Can noise cause high blood pressure? Occupational risk in paper industry

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Abstract

Objectives. The authors hypothesize cardiovascular effects in paper industry workers exposed to noise.

Materials and Methods. The study included 72 paper industry workers exposed to noise and two control groups not exposed to noise. The workers completed a questionnaire and underwent a medical examination, measurement of blood pressure, electrocardiogram, blood tests, audiometry and measurement of noise exposure.

Results. The workers exposed to noise, all hearing impaired, were compared with not exposed and showed: significant increase of mean systolic and diastolic blood pressure values (p <0.001), higher frequency of hypertension, systolic and diastolic blood pressure (p <0.01 and p <0.001) and electrocardiographic abnormalities (p <0.05), significant reduction of blood pressure response in orthostatism (p <0.005).

Conclusion. Our results suggest that for the workers of the paper industry noise is an occupational risk factor for cardiovascular effects.

Key words: coronary artery disease, hypertension, noise, workers

Introduction

Noise pollution is an alarming problem because of its gradual spread not only in the workplace but also in residential areas and inside buildings and because of the large number of people.

Until a few years ago, hypoauscoasia had a great incidence among occupational diseases, together with musculoskeletal diseases, it still remains, in Italy, one of the most reported diseases (1).

An extensive literature (1-4) shows the effects of noise on the health of both general population and outdoor workers. It’s well known that exposure to levels of noise causes hearing loss, affects safety in the workplace, causes accidents (3-6) and can have effects on other systems (7-9). The importance of the problem and the consequences for workers are multiple and still being studied.

The extra-auditory effects of noise are often difficult to quantify (10-15). Chronic exposure to noise can alter cognitive performance (16, 17) giving rise to a series of disorders such as sleep and repose disturbance, interference on verbal communication and learning, psycho-physiological problems as well as discomfort or annoyance (18).

Noise seems to have some effects even on gastrointestinal system (19), the respiratory system (20), the immune system (21), the endocrine system (22), the reproductive system (23) and the neurogenic system (24).

Effects on the cardiovascular system have been studied by several authors (4, 24-27), many studies have found that exposure to noise can cause changes in peripheral vascular resistance (28), in heart rate (29, 30), blood pressure (BP) (24, 31, 32) and in the urinary concentration of catecholamines (33). We have often investigated the effects of urban noise associated with other urban pollutants (metals, etc.) that could damage the cardiovascular system (34, 35).

The results of a number of studies suggest possible cardiovascular effects in workers exposed to noise (28, 36-37). We have recently investigated the relationship between noise exposure and blood pressure in rotogravure industry (38), in bedframe industry (39) and in agriculture (40); the results suggest that the noise has a role in the genesis of the changes of blood pressure.

Considering of the foregoing, the relationship between exposure to noise and cardiovascular effects represents a field of great importance (24).

Aim of this study was to evaluate the relationship between exposure to industrial noise and hypertension. The industrial area we selected is the paper industry. The paper and the paperboard production has a great importance in society because of its wide use not only in the field of communication (newspapers, books) and packaging (cartons, corrugated cardboard boxes, etc...), but also for household, sanitary and industrial use (paper filter).

In particular, we examined whether workers of the paper industry, exposed to levels of noise of varying intensity, show a higher prevalence of cardiovascular effects compared to
bank employees or people who work in a completely automated cycle (both are not exposed to noise).

Materials and Methods

Population and setting

We studied 167 male subjects, employees of a large paper industry, occupationally exposed to noise working in the production of household paper (toilet paper, napkins, paper towels, etc.). The employees rotate in the different departments: paper machines, construction, power plant, cellulose loading, unloading and storage of raw materials, finished goods inventory, shipment.

As a control group we studied 123 workers with the same socio-demographic characteristics, employees of a similar fully automated company sector, and 74 bank employees with a different socio-economic status not exposed to noise.

Questionnaire

All groups of workers completed, a clinical-anamnestic questionnaire in the presence of a physician with items aimed at characterizing the job and the exposure with the following purposes:

- the exclusion of confounding factors for audiological risk: use of ototoxic drugs, acoustic trauma, exposure to blast bombs, mines, use of firearms, previous ear infections, severe head trauma. All the workers with these features were excluded from the study.
- the exclusion of cardiovascular risk factors: familiarity for cardiovascular diseases, regular physical activity, alcohol consumption (a drinker is someone who drinks more than 0.5 L of alcohol/die) smoking habit (41) (defines a smoker someone who has smoked at least 100 cigarettes in a lifetime and currently smokes everyday or almost everyday) and exposure to solvents agents (42, 43).
- socio-demographic characteristics: lifestyle, qualification, health education, nutrition, spare time activities.

The questionnaire items were also investigating in order to exclude from the study, employees working on shift work and/or night work, which may give additional work-related stress and cardiovascular risk factors (44-46).

Blood tests and other clinical measures

All the workers underwent medical examination with body mass index (BMI) evaluation; workers with a BMI >30 (mean or high degree of obesity) were excluded. The blood pressure was measured in supine. The workers were asked to be fasting for 10 hours, at rest for at least 15 minutes and to refrain from smoking for at least 15 minutes before the medical examination, in order to avoid situations that could cause artificial variations of blood pressure and of other parameters.

A mercury sphygmomanometer was used to measure the blood pressure. In the morning from 8 to 10 o’clock avoiding postural variations three measures of blood pressure were taken: the first after five minutes from supine position, the second one three minutes after the first one and the third three minutes after the second one.

To evaluate the change in pressure due to postural changes, the blood pressure was taken 1 minute, and again 5 minutes, after assuming the upright position, in accordance with the European Society of Hypertension (ESH) guidelines and of the European Society of Cardiology (ESC) guidelines (47).

Considering the mean of the three measures, we calculated the rates of basal hypertensive subjects according to ESC/ESH 2007 classification, simplifying and defining as “hypertensive” the subjects with a systolic blood pressure (SBP) >140 mmHg and a diastolic blood pressure (DBP) >90 mmHg.

Blood samples were taken before meals, using standard techniques such as ELAN analyzer® (Eppendorf Merck), to perform the following exams: blood glucose (IS 3.9-5.5 mmol/L), total cholesterol (IS <5.2 mmol/L), triglycerides (IS <1.7 mmol/L). We excluded subjects with blood test values outside the normal range.

Workers exposed to noise included in the study were made comparable with the two control groups not exposed to noise by age, length of service, BMI, blood glucose, total cholesterol and triglycerides. 72 workers exposed to noise were included in the study, together with 87 workers of a similar completely automated company and 32 bank employees not exposed to noise. The characteristics of these groups are shown in Table 1.

All subjects underwent electrocardiogram; ECG abnormalities were classified as follows: disorders of ventricular repolarization, left axis deviation for fascicular disorder, grade I atrioventricular conduction disturbances, right and left intraventricular conduction disturbances, atrial and ventricular arrhythmias (sporadic and multiple), serious disturbances of the rhythm (bigeminal rhythm due to ventricular extrasystoles), left or right ventricular effort, II and III level atrioventricular block, coronary insufficiency, previous myocardial necrosis.

Audiometry

Workers underwent tonal audiometry from 125 to 8000 Hz after an acoustic rest of at least 16 hours in a silent booth. The audiometric curves for workers exposed to noise were classified according to Klockhoff’s classification modified by Merluzzi (48): Class 0: normal bilateral hearing with thresholds <25 dB; Class 1: involvement >25 dB, frequency at 4000 Hz; Class 2: involvement 3000 Hz; Class 3: involvement 2000 Hz; Class 4: involvement 1000 Hz; Class 5 involved 500 Hz, too; Class 6: noise and not noise-induced hypoacusia; class 7: not noise-induced hypoacusia. Classes 1-5 are considered “noise-induced hypoacusia”, class 6 includes other forms of hypoacusia.

The frequency of the hearing loss in relation to hypertension was evaluated. The distribution of subjects in the various classes was calculated as well as the percentage of patients with hypertension.
Environmental evaluation

The workplaces were divided as described in brief in Table 2, section B.

In accordance with the legislation, the phonometric measurements in the departments were performed using a class 1 tool as defined in IEC (International Electrotechnical Commission) n. 651 of 1979 and n. 804 of 1985 and subsequent regulations. Specifically, for the phonometric measurements we used a phonometer Bruel & Kjaer 2231® with condenser microphone Bruel & Kjaer 4155® connected to the phonometer with connection cable Bruel & Kjaer AO 0027®. The microphonic capsule was placed in a hat through appropriate support at the distance of 0.1 m from the ear exposed to noise.

It was therefore rated the equivalent continuous level noise (Leq), which is the average intensity of a variable noise integrated over time in the different activities and phases of work, expressed in dB (A). The levels of individual daily exposure (Lep,d) were calculated (Table 2). The level of daily exposure to noise Lep,d dB (A), that is the equivalent noise exposure of a worker for an 8-hour shift, was calculated considering the positions the worker occupies during the eight hours and for how long. The workers exposed to a Lep,d dB (A) >85 and <85 are described in Table 2; the cut-off was set at 85 dB (A) because the Italian legislation identifies it as the exposure limit value: ‘higher value of action’.

For workers exposed to noise levels >85 dB (A) there was an obligation to use ear protectors; for workers exposed to noise levels between 80 and 85 dB (A) ear defenders were made available by the employer.

Statistical analysis

Statistical analysis of data was based on the calculation of the mean, standard deviation (SD) and the distribution into classes according to the nature of each variable. The difference between mean values was evaluated using Student T test for unpaired data. The frequencies of individual variables were compared using the chi-square test ($\chi^2$) with Yates correction or Fisher’s exact test when the total in the contingency table was lower than 20 or between 20 and 40 and the smallest of the four expected numbers less than 5. Differences were considered significant when $p$ was $\leq 0.05$.

All subjects agreed to the processing of personal data and said they were aware that these data fell into the category of “sensitive” data and agreed that the results from the protocol were treated anonymously and collectively, with methods and purposes in accordance with the scientific principles of the Declaration of Helsinki.

Results

The mean levels of systolic and diastolic blood pressure were significantly higher ($p < 0.001$) in group A than in the two control groups (Table 2, section A). There were no statistically significant differences in the comparison between the two control groups (Table 2, section A).

The data obtained show an increased frequency of hypertensive workers in the group of exposed compared to the two control groups. In the group exposed to noise (Group A), 17 of the 32 workers with systolic hypertension, also showed diastolic hypertension. There were no patients with

### Table 1. Characteristics of the population studied.

<table>
<thead>
<tr>
<th></th>
<th>GROUP A Workers exposed (N. 72)</th>
<th>GROUP B Workers not exposed (N. 87)</th>
<th>GROUP C Bank employees not exposed (N. 32)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>38.1 ± 7.7</td>
<td>38.8 ± 4.0</td>
<td>38.8 ± 3.6</td>
<td>&gt;0.05</td>
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<td></td>
<td>47-32</td>
<td>48-31</td>
<td>45-32</td>
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<tr>
<td><strong>Length of service (years)</strong></td>
<td>10.4 ± 3.1</td>
<td>10.1 ± 3.1</td>
<td>10.5 ± 3.2</td>
<td>&gt;0.05</td>
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<td></td>
<td>15-4</td>
<td>16-4</td>
<td>16-5</td>
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<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>25.4 ± 3.1</td>
<td>25.3 ± 3.0</td>
<td>25.1 ± 2.7</td>
<td>&gt;0.05</td>
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<tr>
<td></td>
<td>29.4-18.8</td>
<td>29.6-18.9</td>
<td>29.1-18.7</td>
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<tr>
<td><strong>Blood glucose (mmol/L)</strong></td>
<td>4.7 ± 0.6</td>
<td>4.7 ± 0.5</td>
<td>4.8 ± 0.6</td>
<td>&gt;0.05</td>
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<td>5.8-4.0</td>
<td>5.7-3.9</td>
<td>5.8-3.9</td>
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<tr>
<td><strong>Total cholesterol (mmol/L)</strong></td>
<td>4.7 ± 0.6</td>
<td>4.8 ± 0.5</td>
<td>4.7 ± 0.6</td>
<td>&gt;0.05</td>
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<td>6.0-3.1</td>
<td>5.9-3.3</td>
<td>5.8-3.2</td>
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<tr>
<td><strong>Tryglicerides (mmol/L)</strong></td>
<td>1.3 ± 0.3</td>
<td>1.2 ± 0.4</td>
<td>1.3 ± 0.4</td>
<td>&gt;0.05</td>
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<td>2.3-0.6</td>
<td>2.4-0.7</td>
<td>2.3-0.7</td>
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</table>
isolated diastolic hypertension. All the not exposed workers (Group B) that showed hypertension (22 subjects), had systolic hypertension. All employees not exposed to noise that showed hypertension (Group C, 8 subjects), had both systolic and diastolic hypertension.

The data obtained demonstrate a higher frequency of systolic and diastolic hypertension among the workers exposed to noise (Group A) (respectively: p <0.01 and p <0.001) compared with two control groups not exposed to noise (Group B and C) (data shown in Table 2, section A). There were no statistically significant differences in the comparison between the two control groups (Table 2, section A).

Table 2. Cardiovascular parameters of the population studied, continuous equivalent level of noise and level of daily exposure to noise.

<table>
<thead>
<tr>
<th>SECTION A</th>
<th>SECTION B</th>
<th>SECTION C</th>
<th>SECTION D</th>
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<tbody>
<tr>
<td>Cardiovascular parameters of groups studied</td>
<td>Sector of production</td>
<td>Continuous equivalent level of noise</td>
<td>Level of daily exposure to noise</td>
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<tr>
<td>GROUP A. Workers exposed (n=72)</td>
<td></td>
<td></td>
<td>Workers exposed to noise with different Lep,d</td>
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<td></td>
<td></td>
<td>Leq dB(A)</td>
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<td></td>
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<td>min - max</td>
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<tr>
<td>PAPER INDUSTRY</td>
<td>Paper Machine:</td>
<td>84.8-103</td>
<td>&gt;85</td>
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<tr>
<td></td>
<td>Rewinding Machine</td>
<td>88.2-96.3</td>
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<td></td>
<td>Paper Preparation:</td>
<td>82.6-98.1</td>
<td></td>
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<tr>
<td></td>
<td>Paper Machine</td>
<td>81.7-92.8</td>
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<td></td>
<td>Packaging</td>
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<td>Power Plant:</td>
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<td></td>
<td>Local Boiler</td>
<td>83.5-91.4</td>
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<td></td>
<td>Load Cellulose:</td>
<td>79.6-88</td>
<td>58 (80.56%)</td>
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<td></td>
<td>Forklift</td>
<td></td>
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<tr>
<td></td>
<td>Unloading raw materials and storage:</td>
<td>79.6-88</td>
<td>&lt;85</td>
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<tr>
<td></td>
<td>Forklift Warehouse</td>
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<td></td>
<td>Finished products: Warehouse center</td>
<td>76.2-86.3</td>
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<td></td>
<td>Shipping: Outside forklift</td>
<td>80.2</td>
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<td>14 (19.44%)</td>
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<td>PAPER INDUSTRY: Leq dB(A) min - max</td>
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<tr>
<td></td>
<td>SBP mean 138.2 ± SD 11.9</td>
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<td></td>
<td>DBP mean 83.6 ± SD 5.9</td>
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<td></td>
<td>**SH 32 (44.4%)</td>
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<td></td>
<td>*DH 17 (23.6%)</td>
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<td></td>
<td>***drop in BP 12 (16.7%)</td>
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<td>*Abnormalities ECG 15 (20.8%)</td>
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<tr>
<td>GROUP B. Workers not exposed (n=87)</td>
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<td></td>
<td>SBP mean 128.9 ± SD 9.9</td>
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<td></td>
<td>DBP mean 73.9 ± SD 5.6</td>
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<td></td>
<td>Sh 22 (25.3%)</td>
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<td></td>
<td>DH 0 (0%)</td>
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<td></td>
<td>drop in BP 8 (9.2%)</td>
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<td>Abnormalities ECG 10 (11.5%)</td>
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<td>GROUP C. Bank employees (n=32)</td>
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<tr>
<td></td>
<td>SBP mean 127.6 ± SD 9.6</td>
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<td></td>
<td>DBP mean 75.1 ± SD 5.8</td>
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<td></td>
<td>Sh 8 (25%)</td>
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<td></td>
<td>DH 8 (25%)</td>
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<td></td>
<td>drop in BP 2 (6.2%)</td>
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<tr>
<td></td>
<td>Abnormalities ECG 1 (3.1%)</td>
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</table>

SBP: Systolic Blood Pressure (mmHg); DBP: Diastolic Blood Pressure (mmHg); H: Systolic Hypertension; DH: Diastolic Hypertension; drop in BP = drop in blood pressure on standing

* p<0.001 in workers exposed to noise vs two control groups

† p<0.05 in workers exposed to noise vs bank employees

** p<0.01 in workers exposed to noise vs two control groups

+ p<0.005 in exposed to Leip,d dB(A)>85

*** p<0.005 in workers exposed to noise vs two control groups

The socio-demographic characteristics of the three groups showed no significant differences, but the qualification that was higher in the employees.

The data obtained show a higher decrease in the frequency of BP in the upright among the normotensive workers exposed to noise compared to the normotensive workers of the groups not exposed to noise (respectively p<0.005 and p<0.005). The workers of Group B and C not exposed to noise, did not show statistically significant differences (Table 2, section A).

The electrocardiographic abnormalities were so represented:
1) disorders of the ventricular repolarization: 13.9% was the frequency among the workers exposed to noise, 6.9% among the not-exposed workers and 3.1% among employees, one of the workers exposed to noise with disturbances of the ventricular repolarization had ventricular extrasystoles;
2) right atrioventricular block: 1 subject in the group of employees;
3) ventricular extrasystoles: 1 subject in the group of workers exposed to noise, 2 subjects in the Group B and none in the Group C;
4) previous lower myocardial necrosis: 1 subject in the group of workers exposed to noise and none in the two control groups;
5) coronary insufficiency: 2 subjects in the group of workers exposed to noise (bigeminal rhythm due to ventricular extrasystoles) and none in the two control groups.

The frequency of ECG abnormalities was significantly increased among the workers exposed to noise rather than among the employees not exposed to noise (p <0.05) (Table 2, section A). While no statistically significant differences appeared when comparing the workers exposed to noise (group A) and the workers not exposed to noise (group B) (Table 2, section A).

The results of the environmental measurements of noise in the different workplaces are shown in Table 2 of section C and are expressed in terms of minimum and maximum noise. As to the workers exposed to noise (group A) of the paper industry, those exposed to Lep, d> 85 dB (A) had a mean diastolic blood pressure higher than their colleagues exposed to lower noise levels (p <0.05), and also a higher frequency of cases of diastolic hypertension (p <0.05) (Table 2, section D).

The evaluation of the audiometries allowed us to point out that all workers of the paper industry exposed to noise had hypoacusia from noise classifiable as follows: 63.5% Class 1, 17.3 % Class 2, 13.5% Class 3, 1.9% 4 and 3.8% Class 5.

The assessment of the frequency of the auditory defect in relation to hypertension, we found that the percentage of patients with hypertension was independent from their classification in a specific Merluzzi Class.

Discussion

The activity of the workers of paper industry showed noise as a risk factor.

We identified and excluded from the initial sample all subjects that had showed exposure to other occupational hazards and other risks (exposure to solvents and shift work and/or night work) that could damage the cardiovascular system (49).

The data obtained from our study show an increased frequency of cases of high blood pressure, diastolic and/or systolic, among the workers exposed to noise compared to the two control groups not exposed to noise; also the mean values of systolic and diastolic blood pressure was significantly higher in the group exposed to noise compared to the two control groups.

We excluded confounding factors or cardiovascular (50-59) and audiological risk factors and considering that the workers we studied were comparable for the traditional cardiovascular risk factors, the results suggest that noise, in the industry we studied, may influence the cardiovascular system.

The influence of noise in the genesis of hypertension (systolic and diastolic) seems to be confirmed by the absence of statistically significant differences in the cardiovascular parameters when comparing workers not exposed to noise and bank employees not exposed to noise.

In our study the noise affects both systolic and diastolic blood pressure. It is to be noted that if we compare the workers exposed to a noise >85 dB with the workers exposed to a noise <85 dB, the role of diastolic blood pressure is clear. The results suggest that the exposure to noise affects both the systolic blood pressure and the diastolic blood pressure and that high levels of intensity have a most significant effect on the diastolic blood pressure.

As to the decrease of arterial blood pressure passing from clino to orthostatism the results confirm our previous research (39, 58-61). We hypothesized that the decrease of blood pressure may be related to the alterations of the baroreceptor sensitivity (62) due to chronic sympathetic activation with consequent dysregulation of the sympathovagal balance.

Although the mechanism of action by which chronic exposure to noise affects the cardiovascular system it is not well studied and documented in literature (34); it can be assumed that noise causes a chronic sympathetic activation. This event causes a high initial catecholamine release, followed by catecholamine depletion and/or reduced catecholamine response, also due to $\beta$-receptor desensitization, with a reduced tissue density which is reversible for short time (62, 64).

Because of the increased exposure to catecholamines, there is often a reduction of: myocardial $\beta_1$ adrenergic receptors, lymphocyte $\beta_2$-adrenergic receptors, platelet $\alpha_2$-adrenergic receptors. The reduction of $\beta$-adrenergic receptors is associated with reduced cardiac responsiveness to catecholamines (65, 66). At the beginning the mechanism has probably the purpose to protect from arrhythmias and toxic effects on the myocardium (37, 67).

The effects of noise on the cardiovascular system may depend on the time/duration of the exposure (initial, intermediate or chronic exposure) and on the consequent dysregulation of the sympathetic nervous system. In this research we studied subjects exposed to noise for a long time; it is assumed that the cardiovascular effects observed in exposed workers may be secondary to: the catecholamine depletion and the impairment of baroreceptor reflexes, presumably irreversible (37).

The most significant effect on diastolic blood pressure and higher levels of noise (> 85 dB (A)) may be associated with a higher action of high noise on arterioles compared to large arteries (33).

The results for the postural changes in pressure seem to confirm the hypothesis of our previous research (26,37): the postural changes in blood pressure may be a sign of cardiovascular effect more sensitive than hypertension and ECG abnormalities.
A similar behavior does not occur in ECG: the frequency of abnormalities is significantly higher in the group of workers exposed to noise (Group A), than in the group of bank employees, these results could be related to the different socio-economic status of the employees, suggesting a less narrow relationship between this parameter and the exposure to noise. 1 case of previous lower myocardial necrosis and 2 cases of myocardial damage among the workers of the paper industry exposed to noise (one with bigeminal rhythm due to ventricular extrasystoles are to be reported); however these subjects were considered suitable to the work for their good clinical- functional compensation. These data confirm our previous research (19, 37, 68, 69) where we assumed that the noise, depending on the type, intensity, length of exposure and individual susceptibility can cause effects with different thresholds for the apparatus affected (cardiovascular and/or auditory) and for the occurrence of the damage (type and entity): audiometric deficit (100%), hypertension (32 subjects representing 44.44% of the sample exposed to noise) and individual susceptibility can cause effects with different thresholds for the apparatus affected (cardiovascular and/or auditory) and for the occurrence of the damage (type and entity): audiometric deficit (100%), hypertension (32 subjects representing 44.44% of the sample exposed to noise) and electrocardiographic abnormalities (20.8%).

The different effects on the cardiovascular system may depend on the phase during which the clinical relevance and/or the research were made rather than on the exposure itself (early, middle or late). Our study is related to workers who were exposed to loud noise for quite a long time: an average of 10 years (range 15-4) (70), long enough to be able to induce changes in the cardiovascular system.

The average elevation of the hearing thresholds in the workers exposed to noise was higher than expected in subjects of the same age not exposed to noise and without otological diseases ISO 1999-1990.

Our study suggests that noise is a cardiovascular risk factor that may influence the cardiovascular effects. It can be assumed that, hearing and cardiovascular changes, are related to the levels of the noise and the exposure time, and often depend on the individual susceptibility, a situation that is confirmed by the mismatch between the severity of the hearing loss and the frequency of hypertension.

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