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EFFECTS OF VIBRATION, FEED FORCE AND EXPOSURE DURATION ON OPERATORS PERFORMING DRILLING TASK

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It has been shown that vibration level, feed force, and exposure duration cause unfavourable effects on the work performance when hand-held vibrating tools are used by operators. Present study analyzed the effects of these variables on the heart rate and blood pressure of the operators carrying out the drilling task. Under three different levels of vibration (0.3, 0.5, and 1m/s^2), the operators performed the drilling for 3 minutes with three different levels of feed force (100, 200, and 300 N) in study 1, and for three different durations (10, 15, and 20 min) with a feed force of 200 N in study 2. Thirty male subjects participated in the two studies and data were analyzed on the basis of two factor repeated measure kind of experimental design. Results showed that in the kind of drilling task undertaken the level of vibration was statistically significant. However, the main effects of feed force and vibration exposure duration were statistically insignificant. These findings are discussed in the light of previous researches conducted on the subject.
Key Words: manual drilling task; vibration level; feed force; exposure duration; heart rate; blood pressure

INTRODUCTION

The hands and arms of operators performing industrial tasks are subjected to vibration of different intensities generated from vibrating tools, vibrating machinery or vibrating workpieces. According to National Institute for Occupational Safety and Health (1989), vibration-induced hand problems are common among workers exposed to vibration with reported prevalences ranging from 6% to 100%. Depending on the type and place of work, vibration from the hand-held tools can usually enter one arm only or both arms simultaneously, and may be transmitted through the hand and arm to the shoulder.

The induced vibrations in different body parts are responsible for the discomfort and possible reduced proficiency. Guillemin and Wechsberg (1953) showed that the use of vibrating tools for a long period of time caused disabilities in humans. Greenstein et al. (1998) also observed that 'white finger' was an occupational disorder associated with long term exposure to hand transmitted vibration.

Burstrom (1997) reported that the mechanical impedance of human hand and arms system during exposure to random vibration was dependent on frequency of the vibration. Griffin (1997) suggested that the frequency of vibration influenced both the manner and the extent to which the vibration was transmitted through hand-held machinery. Radwin et al. (1987), while investigating the short term effect of hand tool vibrations and their relation to the force exerted in intensive hand works, found an increase in average grip force requirement. Many vibration exposed workers have been found to suffer from muscle fatigue and decreased grip strength (Miyashita et al., 1983; Pyykko et al., 1986a). Various other researchers (Griffin et al., 1982; Starck, 1984; Donati et al., 1993;

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Hartung et al., 1993; Burstrom and Lundstrom, 1994; Mano, 1994) have reported a wide range of disorders from exposure to vibrations. Exposure variables are important factors for assessing the effects of vibration on human hand and arm system.

In the manual drilling task, it was observed as above that variables such as feed force, frequency of vibration, magnitude of vibration and exposure time have an important bearing on the operator. Keeping this in view the problem was formulated to study the performance of the operator in a manual drilling kind of task. The experimental hypothesis structured was as follows: the vibration level, feed force and exposure duration have a significant effect on operator's heart rate and blood pressure while carrying out the manual drilling task. To test the hypothesis, experimental investigations were carried out as detailed below.

METHODS

Subjects

Thirty healthy male subjects participated in the two studies described below. Mean height, weight, and age of the subjects are shown in Table 1. The subjects selected were not having any experience in the field of manual drilling operation. This helped in avoiding biasedness, if any, due to the subject's earlier experience in the area. The informed written consent was obtained from each of the subjects before the experimental task according to the Declaration of Helsinki.

Table 1. Characteristics of the subjects participated in different experimental investigations.

Characteristics	Mean	SD
Age (years)	24.7	1.42
Height (mm)	1680	3.01
Weight (kg)	58.5	2.4

Experimental task and procedure

Each subject was required to drill the workpiece material (die steel plate) in an upright standing position as shown in Figure 1. In study 1, the subjects performed the drilling at various feed forces, i.e. 100 N, 200 N, and 300 N under varying levels of vibration, i.e. 88dB (0.3 m/s^2), 94dB (0.5 m/s^2) and 100dB (1.0 m/s^2) for a period of 3 minutes in each experimental condition. Thus a total of 3 x 3 = 9 conditions were generated, which took 9 x 3 = 27 minutes for each subject. The feed forces were obtained by increasing the muscle exertion up to the required level without changing the upright posture. In study 2, the drilling operation was carried out at a feed force of 200 N for varying exposure durations, i.e.10 min, 15 min, and 20 min under the three different levels of vibration stated above. Carrying out the 3 x 3 = 9 conditions took 135 min in total for each subject.

The subject took position in front of a polaroid glass window and a buzzer was used to give signal for starting and finishing the drilling task. Polarity of the glass was arranged in such a way that the observer could watch the task performed without hindrance while the subject was unable to see outside the chamber. All the studies were carried out between 900 hrs and 1300 hrs.

Vibration axis and vibration magnitude

ISO 5349- 1986 has recommended that for multi-axis vibration the assessment be based upon the component with the largest vibration acceleration. Accordingly, the vibrations generated through the drilling task were recorded in x, y, and z directions referring to the recommendations of ISO 5349-1986 that the orientation of the coordinate system for vibration measurement may be defined with reference to an appropriate basicentric coordinate system, originating, for example, in a vibrat-

Figure 1. Posture adopted while performing the experimental task.

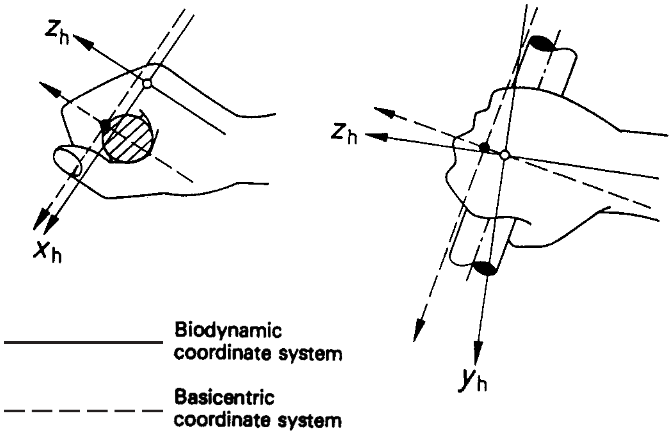

Figure 2. Biodynamic and basicentric coordinate systems (ISO 5349-1986).

ing appliance, workpiece handle, and control device gripped by the hand (Figure 2). It was observed that the level of vibration was higher in z direction in comparison to the other two axes. Thus z-axis vibrations were selected for carrying out experimental investigations in the present work.

Performance measure

In both studies 1 and 2, heart rate and blood pressure were used as a measure of human performance. Recent biomedical research has revealed that heart is a great information processor which continuously communicates with the brain and other body parts with the help of nervous system, hormonal system, etc (HeartMath Institute, USA). When a worker performs some physical task, active organs require more oxygen, which causes blood circulation to increase resulting in an increase in heart rate. Heart rate measurements have been used in the past by several researchers to study the task performance of operators using chainsaws and skidders (Wasterlund and Kufakwandi, 2003). Jang et al. (2002) also showed a significant prevalence of vascular and neurological symptoms for workers exposed to hand-transmitted vibrations.

With the help of Pulse Oximeter, heart rate was continuously measured for 5 minutes immediately before and during the drilling task. The values so obtained were averaged for the pre-task 5 minutes and for the duration of the drilling task, respectively, and the difference between the former and the latter was obtained as an indicator of physiological response of the subject.

Blood pressure in mm of Hg was also measured in the present study to be further sure about the influence of vibration on operators (Bovenzi and Griffin, 1997; Lindsell and Griffin, 1999; Laskar et al., 1999). Systolic and diastolic blood pressures were obtained in both arms by using a digital blood pressure meter immediately before and after performing the task. No significant difference was observed between the values in both arms.

Experimental setup

Experiments were conducted in the simulated environment of industrial task. The setup (Figure 3) comprised of the following subsystems: Vibration level meter (VR 5100, Ono Sokki Co. Ltd., Japan); Drill tool dynamometer (IEICOS, Model-600B); portable drilling machine (General Duty, ϕ13 mm, 435 W); Pulse Oximeter (Model 400, Palco Labs, CA, USA); electronic digital blood pressure meter (A & D Co. Ltd., Model: UA 767, Japan); vice for holding the workpiece; die steel material for drilling (T160Cr12).

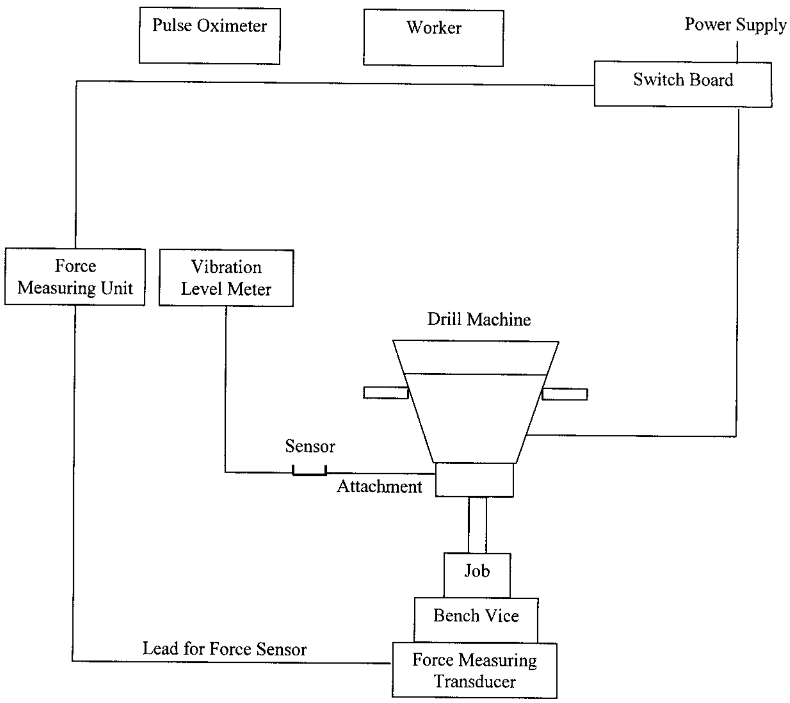

Figure 3. Schematic diagram of the experimental setup.

Vibration level meter: The vibration level meter, conforming to the measurement law of Japan and the Japanese Industrial Standards, JIS C 1510- 1976, was used for measuring vibration levels in three directions. This equipment which processes the rms value circuit and other circuits in digital can calculate time rate level and equivalent vibration level in three directions simultaneously. Also this instrument can send data of DC level output to a three-channel pen recorder.

Drill tool dynamometer: It measures the force of the drill bit on the work piece and can be bolted directly on the bed of the machine using slots provided. The specimen is fixed using a vice or a fixture. The sensing portion of the drill dynamometer is bonded with strain gauge bridge to sense the load.

Drilling machine: The portable drilling machine weighed 4.9 Kg and can accommodate a drill up to 13mm in diameter. The spindle speed of the machine at no load was 700 rpm while at full load it was 475 rpm. The wattage of the machine was 435 watts.

Pulse Oximeter: This is a portable device designed and calibrated to non-invasively monitor heart rate (beats/min) and percentage of oxygen saturation of functional hemoglobin. Arterial oxygen saturation measurement is obtained by directing red and infra-red light through a pulsating vascular bed. The pulsating arterioles in the path of the light cause a change in amount of the light detected by a photodiode. The Oximeter measures within the pulse wave form the ratio of transmitted red to infra-red light and thereby determines the oxygen saturation of arterial blood.

For measuring heart rate during the drilling, a large-sized soft sensor was placed on the index finger of the right hand of the subjects and the measurements were obtained without causing any inconvenience or discomfort to them.

Statistical analysis

A two factor ANOVA was carried out to analyze the data collected. The independent variables selected were vibration level and feed force for study 1 and vibration level and exposure duration for study 2, respectively. The dependent variables used in both studies were heart rate and blood pressure, both systolic and diastolic.

RESULTS

As shown in Table 2, the results of the study 1 involving feed force and vibration level indicated that the main effect of vibration level was statistically significant ($p<0.01$) in the kind of the task undertaken. However, the main effect of the feed force and interactive effect of feed force and vibration level were found to be statistically insignificant. Table 3 illustrates the results of the study 2 involving vibration level and exposure duration. It was shown that the main effect of vibration level was statistically significant ($p<0.01$), while the main effect of exposure duration and the interactive effect of exposure duration and vibration level were insignificant.

Similar results were obtained when the analysis was carried out using blood pressure measurements (both systolic and diastolic) as presented in Tables 4 and 5.

The relationships between the heart rate increase during the drilling and the level of vibration under different levels of feed force and exposure duration are illustrated in Figures 4 and 5. Through the regression analysis, the relationships were found to be linear in nature. The best fit linear models along with the correlation coefficient (r) for each of the varying levels of feed force and exposure duration were calculated as follows, where H and V denote, respectively, rise in heart rate and the level of vibration during the drilling:

Table 2. ANOVA results when operators performed the drilling task under varying levels of vibration and feed force (heart rate measure) – Study 1.

Source of variation	df	MS	F-value
Feed force	2	11.46	0.97
Vibration level	2	274.4	23.31*
Feed force × Vibration level	4	10.27	0.87
Within treatments (error)	36	11.77	-

*$p< 0.01$

Table 3. ANOVA results when operators performed the drilling task under varying levels of vibration and exposure duration (heart rate measure) – Study 2.

Source of variation	df	MS	F-value
Exposure duration	2	18.49	2.70
Vibration level	2	203.29	29.72*
Exposure duration Vibration level	4	1.29	0.19
Within treatments (error)	36	6.84	-

*p<0.01

Table 4. ANOVA results when operators performed the drilling task under varying levels of vibration and feed force (blood pressure measure) – Study 1.

Source of variation	df	Systolic blood pressure (mm Hg)		Diastolic blood pressure (mm Hg)	
		MS	F-value	MS	F-value
Feed Force	2	5.4	0.25	21.69	2.21
Vibration level	2	285.42	13.38*	187.29	19.11*
Feed force Vibration level	4	5.05	0.23	5.55	0.57
Within treatments (error)	36	21.33	-	9.8	-

*p<0.01

Table 5: ANOVA results when operators performed the drilling task under varying levels of vibration and exposure duration (blood pressure measure) – Study 2.

Source of variation	df	Systolic blood pressure (mm Hg)		Diastolic blood pressure (mm Hg)	
		MS	F- value	MS	F- value
Exposure duration	2	21.07	1.33	11.29	2.67
Vibration level	2	326.67	20.64*	117.96	27.95*
Exposure duration × Vibration level	4	5.73	0.36	7.68	1.82
Within treatments (error)	36	15.82	-	4.22	-

*p<0.01

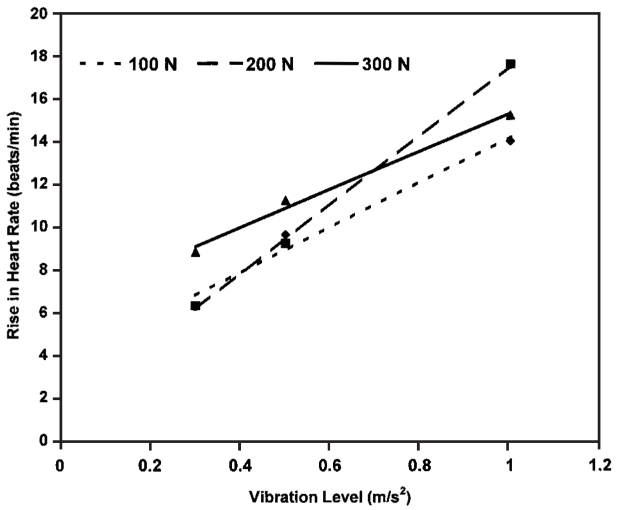

Figure 4. Variation in heart rate (beats/min) with vibration under varying levels of feed force.

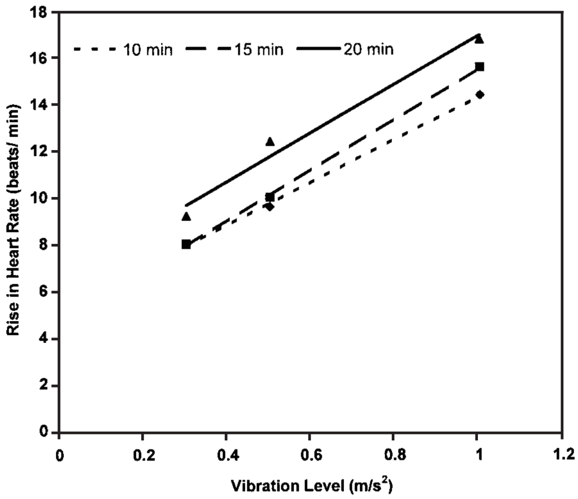

Figure 5. Variation in heart rate (beats/min) with vibration under varying levels of exposure duration.

(i) For a feed force of 100N
H = 3.621 + 10.58V (*r* = 0.97)
(ii) For a feed force of 200N
H = 1.272 + 16.27V (*r* = 0.99)
(iii) For a feed force of 300N
H = 6.379 + 8.92V (*r* = 0.99)
(iv) For an exposure duration of 10 minutes
H = 5.182 + 9.23V (*r* = 0.99)
(v) For an exposure duration of 15 minutes
H = 4.646 + 10.92V (*r* = 0.99)
(vi) For an exposure duration of 20 minutes
H = 6.523 + 10.46V (*r* = 0.97)

DISCUSSION

Although the operation of drilling is very common in small and medium scale industries, it has attracted relatively little interest in recent researches from the hand-arm vibration point of view. Results obtained in the present study showed that the level of vibrations generated while performing manual drilling task had a statistically significant effect on operators. A plausible explanation is that the vibrations, although the mechanism is not clear, caused an increase in the peripheral vascular resistance, thus leading to a higher blood pressure and reduced blood circulation. Under these circumstances, in order to meet the raised O_2 requirement due to muscle contractions, heart rate had to be increased.

These cardiovascular responses naturally mean an occurrence of unfavorable physical load in the operator. Such a finding is in line with those in other studies which have shown that hand held vibrating tools affect operators in negative ways. Workers using the tools have been found to suffer from pains, muscular weakness and fatigue causing a reduction in their performance. Pyykko et al. (1982, 1986), while studying forestry workers using gasoline powered chain saws, found that 34% of them were having hand arm vibration syndrome (HAVS).

Other investigators like Burstrom and Lundstrom (1994) and Mano (1994) have reported various disorders in manual workers exposed to vibrations. Less skilled workers were more prone to damage by vibrations due to their increased transmission to the hand and arm (Teisinger, 1972).

With regard to the relationship between the contact forces (grip force, feed force) and vibrations, it has been shown that these forces increased in the presence of hand-tool vibrations (Radwin et al., 1987) or with increase in the level of vibration (Brustrom and Sorensson, 1998; Nishiyama et al., 1996; Hartung et al., 1993) and decreased over time due to muscle fatigue (Brustrom and Sorensson, 1998). The study conducted by Burstorm (1997) on the influence of biodynamic factors on the mechanical impedance of hand and arm revealed that an increased feed force gave higher impedance as the system became stiffer and more mass-like.

However, the effects of contact forces on the physiological aspects of operators appear not to have been reported yet. In the present study, effects of the feed force were statistically insignificant when the operators were exposed to a vibration level between 0.3 and 1m/s^2. This appears unreasonable because the feed force of 20 to 30 kg must accompany static muscle activities of substantial intensity. The venous occlusion occurring in the vigorously contracting muscles may prevent the washing out of harmful metabolites including lactic acids, which inevitably evoke muscular fatigue and consequently induce a strenuous exertion causing an increase in heart rate and blood pressure.

A possible reason for this discrepancy may be that the vibrations transmitted to the contracting muscles have canceled out the occluding effects and even facilitated blood circulation, thus relieving the heart from beating more frequently against higher resistance. Despite that the two-way ANOVA in this study failed to show any significant interaction between feed force and vibration level, this does not necessarily negate the possibility of the interaction with vibrations higher than 1m/s^2. However, if the above reasonings are correct, the feed force would not affect the cardiovascular conditions interactively with the vibration level.

The other variable investigated in our study was exposure duration. Previous researches have shown that problems associated with the exposure to occupational hand-arm vibration increased with the continued exposure to vibration (Dong et al., 2004; Wang et al., 1999; Peterson et al., 1995; Pyykko, 1986). Nagata et al. (1993) established a dose-response relationship between the prevalence of Raynaud’s phenomenon and duration of exposure to vibration. They found an increase in odds ratio of Raynaud’s phenomenon in groups with long term vibration exposure. Even if the duration was short, there were significant effects when exposed to a vibration level of 3.5 m/s^2 (Barregard et al., 2003) .

Studies have also indicated that there was an improvement in vibration white finger when the operators were not exposed to vibrations (Futatsuka et al. 1985). The investigations regarding the daily exposure duration are important, as reduction in duration of exposure may sometimes be more feasible in comparison to reducing the magnitude of vibration (Griffin, 1997).

In the present study, the two way ANOVA revealed neither statistically significant main effect of exposure duration nor significant interaction between exposure duration and vibration level. However, the subjects performing manual drilling task were exposed to vibrations of 1m/s^2 in maximum. Vibrations generating acceleration of 1m/s^2 has been considered by some researchers as the threshold level below which no noticeable adverse effects would be observed in workers (Brammer, 1982; Miura et al., 1959). Musson (1989) also found no association of vibration with the duration of exposure. Considering the situations shown above, possibility may exist that the duration of exposure affect the physiological responses interactively with vibrations more intense than 1m/s^2.

Since the level of vibration was found in our study to have an adverse effect on the cardiovascular conditions of drilling task operators, we may tentatively conclude that steps should be taken to design and use such type of tools which generate less vibrations.

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