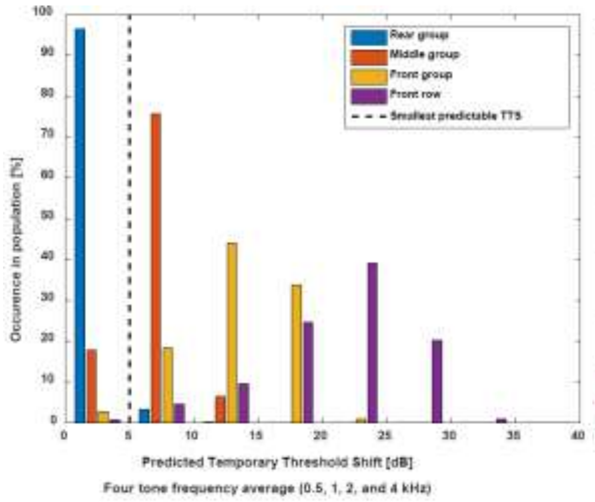

Figure 4. Normalized histogram for simulated TTS for the NIOSH dataset.

The normalized TTS histogram (Figure 4) shows the distribution of TTS as function of the position, which follows directly from the assumption that moving towards the sound source increases the sound level (holds for direct sound fields and do not hold for indoor sound). Moreover, the figure shows that seemingly large variation of the Rear Group TTS is in fact quite small as less than 5% of the Rear Group TTS values exceed 5 dB.

The results shown in Figure 4 indicate:

- that for all the attendees in the front half, the excess sound they are exposed to causes TTS
- that HL and modern HA amplification that do not amplify loud sounds are not causing excess TTS and HL
- any means of attenuating the sound limits the TTS and thus the impact on the individual hearing.

4. Concluding remarks

This report presents a first attempt at the development novel decision models informed by big data analytics to support decisions related to policy making in key HL treatment and management areas.

The models described in the current report specified the generic goal(s) underpinning the decisions to be made, the criteria to be used for making such decisions, the evidence required for applying those criteria and the big data analytics processes for producing it, along with the public health policy (PHP) actions to be followed. A specific scenario based on the Prognosis and Prevention of Noise Induced Hearing Loss model which had been used to demonstrate the potential of introducing such models in the public health policy domain.

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