Effect of Occupational Exposure to Whole-Body Vibration and Noise on Sex Hormone Levels: A Case Study in an Automobile Parts Manufacturing Plant

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Research

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Running Head: Levels of Sexual Hormones and co-exposure to whole-body vibration and noise

ABSTRACT

Background: The present study investigated the effects of exposure to noise and whole body vibration (WBV) on the levels of sex hormones in an automobile parts manufacturing plant.

Methods: The level of workers' exposure (n=162) to each of the mentioned stressors, was measured through standard methods and for each person the time-weighted average (TWA) of exposure was calculated. In order to determine serum sex hormones (free testosterone, LH and FSH), blood samples were taken from all participants after 8-10 hours of fasting between 7-9 am and then the blood samples were analyzed by ELISA method.

Results: In general, regarding testosterone as the main male sex hormone, only 49% of the participants were in the normal range. In total of three sections, the lowest mean testosterone levels was observed in the third exposure group (WBV>1.93 m/s^2; noise >92.69 dB) of the studied stressor, however, only the difference in testosterone levels between the three different groups of exposure to noise was statistically significant (P = 0.001). The relationship between demographic variables and levels of noise and WBV exposure with sex hormones was not linear and only the relationship between noise exposure and testosterone levels was statistically significant (R = -0.201, P = 0.013).

Conclusion: According to the results of Logistic Regression, the WBV had the greatest effect on testosterone levels as the main male hormone. However, according to the results of the correlation test, only the relationship between noise exposure and testosterone levels is statistically significant.

Keywords: Occupational exposure; Noise, Whole body vibration; Sex hormones

Background

Infertility is a worldwide problem effecting people everywhere and its societal-psychological ramifications effect infertile men and women. Male infertility accounts for half of all infertility and is currently a problem for human society [1]. Sex hormones play an important role in the male reproductive system. Sex hormones or gonadal steroids are hormones that interact with vertebrate androgen or estrogen receptors. The most important sex hormones are testosterone and estrogen which play a key role in the emergence of male and female sex characteristics [2].Testosterone is regulated in the thyroid and exists in both males and females but due to its levels being 50 times higher in males, it has been dubbed the "male sex hormone". This hormone is responsible for secondary sex characteristics in men and measuring its concentration can be helpful in evaluating the health of the gonads [3].

The secretion of sex hormones is regulated via the gonadotropin-releasing hormones which starts in the hypothalamus. This hormone controls the levels of two other hormones called the luteinizing hormone (LH) and the follicle-stimulating hormone (FSH) via the pituitary gland. [4] LH causes the activation, synthesis and secretion of testosterone by binding to receptors on the Leydig cells within the testes. FSH is responsible for the regulation of spermatogenesis in men [5].

Studies on the effects of occupational exposures on the reproductive system has expanded in recent decades [6]. A study conducted in the USA regarding the effects of occupational exposure on fertility and birth defects showed one in seven couples having problems with fertility, 7% of live births being underweight and 3% suffering from birth defects [7]. Evidence indicates that the quality of sperm has suffered a significant reduction in the past 50 years. Increasing environmental pollution in industrialized nations in recent decades has raised questions regarding the effects of harmful environmental and occupational hazards on sperm quality [8]. The main known causes of infertility in occupational environments are: exposure to heavy metals, solvents, insecticides or chemical agricultural products, noise, vibration, radiation and heat. Combined exposure to various harmful hazards, such as in welding or driving occupations is also a cause [9].

Noise is generally defined as "unwanted sound". Exposure to high levels of noise is reported as being among the top ten occupational hazards [10]. Noise is considered as a form of stress and can cause biochemical and physiological changes in humans and animals. The harmful effects of noise on the auditory system has been studied extensively, but very few studies have considered the effects of noise on other organs of the human body. Similar to other forms of stress, noise induced stress can cause elevated levels of stress hormones such as norepinephrine and cortisol [11]. Studies have shown that cortisol can activate the secretion of the leptin hormone which is an important hormone related to metabolism, reproduction and food consumption. Since noise exposure elevates corticosterone, it is possible that noise exposure leads to changes in serum leptin levels [12]. An in vivo study conducted on adult male mice showed that exposure to noise (100 dBA, 1 kHz) over a period of 60 days (3 hours/day) caused a reduction in testosterone levels [13]. Studies on rats also showed that exposure to noise (90 to 130 dBA) over a period of 50 days (12hours/day) caused a significant decrease in testosterone, FSH and LH levels along with negative effects on fertility [14].

Whole body vibration (WBV) as an another physical hazards exists in the majority of occupational environments as almost all terrestrial, airborne and naval machines used in industry, agriculture or logistics expose humans to vibration [15]. Vibration can increase the secretion of stimulating hormones and cause neurostimulation resulting in elevated blood pressure and pulse rate. Vibration can also disrupt in the secretion of certain bodily enzymes [16]. Although very few studies have been conducted regarding the direct effects of vibration exposure on reproductive indices, vibration has been reported as being an environmental stressor with the potential of being able to directly influence the reproductive system [17, 18]. A prevalent inability to produce natural sperm among drivers occupied in industrial and agricultural sectors as compared to other occupations has been observed [19]. Similar results have been observed among taxi drivers and those exposed to whole body vibration [20, 21]. In a cohort study, the relationship between occupational exposure to harmful physical factors and the quality of sperm among those seeking help from infertility clinics was assessed. This study found that those with a history of exposure to whole body vibration suffered from a change in their sperm parameters [22].

Generally, it can be said that so far, many in vivo and in vitro studies have been conducted regarding the independent effects of WBV and noise hazards on reproductive indices, however, few studies have evaluated these effects on workers in occupational environments by measuring the level of occupational exposure. A limited number of studies merely used retrospective evaluation of subjects with a history of exposure to these stressors (usually with questionnaires) without considering environmental monitoring [23]. Some studies only assessed reproductive disorders in employees regardless of specifying a particular stressor or its monitoring [24, 25]. Based on a review of the relative literature, it can be stated that no study has attempted a concurrent evaluation of both the level of exposure to these stressors and the relative effect on sex hormones. The results of the present study can, as both a basic-applied research and a field study, determine the effects of each of these stressor on the reproductive indices among workers. Thus, this study is an essential step in the prioritization of control procedures regarding these types of occupational hazards of the reproductive system.

Methods

Study Population

The study population consists of the entire workforce employed in three manufacturing sections of Aluminum, Cast Iron and Grinding in an automobile parts manufacturing plant which were exposed to studied environmental stressors (WBV and noise). Participants were admitted according to sample size calculations, meeting entry criteria and signing of consent forms. Sample adequacy was measured using Equation 1. Since no correlation coefficient between THE environmental stressors and reproductive hormones has been suggested in similar studies, a correlation coefficient of 0.25 was used.

$$n = [\frac{Z_{1-\frac{\alpha}{2}} + Z_{1-\beta}}{0/5 \times Ln\frac{1+r}{1-r}}]^2 + 3$$

(Eq. 1)

Based on Equation 1:

α: Probability of type 1 error; if α=0.05 then Z1-α/2=96.1

β: Probability of type 2 error; if β=0.2 then Z1-β=0.84

The minimum sample size for each estimate (exposure type) was determined to be 121 participants, though after considering entry criteria, 162 participants were eventually enrolled in the study. The participants were all male, between 20 to 50 years of age [26] and with two or more years of employment [27]. Participants who had used steroids, testosterone, prednisolone, anti-oxidants [28]such as selenium, vitamin C, E or B supplements [29] and body-building supplements [30] were not enrolled. Those with a family history of infertility or organic disorders affecting fertility such as diabetes, kidney disorders, angina pectoris, heart disorders, arterial hypertension, pituitary disorders or a chronic pulmonary obstruction disorder were not enrolled. Also, those with testicular infections, orchitis, varicocele [31], history of chemotherapy or radiotherapy [32]and those with abnormal hearing (according to medical records) were not enrolled.

Relevant participant background information was obtained from demographic questionnaires and also by referring to the participants' medical records. Participants who failed to complete the questionnaire or those who wished to leave the program at any stage were dismissed. All participants were required to sign informed consent forms approved by the ethics committee of the Tehran University of Medical Sciences (ethics code: IR.TUMS.SPH.REC.1398.297).

The research environment in the studied industry included Aluminum, Cast Iron and Grinding sections [33] . Their process flowchart has been shown in Figure 1.All participants depending on their job, had appropriate personal protective equipment such as earplug, goggles, helmets, safety shoes, and protective clothing.

Figure 1. The process flowchart of the studied sections

Environmental Measurement

In order to measure the exposure level to occupational noise, a calibrated noise dosimeter (Casella, Cell-320; USA) was used. Since the workers' exposure pattern had a constant cycle, the short-term dosimetry method was used. For this, the dosimeter microphone was placed 10 to 30 cm from the participant's ear and attached to their collar [34]. Base on according to the standard method: ISO 9612, the equivalent level (Leq) of received dose was calculated using Equation 2 and the eight-hour equivalent level was calculated using Equation 3 [35].

$$\text{Leq of Received Dose} = 10\log(\text{Noise Dose} \times \text{Daily Shift} / \text{Exposure Duration} \times 100) + \text{Permissible SPL}$$

(Eq. 2)

$$\mathrm{leq}_{8h} = 10\log\left[\frac{1}{8}\sum_{i=1}^{n} 10^{\mathrm{lp}_i/10} \times t_i\right]$$

(Eq. 3)

In this instance, the daily shift was 8 hours, the exposure duration was 4 hours and the permissible SPL (sound pressure level) was 85 dBA. L_{pi} and t_i are the measured equivalent level and exposure duration, respectively

The whole-body vibration (WBV) was measured according to the standard method: ISO 2631 using a calibrated whole-body vibration meter (Svan 958, Svantek; Poland) [36]. The thin, rubber-covered disk -shaped receiver of WBV meter was placed at the contact point between the body and the ground for a duration of 3 minutes (minimum measurement time) and vibration acceleration was measured in m/s^2 for the X, Y and Z axes. The vector sum was then calculated using the relevant formulas[36]. Three readings were made for each axis to ensure measurement validity. The root mean square (RMS) of acceleration for each of the X, Y and Z axes are obtained using Equation 4 and is based on the measurement duration.

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{\frac{1}{2}}$$

(Eq. 4)

In this equation, a_w is the frequency weighted RMS acceleration (m/s^2) in particular time (t) and T is the duration of measurement(s). The vector sum of the vibration acceleration for each axis is obtained in m/s^2 from Equation 5, where a_v is the vector sum of the frequency weighted RMS acceleration and a_x, a_y and a_z represent the frequency weighted RMS acceleration of each of the three axes.

$$a_v = \sqrt{(1.4a_{wX})^2 + (1.4a_{wY})^2 + (1.4a_{wZ})^2}$$

(Eq. 5)

Since workers may not have a daily exposure duration of 8 hours, Equation 6 is used to calculate the eight-hour equivalent frequency-weighted RMS acceleration (A(8)) [37].

$$\mathrm{A}(8) = av\sqrt{\frac{T}{8}}$$

(Eq. 6)

Hormone measurements

Blood samples were taken from each participant between 7 and 9_{AM} after 8 to 10 hours of hunger [38]. Samples were taken by laboratory professionals at the studied plant and were immediately taken to the laboratory under controlled conditions (ice box) and kept at -20 °C.

According to the kit manufacturer's guidelines, free serum testosterone levels (AccuBind ELISA test system, Monobind Inc., USA) and LH/FSH levels (Padtan Gostar Isar Inc., Iran) were measured using the Enzyme-Linked Immunosorbent Assay (ELISA) method and read using a STAT FAX 2100 EIA analyzer and microplate reader. The principle of test is immune-enzymetric which done with the aid of specific monoclonal antibodies and is based on the sandwich method. A monoclonal anti-hormone is used for solid surface fixation and another anti-hormone is used for conjugation with horseradish peroxidase (HRP). When the serum sample is added, the hormone molecule reacts with both antibodies simultaneously and is sandwiched between the solid surface antibody and the enzyme conjugated antibody. After the incubation period at room temperature and washing of the sumps, the substrate and oxidation solutions are added and a blue color will appear. This blue color will change to yellow after adding the stop solution. The intensity of this color is measured at 450 nanometers and corresponds to the hormone levels in the sample. Standard hormone concentrations are tested alongside the unknown samples and the hormone concentrations of the unknown samples are obtained according to the standard curve of light absorption relative to hormone concentration [39].

Data Analysis

Data analysis was performed using the SPSS v22 software (Chicago Il, USA). Descriptive statistics such as percentage, percentile, minimum, maximum, average, median and standard deviation were used to present demographic data, environmental monitoring results and hormone analysis. The Shapiro-Wilk Test was used to determine data distribution normality. The one-way analysis of variance (ANOVA) or corresponding non parametric test was used to compare mean hormone levels at different exposure levels. Partial correlation tests were used in order to remove or control influencing factors (background variables) on hormone levels. Also, in order to analyze the effect of, or find the relationship between, occupational exposure and sexual hormone levels by sdjusting the effect of other variables, linear (or nonlinear) regression was used. Logistic regression was used to analyze the relationship between the studied variables. A probability value (p-value) of 0.05 was considered as statistically significant.

RESULTS

Table 1 presents descriptive statistics regarding the demographic characteristics of participants working in each section of the manufacturing plant. The average age and employment duration of participants were 36.15 (7.16) and 10.16 (6.26) years respectively. Among the participants, 68% had a normal Body Mass Index (BMI) and 39% had a healthy Waist-Hip Ratio (WHR). Of all participants enrolled, 83 % were married and 56 % had no history of smoking. Workers of the Cast Iron section had the highest average age, BMI and WHR, while those occupied in the aluminum section had the highest average employment duration. A statistically significant mean difference was observed between the three sections of the plant in regards to age, employment duration, BMI and WHR ($P<0.05$). The Cast Iron section also had the highest number of smokers and also the highest number of married participants. A statistically significant frequency difference was observed regarding the number of smokers and married participants among the three sections of the manufacturing plant ($P<0.05$).

Table 1. Demographic characteristics of participants.

The participants were classified into separate groups based on the level of noise and WBV exposure. The cutoff point for separating the exposure groups was the 33rd and 66th percentile. Table 2 presents the descriptive-analytic exposure statistics for the various exposure groups. A time-weighted average was calculated for each participant according to their presence in the work station and level of exposure. The Shapiro-Wilk test indicated a non-normal distribution of exposure data ($P<0.05$). Regarding WBV, the level of exposure among 48% of the second group (0.51-1.93 m/s^2) and all of the third group (>1.93 m/s^2) was higher than Threshold Limit Value (TLV) with the difference being statistically significant ($P=0.001$). In the second group, the mean difference of WBV exposure level between the three manufacturing sections was statistically meaningful ($P=0.047$). The level of noise exposure among 28% of the first group (<85.71 dBA) and all of the second (85.71-92.69 dBA) and third (>92.69 dBA) groups was higher than Threshold Limit Value (TLV) with the difference being statistically significant ($P=0.001$). For the three groups, mean difference of noise exposure level between the three manufacturing sections was statistically ($P<0.02$). The highest mean exposure to WBV (3.98 m/s^2) and noise

(100.17 dBA) in the third group belonged to the Cast Iron section. In the Aluminum section, highest percentage of exposure to WBV (49%) and to noise (80%) was observed in the first and second groups, respectively. In the Cast Iron section, highest percentage of exposure to WBV (46%) and to noise (72%) was found in the third and first groups, respectively. In the Grinding section, highest percentage of exposure to WBV (49%) and to noise (85%) was found in the third and third groups, respectively.

Table 2. Level of exposure to noise and WBV among participants.

Table 3 presents the descriptive-analytical statistics regarding sex hormone levels classified according to their normal range. Overall, testosterone levels were normal in only 49% of participants which among the participants, 21% were 20 to 29 years of age and 28% were above 40 years of age (40 to 50 years). Among all the participants, 51% suffered from low free testosterone levels. The mean testosterone level at 20 to 39 years of age is 7.89 pg/ml (±3.22) and 7.20 pg/ml (±2.38) in those above 40 years of age. Among the participants, 86% had normal FSH hormone levels and 89% had normal LH hormone levels. The mean FSH level was 3.45 mIU/ml (±1.55) and LH hormone was 2.04 mIU/ml (±1.13). No significant mean difference was observed in sex hormone levels among the various manufacturing sections (P>0.05). The lowest average testosterone levels among 20-39 year-old participants were found in the Grinding section (5.86 ±1.62) with 76% having lower than normal range. Participants in the Grinding section above 40 years of age had the lowest testosterone levels with 40% of them having lower than normal levels of testosterone.

Table 3. Descriptive-Analytical statistics regarding hormone levels of participants.

Table 4 presents the studied hormone levels for each exposure group of WBV and noise. Regarding WBV exposure, the lowest serum testosterone levels (7.72 pg/ml ±2.76) belonged to the third exposure group (>1.93 m/s^2), though the mean difference in hormone levels among the three exposure groups were not statistically meaningful ($P=0.563$). Regarding noise exposure, the lowest serum testosterone levels (6.62 pg/ml ±2.37) belonged to the third exposure group (>92.69 dBA) and was statistically meaningful ($P=0.001$). Under the various investigated exposure scenarios in the present study, the lowest serum testosterone (6.62 pg/ml ±2.37), FSH (2.91 mIU/ml ±0.87) and LH (1.63 mIU/ml ±0.87) levels were observed among the third group of noise exposure.

Table 4. Sex hormone levels among various exposure groups.

It was observed that among the two age groups, lowest serum testosterone levels (6.58 pg/ml ±2.16 for those with 20 to 39 years of age and 6.70 pg/ml ±2.87 for those above 39 years of age) were observed under high levels of noise exposure (>92.69 dBA), although only those that were 20 to 39 years old (Figure 2) showed a statistically significant difference in hormone levels within the three noise exposure groups (P=0.001).

Figure 2. Mean testosterone levels under various noise exposure scenarios among participants aged 20 to 39 years old.

Table 5 presents mean testosterone levels in the various manufacturing sections among the different exposure groups. For participants above 40 years of age, the lowest testosterone levels (6.28 pg/ml± 2.59) were observed in the third WBV exposure group in the Grinding section. For 20-39 years old workers, the lowest testosterone levels (6.28 pg/ml± 2.15) were observed in the third noise exposure group in the Grinding section.

In the three sections of the plant, mean differences of testosterone levels between the various exposure groups were not statistically significant (except for testosterone levels of 20 to 39-year-old participants in the various noise exposure groups of the grinding section: P=0.001). Mean differences of testosterone levels of the 20-39 year-old participants were not statistically meaningful in the various sections of the plant (except for the second WBV exposure group P=0.037). Mean differences of testosterone levels of those above 40 years of age in the various sections of the plant were not statistically meaningful (expect for the second noise exposure group P=0.047). Moreover, the lowest mean levels of testosterone for all age groups, were found in the Cast Iron, (8.73 pg/ml), (Grinding 8.93 pg/ml), and Aluminum (9.09 pg/ml) sections, respectively, **This is while** the highest mean exposure level to whole body vibration was related to Cast Iron (1.68 m/s2) and the highest mean exposure to noise (95.93 dB) was observed in Grinding section.

Table 5. Mean testosterone levels in the manufacturing sections under study.

The results of the correlation test and subsequent scatter plots showed no linear relation between demographic characteristics, exposure levels and sex hormone levels. Only the relation between noise exposure and testosterone levels (Fig.3) was statistically significant (R=-0.201, P=0.013).

Figure 3. Changes in free testosterone levels relative to changes in noise exposure levels.

In order to model the relationship between exposure and demographic variables with the hormone levels, a binary logistic regression was done with order of Binary Logistic of categorized testosterone and considering normal range of testosterone as the Reference Category. For this, a simple logistic regression was initially performed and then, for the multiple logistic regression, variables with sig>0.3 were removed from the model. The results are presented in Table 6 and 7.

Table 6 shows the results of the logistic regression of the demographic and exposure variables with testosterone levels for those aged 20 to 39. Based on the results obtained, no significant relationship was found between input variables in the simple logistic regression analysis. The WBV had the most effect on testosterone levels, so for every one unit increase in level of WBV exposure, the probability of testosterone levels falling below 9.2 pg/ml was increased by 30%. Among the exposure variables, noise had the smallest confidence interval range and is close to significant levels. For every one unit increase in noise level, the probability of testosterone levels falling below 9.2 pg/ml was increased by 5%. Among the demographic variables, marital status had the most effect on testosterone levels as married participants were 2.3 times more probable to have a lower than 9.2 pg/ml testosterone level. Again, with this range, a confidence level of 95% is rather large for this exposure variable. Considering the confidence interval, BMI was closer to meaningful levels among the demographic variables.

Table 6. Results of the logistic regression test for demographic and exposure variables with testosterone levels for participants aged 20 to 39.

Table 7 shows the results of the logistic regression of the demographic and exposure variables with testosterone levels for those aged 40 and above. Based on the results obtained, no significant relationship was found between input variables and the results of the simple logistic regression analysis, although WBV had the most effect on testosterone levels. For every one unit increase in WBV acceleration, the probability of testosterone levels falling below 6.1 pg/ml was increased by 18%. Among the exposure variables, noise is closer to significant levels considering the confidence interval. Among the demographic variables, employment duration was closer to meaningful levels considering the confidence interval. For every single unit increase in employment duration, the probability of testosterone levels falling below 6.1 pg/ml was increased by 7%.

Table 7. Results of the logistic regression test for demographic and exposure variables with testosterone levels for participants aged 40 and above.

DISCUSSION

Knowledge regarding the effects of occupational hazardous agents on male fertility is limited. Workers around the world are increasingly exposed to hazardous physical and chemical hazards which can affect the male reproductive system. Expanding the knowledge regarding types of exposure that effect male fertility is especially important for preserving the health of workers and their family life since unlike cancer, they become apparent shortly before imposing damage. Therefore, protecting workers against exposures that effect the reproductive system can prevent other negative effects on their overall health [40].

The present study investigated the effects of exposure to noise and WBV on the levels of sex hormones influential in the performance of the male reproductive system in an automobile parts manufacturing plant. According to the results, overall, testosterone levels were normal among 49% of participants with 51% having lower than normal levels of testosterone. Sex hormone levels can be affected by genes, age, background illnesses, diet, medication, or drug use as well as exposure to occupational hazardous agents. Although certain entry criteria were set for enrollment and efforts were made to control influential factors, it is impossible to account for and control all influential factors which is a common problem with field studies. Even so, the theories tested in these types of studies are valuable since they reflect real world situations [33].

Noise

According to the results of the present study, mean exposure level to noise in all manufacturing sections was above TLV and the difference between them was statistically meaningful. The difference between all three exposure groups in the various manufacturing sections was also statistically meaningful with the highest average exposure to noise being observed in the Grinding (98.72 dBA ±4.13) section followed by the Aluminum (89.42 dBA ±2.84) and Cast Iron sections (83.94 dBA ±4.13). Previous studies have shown that the majority of noise produced in the grinding process is caused by air exhaust systems and can range from 90 to 120 dBA. In casting, repeated impacts of the chisel causes vibration at resonance frequencies and produces loud noise [41]. The lowest average testosterone levels were observed in the Grinding section (7.01 pg/ml ±3.09) followed by the Cast Iron section (7.76 pg/ml) and the Aluminum section (8.19 pg/ml ±2.96) but the differences between them were not statistically significant.

The highest average noise exposure for the third exposure group (99.95 dBA ±3.15) was observed in the Grinding section with 85% of participants being exposed to higher than noise 92.69 dBA. Around 65% of participants in this section had lower than normal testosterone levels. Serum testosterone levels were measured under various exposure scenarios for those between 20 to 39 years of age and also those above 39 years of age. The results showed that in both age groups, lowest testosterone levels belonged to those exposed to noise >96.69 dBA with the differences in testosterone levels among those 20 to 39 years of age being statistically meaningful. Correlation tests and scatter plots determined that among the demographic and exposure variables, only noise exposure and testosterone levels had a statistically significant relationship. According to the simple logistic regression, among those 20 to 39 years of age, noise had the smallest confidence interval range and was close to meaningful levels. For each one unit increase in noise levels, the probability of testosterone levels falling below 9.2 pg/ml was increased by 5%.

Chamkoory et al. conducted a study in 2016 titled "Effect of noise pollution on the hormonal and semen analysis parameters in industrial workers of Bushehr" where a group of 27 men were continually exposed to 107 to 119 dBA noise while another group of 27 men worked in a quite environment. The men were then sent to fertility clinics where blood samples were taken in order to determine levels of adrenocorticotropic (ACTH) hormones, cortisol, testosterone, prolactin, follicle stimulating hormone (FSH), luteinizing hormone (LH), thyroxine hormones (T3, T4) and thyroid stimulating hormones (TSH). The results of that study showed that noise stress had significantly reduced the concentration of testosterone, prolactin, LH, FSH, thyroxin hormones and TSH while causing a meaningful increase in ACTH and cortisol levels [42]. Results of the present study agrees with Chamkoory et al, in the case of reduced testosterone, LH and FSH levels in those exposed to high levels of noise.

In a review study conducted in 2016 by Nadry et al. the effects of noise on male fertility (human and lab animals) was investigated [43]. The study concluded that exposure to noise can affect testicular weight, sperm parameters (sperm count, vitality, mobility and morphology), sex hormone levels, testicular tissue and oxidative stress levels which in turn can be influential in male infertility. The present study[43] also found noise to be the main exposure variables that affects sex hormone levels.

An in vivo study showed that exposure to noise (100 dBA) during a 50-day period (3 hours per day) caused reduced testosterone levels in adult male mice [44]. Exposure to noise (90 to 130 dBA) during a 50-day period (12 hours per day) also caused a considerable reduction in testosterone, FSH, LH and Lutropin (LH) hormone levels in lab rats which had negative effects on fertility [45].

The results of Farzadnia et al. (2016) showed reduced testosterone levels in lab rats when exposed to noise at 115 dBA while increasing adrenocorticotropic (ACTH) hormone and cortisol levels in lab rats [46]. Testicular histology showed reduced average seminiferous tubule diameter and reduced thickness of the germinal epithelium compared to the control group. These in vivo results are in agreement with the findings of the present field study.

A research study conducted by Jurewicz et al. investigated the effects of occupational exposure on sperm quality using occupational questionnaires. The study population consisted of 336 male infertility clinic clients who had an ejaculate concentration of less than 15 mg/ml which is considered normal according to the WHO. The correlation between occupational exposure and sperm quality parameters such as sperm concentration, mobility and sperm chromatin structure were investigated using occupational questionnaires. Their results showed a meaningful relation between the existence of occupational noise and reduced sperm motility and increased DNA breakup [47].

Considering the relevant literature in this regard, it seems that among all physical hazardous agents, the effects of noise exposure on male fertility are better understood. Noise exposure is considered to be among the top ten occupational hazards and is a known stressor that can cause physiological and biochemical changes in the human body. Certain studies report that exposure to high levels of noise cause reductions in testosterone levels, sperm motility, average seminiferous tubule diameter and thickness of the germinal epithelium while increasing DNA breakup [14, 44, 47]. These studies state that the mechanism of effect is dependent on the increase in stress hormone levels such as corticosterone and norepinephrine due to noise exposure and the resulting changes in the secretion of the leptin hormone which is an important hormone in metabolism and reproduction [12].

Vibration

The results of the present study show that mean exposure to whole body vibration was above TLV in all manufacturing sections. The largest difference was observed in the Cast Iron section with a mean exposure of 2.10 m/s2 ±1.92. In this section, 46.8% of participants had a Time-weighted Average (TWA) exposure above 1.93 m/s2. Around 44% of participants in the Cast Iron section had a lower than normal testosterone level. Overall, the lowest testosterone level observed among the three sections of the plant belonged to the third exposure group (>1.93 m/s2). Still, the correlation test showed no linear and significant relationship between testosterone level and WBV acceleration.

Based on the results of the simple logistic regression, though not meaningful, among those 20 to 39 years of age, for each one unit increase in WBV acceleration, the probability of testosterone levels falling below 9.2 pg/ml was increased by 30%. This probability will rise to 38% if those variables with a sig>0.3 are excluded from the model. For those aged 40 and above, though no significant relationship was observed between input variables and results of the simple logistic regression, vibration had the most pronounced effect on testosterone levels. For every single one increase in vibration acceleration, the probability of testosterone levels falling below 6.1 pg/ml was increased by 18%.

Considering the limited number of studies that have evaluated both occupational exposure to vibration and reproductive indices, it is difficult to arrive at a definitive conclusion regarding the effects of vibration. The potential dangers of mechanical vibration and its effect on the reproductive system is limited to experimental, clinical or epidemiological studies (lab animals, men working in transportation and industrial occupations) and also its effect on libido [48].

Eisenberg et al. (2015) conducted an observational prospective cohort study entitled "Relationship between physical occupational exposures and health on semen quality: data from the Longitudinal Investigation of Fertility and the Environment (LIFE) Study" [22]. In this study, a total of 501 couples who had stopped using contraceptives and were willing to conceive were observed for a period of 1 year. During this time, 473 men (94% of male participants) provided one sperm sample while 80% provided two sperm samples. The type of occupational exposure was determined via questionnaires. Based on the self-reported questionnaires, 23% of participants had been exposed to WBV and 27% had been exposed to noise in their occupational environments. Regression analysis had revealed that average ejaculate volume, overall sperm count and the DNA fragmentation index (DFI) was lower in the vibration exposure group compared to the control group though this was not statistically meaningful. Average ejaculate concentration, overall sperm count, abnormal sperm morphology and DFI was also higher in the sound exposure group compared to the control group though this was not statistically meaningful [22].

In a review article titled "Effect of vibrations on male reproductive system and function" Penkov and Tzetkove state that based on experimental and clinical studies, exposure to vibration results in reduced sperm count, lower spermatogenesis index, shrinking of the testes, changes in motility, chronic venous stagnation, dystrophic alterations in tubuli contorti, changes in ScDH, ATP-ase, LDH, GL-6-PDH activity and structural damage to the germ cell[48]. They also point out that oligozoospermia, asthenozoospermia teratozoospermia is prevalent among workers exposed to vibration while sexual disorders have also been observed [48].

In the aformentioned study by Jurewicz et al. (2014), it was shown that among the participants, 17% had been exposed to vibration but no significant relationship was found between sperm parameters and occupational exposure to vibration [47]. A cohort study investigated the relationship between occupational exposure to hazardous physical agents and sperm quality among clients seeking help from infertility clinics. Their results showed changes in sperm parameters in those who had a history of WBV exposure [22].

As is apparent, considering the lack of adequate information and the existence of contradictory results from other studies, it is difficult to arrive at a definitive conclusion, however, there is no doubt that that chronic exposure to WBV, especially in occupations involving working while sitting down, can have negative effects on the male reproductive system [47]. Despite its limitations, the presents study has shown how exposure to WBV can effect sex hormone levels. Vibration has been identified as an environmental stressor with the potential to affect the male reproductive system [17, 18] and this is due to the prevalence of disorders related to sperm production among drivers occupied in industry and agriculture and also among taxi drivers compared to other occupations [19-21].

Despite the limited available scientific sources, it seems that the possible effect mechanism of vibration exposure on the reproductive system is related to changes in hormonal and enzymatic levels, vascular disruptions within the testicular tissue, entropy and temperature changes [49]. It must be noted that in vitro studies involving short term exposure to vibration have reported increased sperm motility without accompanying changes in sperm count or morphology [50].

In total, considering the wide range of normal testosterone levels, daily hormone fluctuations and influencing parameters such as psychological stressors, quality of sleep, background diseases and etc., it is suggested that a follow-up study be conducted from the beginning of employment with a large enough sample size and a control group in order to definitively evaluate the effects of these physical hazards on sex hormone levels and reproductive indices. Due to a limited budget, the present study was conducted using cross sectional measurements along with exposure group categorizations. Also due to cultural and religious reasons, sperm samples were not taken from participants and sex hormones were only measured using blood samples in the preliminary phase of the study. This does not however reduce the value of the present study as it is hard to find any study that investigates the effects of physical stressors on reproductive indices in occupational environments while also attempting to calculate the amount of occupational exposure received.

CONCLUSION

The aim of the presents study was to evaluate the effects of exposure to noise and WBV on sex hormone levels in men. According to the logistic regression, WBV had the strongest effect on testosterone levels among those all participants. Based on the correlation analysis, only the relationship between noise and testosterone level was statistically significant. The lowest levels of testosterone were observed in the third exposure group in all sections of the manufacturing plant and for two studied physical hazardous agents. Lowest average testosterone levels were observed in the Grinding section followed by the Cast Iron and the Aluminum sections. Highest average exposure to whole body vibration was observed in the Cast Iron section while the highest average exposure to noise was observed in the Grinding section of the plant. The correlation test and scatter plots showed no linear meaningful relationship between demographic variables and sex hormone levels. Reaching a definitive conclusion regarding the effects of each harmful physical hazards is difficult due to the existence of intervening factors such as chemical pollution (heavy metals, PAH) and ergonomic factors (posture or working while sitting down).

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Consent for publication

Not applicable.

Ethics approval

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Competing Interests

The authors have no competing interests to declare.

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Author Contribution

HM designed and performed experiments, analyzed data and co-wrote the paper. FG supervised the research, provided critical revision of the article and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. SFD contributed to the study design, managed and planned the project and drafted and provided critical revision of the article. SK performed data analysis and interpretation. HI and FRT contributed substantially to the conception and design of the study. All authors reviewed and provided final approval of the version to publish.

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Table 1. Demographic characteristics of participants.

Parameter	Total Count	Manufacturing Section	P-

		(N=162)			**Aluminum (N=39)**	**Cast Iron (N=71)**	**Grinding (N=52)**	**value***
		Mean (SD)	**Median (IQR)**	**Max-Min**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	
Age (Year)		36.15 (7.16)	37 (11.25)	50-22	37.02 (7.09)	37.23 (6.67)	34.01 (7.50)	**0.032**
Employment Duration (Year)		10.16 (6.26)	9 (11)	24-1	11.41 (7.00)	11.30 (6.03)	7.65 (5.28)	**0.002**
BMI (kg/m^2)		25.56 (3.79)	25.7 (5.07)	35.16-16.33	25.27 (3.51)	26.62 (3.54)	24.34 (3.99)	**0.003**
N (%)	Underweight (<18.5)	4 (2)			-	1 (25)	3 (75)	0.051
	Normal (18.5-24.9)	68 (42)			19 (28.0)	22 (32.3)	27 (39.7)	
	Overweight (25-29.9)	68 (42)			17 (25)	34 (50)	17 (25)	
	Obese (>30)	22 (14)			3 (13.6)	14 (63.6)	5 (22.8)	
WHR		0.92 (0.12)	0.92 (0.10)	1.95-0.1	0.91 (0.06)	0.95 (0.13)	0.89 (0.13)	**0.012**
N (%)	Healthy (≤0.9)	63 (39)			17 (27.0)	18 (28.6)	28 (44.4)	**0.005**
	Unhealthy (>0.9)	99 (61)			22 (22.2)	53 (53.5)	24 (24.3)	
Smoker- N (%)	Yes	72 (44)			10 (13.9)	34 (47.2)	28 (38.9)	**0.020**
	No	90 (56)			29 (74.4)	37 (52.1)	24 (46.2)	
Marital Status N (%)	Single	27 (17)			2 (7.4)	12 (44.4)	13 (48.2)	**0.042**
	Married	135 (83)			37 (27.4)	59 (43.7)	39 (28.9)	

* Mean differences of variables between different manufacturing sections
SD= Standard Deviation
IQR=Interquartile Range
BMI= Body Mass Index
WHR=Waist to hip Ratio

Table 2. Level of exposure to noise and WBD among participants.

Exposure	**Categorized values**	**TLV**	**Total (N=162)**				**Units**						**P-value***
							Aluminum (N=39)		**Cast Iron (N=71)**		**Grinding (N=52)**		
			N	**Mean (SD)**	**Min-Max**	**Median (IQR)**	**N (%)**	**Mean (SD)**	**N (%)**	**Mean (SD)**	**N (%)**	**Mean (SD)**	
WBV (m/s^2)	<0.51	0.87	57	0.30 (0.09)	0.14-0.51	0.29 (0.15)	19 (49)	0.31 (0.06)	24 (34)	0.29 (0.10)	14 (27)	0.31 (0.11)	0.859
	0.51-1.93		52	0.96 (0.30)	0.68-1.93	0.83 (0.36)	13 (33)	1.04 (0.22)	14 (20)	0.79 (0.17)	25 (48)	1.01 (0.35)	**0.047**
	>1.93		53	3.80 (1.09)	2.05-6.86	4.23 (1.40)	7 (18)	3.41 (0.83)	33 (46)	3.98 (1.10)	13 (25)	3.54 (1.17)	0.288
Noise (dBA)	<85.71	83	54	81.49 (2.70)	72.15-85.53	80.68 (2.83)	3 (7)	84.95 (0.13)	51 (72)	81.29 (2.64)	-	-	**0.020**
	85.71-92.69		56	89.43 (1.97)	86.09-92.69	89.35 (3.41)	31 (80)	89.00 (1.62)	17 (24)	89.04 (2.13)	8 (15)	91.91 (0.84)	**0.001**
	>92.69		52	99.46 (3.50)	92.91-106.01	100.00 (4.03)	5 (13)	94.73 (2.34)	3 (4)	100.17 (5.16)	44 (85)	99.95 (3.15)	**0.005**

* Mean differences of exposure levels between different manufacturing sections

SD= Standard Deviation

IQR=Interquartile Range

TLV= Threshold Limit Value

Table 3. Descriptive-Analytical statistics regarding sex hormone levels of participants.

Serum Hormone	**Categorized values**	**Total N=162**				**Units**						**P-value***
						Aluminum N=39		**Cast Iron N=71**		**Grinding N=52**		
		N (%)	**Mean (SD)**	**Min-Max**	**Median (IQR)**	**N (%)**	**Mean (SD)**	**N (%)**	**Mean (SD)**	**N (%)**	**Mean (SD)**	
Free Testosterone (pg/ml) for 20-39 years old (N=100)	**<9.2**	65 (41)	5.95 (1.72)	2.10-8.90	6.50 (2.40)	13 (56)	5.89 (1.98)	24 (60)	6.08 (1.74)	28 (76)	5.86 (1.62)	0.100
	Normal Range (9.2-34.6)	35 (21)	11.50 (2.02)	9.40-17.90	10.90 (2.30)	10 (44)	11.66 (1.81)	16 (40)	11.26 (2.2)	9 (24)	11.68 (2.11)	0.678
	>34.6	-	-	-	-	-	-	-	-	-	-	-
Free Testosterone (pg/ml) for 40 years and older (N=62)	**<6.1**	16 (10)	4.83 (1.38)	2.30-6.10	5.45 (2.77)	13 (81)	7.05 (1.53)	26 (84)	6.5 (1.05)	13 (87)	5.41 (1.73)	0.759
	Normal Range (6.1-30.3)	46 (28)	8.02 (2.08)	6.20-15.30	7.10 (1.77)	3 (19)	11.6 (1.47)	5 (16)	11.10 (0.87)	2 (13)	12.65 (3.47)	0.596
	>30.3	-	-	-	-	-	-	-	-	-	-	-
FSH (mIU/ml)	**<1**	19 (12)	0.60 (0.32)	0.10-1.00	0.70 (0.50)	-	-	6 (9)	0.70 (0.36)	13 (24)	0.70 (0.36)	0.397
	Normal Range (1-14)	140 (86)	3.41 (1.71)	1.10-9.30	3.10 (1.77)	38 (97)	3.87 (2.17)	64 (90)	3.23 (1.44)	38 (74)	0.70 (0.36)	0.157
	>14	3 (2)	23.56 (11.32)	16.10-36.60	18.00 (2.00)	1 (3)	-	1 (1)	-	1 (2)	-	-
LH (mIU/ml)	**<0.7**	16 (10)	0.53 (0.19)	0.10-0.70	0.60 (0.28)	2 (5)	0.55 (0.21)	7 (10)	0.62 (0.09)	7 (14)	0.42 (0.22)	0.149
	Normal Range (0.7-7.4)	145 (89)	2.15 (1.13)	0.80-6.60	1.90 (1.00)	36 (92)	2.49 (1.47)	64 (90)	2.11 (1.07)	45 (86)	1.94 (0.82)	0.088
	>7.4	1 (1)	11.00 (0.00)	11.00-11.00	11.00 (0.00)	1 (3)	-	-	-	-	-	-

* Mean differences of hormone levels between different manufacturing sections
FSH = Follicle stimulating hormone
LH = Luteinizing hormone

Table 4. Sex hormone levels among various exposure groups.

Exposure	Categorized Values	Serum Free Testosterone (pg/ml)			Serum FSH (mIU/ml)			Serum LH (mIU/ml)		
		Mean (SD)	**Median (IQR)**	**P-value***	**Mean (SD)**	**Median (IQR)**	**P-value**	**Mean (SD)**	**Median (IQR)**	**P-value**
WBV (m/s^2)	<0.51	7.77 (2.95)	7.20 (3.70)	0.563	4.35 (5.45)	3.20 (2.65)	0.471	2.29 (1.71)	1.90 (1.25)	0.228
	0.51-1.93	7.83 (3.12)	7.10 (4.63)		2.92 (1.91)	2.65 (2.55)		1.90 (1.26)	1.60 (1.20)	
	>1.93	7.20 (2.76)	6.90 (2.50)		3.03 (1.46)	2.80 (1.45)		1.92 (1.00)	1.70 (1.15)	
Noise (dBA)	<85.71	7.52 (2.72)	7.05 (3.52)	**0.001**	3.29 (2.42)	2.75 (1.80)	0.086	1.86 (0.98)	1.70 (1.00)	**0.007**
	85.71-92.69	8.66 (3.30)	7.50 (4.38)		4.11 (4.85)	3.10 (2.00)		2.61 (1.83)	2.00 (2.10)	
	>92.69	6.62 (2.37)	6.65 (1.98)		2.91 (2.75)	2.50 (2.45)		1.63 (0.87)	1.60 (1.33)	

* Mean differences of hormone levels between categorized values of exposure

Table 5. Mean testosterone levels in the manufacturing sections under study.

Exposure	**Categorized values**	**Manufacturing Section**												**P-value*****	**P-value******
		Aluminum (N=39)				**Cast Iron (N=71)**				**Grinding (N=52)**					
		Aged 20-39 (N=23)	**P-value***	**40 and Above (N=16)**	**P-value****	**Aged 20-39 (N=40)**	**P-value**	**40 and Above (N=31)**	**P-value**	**20-39 years old (N=37)**	**P-value**	**40 years and older (N=15)**	**P-value**		
WBV (m/s^2)	**<0.51**	7.69 (4.41)	0.626	7.73 (2.22)	0.238	7.79 (2.30)	0.526	7.42 (1.61)	0.790	8.67 (4.19)	0.201	6.53 (0.56)	0.995	0.805	0.612
	0.51-1.93	9.27 (2.90)		9.30 (2.08)		9.26 (3.23)		7.50 (2.64)		6.72 (2.55)		6.38 (4.34)		**0.037**	0.426
	>1.93	8.20 (1.78)		6.56 (0.93)		7.89 (3.60)		6.92 (2.24)		6.60 (1.75)		6.28 (2.59)		0.565	0.857
Noise (dBA)	**<85.71**	7.85 (4.03)	0.776	-	0.709	7.69 (3.08)	0.200	7.26 (2.17)	0.971	-	**0.001**	-	0.193	0.946	0.944
	85.71-92.69	8.75 (3.99)		7.96 (2.18)		9.70 (3.51)		7.27 (1.88)		11.52 (2.83)		-		0.261	**0.047**
	>92.69	7.50 (0.88)		-		-		6.90 (0.70)		6.28 (2.15)		6.67 (3.07)		0.056	0.920

* Mean differences of testosterone levels between categorized values of exposure (20-39 years old)
** Mean differences of testosterone levels between categorized values of exposure for (40 year old and above)
*** Mean differences of testosterone levels between different manufacturing sections (20-39 years old)
**** Mean differences of testosterone levels between different manufacturing sections (40 year old and above)
-Normal range of testosterone for 20-39 years of age is 9.2-34.6 pg/ml
-Normal range of testosterone for 40 years and above is 6.1-30.3 pg/ml

Table 6. Results of the logistic regression test for demographic and exposure variables with testosterone levels for participants aged 20 to 39.

Variable		**Simple Logistic Regression**		**Multiple Logistic Regression**	
		Exp (B)	**95% Confidence Interval**	**Exp (B)**	**95% Confidence Interval**
Whole body vibration		1.299	0.971-1.738	1.378	0.947-2.006
Noise		1.050	0.998-1.116	1.116	0.982-1.268
Age		1.050	0.965-1.144	0.986	0.869-1.118
Duration of Employment		1.015	0.933-1.105	-	-
BMI		1.094	0.973-1.231	1.238	1.048-1.464
WHR		1.107	0.021-59.241	-	-
Smoking Status (Smokers)		0.908	0.399-2.067	-	-
Marital Status (Married)		2.364	0.946-5.909	5.216	1.115-23.568
Working Unit	**Aluminum**	0.418	0.137-1.275	0.389	0.067-2.241
	Cast Iron	0.482	0.181-1.287	0.362	0.041-3.193

Table 7. Results of the logistic regression test for demographic and exposure variables with testosterone levels for participants aged 40 and above.

Variable		**Simple Logistic Regression**		**Multiple Logistic Regression**	
		Exp (B)	**95% Confidence Interval**	**Exp (B)**	**95% Confidence Interval**
Whole body vibration		1.179	0.863-1.611	1.126	0.811-1.563
Noise		1.001	0.940-1.078	-	-
Age		0.981	0.817-1.178	-	-
Duration of Employment		0.929	0.867-1.025	0.944	0.847-1.563
BMI		0.999	0.842-1.150	-	-
WHR		0.978	0.017-57.092	-	-
Smoking Status (Smokers)		0.853	0.265-2.747	-	-
Marital Status (Married)		-	-	-	-
Working Unit	**Aluminum**	0.346	0.068-1.759	0.422	0.811-1.563
	Cast Iron	0.438	0.115-1.659	0.944	0.847-1.052

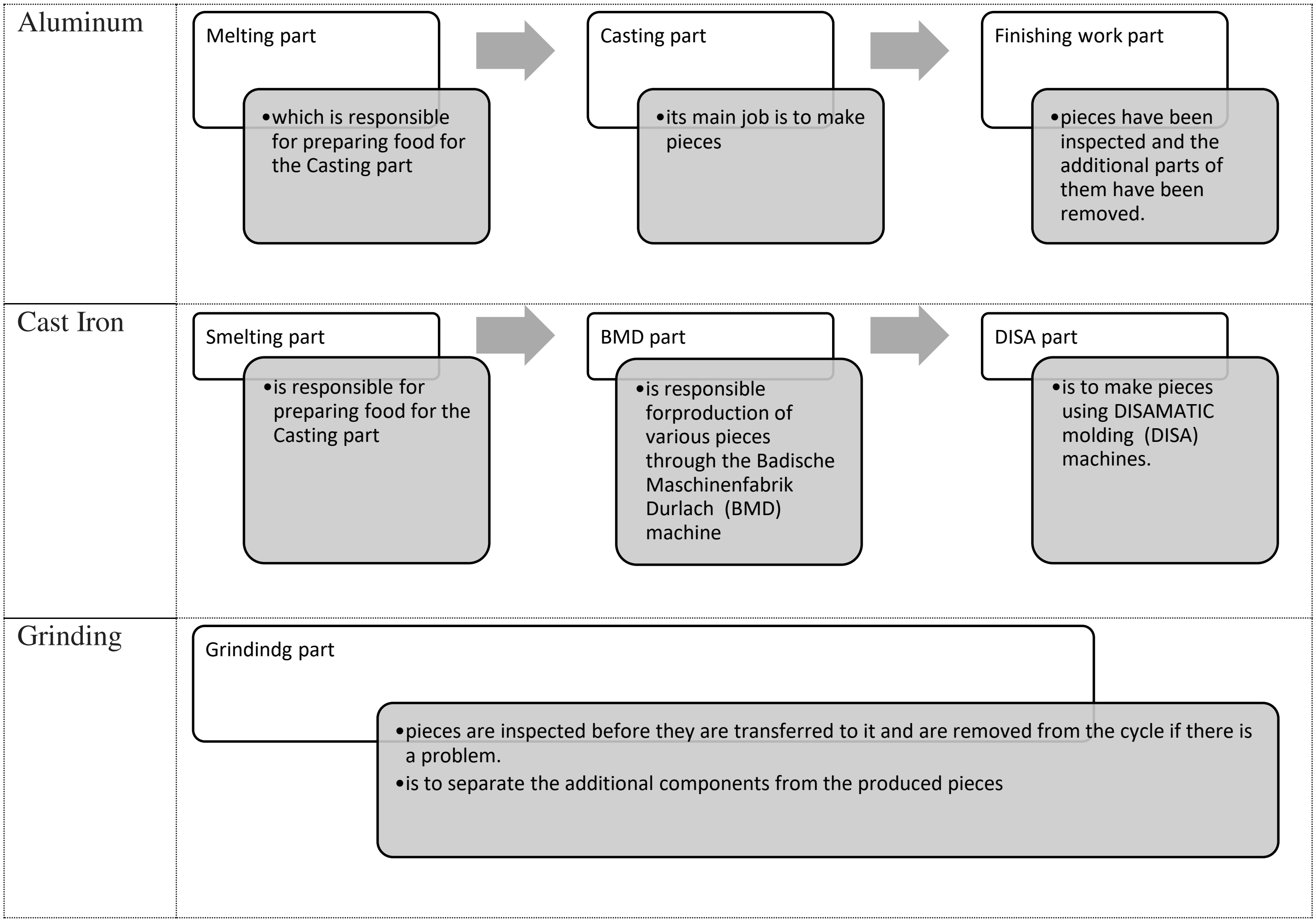

Figure 1. The process flowchart of the studied sections

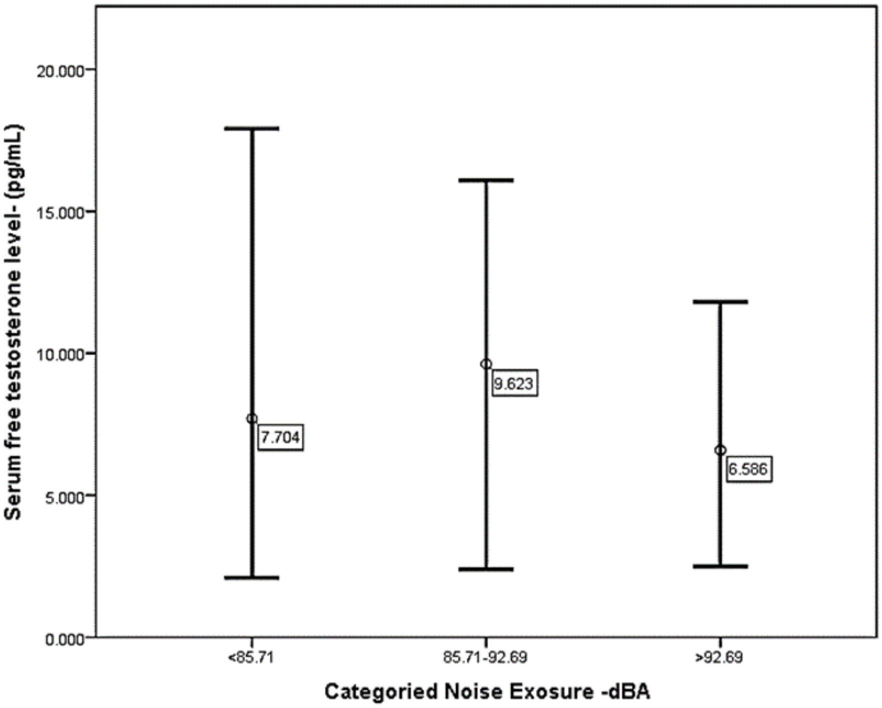

Figure 2. Mean testosterone levels under various noise exposure scenarios among participants aged 20 to 39 years old.

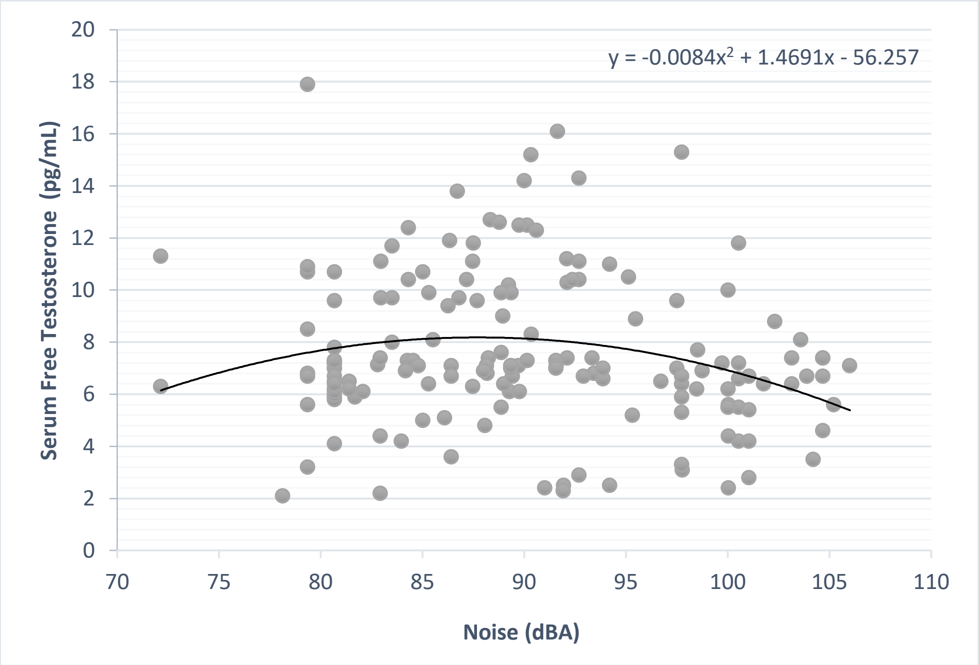

Figure 3. Changes in free testosterone levels relative to changes in noise exposure levels.

Figures

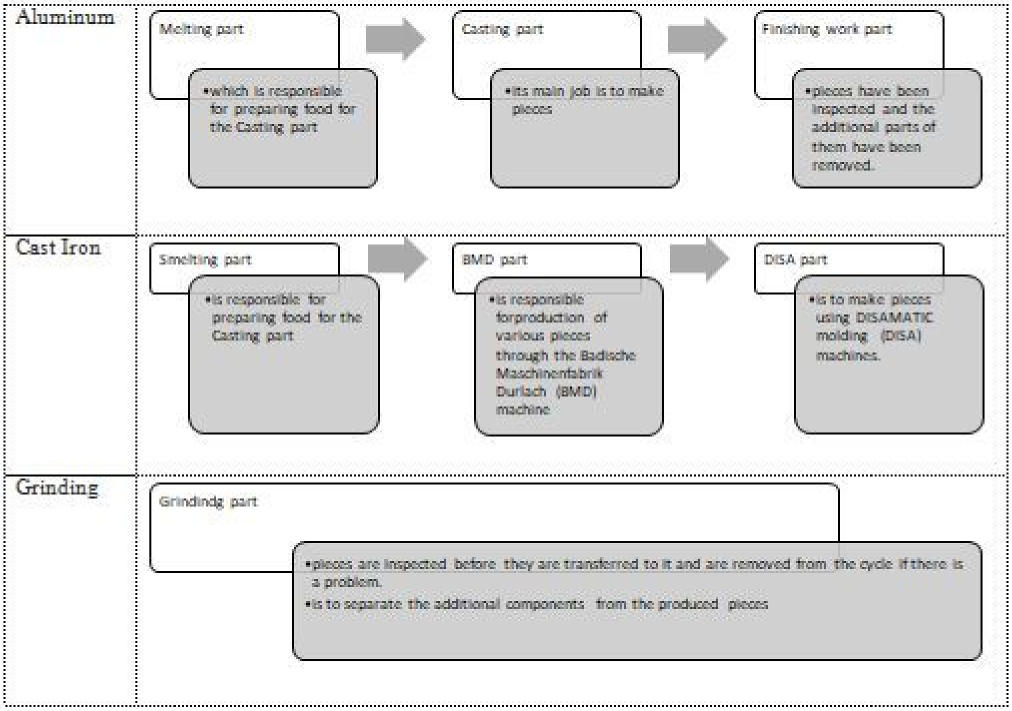

Figure 1

The process flowchart of the studied sections

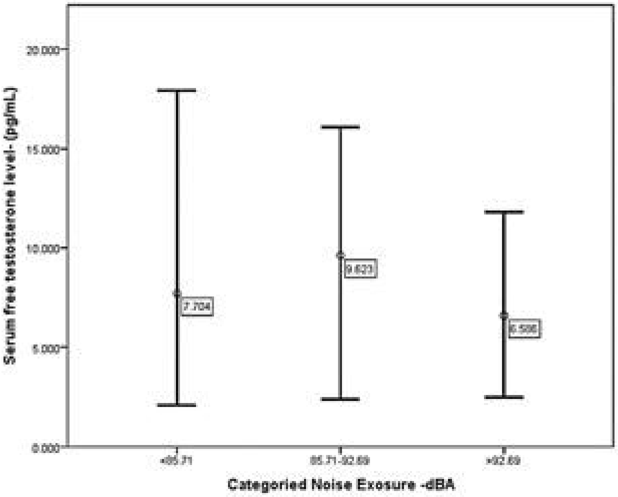

Figure 2

Mean testosterone levels under various noise exposure scenarios among participants aged 20 to 39 years old.

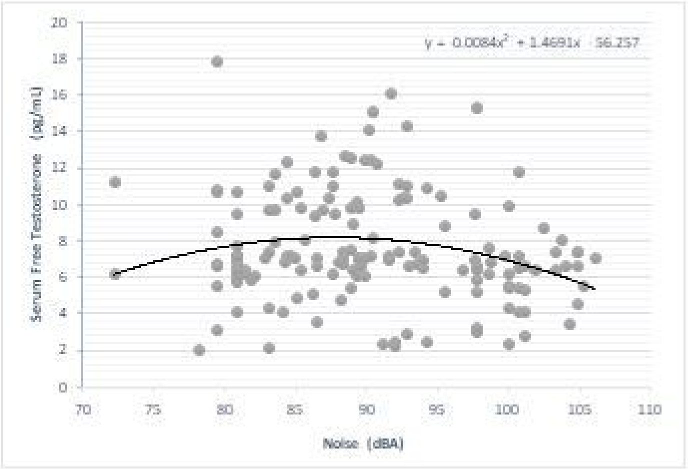

Figure 3

Changes in free testosterone levels relative to changes in noise exposure levels.