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WORKER QUESTIONNAIRE FOR AFFORDABLE OCCUPATIONAL NOISE EXPOSURE EVALUATIONS

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Compliance with European laws on noise in the workplace implies costly efforts to measure and map out noise in industrial facilities. This is a potential roadblock for small and medium-sized enterprises. Using the competence of workers in recognizing the quality of their environment is suggested here as an efficient and cheap alternative. For demonstration purposes, we present the data from a noise measurement campaign in a Belgian food processing factory in parallel with the answers to a simple questionnaire submitted to the line operators. The individual daily noise exposure levels were estimated for every job in the factory, using over 200 noise readings that were taken throughout the facility. Some of the exposure levels were found to be near or above the legal threshold that triggers proactive hearing protection policies. In the questionnaire, workers had to estimate the quality of communication at 50 cm and at 5 m in the vicinity of various operating equipment. A four-level rating scale was used (normal voice, raised voice, shouting and impossible communication) and empirically linked to sound pressure levels. The levels estimated by the workers show a remarkable agreement with the measurements. Dangerous exposure levels are correctly identified. Still, Hearing Protection Devices (HPD) use is limited to individuals who are sensitive to noise (21% of the surveyed pool). As the questionnaire was filled in during individual consultations, workers experiencing noise-induced headaches could be convinced to wear HPD. This is a non-negligible secondary benefit of our approach.

1. Introduction

The European law that frames noise exposure for workers [1] defines two thresholds for action: the lower level corresponds to a 80 dB(A) daily exposure or a peak pressure of 135 dB(C) and the higher level to a 85 dB(A) daily exposure or a peak pressure of 137 dB(C). When the lower level is reached, Hearing Protection Devices (HPD) must be made available to workers; when the higher level is reached, the use of HPD is to be enforced. Daily exposures above 87 dB(A) or peak pressures above 140 dB(C) inside workers' ears (with HPD) are not acceptable. These dispositions were incorporated into Belgian law in 2006 [2]. Since then, employers are expected to maintain noise maps of their facilities and flag the dangerous zones where HPD must be worn. Noise level reductions on the premises can be obtained by limiting emissions at the sources. But engineering solutions are often costly and in practice, many industries focus on HPD as the only countermeasure to noise [3, 4, 5].

Accordingly, workers are informed about the possibility of hearing loss and given protecting equipment which they may choose to wear or not. Sadly, the consequences for not wearing the HPD are significant. Pelegrin et al. [6] for example reported on a group of construction workers experiencing high noise exposure and found that 94.1% of those who had never worn HPD had abnormalities

in their audiometric tests. The resistance to HPD amongst workers (see the low wear scores in Table 1) and the increasing prevalence of noise-induced hearing loss [3, 13] motivated a swarm of research into the factors that are instrumental to increase HPD use. The following are accepted to be the top three: understanding (internalization) of risk by the worker, HPD comfort, and safety culture at the company [7, 8, 9]. In other words, the employer can impact HPD use, through the dissemination of information, by providing adequate HPD and by cultivating a safety culture including potential sanctions if HPD are not worn. The participation of workers in devising noise reduction programs is foreseen as another positive reinforcement [10].

For a large number of Small and Medium Enterprises (SME), the first step of assessing noise levels is already above their financial means because of the required expertise and equipment. This is a definite hurdle in their efforts to comply with the law. The purpose of the present paper is therefore to propose an alternative approach which a company's Safety Adviser (SA) can implement at a minimal cost. The methodology is presented through the working example of a food company based in the Walloon Region in Belgium. Objective Sound Pressure Level (SPL) data is compared to the outputs of a questionnaire whose ambition is to let the factory workers estimate the noise level themselves. The general idea is to delay the call for proper expertise until questionable zones and machines have been reliably identified.

2. Materials and Methods

2.1 Factory and Context

There are ten production lines with 31 workers at the surveyed site and seven packaging lines with 11 workers. The factory lines (A, B…) are subdivided into tasks (A1, A2…). The workers are versatile, i.e. can adapt to multiple lines. An external noise survey was conducted in 2008. As a result, several production lines were determined to generate dangerous noise levels and wearing HPD became mandatory for the workers operating these lines. The present measurement campaign took place in the spring of 2015 and was conducted entirely by the company's SA, using supplied equipment and under guidance of the authors. The SA also prepared the questionnaires and collected the answers.

Table 1: Self-Reported HPD Use in the Literature.

Source	Numbers
Savage [3]	22.8% all the time, 67.8% intermittently
Morata et al. [4]	13% all the time, 51% intermittently
Azeres et al. [7]	Men 56.4%, Women 18.2% < 25 years old 86.2%, > 45 years old 40.1% Seniority < 10 years 66.0%, 20-30 years 42.1% Lowest education level 37.4%, highest education level 80.0%
Azeres et al. [8]	27 % all the time, 28% intermittently HPD are worn 18.6% of the exposure time if low risk perception, 70.8% if high risk perception
Bockstael et al. [9]	67 % across 4 companies, the lowest performance being 5%
Williams et al. [10]	18% Workplace A, 8% Workplace B
Hughson et al. [11]	48% all the time (59% if high risk perception), 42% intermittently
Lusk et al. [12]	18% to 46%

2.2 Noise Maps and Daily Exposures

Approximately 200 Sound Pressure Level (SPL) measurements were taken at locations spread over the factory hall to create a noise map. Measurements were scheduled when the targeted nearby machinery was in operation. The sound level meter was a SVANTEK 957 connected to a 0.5" microphone. Daily exposures were obtained from analysis of each individual job: a task list for a typical work day was drafted and the duration of each task was estimated; then, using the measured noise levels, the task contributions were straightforwardly summed up and yielded the daily exposures.

2.3 Questionnaires

Two questionnaires were submitted to the respondents. The forms were filled out through meetings with the SA and therefore were not anonymous. The sessions also served as individual consultations. The workers received feed-back on whether their estimation of noise levels was accurate. The risk of hearing loss was discussed and suggestions were offered on the circumstances during which wearing HPD was beneficial.

The first questionnaire (eight questions) covers demographic data (age, sex, seniority), attitude to noise-induced hearing loss (awareness, HPD use) and health impacts (tinnitus, headaches, need to raise TV volume or to ask others to repeat sentences). Difficulties in communication with others are commonly used to detect hearing damage. McCullagh [15] found that the question "do you have to strain to understand conversations?" was a top performer to that effect. Nondahl et al. [16] however showed that asking workers whether they felt they had a hearing loss offered the greatest correlation with audiometric exams.

The second questionnaire targets the perception of noise levels. This is done by judging the quality of face-to-face communication and communication to someone standing five meters away. For each task on their jobs, workers may choose from a four-level scale: 1) it is possible to talk normally; 2) they need to raise their voice; 3) they need to shout; 4) all communication is impossible. Each degree in the scale is then linked to a probable range of noise levels, with central values shown in Table 2. The "impossible to communicate" value is on par with the highest noise levels measured at the plant. The other three are taken from Beranek [12]. Beranek documents the speech interference levels for the following four scales: normal voice (71 dB(A) at 15 cm), raised voice (77 dB(A)), very loud (83 dB(A)) and shouting (89 dB(A)). We shifted this scale for a better match to the experimental data, which is not unreasonable in an industrial context where the understanding of what is a normal voice might be skewed. Popescu [12] also connects the need to shout with a noisy environment where HPD should be worn. With α_i the percentage of respondents that selected the i^{th} level for a task and Π_i the acoustic power assigned to that level, the acoustic power for the task Π_{task} is computed as in Eq. (1). The results from the near field and far field questionnaires are then averaged and converted to decibels.

$$\Pi_{task} = \sum_{i=1}^{4} \alpha_i \cdot \Pi_i \tag{1}$$

Table 2**:** Noise Level Subjective Evaluation Scale.

Worker Communication Assessment	SPL
Normal voice	77 dB(A)
Raised voice	83 dB(A)
Shouting	89 dB(A)
Impossible to communicate	100 dB(A)

3. Results

3.1 Noise Map and Daily Exposures

Inside the factory, noise levels range between 70 dB(A) and 110 dB(A). The problematic lines are visible in Fig. 1, which depicts the SPL at all locations where the workers perform their tasks. The calculated daily exposures are gathered in Table 3. These balance the task noise levels with their durations. For example, on Line A, the loudest tasks are also the shortest and the Kärcher (A3, with a defective pressure pump) ends up being the noise source that puts the worker in this job at risk. In the end, three jobs have noise exposures well above 85 dB(A). Enclosing the jet pump on Line F (F4) and repairing the Kärcher (A3) are obvious priorities for the company. Four jobs return exposure levels approaching the upper action limit of 85 dB(A): Line B, D1, D2/D3 and Line G. For these, dosimetry is recommended to determine whether wearing HPD shall be strongly encouraged or mandatory.

3.2 First Questionnaire

28 workers (11% women) answered the first questionnaire. 61% of participants have more than 10 years of seniority and only 5% of the workforce is younger than 30 (Table 4 (a) and (b)); strong habits are in place. According to Table 5, the rate of HPD use is dismal in comparison to other reported scores (Table 1). The reasons offered for not wearing HPD are mostly comfort and habit. One worker mentions the need to listen to his machine to detect operational issues. Headaches are the main reason for wearing the HPD. Only 7% of the workers have a preventive attitude and wear HPD by default. *All* workers declare being aware of the risks associated with noise exposure. Noise impacts at the end of the work day are tinnitus or headaches (25% of respondents), need to increase the volume of the TV or radio set (21%) and need to have sentences repeated (21%). Line C and Line E are mentioned as specific causes for headaches and tinnitus. The workers affected by these ailments are essentially the ones that declare using HPD systematically or after some time of exposure. They typically belong to the 30–40 age group and have 5–10 years of seniority. Another 4% of the respondents experience negative effects and yet seldom wear HPD.

Table 3: Peak Level and Daily Noise Exposures for all Lines.

Line	Peak Level (dB(C))	Daily Exposure (dB(A))	Daily Exposure from Questionnaires (dB(A))
Line A	104.0	**93.5**	94.4
Line B	125.0	85.2	91.4
Line C	117.9	**94.3**	92.3
D1	110.0	85.7	93.0
D2/3	99.0	84.2	80.7
E1	116.0	75.7	84.6
E2	116.0	80.7	90.1
E3	116.0	79.7	91.9
E4	98.0	75.7	87.8
Line F	113.0	**88.9**	90.0
Line G	108.3	84.6	86.7

3.3 Second Questionnaire

21 workers (10% women; 48% aged 40 and less) filled in the second questionnaire. Here, the purpose was to seek links between self-reported ability to communicate, actual noise levels and attitude to risk. Figure 1 shows the comparison between the measured SPL and the SPL that was derived from the questionnaire answers. 70% of the estimations are within 5 dB of measurements and 93% within 10 dB. The strongest deviations are reported for line E, where all worker sub-groups overestimate the noise (see Fig. 2). Their evaluations take into account a discontinued shrill that occurs during the line cleaning phase. Two explanations can be proposed for the fact that the SPL remains low in spite of it: a) this noise is intermittent and b) the SPL is not the proper indicator to reflect the annoyance created by a sharp high frequency peak. Regarding the second option, prominence indicators would be more apt at flagging the issue. These interpretations are backed up by the outstanding 116.0 dB(C) peak level measured by line E (see Table 3).

In Fig. 2, sub-group results are singled out for workers younger than 40 and older than 50. The age group below 40 yields consistently higher SPLs than the age group above 50. The younger workers have a more pronounced tendency to over-estimate the noise level. When considering the C line, which is flagged as one of the most distressing in terms of noise, the younger workers estimate the risk with a much greater precision. At C1, by the noise source, workers 50 and older are 10 dB off. Multiple other tasks see gaps of ~5 dB between younger and older workers.

Using the noise levels obtained from the questionnaires, the daily exposures (doses) are re-calculated and compared to the values previously obtained from measurements (see Table 3). With two exceptions, the workers tend to slightly overestimate the doses. The largest gap is for Line E where the workers give an important weight to the high frequency source. Every job with a dose greater than 85 dB(A) is flagged as such by the workers.

Figure 3 shows the number of workers involved in each task that experience headaches or tinnitus and wear HPD. Health impacts and HPD use are found across all lines except Line G. We find no correlation between daily dose and declared health impacts. HPD use remains driven by personal sensitivity and risk awareness rather than by actual risk; e.g. 4 workers on the C line do not wear hearing protections despite the 94.3 dB(A) daily dose. Here the risk underestimation is clear on Fig. 2 (workers older than 50) and confirmed in counselling notes. We can put this in perspective with Savage [3] who writes that existing hearing loss influences noise perception and HPD use.

Table 4: Worker Demographics.

(a) Worker experience x (years) – 1st Questionnaire Participants

$x \leq 5$	7 %
$5 < x \leq 10$	32 %
$10 < x \leq 15$	43 %
$15 < x \leq 20$	18 %

(b) Ages y (years) – Production and Packaging Lines

$21 < y \leq 30$	5 %
$30 < y \leq 40$	33 %
$40 < y \leq 50$	40 %
$50 < y \leq 60$	21 %

Table 5: Self-Reported HPD Use – 1st Questionnaire Participants.

Frequency of HPD use	Respondents
Never	36 %
Rarely	43 %
Often	14 %
Always	7 %

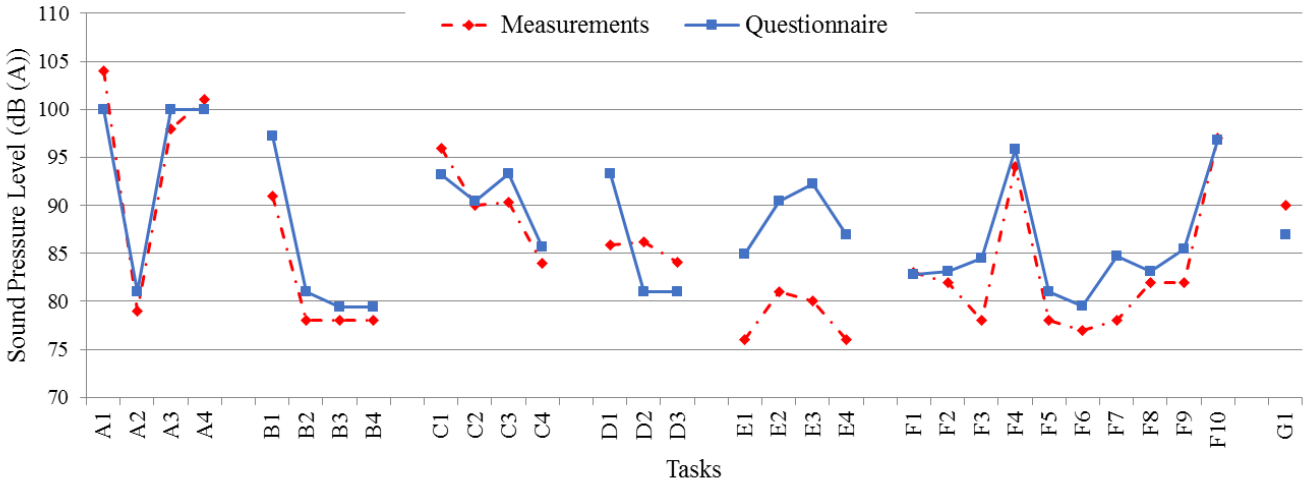

Figure 1: Measured SPL vs. Estimation from Questionnaire.

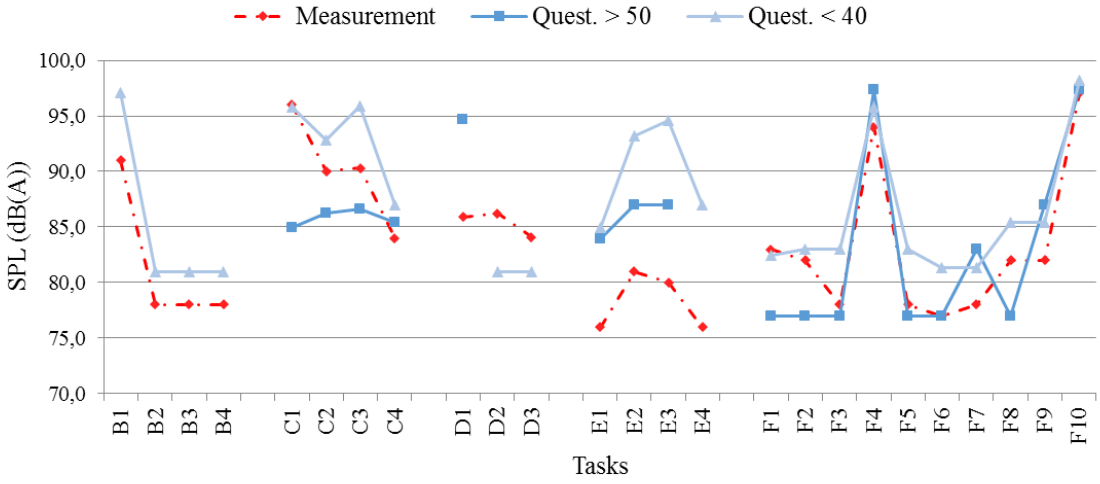

Figure 2: SPL Estimations by Sub-Groups of Workers.

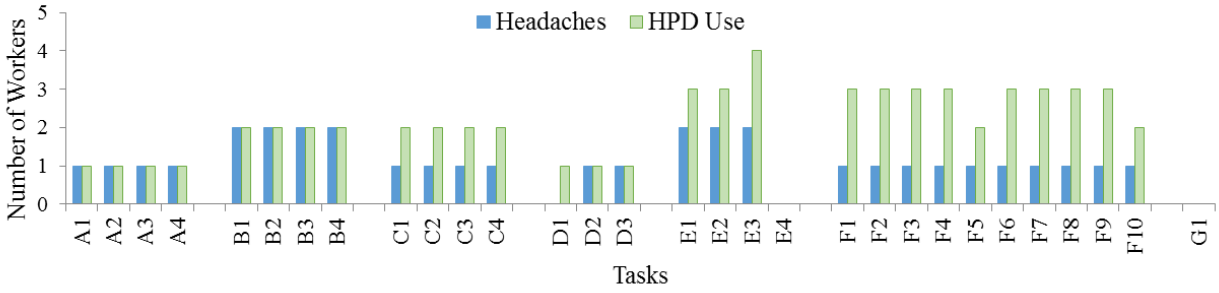

Figure 3: Self-Reported HPD Use and Health Effects.

4. Discussion

The results from the questionnaires are sufficient to determine where actual noise measurements are most urgently needed. If we abate all estimated doses in Table 3 by 5 dB, as we know workers might overestimate the results, the conclusion would be to conduct dosimetry readings on Jobs E4 and Line G. Line G is indeed a legitimate borderline case. The dosimetry results for E4 would then show that there is no issue there in legal terms and would lead to reconsidering the entire Line E. Without discussion, for Lines A, B, C, D1 and F, the HPD are required.

As we see, workers are reasonably competent to assess the noise level of their work environment. This good judgement is an asset that any SA can exploit to conduct a cheap preliminary assessment of noise levels in a factory. Moreover, through their experience, the workers effortlessly take into account interactions between production lines and realistic task conditions. It must be said however that the studied factory is obviously very noisy and therefore the study lacks counterexamples to identify as safe or above the first level of 80 dB(A). In our case the most compelling examples would be on Line E, but this line has a peculiar high-frequency issue which compromises the analysis. Moreover, the workers estimate all jobs to be above the lower limit of 80 dB(A) (Table 3), but does the bias apply uniformly to all noise levels or are the workers prejudiced towards describing their noise environment as noisy by default? This would be answered if workers were put in the situation of having to identify unequivocal exposure levels below 80 dB(A).

Unfortunately, the workers' correct noise estimations do not necessarily translate into a protection behavior. As Azares et al. comment, workers use HPD based on their perception of risk but are poor judges of the risk [7]. One operator of Line C for example refused to believe the noise readings by his workstation. The personal consultations still had a few positive impacts. One worker declaring headaches and a partial deafness was convinced to switch from never using HPD to permanent use (which terminated the headaches). Two more modified their HPD use from "rarely" to "often". On a pool of 21 workers, this brings overall HPD use from 24% to 38%, i.e. an increase of 14%. We note that the primary discussion arguments are noise level readings; the notion of daily exposure is hardly used.

From a sociological perspective, other factors might impact (positively or negatively) the acceptance and legacy of this noise study. One is the fact that it was conducted by the SA as an internal project rather than by calling for outside expertise. In 2008, when the first study conducted by an external firm concluded to mandatory HPD use, the follow through at the factory was limited. Here, the SA ordered high-grade molded HPD, set-up a schedule of regular HPD usage audits and planned communication on the findings. Other potential impacting factors are the quality of the personal relationship between the SA and the workers and the depth of involvement from the hierarchy.

5. Conclusion

The present study demonstrated how questionnaires on the ability to communicate in a work environment can be used to estimate noise levels and ultimately daily noise exposure. This is proposed as a hands-on and cheap alternative to an expert acoustic audit. The methodology relies solely on workers' experience. The input information is gathered through two-ways consultations where employees also receive feed-back on the risk of hearing loss and the benefits of wearing HPD. Hence, the noise study itself becomes an opportunity to influence HPD use amongst the workers.

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