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ACOUSTIC MEASUREMENTS AND EMPLOYEE FEEDBACK: ADDRESSING NOISE IN INDUSTRIAL WORK ENVIRONMENTS – A CASE STUDY.

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ABSTRACT

(introduction) This study aims to evaluate the impact of high noise levels in an industrial hall on workers' health, wellbeing and productivity, with a focus on room acoustic measurements and employee feedback. (method) Various room acoustic measurements were conducted within the production hall to assess reverberation time and sound levels. Additionally, a survey was distributed to 83 workers to collect qualitative data on their experiences with noise exposure and its effects on their work environment. (results) The measurements indicated reverberant noise levels (L_{eq}) reaching up to 92 dB(A), and performed dosimeter readings among employees showed noise levels (L_{ex}) between 85 and 89 dB(A), highlighting a challenging indoor acoustic environment. Survey results revealed that a significant number of workers found their workplace to be excessively noisy, negatively affecting their stress levels, wellbeing, productivity, concentration and communication. (conclusions) The findings suggest that implementing sound-absorbing materials, such as suspended acoustic ceilings, could reduce noise levels by 5 to 6 dB(A), thereby improving working conditions. This study underscores the importance of addressing noise in industrial settings to enhance worker wellbeing and productivity, indicating that effective acoustic treatments can lead to a healthier and more happier workplace.

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1. INTRODUCTION

Noise pollution in industrial work environments is a significant concern that can have far-reaching effects on employee health, wellbeing and productivity. In industrial settings, where machinery and equipment are primary noise sources, sound levels can easily exceed the World Health Organization's recommended level of sound exposure of 80 dB(A) for a maximum of 40 hours per week [1].

1.1 Noise exposure and its' impact on health and wellbeing

Short-term and long-term health effects have been associated with prolonged exposure to high levels of noise. Transient auditory fatigue and noise annoyance are short-term health effects of high noise levels (88 – 92 dB(A)) in factories, leading to substantial discomfort among workers [2]. Moreover, >85 dB(A) sound exposure during a working day dramatically raises the levels of the stress marker cortisol, and consequently fatigue and irritability [3]. Chronic noise exposure is associated with psychological symptoms such as anxiety and sleep disturbances. Workers in automotive industries reported increased stress and fatigue due to prolonged noise exposure [4-5]. Long-term health effects due to prolonged exposure to high-intensity noise is a leading cause of occupational hearing loss. According the WHO there is an increase in prevalence of all grades of hearing loss in Europe. In 2019 it was 197 million people and estimated that it will be 236 million in 2050 [1]. Studies in various industries, including automotive and textile manufacturing, have documented a high prevalence of Noise-Induced Hearing Loss (NIHL), often progressing to permanent sensorineural hearing loss if left unaddressed [6-7].

1.2 Impact on productivity and job satisfaction

Noise levels in production facilities has negative effect on human productivity which leads to decrease in organization productivity and decrease in quality and quantity of services and products [8]. Another study on press machine operators found that reducing reflected and direct sound levels improved both health outcomes and production quality [9]. Poor acoustic conditions can reduce job satisfaction and overall engagement. A study comparing two industries found that reducing noise levels led to greater environmental satisfaction and improved company attachment [5].

2. GENERAL INFORMATION ABOUT THE INDUSTRY HALL

The investigated industry hall is located near Antwerp in Belgium. The hall has different production lines used for the production of metal profiles, key activities include cutting metal sheets or coils into specific shapes, roll forming to shape the profiles, cutting to different sizes and punching to create holes or slots. The total production area covers 8000m^2 with an average ceiling height of 8,20m[1]. The hall has a concrete floor, brick and steel walls and the ceiling has an unperforated steel deck, see Fig. 1.

Figure 1. Production lines in the industry hall

3. ACOUSTIC PARAMETERS; METHODS, MEASUREMENTS RESULTS AND CALCULATIONS

Room acoustic measurements were conducted within the production hall to assess reverberation time (RT) and sound levels. Equivalent sound pressure levels (L_{Aeq}) were measured to determine the overall noise exposure. These measurements provide quantitative data on the noise environment to which workers are exposed. Dosimeter readings were also taken for some employees to assess personal noise exposure levels (L_{ex}), giving a more detailed understanding of individual noise exposure variations throughout the workday.

3.1 Acoustic measurements methods

Acoustic measurements are performed on Sept. 16th 2021 using a Class 1 calibrated sound level meter Norsonic type Nor140. The noise levels were measured in more than 150 points in the entire production hall. In all points, measurement durations of ca. 1 minute were appropriate since the noise field was sufficiently stable.

Figure 2. Employee with dosimeter

In total 6 workers were equipped with a noise dosimeter. This dosimeter measured the noise pressure level at about 10 cm distance from the ear, see Fig.2. The results of the measurement render a realistic representation of the daily noise exposure of each participant. According to the European and Belgian labour legislation this “daily dose” of noise exposure is the most important indicator for determining the risk of noise induced hearing damage [10]. Raw measurement results were elaborated such that a correct interpretation of the legislation is possible. For the calculations of the $L_{EX,8h,}$ the working conditions during the measurement period were evaluated as representative for the activities during the whole day.

3.2 Measurements results

The data obtained from acoustic measurements are analysed to determine compliance with regulatory limits and assess the potential risk to worker health, see Table 1.

Table 1. Legal limits according the 2003/10/EU directive.

Legal limits	Doses	
	$L_{EX,8H}$ dB(A)	L_{peak} dB(C)
No legal health risk	< 80	< 135
Exceedance of the lower action value	≥ 80	≥ 135
Exceedance of the upper action value	≥ 85	≥ 137
Exceedance of the limit value when not wearing hearing protection	≥ 87	≥ 140

Equivalent sound pressure levels (L_{Aeq}) were measured to determine the overall noise exposure, see Fig. 3. The active production lines are highlighted in white, and the most important operator positions are indicated by grey rectangles. Numerous areas exhibit noise exposure levels exceeding 85 dB(A), with operators frequently working in close proximity to the noisiest zones. The decay of sound levels is rather limited, indicating that noise from one production line can easily affect adjacent lines. Acoustic measurements conducted on June 22nd 2020, revealed L_{Aeq} levels reaching even up to 92 dB(A).

All operators equipped with a dosimeter exceed the upper legal limit values according the 2003/10/EU directive, see Table 2. There is a substantial risk of noise induced hearing loss when not wearing hearing protectors. Five out of six operators even exceeded the limit value of 87 dB(A) when not wearing hearing protectors. The Lpeak-values values are less critical in determining health risk and remain within the legal limits. For a more detailed description of the noise sources that are responsible for the measured $L_{EX,8H}$-values, of one of the participants see Fig.4. The graphs shows the measurement dB(A) levels per minute.

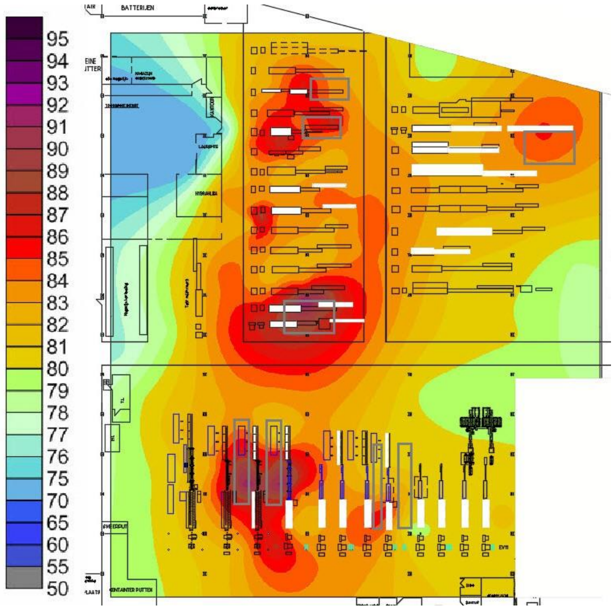

Figure 3. Noise map (L_{Aeq}) in dB(A)

Table 2. Measured dosimeter levels

Participant	Measurement duration (hr)	$L_{EX,8H}$ dB(A)	L_{peak} dB(C)
Operator 1.	5:25	87	131
Operator 2.	5:20	85	133
Operator 3.	5:25	88	127
Operator 4.	5:25	87	132
Operator 5.	5:19	89	132
Operator 6.	5:39	87	131

3.3 Acoustic modeling and calculations

To improve the indoor acoustic environment, it was recommended to add sound-absorbing materials. Given that the ceiling is the largest available surface, the impact of installing a highly sound-absorbing suspended ceiling was calculated. To predict the effect of the added sound-absorbing material on the ceiling, the production hall was modeled using Catt Acoustic / TUCT software. The reverberation time was measured at five locations and used to calibrate the model. During measurements, the signal-to-

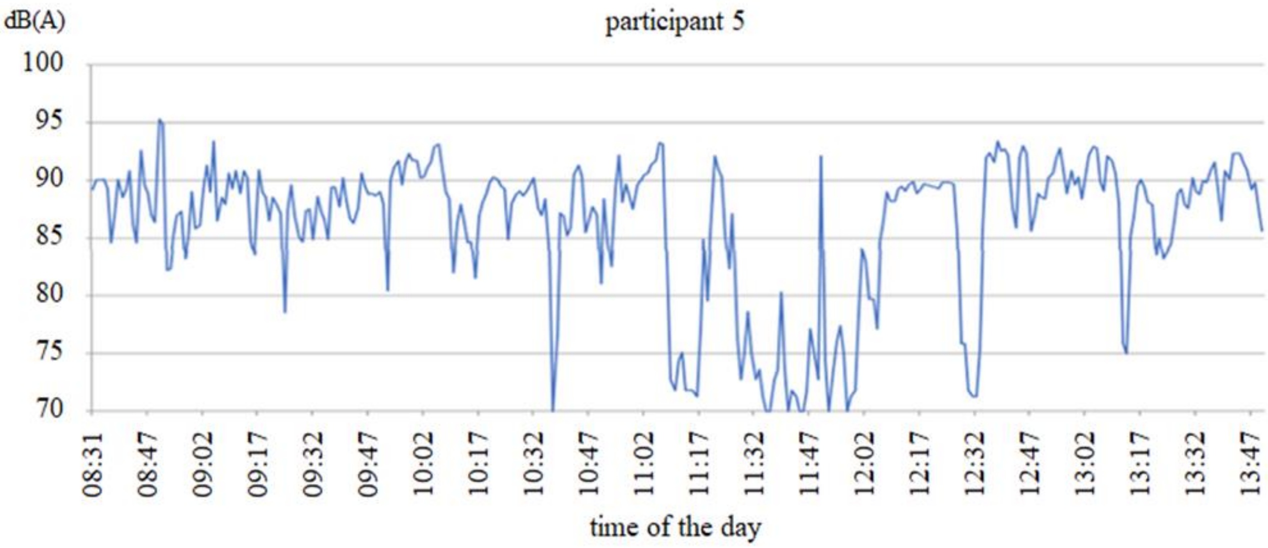

Figure 4. Dosimeter measurements per minute

noise ratio was often too weak in the 125 Hz octave band. The results of the reverberation time measurements are presented in Table 3. Room acoustic modelling shows that a Class A sound absorbing suspended ceiling will reduce the reverberant sound level by 5 to 6 dB(A).

Table 3. Measured reverberation times

Frequency	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Reverb. time (sec.)	2,7	2,3	2,6	2,4	1,9

4. QUESTIONNAIRE; METHODS AND RESULTS

A survey was distributed among the employees to collect qualitative data on their experiences with noise exposure and its effects on their work environment. The survey aimed to capture the subjective impact of noise on various aspects of their work, including stress levels, wellbeing, productivity, concentration and communication. This feedback provides valuable insights into how workers perceive and are affected by the noise environment.

4.1 Questionaire methods

Surveys were administered from March 8 to March 14, 2022, to collect subjective feedback from employees (n=83). Participants used tablets and were provided with information about the study, along with a link to the questionnaire facilitated by the online tool 'SurveyMonkey'. Table 4 presents the age distribution of the participants, while Table 5 details their tenure with the company.

Table 4. Age range of the participants

Age	Number of employees	
(years)	(n)	(%)
18 - 24	9	11
25 - 40	21	25
41 - 56	31	38
57 - 67	22	26
Total	83	100

Table 5. Tenure with the company of the participants

Years working	Number of employees	
(years)	(n)	(%)
< 1	17	21
1 - 5	11	13
6 - 10	7	8
11 - 20	4	5
> 20	44	53
Total	83	100

Table 6. Sound environment

	totally don't agree	don't agree	neutral	agree	totally agree
My workplace is too noisy	2%	6%	16%	56%	20%
I have to raise my voice to be able to talk to my colleagues	1%	2%	16%	51%	30%
I need a quiet work environment to perform my tasks well.	5%	15%	42%	30%	8%

Table 7. Health and wellbeing

	never	seldom	sometimes	often	always
I have headache after a working day	22%	19%	40%	11%	8%
I hear a 'beeb' in my ears	40%	11%	31%	5%	13%
I lose my voice because of shouting to my colleagues	45%	29%	17%	4%	5%
I get home exhausted after a working day	16%	16%	45%	13%	10%
I get stressed at work	19%	23%	40%	10%	8%

4.1 Questionaire results

From the participants of the survey 76% indicate (agree and totally agree) that their workplace it too noisy. Because of that, 81% indicates (agree and totally agree) that they have to raise their voices to be able to talk to their colleagues. See Table 6. Health and wellbeing related questions are shown in Table 7. One of the results that stands out is the questions about *"I hear a 'beeb'in my ear",* which is related to tinnitus. Tinnitus is characterized by the perception of sound without an external source, often described as ringing or beeping in the ears, and can be constant or intermittent [11]. In the survey, participants reported their experiences with hearing a beeping sound in their ears as shown in Table 7. Seldom beeping might not necessarily indicate tinnitus, as transient auditory perceptions can result from temporary factors such as exposure to loud noise, earwax buildup, or certain medications [12]. However, persistent or frequent beeping is more indicative of tinnitus, a condition that significantly impacts quality of life [13]. The prevalence of tinnitus varies, but it is commonly reported that at least 10% of the global population experiences tinnitus at some point in their lives [13-14]. With 18% of participants indicating to have a beebing sound (often and always), we can conclude a very high average of workers in the industry hall suffer from tinnitus.

Survey results revealed that a significant number of workers found their workplace to be excessively noisy, negatively affecting their stress levels, wellbeing, productivity and concentration. Fig. 5 shows the percentage answers 'often' and 'always'.

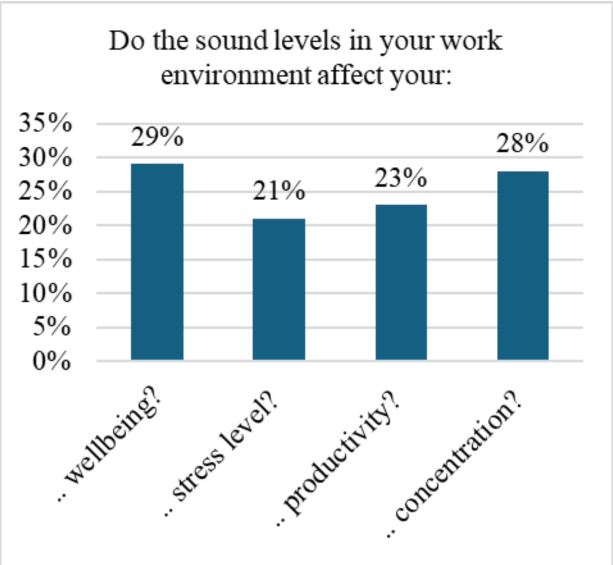

Figure 5. Subjective experience of sound levels

According to Directive 2003/10/EC [10], hearing protection must be worn when exposed to noise levels above 85 dB(A). When asking *'how often do you wear personal hearing protection'* only 20% replied with *'always'*, see Fig. 6. The stated reason is that some employees find hearing protection devices uncomfortable to wear for extended periods and some say they find it challenging to communicate with colleagues while wearing hearing protection, especially in areas where verbal communication is essential.

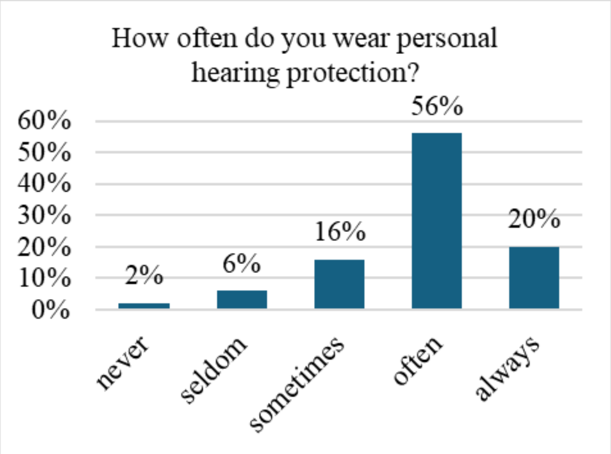

Figure 6. Personal hearing protection

5. CONCLUSION

This study evaluated the impact of high noise levels in an industrial hall, focusing on room acoustic measurements and employee feedback on their health, wellbeing and productivity. The measurements indicated noise levels (L_{eq}) reaching up to 92 dB(A), and dosimeter readings among employees showed noise levels (L_{ex}) between 85 and 89 dB(A), underscoring a challenging indoor acoustic environment. Survey results revealed that a significant number of workers found their workplace excessively noisy, negatively affecting their stress levels, wellbeing, productivity, concentration and communication. The findings suggest that implementing sound-absorbing materials, such as Class A sound absorbing suspended ceiling and wall panels, could reduce noise levels by 5 to 6 dB(A), thereby improving working conditions. This study emphasizes the importance of addressing noise in industrial settings to enhance worker wellbeing and productivity, indicating that effective acoustic treatments can lead to a healthier and more satisfying workplace. Future research should focus on long-term monitoring and the effectiveness of various acoustic interventions, specifically evaluating how the indoor acoustic environment is improved after installing the acoustic ceiling and wall panels, to ensure sustained improvements in industrial work environments.

6. ACKNOWLEDGMENTS

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