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Occupational noise exposure in natural stone processing plants

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Abstract

Occupational noise exposure is a serious physical risk factor leading to occupational diseases including hearing loss. In this study, occupational noise measurements taken at seven natural stone processing plants operating in Sivas, Turkey and its environs are evaluated in accordance with the task-based assessment method given in TS EN ISO 9612-2009 standard. Though the processes in natural stone processing plants are similar, significant differences were observed in the noise levels, which are often above the limits specified in the relevant regulation. The highest noise levels to which workers were exposed are S/T, bridge cutting, sizing/honing, head/side cutting machines while the lowest noise levels were from narrow polishing machine and gang saw machines. In plants B, F and G the S/T block cutting machines, in plants B and D the head/side cutting machines, in plants C and E the sizing/honing machines and in plant D the bridged cutting and narrow polishing machines exposed workers to noise levels above the lowest exposure action value of 80 dBA. The bridge cutting machine in plant D exposed the workers to noise levels above the highest exposure action value of 85 dBA. High noise emitting machines were proposed to be isolated in separate compartments.

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1. Introduction

Noise or unwanted noise is one of the most common pollutants that penetrate many aspects of our lives. People exposed to noise in and/or outside the workplace are adversely affected by both their health and work efficiency [1, 2].

Research has shown that hearing loss is one of the most common physical risk factors in the United States after high blood pressure and joint disorders. It is also reported that around 22 million workers (17%) are threatened with hazardous noise levels (> 85 dBA) in this country, and 19% of those exposed to noise have hearing impairment. Hammer *et al* stated that in the US, workers under the threat of hearing loss mostly work in the mining, construction and manufacturing sectors [3]. As far as the mining industry is concerned, noise levels are higher than other sectors. Therefore, noise exposure and noise-related hearing loss are common in workers in this sector [4-7]. When the occupational disease statistics between 2015 and 2019 are examined in Turkey, the ratio of the insured male and female workers who had occupational diseases due to noise exposure varied between 1.1% to 6.6% and 0% to 7.5% of the total number of occupational diseases, respectively [8].

Following the extraction and processing stages, natural stones are used in various fields such as construction, coating, flooring, sculpture, tombstone construction, stone chips, porcelain, glass/optical industry and ornaments. The world's richest deposits of natural stone found in the Alpine zone is located in Turkey with a total estimated reserve of 5.2 billion cubic meters (13.9 billion tons). This corresponds to approximately 33% of world's total reserves [9, 10]. With its 335 million m^3 natural stone reserves, Sivas has approximately 6.5% of the total reserve in Turkey. Furthermore, travertine, which is by far the most produced natural stone in the region, has a share of 18% in Turkey's potential [11, 12]. In 2019, Turkey's natural stone exports amounted to 1.86 billion USD, accounting for about 43% of national total mineral exports [13].

Natural stone industry seeks the maximum use of labor and technology in both quarries and processing plants. Thus, due to the high number of machinery and equipment used in this sector, safety measures to be taken have also increased [14].

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Natural stone extraction and processing is based on intensive manpower in Turkey and there are many quarries and processing plants scattered throughout the country. A typical operation starts with transportation of natural stone blocks with various physical, textural and mechanical properties to the plant. Large blocks of uniform dimensions are cut into slabs using multi-wire cutters, which comprise diamond wires that can cut the block in a vertical direction. Similarly, irregular blocks are cut into strips with block cutters that are equipped with a large diameter diamond saw blade to cut blocks in a vertical direction. Strips are further processed to reduce the product into desired dimensions. Following the main cutting and size reduction operations, natural stone slabs or tiles are treated in various processes to remove cutting marks and to give an appearance suitable for the intended use. These include polishing, honing, ageing, sanding and bush hammering. All these processes are carried out simultaneously in a space-restricted environment where workers indoors can be exposed to high levels of noise [15].

Studies in natural stone processing plants revealed that noise emission by equipment may pose a risk in terms of safety and health of employees [16-22]. Fişne noted that noise exposure can cause significant physiological reactions on employees such as increased blood pressure, acceleration in heart rate and respiration, low cerebrospinal fluid pressure, sudden reflexes and headache [23]. Kumari *et al* conducted hearing tests on employees in 30 marble factories in Rajasthan, India. 20% of the employees had mild hearing loss, 16.67% had moderate hearing loss, 36.67% had moderate and severe hearing loss and 26.66% had severe hearing loss [24]. Rutilo *et al* investigated workers' noise exposure in two marble quarries in Brazil where noise levels varied between 95.0 dBA and 103.3 dBA [16]. In the study where the main sources of noise were identified as marble cutting and polishing machines, it was suggested that workers use personal protective equipment. In a natural stone processing plant, Arıtan and Tümer recorded a noise emission level of 86.9 dBA during the operation of the diamond wire cutting machine stating that given the noise level, health of employees would be at risk and the possibility of occupational diseases may increase by prolonged exposure to loud noise [19].

Noise Measurement Strategy TS proposes three different measurement strategies for the determination of noise in workplaces [25]. These are

Task-based noise measurement: This is the noise measurement method used in cases where the work performed in shifts is analyzed and divided into sub-tasks, the duration of each task can be determined precisely, a small amount of change is observed in the sound level (stable noise) and many workers do similar work in the same noise environment. In this method, each measurement time must be long enough to represent the average equivalent continuous sound pressure level for the actual task. Each task requires three measurements each at least five minutes. If the task takes less than five minutes, the duration of the measurement shall be equal to the duty time. For longer tasks, the duration of each measurement should be at least five minutes. However, if the noise level is determined to be constant or reproducible or if the noise in the task is considered to be a minor contribution to total noise exposure, the duration of each measurement can be reduced [25-27].

Job-based noise measurement: When it is difficult to allocate tasks to a specific job or if the duration of the tasks varies greatly then this noise measurement method is applicable. In this method, homogeneous noise exposure groups are determined per job title, duties, working areas or occupations of the employees. Employees in the group consist of people who do the same job and are expected to be exposed to similar noise during one working day. A random sound pressure level is measured from the group and is considered to represent the entire group [25-27].

Full-time noise measurement: This method is used in cases where detailed job analysis is difficult to perform or when it is difficult or it cannot be determined to define the work done and working time or noise exposure of the employees is complex and cannot be estimated. In this method, sound pressure level is continuously measured during full working days [25-27]. Choice of the measurement strategy usually depends on a number of factors such as type of work, complexity of the work situation, number of employees, duration of work and the appropriate time for measurement and analysis. Noise measurement strategies are given in Table 1 [25].

Table 1. Basic measurement strategy selection [25]

Type or order of work	1. Strategy Task-based measurement	2. Strategy Job-based measurement	3. Strategy Full-day measurement
Stationary place - Simple or single task	☺*	-	-
Stationary workplace - Complex or multitasking	☺*	☺	☺
Employee on Wheels - Predictable work-few tasks	☺*	☺	☺
Employee on Wheels - Predictable work-multiple tasks or complex work order	☺	☺	☺*
Employee on Wheels - Unpredictable work order	-	☺	☺*
Fixed or roaming employee - Multiple tasks with indefinite duty duration	-	☺*	☺
Fixed or roaming employee - Multiple tasks with indefinite duty duration	-	☺*	☺

☺ Strategy can be used.
* Recommended strategy

2. Materials and Methods

In this study, noise exposure of workers in natural stone processing plants has been evaluated in accordance with the task-based measurement method of TS EN ISO 9612-2009 standard. Field measurements were carried out using a high-precision sound level meter capable of ⅓ octave real-time frequency analysis. The instrument is suitable for all noise measurements stated in the Regulation of "Assessment and Management of Environmental Noise" issued by the Ministry of Environment and Urbanization of Turkey (Figure 1). The sound level meter was calibrated with an acoustic calibrator before and after each measurement round.

Article 5 of the Regulation on the "Protection of Employees from Noise-Related Risks" has specified three threshold levels for 8-hour time-weighted average noise level ($L_{EX,\ 8h}$) for a worker's noise exposure; the lowest exposure action value of 80 dBA, the highest exposure action value of 85 dBA and the exposure limit value of 87 dBA [28]. Hereafter, these threshold values will be called as EAV_L, EAV_H and ELV, respectively.

Noise measurements were taken from seven natural stone processing plants operating in Sivas and its environs. Measurements were taken when the personnel were wearing personal protective equipment in the form of earplugs, corded earplugs and to a lesser degree helmet mounted earmuffs. In accordance with the agreements made with the management of natural stone processing plants, the company names are coded from A to G throughout the text in order to avoid any misunderstanding. Each plant operated some or all of the machinery given in Table 2.

Figure 1. Sound level meter [29]

Table 2. Distribution of noise generating machines

Machine name	Representative image	Quantity
Gang saw Used for cutting natural stone blocks into plates of certain thickness.		Plant A → 1 Plant B → 1 Plant C → 1 Plant D → 1 Plant E → 1 Total 5
Bridge cutting machine Used for cutting natural stone plates to appropriate sizes.		Plant A → 1 Plant B → 1 Plant C → 1 Plant D → 1 Total 4
S/T machine Used for cutting natural stone blocks to a certain thickness.		Plant A → 1 Plant B → 1 Plant C → 1 Plant D → 1 Plant E → 1 Plant F → 1 Plant G → 1 Total 7
Head/side cutting machine Used for cutting and straightening the ends of natural stone plates.		Plant A → 1 Plant B → 1 Plant C → 1 Plant D → 1 Plant F → 1 Plant G → 1 Total 6
Sizing/honing machine Used to cut natural stone plates with proper precision and to remove surface roughness.	 	Plant A → 1 Plant B → 1 Plant C → 1 Plant E → 1 Plant G → 1 Total 5
Narrow polishing machine Used for grinding and polishing natural stone plates of certain sizes (30 cm - 45 cm).		Plant A → 1 Plant B → 1 Plant C → 1 Plant D → 1 Plant G → 1 Total 5

3. Results and Discussion

Noise exposure of workers in natural stone processing plants were recorded and evaluated in accordance with TS EN ISO 9612-2009 standard. It should be noted that the following machines in all natural stone processing plants were evaluated individually: gang saw, bridge cutting machine, S/T machine, head cutting machine, side cutting machine, sizing/honing machine and narrow polishing machine. Thus, the sound pressure level recorded by the noise level meter reflected the noise emission of a specific machine at a particular moment on which other machinery were accepted not in operation. Table 3 summarizes the continuous sound level in dBA equivalent to the total sound energy measured over the sampling period ($L_{p,A,eqT,m}$), daily noise exposure for a nominal 8-hour working day ($L_{EX,8h,m}$), noise level ($L_{EP,?h}$) equivalent for a specific working time (h, hours) based on equations 1 and 2 and time to reach EAV_L, EAV_H and ELV for a specific L_{Aeq} [25]. For Plant A with an equivalent continuous sound pressure of 88.8 dBA, a worker would reach the lowest exposure action value of 80 dBA, the highest exposure action value of 85 dBA and the exposure limit value of 87 dBA after working 66 minutes, 198 minutes and 318 minutes on the gang saw, respectively.

$$L_{P,A,eqT,m} = 10 \cdot \log\left(\frac{1}{I}\sum_{i=1}^{I} 10^{0.1 \cdot L_{P,A,eq,T,mi}}\right) \text{dB} \quad (1)$$

$$L_{EX,8h,m} = L_{P,A,eqT,m} + 10 \cdot \log\left(\frac{\bar{T}_m}{T_0}\right) \text{dB} \quad (2)$$

Where

$L_{p,A,eqT,mi}$: the A-weighted equivalent continuous sound pressure level during a task of duration *Tm*
$L_{EX,8h,m}$: the noise contribution from task m to the daily A-weighted noise exposure level
i : the number of task sample m
$\bar{T}_m$: the arithmetic average duration of task m
I : the total number of task samples m
To : the reference duration, T_0 = 8 h.

Table 3. Calculated noise parameters in natural stone processing plants

Machine	Plant code	L_{Aeq} (dBA)	$L_{EX,8h}$ (dBA)	$L_{EP,6h}$ (dBA)	$L_{EP,4h}$ (dBA)	$L_{EP,2h}$ (dBA)	$L_{EP,0.5h}$ (dBA)	Working time EAV_L (min)	EAV_H (min)	ELV (min)
Gang saw	A	88.8	88.5	87.6	85.8	82.8	76.8	66	198	318
	B	88.6	88.3	87.4	85.6	82.6	76.6	66	210	330
	C	94.7	94.4	93.5	91.7	88.7	82.7	16	51	84
	D	89.3	89.0	88.1	86.3	83.3	77.3	57	180	282
	E	84.5	84.2	83.3	81.5	78.5	72.5	174	540	846
Bridge cutting machine	A	92.8	92.5	91.6	89.8	86.8	80.8	25	84	126
	B	95.9	95.6	94.7	92.9	89.9	83.9	13	39	60
	C	87.8	87.5	86.6	84.8	81.8	75.8	80	252	402
	D	103.5	103.2	102.3	100.5	97.5	91.5	-	-	11
S/T machine	A	96.1	95.8	94.9	93.1	90.1	84.1	12	37	59
	B	101.1	100.8	99.9	98.1	95.1	89.1	-	12	19
	C	98.8	98.5	97.6	95.8	92.8	86.8	6	20	32
	D	96.8	96.5	95.6	93.8	90.8	84.8	10	32	51
	E	94.6	94.3	93.4	91.6	88.6	82.6	17	54	84
	F	100.0	99.7	98.8	97.0	94.0	88.0	-	16	24
	G	98.5	98.2	97.3	95.5	92.5	86.5	-	22	34
Head/side cutting machine	A	96.7	96.4	95.5	93.7	90.7	84.7	10	32	52
	B	99.3	99.0	98.1	96.3	93.3	87.3	-	18	28
	C	93.3	93.0	92.1	90.3	87.3	81.3	22	70	113
	D	99.9	99.6	98.7	96.9	93.9	87.9	-	16	25
	F	91.7	91.4	90.5	88.7	85.7	79.7	32	102	162
	G	95.3	95.0	94.1	92.3	89.3	83.3	14	45	72
Sizing/honing machine	A	93.6	93.3	92.4	90.6	87.6	81.6	21	66	105
	B	95.9	95.6	94.7	92.9	89.9	83.9	12	39	61
	C	100.3	100.0	99.1	97.3	94.3	88.3	-	14	22
	E	100.1	99.8	98.9	97.1	94.1	88.1	-	15	23
	G	93.0	92.7	91.8	90.0	87.0	81.0	24	76	120
Narrow polishing machine	A	89.1	88.8	87.9	86.1	83.1	77.1	59	186	294
	B	94.9	94.6	93.7	91.9	88.9	82.9	16	49	78
	C	86.5	86.2	85.3	83.5	80.5	74.5	108	336	540
	D	97.2	96.9	96.0	94.2	91.2	85.2	-	29	46
	G	92.7	92.4	91.5	89.7	86.7	80.7	26	82	129

Among the gang saw machines, the equivalent noise level (L_{Aeq}) varied between 84.5 dBA in Plant E and 94.7 dBA in Plant C, averaging 94.0 dBA. This result is consistent with the literature where Çınar and Şensöğüt measured 87.51 dBA in the sheet machine [17]. Considering the legal limitations, daily noise exposure of workers in all plants except Plant E is higher than EAV_H and ELV. If the situation is examined from another perspective, the following conclusions are reached. The workers operating the machines in Plants A, B, C, D and E reach the EAV_L after 66, 66, 16, 57 and 174 minutes of work, respectively. Similarly, Plants A, B, C and D reach the ELV before the end of a typical shift while Plant E remains in the lowest exposure action zone. The daily equivalent noise exposures of the workers on the gang saw machines among processing plants calculated using Equation 1 and 2 are given in Figure 2.

Among the bridge cutting machines the equivalent noise level (L_{Aeq}) varied between 87.8 dBA in Plant C and 103.5 dBA in Plant D, averaging 102.90 dBA. A difference of 15.7 dBA reveals the fact that the highest equivalent sound pressure recorded on bridge cutting machines was 6.1 times the lowest one. When the limits specified in the relevant Regulation are taken into account, the daily equivalent noise exposure of employees working on bridge cutting machines exceeds the EAV_H and ELV before the end of the shift. The workers operating the machines in Plants A, B and C reach the EAV_L after 25, 13 and 80 minutes of work, respectively. However, the machine in Plant D immediately exposes its operator to the EAV_L, EAV_H and ELV after two, ten and eleven minutes, respectively.

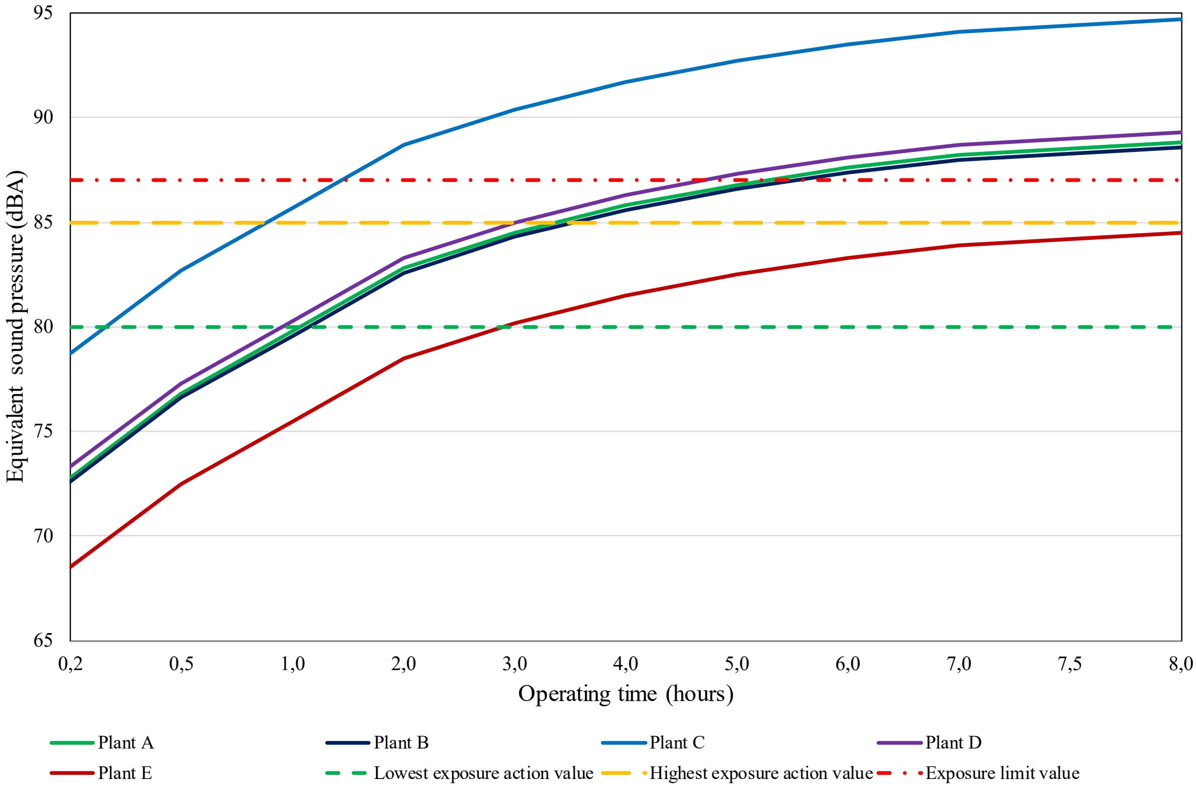

Figure 2. Time-dependent equivalent noise exposure of workers on gang saw machines

The noisiest machines in natural stone processing plants are S/T machines. The equivalent noise level (LAeq) varied between 94.6 dBA in Plant E and 101.1 dBA in Plant B, averaging 100.29 dBA. Measurement results are compatible with previous studies where Lindawati *et al* recorded a noise level of 94 dBA and 96 dBA when the S/T machine was idle at a marble factory in South Aceh, Indonesia [22]. A difference of 6.5 dBA gives a 2.1 times higher sound pressure level between the highest and the lowest equivalent sound pressure. The daily equivalent noise exposure of employees working on S/T machines exceeds the ELV before the end of the shift. The workers operating the machines in Plants A through G reach the ELV after 59, 19, 32, 51, 84, 24 and 34 minutes of work, respectively.

The difference between the equivalent noise level (L_{Aeq}) measured on the head/side cutting machines is 8.2 dBA. The processing plant of the highest noise level is Plant D with 99.9 dBA and that of the lowest noise level is Plant F with 91.7 dBA, averaging 99.22 dBA. A similar result supporting this study was reported by Engin *et al* on the head/side cutting machine with 90 dBA when in operation and 82 dBA when idle [21]. The $L_{EX,8h}$ calculated on head/side cutting machines in all natural stone processing plants exceeded the EAV_L and EAV_H as well as the ELV specified in the relevant regulation. The workers operating the machines in Plants A, B, C, D, F and G reach the ELV after 52, 28, 113, 25, 162 and 72 minutes of work, respectively.

The equivalent noise level (L_{Aeq}) measured in sizing/honing machines ranged between 93.0 dBA at Plant G and 100.3 dBA at Plant C, averaging 99.81 dBA. The 7.3 dBA difference between the lowest and highest measured values corresponds to a 2.3-fold ratio between equivalent pressure levels. In a similar study, Çınar and Şensöğüt presented the noise level of a sizing machine in a marble processing plant as 96.74 dBA [17]. The $L_{EX,8h}$ calculated on sizing/honing machines in all natural stone processing plants exceeded the EAV_L and EAV_H as well as the ELV specified in the relevant regulation. The workers operating the machines in Plants A, B, C, E and G reach the ELV after 105, 61, 22, 23 and 120 minutes of work, respectively.

The difference between equivalent noise levels (L_{Aeq}) measured in narrow polishing machines in natural stone processing plants is 10.7 dBA corresponding to a 3.4-fold ratio between the lowest equivalent pressure level of 86.5 dBA at Plant C and the highest equivalent pressure level of 97.2 dBA at Plant D, averaging 96.50 dBA. The workers operating the machines in Plants A, B, C and G reach the EAV_L after 59, 16, 108 and 26 minutes of work, respectively. Similarly, Plants A, B, D and G reach the ELV before the end of a typical shift while Plant C remains in the highest exposure action zone.

When the evaluations are made on the plant basis, the following conclusions are reached when the daily equivalent noise exposure is regarded. At Plant A, the highest noise exposure is caused by the head/side cutting machine with 96.4 dBA and the lowest exposure by the gang saw with 88.5 dBA, giving a 2.48-fold ratio in terms of sound pressure. Time-dependent equivalent noise exposure of workers in Plant A is depicted in Figure 3. At Plant B, the highest noise is emitted by the S/T machine with 100.8 dBA while the lowest by the gang saw with 88.3 dBA, giving a 4.22-fold ratio in terms of sound pressure. At Plant C, the sizing/honing machine was the noisiest unit with 100.0 dBA while the narrow polishing machine was the quietest with a daily equivalent sound pressure level of 86.2 dBA. These values correspond to a 4.90-fold difference in terms of daily equivalent sound pressure. At Plant D, the highest noise level was sourced from the bridge cutting machine with 103.2 dBA and the lowest noise level from the gang saw with 89.0 dBA, giving a 5.13-fold ratio in terms of sound pressure. At Plant E, the sizing/honing machine was the noisiest unit with 99.8 dBA while the gang saw was the quietest with a daily equivalent sound pressure level of 84.5 dBA, corresponding to a 5.82-fold difference in terms of daily equivalent sound pressure. At Plant F, the highest noise sourced from the S/T machine with 99.7 dBA while the lowest by the head/side cutting machine with 91.4 dBA, giving a 2.60-fold ratio in terms of sound pressure. At Plant G, the S/T machine was the noisiest unit with 98.2 dBA while the narrow polishing machine was the quietest with a daily equivalent sound pressure level of 92.4 dBA, corresponding to a 1.95-fold difference in terms of daily equivalent sound pressure.

Among the seven natural stone processing plants where the noise exposure measurements were taken the S/T machine, the sizing/honing machine, the bridge cutting machine and the head/side cutting machine had the highest noise level at three, two, one and one plant, respectively. On the other hand the gang saw, the narrow polishing machine and the head/side cutting machine had the lowest noise level at four, two and one plant, respectively. According to these results, the S/T machine has the highest noise level and the gang saw has the lowest noise level.

4. Conclusions

Within the scope of this study, a total of 96 noise measurements were taken on six different machine groups encompassing gang saw, bridge cutting, S/T, head/side cutting, sizing/honing and narrow polishing machines in seven natural stone processing plants in Sivas, Turkey. Measurements were evaluated in accordance with task-based measurement method given in TS EN ISO 9612 (2009) "Acoustic-Occupational Noise Exposure Determination-Engineering Method" standard.

Evaluation of the measurements indicated a large difference between the noise levels produced by the same type of machines operated in different processing plants. The machines with the highest noise level are bridge cutting, S/T, sizing/honing and head/side cutting machines. Compared to these machinery, narrow polishing machines and gang saws produce less noise. In this context, the maximum daily equivalent noise level ($L_{EX,8h}$) is generated by the bridge cutting machine at 103.2 dBA operating in Plant D while the minimum level by the gang saw at 84.2 dBA in Plant E.

Considering daily equivalent noise levels, noise generated by all natural stone processing machines is above the minimum and maximum exposure action values and exposure limit values specified in the relevant Regulation. Therefore, workers must be protected against hearing-related occupational diseases with appropriate measures including but not limited to isolating high-noise emitting machines in separate compartments, placing barriers between the noise source and employees, maintaining stone-processing machinery, operating noisy machines during shifts when fewer people are exposed, shortening the shift and finally, using hearing protectors suitable for high-frequency noise.

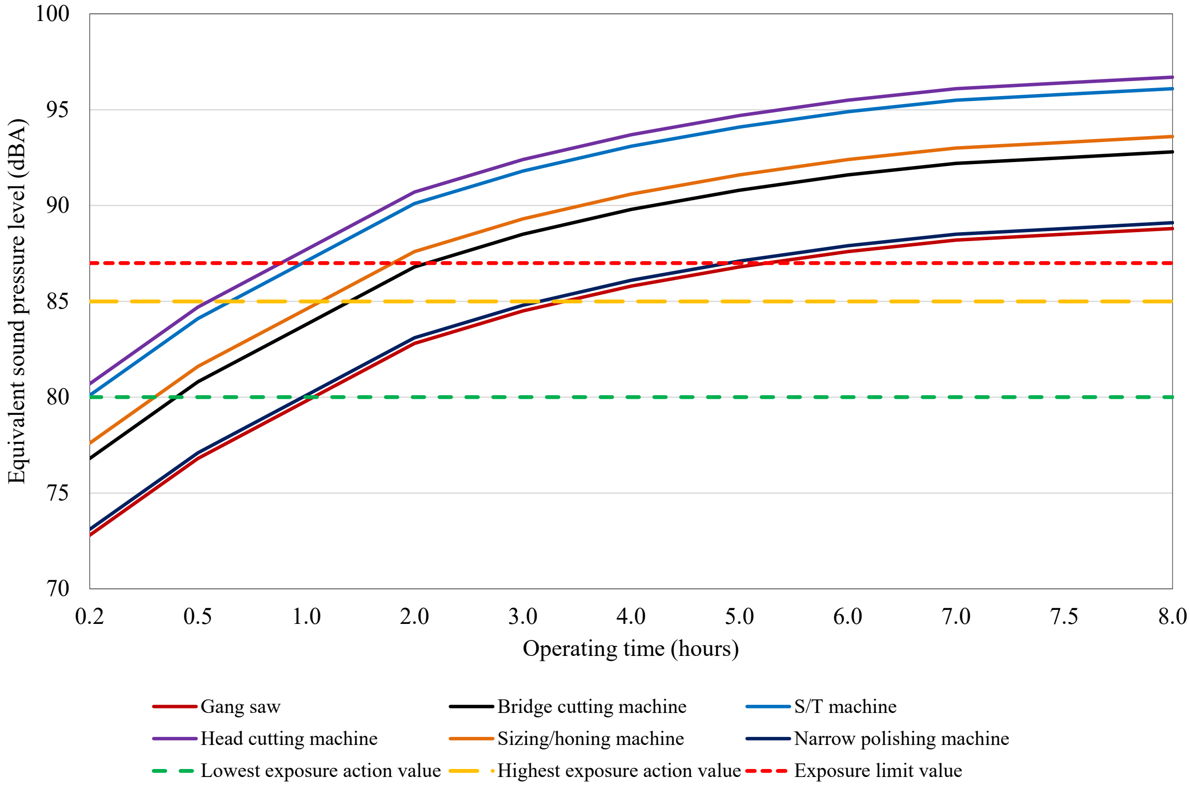

Figure 3. Time-dependent equivalent noise exposure of workers in Plant A

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Conflicts of interest

The authors have stated that they have no conflicts of interest.

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