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Physiological Effect of Vibrations on Tractor Drivers under Variable Ploughing Conditions

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Abstract: Physiological Effect of Vibrations on Tractor Drivers under Variable Ploughing Conditions: Mohammad MUZAMMIL, *et al*. Department of Mechanical Engineering, Ergonomics Laboratory, Faculty of Engineering & Technology, Aligarh Muslim University, India—The vibration conditions to which tractor operators are subjected are complex and varied with multi axis translation and rotational vibration inputs to different parts of the body. Working under such conditions may lead to human fatigue and other driving related hazards. The present research was carried out to study the operators under varying conditions of vibration while driving a tractor with and without farm equipment on different fields. Test runs were conducted in wet and dry fields to determine the levels of vibration generated at different engine speeds. On the basis of this study three levels of vibration namely 2.5, 3.5 and 5.0 m/s^2 were selected. Five subjects, all males, with no experience in the field of tractor driving participated in the study. The data were analyzed on the basis of three factor repeated measure kind of experimental design. The results showed that the main effects of farm equipment and the vibration level were statistically significant but the effect of field type was found to be statistically non-significant. The results of the study call upon the ergonomists to design and develop a tractor where the driver may be relieved of vibration induced stresses. Front loading of farm equipment is recommended for improved visibility and better working posture.
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Key words: Vibration level, Pulse rate, Farm equipment, Field

A large percentage of the work force in the world is associated with agriculture or related trades. Farm workers functioning as the drivers of agricultural tractors are exposed to whole body vibrations, which may be extremely severe depending upon such factors as the attached farm equipment, speed of travel, condition of the field, etc. These vibrations are extremely complex and varied, with multi-axis translational and rotational vibration inputs to different parts of the body. Working under such an environment results in human fatigue, which contributes to driving related accidents and other health hazards. The vibrations produced by tractors and other off road vehicles and earth moving machinery were found to have a detrimental effect on the driver's performance (Rosegger and Rosegger; Grandjean; Goglia *et al.*)[1–3]. Decrements in occupational performance were also observed by Wertheim[4] while evaluating the effect of the moving environment on operators. Several studies conducted by Milosevic[5] on drivers of heavy vehicles revealed significant changes in body temperature, diastolic blood pressure and an increase in accommodation visual reaction time after prolonged driving. Longer exposure duration while performing ploughing and harrowing operations may also cause severe discomfort, pain and injury (Mehta *et al.*)[6]. Increased risks for low back pain (LBP) disorders were reported by Bovenzi[7] among tractor drivers due to continuous exposure to whole body vibration (WBV). Similar results were obtained by Toren *et al.*[8] while quantifying tractor-driving time among Swedish farmers. It has also been shown that the vibration levels of heavy equipment such as tractors, dozers, skidders, etc., coincided with the most sensitive frequencies of the body organs and exceeded the International Standard Organization (ISO 1978)[9] guidelines for exposure to whole body vibration (Wasserman, Hanson and Wickstrom and Corolla)[10–12]. A study conducted by Rosegger[1] on health complaints among tractor drivers, revealed that spine disorders particularly in the lumbar and thoracic regions and stomach complaints were

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common among them due to long periods of tractor operation. Also tractor drivers were shown to be prone to haemorrhoids by Grandjean[2]. A high prevalence of degenerative changes in the spine of persons exposed to whole body vibration at work including truck, bus and earthmover drivers have also been reported (Dupuis and Zerlett)[13]. The damage to health caused by mechanical vibrations may be aggravated in the presence of attached farm equipment when ploughing is carried out. The literature review revealed that not much work has been done in the past to investigate the effect of farm equipment while ploughing. The type of field (wet or dry) on which ploughing is done might be another factor contributing to the increase in human fatigue. Although humans working under adverse conditions adjust themselves to the environment, the optimum range of any environmental factor for performance is very narrow. Keeping this in view, the present experimental investigation was carried out to investigate the effect of vibration on tractor drivers doing ploughing on different fields. The experimental hypothesis tested was as follows: "Driving agricultural tractors with or without farm equipment on different fields under varying levels of equivalent vibration has a bearing on the occupational performance of the operator". To test the hypothesis, experimental investigations were carried out as detailed below.

Methods

Subjects

Five subjects, all teetotalers, not consuming psychotropic drugs and enjoying sound health were selected for the present study (Table 1). The subjects selected did not have any previous experience of tractor driving. This helped to avoid any bias due to the subjects' earlier experience of driving. The subjects had normal vision and no previous history of neuromuscular disorders. All the experimental sessions were conducted between 10:00 and 12:00 h. Informed written consent was obtained from the subjects before performing the experimental task as per the Helsinki declaration.

Experimental Task

Each subject was given enough training to get him completely familiarized with the task. Each subject drove the agricultural tractor at varying levels of vibration with and without the attachment of farm equipment on dry and wet fields for a period of 60 min. While performing the experimental task, the level of vibration on both the fields was kept at a predetermined value by constantly monitoring it in x, y and z directions manipulating the speed of the tractor. A gap of one day was kept between two successive cycles of operation. The operator's performance was recorded in terms of heart rate with the help of a pulse oximeter. The subjects were asked to maintain a posture comfortable to them by adjusting the seat height and to maintain the backrest in contact while driving. A buzzer was used to signal starting the task. After the stipulated period of driving, the buzzer was operated again to mark the end of the experimental period.

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

Characteristics	Mean value	Standard Deviation
Age (yr)	26.4	2.4166
Height (cm)	173	4.36
Weight (kg)	56.6	4.2708

Statistical Analysis

A three factor ANOVA was carried out to determine the effects of parameters under investigation. The independent variables taken were type of field (two levels: wet and dry), levels of vibration (three levels: 2.5, 3.5 and 5.0 m/s^2) and farm equipment condition (two levels: with and without) while the dependent variable used was heart rate.

Performance Measure

Recent biomedical research has revealed that the heart is a great information processing center. The messages sent to the brain by the heart can influence performance, health, etc. in a significant way (HeartMath Institute, USA)[14]. Heart rate (ECG) has been used as a physiological measure of workload during driving (Lal)[15]. Studies have shown that exposure to mechanical vibration was responsible for overtaxing of the sympathetic nervous system of the operator (Uchikune)[16]. Increase in exposure to vibration has been found to augment the heart rate and the change in the heart rate was independent of the mode of transport (Uchikune)[16]. Heart rate is affected by not only physical factors but also by mental stress. According to Hennessy[17] mental stress may be encountered due to various factors such as rush hour congestion, driving closely behind other vehicles, avoiding the blinding high beam, reaching a destination on time and traffic jams, etc. In the present study, the effect of mental stress on heart rate was minimized by ensuring the sound sleep of the subjects, selecting those subjects who were teetotalers, not taking drugs or smoking and not involved in any type of physically strenuous work for at least six hours before the experiment. The other factors as given by Hennessy[17], which might contribute to mental stress did not have any bearing on the ploughing operation and therefore did not affect the operator. Hence it were the physical factors only which were more pronounced in the task of tractor driving. To carry out physical work, muscle action is required for which more oxygen was needed. Increase in the demand of oxygen resulted in an increase in heart

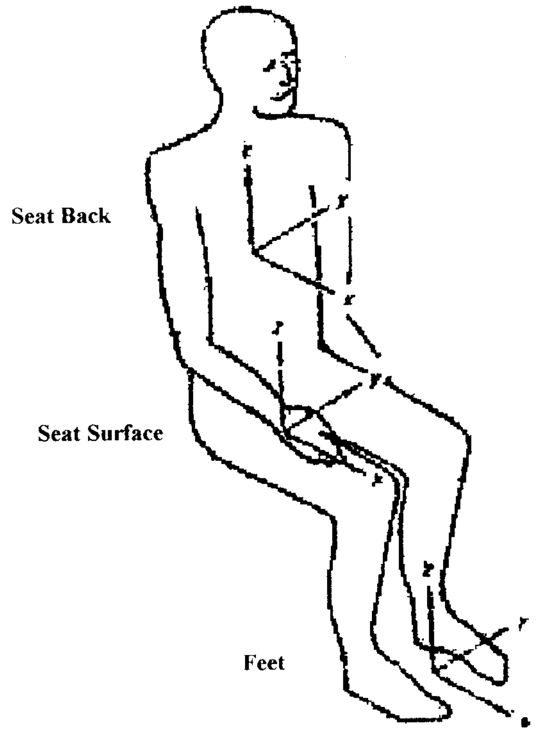

Fig. 1. Whole body vibration biodynamic coordinate system for seated subject.

rate (Porges)[18]. Porges[18] also suggested that heart rate was the most sensitive cardiovascular index of the work load and the fatigue associated with driving. Thus heart rate has been used as a physiological indicator for measuring the performance of the operator in the present work.

Vibration Measurement

The vibration level meter (VR 5100, Ono Sokki Company Limited, Japan) conforms to the measurement law of Japan and the Japanese Industrial Standards (JIS C 1510–1976) and is used for measuring vibration levels in three different directions. This equipment processes the root mean square value of the equivalent vibration level in three directions simultaneously. Root mean square is the square root of the arithmetic mean of instantaneous values (amplitude or acceleration) squared. Root mean square acceleration gives the total energy across the entire range. The weighted rms acceleration is expressed in m/s^2 and is calculated by the following equation.

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

Where, $a_w(t)$ is the weighted acceleration as a function of time in m/s^2 and T is the duration of measurement in seconds.

ISO 2631-1 (1997)[19] has provided frequency-weighting curves for various directions. The vibration pickup (NP-7210) containing three independent shear type piezoelectric elements for detecting signals was placed on the driver's seat. The vibration levels were measured with respect to the standard biodynamic coordinate system according to ISO-2631-1 (1997)[19] at the person seat interface in longitudinal, lateral and vertical directions (Fig. 1). The vibration level meter was calibrated in x, y and z directions prior to measurement. The measuring range of the equipment and measuring frequency range were 30 to 120 dB and 1 to 90 Hz respectively. To check the suitability of the basic evaluation method, the crest factor was calculated for x, y and z directions. According to ISO 2631-1 (1997)[19], the crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency weighted acceleration signal to its rms value. The peak shall be determined over the duration of measurement. The crest factor values for x, y and z directions obtained were within the limits prescribed by ISO 2631-1 (1997)[19]. As per ISO 2631-1 (1997)[19] recommendations, for vibration with crest factors below or equal to 9, the basic evaluation method is normally sufficient.

Vibration Levels

A study was carried out to determine the level of vibration in x, y and z directions to which the operators were subjected while driving a tractor on different fields at various speeds as shown in Table 2. The total equivalent vibration of weighted rms acceleration was calculated as per the recommendations of ISO 2631-1 (1997)[19]

Resultant Total Vibration,

$$V = \left[k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2\right]^{1/2}$$

Where a_{wx}, a_{wy} and a_{wz} are the weighted rms acceleration in x, y and z directions and k_x, k_y and k_z are the multiplying factors. For the evaluation of the effect of vibration on health the values for multiplying factors given by ISO 2631-1 (1997)[19] are as follows: k_x=1.4; k_y=1.4; k_z=1.0. The factor 1.4 is the ratio of the longitudinal to the transverse acceleration limits for the frequency range in which humans are more sensitive. The level of vibration in the present study was kept at a predetermined value by constantly monitoring the vibration level in x, y and z directions and running the vehicle at the desired speed. The data so collected were transferred to a computer through an RS 232C interface to further confirm the level of equivalent vibration generated at a particular speed. Accordingly vibration levels were set at 2.5, 3.5 and 5.0 m/s^2 for both types of field.

Table 2. Weighted rms acceleration in x, y and z directions and the values for total vibration V at different speeds of the vehicle

Site	Speed (rpm)	Longitudinal a_x (m/s^2)	Lateral a_y (m/s^2)	Vertical a_z (m/s^2)	Resultant, V (m/s^2)
Dry Field Ploughing	1,000	1.0	1.2	1.9	2.65
	1,600	1.0	1.4	2.5	3.22
	2,000	0.99	1.4	5.0	5.359
Wet Field Ploughing	1,000	1.3	1.2	1.3	2.464
	1,600	1.3	1.5	2.0	3.084
	2,000	1.3	1.6	5.0	5.563

Agricultural Tractor and Farm equipment

SAME GREAVES 503 Tractor was used for carrying out the present study. The important specifications of the tractor were as follows:

Model	1,000.3 W
Type	4 Stroke, direct injection, water cooled.
Number of Cylinders	3
Maximum Power (at 2,350 rpm)	50 HP
Maximum Torque (at 1,200 rpm)	18.5 kg-m
Steering type	Recirculating ball type single drop arm.
Turning Radius (without brakes/ with brakes)	3,790/3,280 mm
Total weight	2,000 kg
Ground Clearance	370 mm
Brake	Hydraulic

As far as farm equipment was concerned, a cultivator manufactured by Mahindra, India was selected out of the several types available because of its wide use in ploughing operation. The specifications of the cultivator used were as follows

Model	HST-2511
Type	Spring loaded
Material	Alloy steel
Overall Length (mm)	2,415
Overall width (mm)	870
Overall height (mm)	1,130
Under frame clearance (mm)	552
Fore & Aft clearance (mm)	357
Weight (kg)	324
Compatible tractors	45 HP and above

Pulse Oximeter

The pulse oximeter is a portable device designed and calibrated to non-invasively monitor pulse rate (beats/min) and the percentage of oxygen saturation of functional hemoglobin. Non-invasive 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 light cause a change in the amount of 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. The non-pulsating signal is removed electronically for the purpose of calculation and therefore skin, bone and other non-pulsating substances do not interfere with the calculation of arterial saturation. To measure the pulse rate, a large, soft sensor is used as it fits the fingers of the subjects and tolerates a moderate amount of the subject's activity. The sensor should fit comfortably without constricting or compressing the digit.

Heart Rate Measurement

For measuring heart rate, a soft sensor was put on the index finger of the subject. Before applying the sensor to the subject the surface of the sensor was wiped with a soft cloth and warm water-antibacterial solution. All the surfaces of the sensor were dried thoroughly. The sensor was inserted gently until an audible "click" was heard indicating that the plug tab is latched in place. The pulse oximeter recorded the heart rate immediately before and after the task. The automatic recording was discontinued by powering off the instrument after completion of the task. The equipment was operated in normal ambient light conditions avoiding bright light or glare to ensure correct reading.

Results

The average heart rate values (in beats per minute) for both dry and wet fields are shown in Table 3. From the table it can be observed that there was a noticeable change in heart rate in the kind of task undertaken in the present study. The heart rate increased with the increase in the level of vibration in both dry and wet fields. The increase

Table 3. Average heart rate values under varying levels of equivalent vibration in dry and wet fields

Field condition	Equivalent Vibration Level (m/s²)								
	2.5			3.5			5.0		
	Heart Rate (beats/min)								
	Initial	Final	Variation	Initial	Final	Variation	Initial	Final	Variation
Dry Fieild									
Without Farm equipment	71.2	78.4	7.2	74	84.6	10.6	72.8	88.4	15.6
With Farm equipment	70.6	83.0	12.4	73.8	89.2	15.4	72.4	95.2	22.8
Wet Field									
Without Farm equipment	72.4	77.0	4.6	72.8	83.6	10.8	73.0	88.6	15.6
With Farm equipment	69.5	80.8	11.3	71	88.4	17.4	70.8	94.6	23.8

Table 4. ANOVA results when subjects performed the Ploughing task under varying levels of equivalent vibration under different fields with or without using farm equipment

Sources of variation	df	MS	F-value	*p*-value
Between Subjects	4	127.36		
Farm equipment (Factor A)	1	504.60	35.10	0.00
Field Type (Factor B)	1	8.07	0.56	0.458
Equivalent Vibration Level (Factor C)	2	673.62	46.86	0.00
Farm equipment × Field Type (A × B)	1	0.27	0.02	0.892
Farm equipment × Equivalent Vibration Level (A × C)	2	18.05	1.26	0.295
Field Type × Equivalent Vibration Level (B × C)	2	38.22	2.66	0.081
Farm equipment × Field Type × Equivalent Vibration Level (A × B × C)	2	5.12	0.36	0.703
Error	44	14.38		

was less predominant when the task was carried out without the ploughing equipment. The hypothesis structured in the present research was supported for the farm equipment type and equivalent level of vibrations while it was contradicted for the type of ploughing field. Results of the analysis of variance summarized in Table 4 indicate that the main effects of the vibration level and farm equipment were statistically significant, whereas the type of field was found to be statistically non-significant. Also, the interaction effects the farm equipment and field; farm equipment and equivalent vibration level; field and equivalent vibration level; farm equipment, field and equivalent vibration level were all observed to be statistically non-significant. Through the regression analysis the relationship between the heart rate response (beats/min) and the level of equivalent vibration (V) under different field conditions was explored and found to be linear in nature. The best-fit models along with the correlation coefficients (r^2) for the varying levels of vibration (Fig. 2) are shown below.

(i) For wet field with farm equipment
$H_{P1}=74.133 + 6.9\ V$ ($r^2=0.99$)
(ii) For wet field without farm equipment
$H_{P2}=71.467 + 5.8\ V$ ($r^2=0.99$)
(iii) For dry field with farm equipment
$H_{P3}=76.931 + 6.1\ V$ ($r^2=0.99$)
(iv) For dry field without farm equipment
$H_{P4}= 73.8 + 5.0\ V$ ($r^2=0.98$)

Where H_{P1}, H_{P2}, H_{P3} and H_{P4} represent human performance (heart rate measure) and V is the level of equivalent vibration.

Discussion

Results of the study showed that the vibrations generated during tractor driving and the presence of tractor farm equipment have a strong statistically significant effect on operators. Although one could hardly find a study involving an investigation of the vibration effects on operators of agricultural tractors on different fields, other researchers working on similar topics (Porges, DeWaard and Kjellberg *et al.*)[18, 20, 21] have shown that whole body vibrations encountered in moving heavy vehicles affect the operators in a negative significant way. While carrying out the task of driving, operators exposed to vibration require an extra effort to ward off its effect. If the level of vibration is within the permissible limits, the muscular energy metabolism is largely aerobic and hence the fatigue would appear late. But under stressful

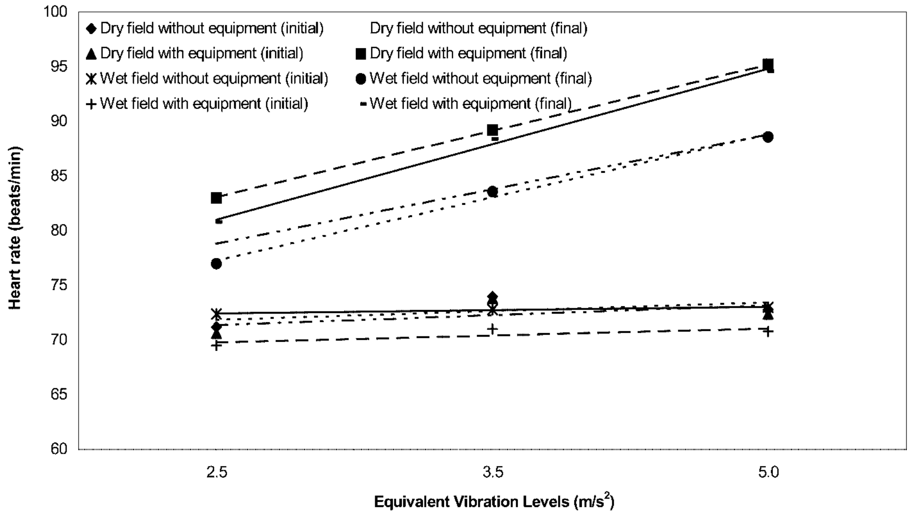

Fig. 2. Effect of vibration level on human fatigue (heart rate measure) under different fields and farm equipment conditions.

vibration conditions, the oxygen requirement of the muscles is much more than the oxygen available through the circulation. The resultant accumulation of lactic acid; greater effort on the part of the muscles, neuronal (spinal) and neuromuscular junction give rise to fatigue in a short time. Many researchers (Grandjean, Seidel and Heide)[2, 22], have concluded that physiological damage occurred when subjects were exposed to vibrations. Low back pain, postural stress and hemorrhoids, physiological fatigue (Bovenzi, Grandjean, Mehta *et al.*)[7, 2, 6] are a few of the manifestations of exposure to whole body vibration. Since employing a tractor for ploughing and transportation is very common in all the agro based industries of the world, the large number of workers associated with the trade should be provided with a better working environment, as the operators' immediate workplace affects their performance significantly. Studies conducted by Harrison and Wickstrom[11] and Crolla *et al.*[12] have revealed that vibration levels of heavy equipment such as tractors and scrapers concided with the most sensitive frequencies of the body and exceeded the international standards agencies guidelines for exposure to whole body vibration. In this context there is a great need to design and develop a tractor, keeping in mind the capabilities and limitations of human beings so that they should not get exposed to those levels of vibrations which are above the permissible limits. In the present study, heart rate was taken as a measure of task performance. Many indices have been used to measure driving fatigue but the physiological measure was found to be the most appropriate index (Porges, Crawford)[18, 23]. The accumulation of carbon dioxide and other products of anaerobic metabolism increase the heart rate through the cardiovascular control center located in the ventrolateral medulla. The heart rate was observed to be greatly increased when the subject was exposed to a vibration level of 5 m/s^2. An increased heart rate of more than 90 beats per minute resulted in the subject's becoming aware of his heart rate and complaining of it as palpitation. The study therefore suggested that the vibration had a direct effect on the heart rate of the subject and the increase in the level of vibration produced a greater increase in the heart rate. In the light of the above therefore, it could be said that individuals with compromised cardiovascular function could have these problems aggravated due to exposure to vibration. These observations are in line with the study conducted by Uchikune[16] who showed that there was an increase in heart rate with the level of vibration. The present research also observed that the levels of vibration generated were much higher than the recommended limits. Exceeding ISO norms for vibration exposure may cause back pain and other health related problems. Although the vibration exposure duration has not been taken as a variable in this study, other researchers have quantified this limit. The work carried out by Mehta *et al.*[7] showed that the exposure time for the tractor operator should not exceed 2.5 h per day during ploughing and harrowing operations. In another study (Toren *et al.*)[8] the mean annual tractor driving time was found to be 472 h. The type of equipment used for ploughing had an adverse effect on the operator. The increase in heart rate was greater in wet fields than in dry fields when the ploughing was done with the farm equipment possibly because extra effort was required to be exerted by the operators due to the presence of water in the soil. In addition, the place of

attachment of farm equipment might contribute to the extra effort required on the part of the operator. Porges[18] also observed that the increase in heart rate was due to the physical demands required in carrying out the driving task. Farm equipment in many Asian countries is generally attached opposite to the direction of the operator's visual field. While doing ploughing the operator used to look at the field being ploughed very frequently, thus twisting his neck and spine. If a mirror is provided, the frequent change in posture can be avoided. Farm equipment should be designed in a way to minimize strain, which would, in turn, relieve the operator from undue stress both in dry and wet field conditions. Since ploughing is one of the most time consuming operations and is responsible for vibration exposing operators to a considerable amount of vibration, there is an urgent need to bring the levels of vibration down to within permissible limits. One such measure to reduce vibration could be the provision of a suspension system to attenuate the vibration. Vibration attenuating seats and correct ergonomic layout of the cabs might also reduce vibration exposure-related problems (Pope *et al.*)[24) Providing a cabin to isolate the operator from getting exposed to other environmental stressors such as noise may have a positive affect on tractor drivers as apart from other effects, because vibration in tractor driving can also cause deafness (Mehta *et al.*)[6].

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