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Musculoskeletal Disorders and Whole Body Vibration Exposure among Auto-Rickshaw (Three Wheelers) Drivers: A Case Study in Northern India

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Abstract

Basic Background: The three-wheelers (auto rickshaw) are predominantly being used as a mean of transportation of goods in industries and local transportation in cities and suburban areas of northern India. This study aims to assess the whole body vibration exposure and prevalence of musculoskeletal disorders among auto rickshaw drivers.

Procedure and Methods: The study included four models of auto rickshaws for assessment of whole body vibration exposure with different road conditions and the number of passengers boarded and its association with musculoskeletal complaints. Whole body vibration exposure was measured using SVAN 106 tri-axial accelerometer and SVANPC+ software. A comprehensive questionnaire was devised and used for the subjective assessment of musculoskeletal complaints. The data were analyzed using analysis of variance and Chi-Square test to check the variability and association of whole body vibration exposure and musculoskeletal disorders for all the models of auto rickshaws.

Results: There is a significant dependency of the magnitude of whole body vibration exposure on the road conditions and a number of passengers. Also, there is a significant influence ('p' value < 0.05) of whole body vibration exposure due to driving experience and age of auto rickshaw drivers on musculoskeletal complaints, low back pain is found more prominent factor.

Conclusions: The auto rickshaw drivers are working at high exposure to WBV and consequently at high risk of musculoskeletal disorders, therefore it is recommended that auto-rickshaw drivers must adjust the vehicle speed to suit the road conditions to avoid excessive bumping and jolting. In rough road conditions less number of passengers should be avoided.

Keywords: WBV; MSD; Auto Rickshaw Drivers in Punjab India

Abbreviations: WBV: Whole Body Vibrations; MSD: Musculoskeletal Disorders; LBP: Low Back Pain; VDV: Vibration Dose Value; RMS: The Root Means Square; EAV: Exposure Action Value; ELV: Exposure Limits Value, ANOVA: Analysis of Variance.

Introduction

In India different types of modes of public transport are prominently used, mainly including, car, busses and three-wheeler auto-rickshaw in urban, suburban and rural areas. Auto-rickshaw is the cheap and easily available source of public transport throughout the country. The auto rickshaw drivers spend a significant proportion of their work time under exposure to traffic noise and whole body vibration (WBV), with persistent, long time sitting posture while driving. Such type of occupational hazardous can lead to the spinal health issue, neurovascular changes, hearing and other problems. The exposure to WBV vibrations is influenced by the road conditions, driving habits and number of passengers boarded. In suburban cities and rural areas, road conditions are relatively poor and road maintenance is a still challenge for the local authorities. There are more chances of jerks due to pits on road in rural and suburbs. Moreover Increased vehicle speed, poor suspension design, and vehicle engine capacity can also be additional factors to WBV exposure of auto rickshaw drivers. Hence, it can be assumed that these individuals are working under risk of whole body vibration exposure during their working hours. Therefore the present study assumes its significance to assess the WBV exposure of three wheeler auto rickshaw drivers and the associated musculoskeletal complaints.

Different researchers have contributed some methods for the WBV exposure assessment and its hazardous effects, according to Anon, [1], there are some assessment questions based on WBV risk assessment, such as: whether vibration cause the operator to hold on to the steering wheel or other support for stability? Do the operators report about pain or discomfort in the back, buttocks or feet because of jerks or vibration? Whether the operators usually jump up during operating the vehicle? The positive response to these questions is indicators of the possibility of WBV exposure.

Some authors like Stayner [2] reported an association of exposure to WBV and back problems and reported such incidence among 60 percent of the population. Also, Palmer, et al. mentioned that most people will have suffered from back problems of one kind or another by the time they reach retirement age. Hughes and Ferret have defined whole body vibration (WBV) as the transmission of vibration into the human body through a supporting surface like seat or the floor when driving or riding a vehicle over uneven paved surfaces or moving over obstructions or into potholes, construction sites being flipped when carrying out physical work excavating holes etc.

The problem of WBV is intensified just because of resonant frequencies. The human body and its organs (all masses) are having a specific frequency that excites the mass. This excitement used to amplify or intensify the whole body vibration energy. This resonance increases the total oscillatory energy absorbed by the body when the frequency of whole body vibration matches the natural frequency of the human body. Vibration applied to the human body at frequency 2.5 to 5 Hz can stimulate the resonance in the neck and lumbar area. At frequency 4 to 6 Hz the resonance get excited in the trunk of the body (i.e. the body, excluding the head and limbs) up to 200 percent such that seat motion is amplified in the vertical motion of the lumbar/thoracic section [2]. The effects of exposure to whole-body vibration are not convenient to analyze, although it can be felt either from the change in the frequency range to which the drivers, workers are exposed to vibration or from physiological point of view. Whole body vibration can be classified into two types. The first type is the continuous lower-magnitude vibration that having less severe effect during a normal vehicle operation. But this kind of result only can get when driving over a relatively smooth road, generally having the combined effect of vibrations from vehicle mechanism and from vibration caused by moving on many minor bumps and lumps on the road surface. Vibration exposure with lower magnitude may cause a feeling of fatigue and sleepiness [1]. The second type of vibration is more severe in magnitude and unpredictable in nature. It can be experienced when driving a vehicle over a large obstacle or into the deep pits or at construction sites being flipped when carrying out physical work excavating holes or rotating blades of helicopters and boats moving rapidly across rough water, when working on large, powerful and less maintained machinery like as milling machines, drilling machines, grinding machines, hammering machinery, and mobile crushers which is impacting or vibrating. It is considered that a high magnitude of vibration is the result of high acceleration events. This type of vibration exposure mainly contributes to fatigue in the back spine [2].

The human body response to the whole body vibration exposure having potentially five adverse effects such as it may cause general discomfort, present a health and safety risk, reduce performance, reducing the sensitivity of a control, cause or increase motion sickness [3]. Nevertheless, the comprehensive remit of these potential effects, most attention focused on back disorders, especially low back pain [4]. Some definitely reported a cause and effect relation between whole-body vibration and back disorders to include lumbago, sciatica and low back pain, intervertebral disc herniation and degeneration [5]. The younger workers may be at higher risk of damage to the spine because muscles are still developing and bones may not have completely matured.

Biodynamic experiments have shown that WBV exposure associated with obligate sitting posture can put the lumbar intervertebral disk at risk of failure. The musculoskeletal injuries are painful in the bones, body muscles, tendons, and other soft tissues. These consequences are responsible for body sickness in many people who exposed to excessive vibration environment cause prominent occupational problems with increased compensation and costs for poor health, reduced productivity and poor quality of life [6]. Moreover Discomfort can be frequently felt by the professional drivers when they are exposed to vibration environment and it depends upon the magnitude and duration of exposure to vibration [7].

Vehicles such as dump trucks, agricultural tractors, cranes, buses, Lorries, motorcycles, and three-wheeler auto-rickshaws are driven on well-maintained roads and lead to mild exposure to WBV, so the probability of related health risks is low. However, sometimes the drivers may be exposed to high levels of WBV especially on off-road or construction site roadways or farm tracks [8].

Today in modern India despite that most of the people are having two or four-wheeled vehicles in cities, however still significant people used to travel by buses, auto-rickshaws, trains, cycles [9]. Three wheeler auto-rickshaw, four and two-wheelers are the main mode of public transport in urban, suburban and rural areas. Like other, the auto-rickshaws (three-wheelers) are cheap and easily available means transport. The drivers of these vehicles spend most of the daily time in environment pollutant; emission gases, also exposed to WBV, vehicle noise, bad sitting posture while driving etc.. These work-related harmful factors can lead to symptoms like; cardiovascular, respiratory, spinal health risk, neurovascular changes, hearing and other problems which can have driving safety implications.

The level of WBV also depends upon the road conditions. In major cities road conditions are favorable, but in rural and suburban areas roads are full of pits and jerks. Beside the road conditions vehicle speed, suspension design and engine capacity can also affect WBV and lifespan of the vehicles.

There are some other factors responsible for poor health resulting directly from WBV exposure including; poor level of personal fitness or being overweight [5,9]. Smoking habit which appears to amplify the potential for back problems generally [5], poor posture which can amplify the adverse effects of exposure. Also work-related activities such as manual handling or lifting of heavy objects [5,9]. Seating dynamics i.e. the dynamic response of an operator’s seat can also influence whole boy vibration [10]. Poor selection of seating can actually amplify the vibration. Although, back injury is the principal negative effect of WBV exposure, but there are some other health risks from WBV have been reported and these includes; Headache [11], chest and abdominal pain (ibid.), hyperventilation, increased heart rate, high blood pressure, increased muscle tension and muscle fatigue. Moreover induced sleep from low-frequency vibration and blurred vision can be experienced by the operators. There are some other effects like; kidney disorders, impotence, improved/reduced task performance, and motion sickness [1,3].

Ismail R, et al. [12] calculated the vibration dose value by experiment on a car driver at two different speeds for 10 minute exposure time, using a tri-axial accelerometer by placing between driver and driver seat as per ISO 2631-1:1997 [13]. It was concluded that vibration exposure of WBV increased with an increase of the magnitude and duration of exposure. The daily action value to vibration A(8) and VDV values increased with increasing exposure time.

Bovenzi, et al. [14], investigated the effect of WBV mainly on low back pain (LBP) and identified the factors contributing low back pain among bus and tractor drivers. The LBP was found associated with age, back accidents, mean WBV dose, and posture overload. The improper seating might increase the levels of WBV experienced by operators of buses and tractors. The age of the vehicle may also influence WBV exposure.

Vikas Kumara, et al. [15], measured VDV value of WBV for the driver as well as the pillion of two-wheeler vehicle with different road profile having speed breakers, at different speeds for 2 minute exposure time. Psychophysical responses were measured with the help of Borg CR10 scale. It concluded that the time is taken to reach 15 m/s 1.75 and comfort decreases as the vehicle speed and speed breaker's height increases, for both driver and pillion. Pillion feels more discomfort as compared to the driver.

Melemez K, et al. analyzed WBV during occupational operation of loading tractor using tri-axial accelerometer placed under driver sitting on driver seat for 145 forestry loading operation. Regression analysis concluded that WBV exposure was affected by surface roughness condition, wheel pressure, machine type, seat condition, operator weight and gross weight of the vehicle. Similarly, Ozkaya, et al. [16], measured the WBV on the seated train operators and identified the factors influencing the exposure dose value. A total of 48 round trips were made and more than 100 hours of data were collected and analyzed. It was determined that 6 out of 20 subways had vibration levels greater than the daily exposure limit according to standard. The analysis shows that the track conditions of subway lines and train speed and vehicle maintenance significantly affected the level of WBV exposure experienced by the train operators. Bovenzi, et al. [17], investigated 1155 tractor drivers exposed to WBV and postural stress and in a control group of 220 office workers. Vibration magnitudes and exposure time were used to calculate a vibration dose for each tractor driver. The perceived postural load was assessed in terms of frequency and/or duration of awkward postures at work. The low-back disorders were found significantly associated with both vibration dose and postural load and, age were also significant predictors for LBP. Regression analysis of experimental data shows that vibration exposure and postural load were independent contributors to the increased risks for LBP according to a multiplicative model. Malchaire J, et al. [18], investigated the effects of working conditions on the vibration exposure for fork-lift trucks. The various conditions included; four types of tires, normal seat v/s anti-vibration seat, smooth or rough track and driven while empty or loaded tracked by three workers. Variance analysis revealed significant influence on vibration exposure mainly by road conditions, loaded or empty vehicle and the quality of the seat. It suggested preferring inflated tires when an anti-vibration seat with a very low resonance frequency is used. Village J, et al. [19], considered load-haul-dump (LHD) vehicles to measure the WBV in the mining industry. For the measurement of WBV, 22 observations conducted on 11 different vehicles with 8 different operators and 4 different work locations. The analysis concluded that vehicle size also plays a significant role in WBV exposure.

Chen, et al. assessed WBV on 247 taxicab drivers, Mixed effect model was used to analyze the frequency-weighted vertical acceleration (z-axis) over the drivers' seat surface including repeated measures. Conclusions indicated engine size and surface conditions were the possible factors influencing WBV exposure. Sujatha C, et al. [20], determined the vibration response of the driver's and passenger's seat in Indian buses with different road condition at the different speed (30 & 60 Km/h). The vibration exposures were compared with the 8-hour fatigue, decreased proficiency boundary and 1 hour reduced comfort boundary for vibrations at the driver's seat and passenger's seat, respectively. The suspensions used for the buses under this study were leaf springs, however, it was suggested that less WBV may be experienced by the air suspension system.

Paddan, et al. [10], assessed the effect of seating on WBV exposure in 100 vehicles of different categories (cars, vans, lift trucks, lorries, tractors, buses, dumpers, excavators, helicopters, armored vehicles, mobile cranes, grass rollers, mowers, and milk boats) with 67 conventional seats and 33 suspension seats. Here also, vertical acceleration was measured on the floor and seats of the vehicle. The severity of whole-body vibration exposures in many work environments can be reduced by improvements to seating dynamics.

Kharat RM, et al. [21] determined the effect of WBV on the health of drivers of three wheeler vehicles due to the irregular surface of road or soil profile, engine vibration and condition of the vehicle. The result shows that as the road condition varies from smooth to rough surface, the acceleration magnitude of vibration also increases, therefore the driver and passengers experienced very discomfort. Koley S, et al. [22], investigated the severity of LBP in169 professional tractor drivers participating aged between 21-60 years and observed a gradual increase of pain scores with the increased vibration exposure to WBV with the increase of age.

Existing Gaps in Literature

Most of the literature pertains to whole body vibration exposure and its negative effects on the human health in vehicles such as agricultural tractors, forklift trucks, buses, helicopters, concreter production machinery, cars, two-wheeler motorcycles, and railways drivers. However, as far as the WBV exposure and its association with MSD among the drivers of three-wheeler auto-rickshaw are concerned a very limited literature is witnessed especially in the northern part of India. Therefore, this study assumes it's significance to investigate the prevalence of WBV exposure and MSD among three-wheeler auto-rickshaw drivers.

Objective

This study is aimed to compare the four different models of auto-rickshaw on the basis of induced whole body vibration and its adverse effects in terms of MSD among the drivers. It also finds out the factors which influence the magnitude of vibration as well as the extent of its effects.

Procedure and Methods

The study is devised to compare the four models of auto-rickshaws on the basis of WBV (RMS acceleration value, Vibration dose value and the average time required to reach EAV value). In this experiment, four different models (Mahindra, Atul, Piaggio, and Bajaj) of auto-rickshaw are compared on the basis of their model specifications, the magnitude of vibration induced and the effects of vibration on the health of drivers. There are approximately 350 auto-rickshaws available in between Jalandhar railway station, bus stand and Kartarpur in Jalandhar. Therefore, auto-rickshaw drivers of Jalandhar city and around were considered. The characteristics of vehicles are given in Table.1. Exposure to mechanical WBV vibration may be found in different working environments, mainly in the building construction sites, in the manufacturing industry, in transportation and in agriculture and forestry. There are several vibration levels that occur in a complex system like three-wheeler auto-rickshaws which are transmitted to the operator in three basic ways -Petrovich, et al.:

a) Through the supporting surface (seat)

b) Through the manual controls and the steering wheel, when vibrations in upper limbs of the operator are induced.

Through the supports and the floor of the cab as well as foot controls (brakes), when most local vibrations in lower limbs of the operator are induced.

Model Specification	Model : A	Model : B	Model : C	Model : D
Dimension (l×b×h in mm)	2978×1452×1866	2720×1305×1750	2940×1465×1840	3063 ×1422 ×1849
Kerb weight (kg)	480	420	420	367
Gross weight (kg)	800	710	730	690
Wheel base (mm)	2005	1818	1920	2025
Suspensions	Front: Anti-dive leading link Helical compression spring Hydraulic shock absorber Rear: Swinging arm Rubber compression spring Hydraulic shock absorber.	Front: Anti-dive leading link Double acting hydraulic shock absorber Rear: Heavy duty rubber compression spring Double acting hydraulic shock absorber.	Front: Anti-dive leading link Helical compression spring Hydraulic shock absorber Rear: Triangle arm Rubber compression spring Hydraulic shock absorber.	Front: Anti-dive leading link with Helical compression spring, Double acting hydraulic shock absorber Rear: Helical compression spring, Double acting hydraulic shock absorber.

Model: A: Mahindra, Model B: Atul, Model C Piaggio, Model D: Bajaj

Table 1: Specifications of different model.

Measurement of Vibration Exposure

Six students volunteered to participate as passengers with a mean (SD) weight of 69.35 (3.5) kg. Four drivers with age range 30-40 years having minimum 4 years of experience of auto-rickshaw driving on the same route were selected. A tri-axial seat pad accelerometer (SVAN 106) was placed under the buttocks of the seated driver to measure the whole body vibrations. The SVAN 106 device is a six-channel human vibration meter that meets ISO 8041:2005 standard for the measurement according to ISO 2631- 1, 2 & 5 and ISO 5349 standards [23,24]. The data was downloaded to a laptop using USB interface and SVANPC+ SOFTWARE. The root means square (RMS) value of vibration was calculated for accelerations from six channels, three for whole body vibration and three for hand-arm vibration. The equipment enables to measure the current value of exposure to vibration (for each channel), daily dose value, (VDV) values (for each axis), measurement duration (in minutes), exposure action value (EAV) time and exposure limit value (ELV) time. It can plot the graph of RMS acceleration with duration of exposure time. The equipment SVAN 106 device with tri-axial accelerometer used for the measurement is exhibited in Figure 1.

Figure 1: SVAN 106 device with tri-axial accelerometer.

(Source: SVAN 106 manual).

The observations were taken on 8 km route starting from the main gate of the institute through Patel Chowk to Jalandhar city bus stand comprising approximate 6 km of the smooth road without jerk and 2 km of rough road (with jerk). Measurements were conducted during 10:00 am to 12:00 pm or 2:00 pm to 4:00 pm to ensure consistent traffic condition and to avoid traffic jams.

The standard testing procedure of the driving test and details instruction was given to each driver before the test. Each auto-rickshaw driver performed three rides; first with one passenger on the rear seat, second with 4 passengers and third riding with 7 passengers. In all three cases, followed the same route at normal speed (on a smooth road, speed was about 30- 40 km/h and on a rough road, speed was below 20 km/h). All the three rides were performed with the same model of auto-rickshaw on the same route on three consecutive days. A tri-axial accelerometer was placed under the driver on the seat in accordance with ISO 2631-1 standard [13]. Each reading consists of 1 minute of exposure time duration and the same process repeated for 6 to 8 times with both road conditions (Figures 2a & 2b).

MINITAB software was used to perform statistical test and check the significance of the RMS values of acceleration, VDV values and average time to reach EAV on both road conditions, and to check the relationship between the dependent variables (RMS acceleration values, VDV values and average time to reach EAV) and independent variable (number of passenger and road conditions) with level of significance 0.05.

a) Smooth road surface condition b) Rough road suface condistion

Figure 2: Road surface condition.

Discomfort Assessment

A qualitative survey was performed to assess the discomforts due to whole body vibration for long duration exposure. Discomfort is measured in terms of pain in the different body parts like the neck, shoulder, arms, low back, elbow, wrist, and ankles. A questionnaire was used on 120 auto-rickshaw (30 of each auto-rickshaw) drivers with age between 23-62 years and having 1-35 years of driving experience, on the same route from Kartarpur to Jalandhar city bus stand. The study considered only those who were facing MSD problems last year or before. The prevalence of discomfort was asked through a questionnaire at three levels; never, sometimes and often with rating scale 1, 2 and 3 respectively. The ratings were assigned to each of body parts (neck, shoulder, arms, low back, elbow, wrist, and ankles) and a total score calculated by adding all the values for each model of auto rickshaw. All four models were compared on the basis of their total score. One way ANOVA test at level significance ('p' value ≤ 0.05) is performed to check the significant difference for all discomfort problems and to check the relationship between the effects of WBV with age and driving experience of the auto-rickshaw driver's CHI-SQUARE test is applied to check the significant difference between all the responses.

Average Daily Vibration Exposure

Root mean square (RMS) acceleration of vibration is measured in three directions (x, y and z) by using the tri-axial accelerometer for each of the auto rickshaw models. The entire axis indicates directions; x is in forwarding and backward direction, y is in the side of RMS acceleration are calculated by the SVAN 106 device by considering the multiplying factors in each direction. The multiplying factor for x-axis and y-axis are 1.4, and for z-axis value is 1. The RMS acceleration value for each of vehicles (mostly) in x-axis and y-axis for both road conditions are within the EAV limit, however the z-axis, RMS acceleration values are higher than EAV limit for all the four models except one like Bajaj having greater than ELV limit. Hence, only z-axis value is considered for the further analysis, because there is a significant difference between the values of both axes (x and y) to the z-axis. All the measurements are taken on a smooth road (without jerk) and rough road (with jerk) separately for a 1-minute time duration of exposure.

The Directive sets the limit values of daily exposure of workers to WBV:1. Daily exposure limit value (ELV) - which must not be exceeded in professional working conditions and is 1.15 m/s^2, A(8)

2. Daily exposure action value(EAV) - above which employers must control risks coming from vibrations and is 0.5 m/s^2, A(8).

3. Results Comparison between Four Models

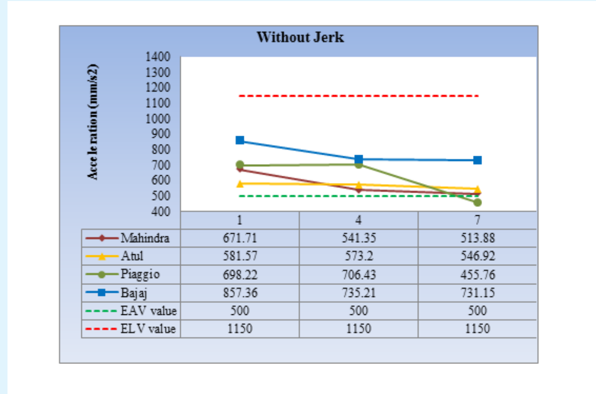

Figure 3: Average Daily Vibration exposure value (mm/s2) with smooth road condition (Without Jerk).

The observations indicate that all the four auto-rickshaw models have the RMS acceleration value above the EAV value (Figure 3). Therefore some measures are required to keep the exposure value in safe renege in accordance with the European Vibration Directive. The RMS acceleration values of Mahindra and Piaggio are higher than Atul, and above the EAV limit. So, these models need some interventions. For Bajaj, RMS acceleration value is much higher than all of them. So, there is an urgent need of appropriate preventive measures may be through some modification in the design of vehicle components such as the driver's seat and suspensions (front and rear). As the number of passenger increases, RMS acceleration value of Mahindra, Atul and Piaggio vehicle getting closer to EAV value.

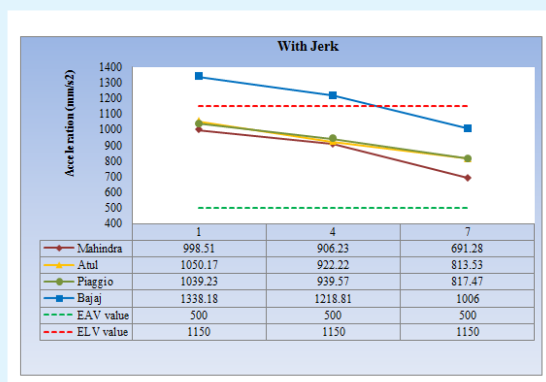

Figure 4: Avg. Daily Vibration exposure value (mm/s^2) with smooth road condition (With Jerk).

Over rough road condition (with jerk) with the different number of passenger results exhibit that the RMS acceleration values for all the vehicles approach to ELV value, however, the value shows dipping with increasing the number of passengers (Figure 4). It seems to approach closer to EAV value; however minimum value (691.28 m/s^2) is even higher than EAV value (138.25 % of EAV). Therefore, driving with the less number of passengers should be avoided. Out of the four models, Bajaj auto-rickshaw showed the highest value of RMS acceleration value on rough road conditions. The RMS acceleration value on a rough surface (with jerk) is above the ELV value and minimum value (1006 m/s^2) is much higher than EAV (201.2 % of EAV). Therefore, some preventive actions such as proper maintenance of the vehicle, modification in seat design, cushioning of the seat, change the suspension design to reduce the amount of vibration transmitted.

Average Daily Dose Value

The vibration does value assessment was made in all three directions (x, y, and z) and however, the maximum value is found in the z-direction. Therefore, it was decided to considered vibration dose value only in the z-direction for further calculation.

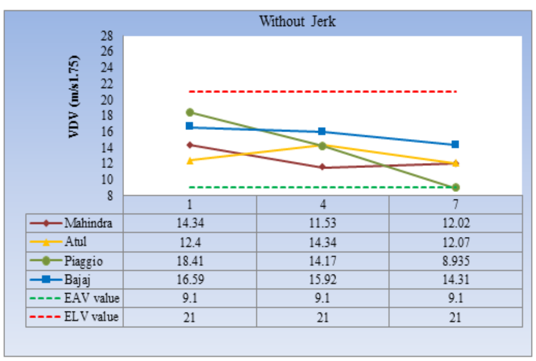

Figure 5: Vibration dose value (mm/s1.75) with smooth road condition without Jerk.

Over smooth road condition with a different number of passengers (1, 4 and 7) indicate that delivery of all the four auto-rickshaw models experienced the significantly high value of VDV than the EAV value, although within ELV (Figure 5). The vibration dose values of Bajaj auto-rickshaw are comparatively higher than the other models. Therefore, it is suggested to the drivers of Bajaj auto-rickshaw to take some preventive measures.

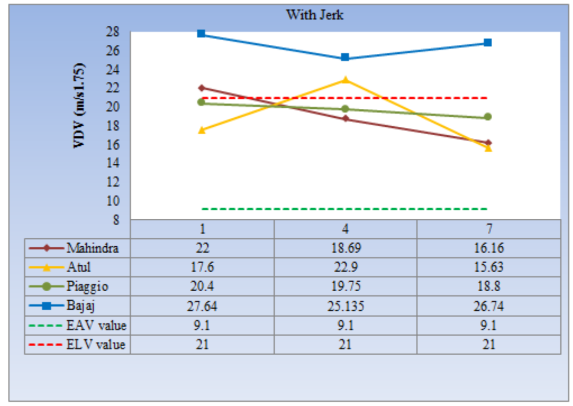

Figure 6: Vibration dose value (mm/s1.75) with smooth road condition (With Jerk).

It is observed that the vibration does value over a rough surface (with jerk) for all the vehicles exceed EAV value and again Baja model showed a significantly higher value than the ELV (Figure 6). There is slight variation in the vibration dose values as the number of passenger increases for all the four models. In the case of Bajaj auto-rickshaw, minimum vibration dose value is much higher than ELV value (119.69 % of ELV). Therefore, there are more chances of health issues in Bajaj auto-rickshaw drivers as compared to others.

Average Time to Reach EAV

The average time required to reach EAV value is calculated by using the SVANPC+ software. This is the driving duration after which drivers are suggested to take some preventive action so that the effects of vibration on the driver's health can be reduced. The analysis of result is exhibited in Figure 7 which shows that on rough road (jerk) conditions the maximum average time required to reach EAV is less than 3 hours. However, on a smooth road (without jerk) conditions the maximum average time required more than 6 hours. There is an inverse relationship with the RMS vibration value increases, the time required to reach EAV value decreases. Due to the higher value of RMS acceleration, Bajaj auto-drivers supposed to take some preventive action after 3.5 hours over the smooth surface and 1.5 hours over the rough surface and similarly for the other drivers.

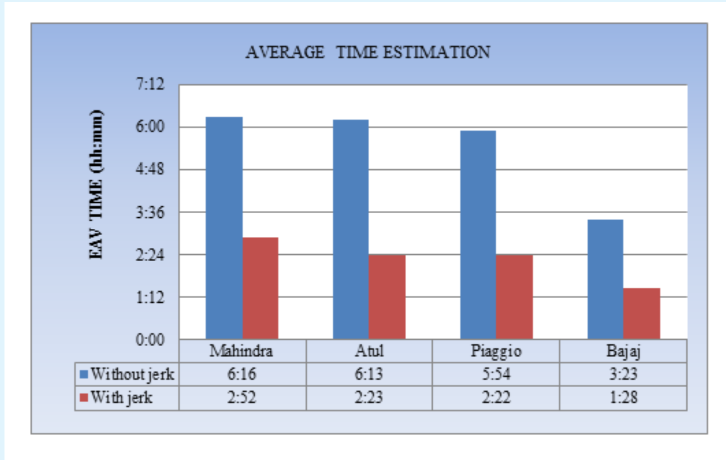

Figure 7: Average Time to reach EAV for all the models.

	Road Conditions (α = 0.05)	Number of Passenger (α = 0.05)	Road condition and Number of passenger
RMS Acceleration Value	F=19.09, P=0.000	F=0.46, P=0.639	F=0.02, P=0.985
Average Vibration Dose Value	F=20.69, P=0.000	F=3.12, P=0.069	F=0.63, P=0.545
Average Time To Reach EAV	F=19.71, P=0.000	F=5.10, P=0.018	F=0.71, P=0.504

Table 2: Results of significance tests for all models.

It has been observed that as the number of passenger increases, the RMS acceleration values (F=0.46, P=0.639) and average vibration dose values (F=3.12, P=0.069) decreases, and time required to reach exposure action value increases (F=5.10, P=0.018). Similarly, as the road conditions changes from smooth to rough surface, the average RMS acceleration values (F=19.09, P=0.000) and average vibration dose values (F=20.69, P=0.000) increases rapidly and the time required to reach exposure action value decreases rapidly (F=19.71, P=0.000). The results are shown in Table 2. There is a significant difference between all models with respect to RMS acceleration values (F=5.6, P=0.002), vibration dose values (F=4.04, P=0.01) and the average time required to reach EAV value (F=4.33, P=0.007) on both road condition and number of passengers, the same results are exhibited in Table 3.

Model No.	No of passenger	Road type	Avg. accn. X (mm/s2)	Avg. accn. Y (mm/s2)	Avg. accn. Z (mm/s2)	Avg. Daily Vibration exposure (mm/s2)	Avg. Daily VDV (m/s1.75)	EAV time (hh:mm)	ELV time (hh:mm)
Mahindra	1	No jerk	179.4	154.23	671.71	671.71	14.34	4:25	23:26
	1	jerk	402.23	348.533	998.51	998.51	22	2:00	10:36
	4	No jerk	138.86	139.59	541.35	541.35	11.53	6:49	>24:00
	4	jerk	256.87	388.85	906.23	906.23	18.69	2:26	12:52
	7	No jerk	144.24	120.17	513.88	513.88	12.02	7:34	>24:00
	7	jerk	389.61	292.11	691.28	691.28	16.16	4:11	22:08
	1	No jerk	174.74	186.95	581.57	581.57	12.4	5:54	>24:00
	1	jerk	394.38	581.33	1050.17	1050.17	17.6	1:48	9:35
Atul	4	No jerk	231.13	240.4	573.2	573.2	14.34	6:05	>24:00
	4	jerk	333.82	422.13	922.22	922.22	22.9	2:21	12:26
	7	No jerk	222.91	197.26	546.92	546.92	12.07	6:41	>24:00

	7	jerk	418.54	546.87	813.53	813.53	15.63	3:01	16:00
	1	No jerk	238.63	330.59	698.22	698.22	18.41	4:06	21:42
	1	jerk	636.82	417.83	1039.23	1039.23	20.4	1:51	9:47
Piaggio	4	No jerk	252.78	251.58	706.43	706.43	14.17	4:00	21:12
	4	jerk	395.08	298.44	939.57	939.57	19.75	2:15	12:00
	7	No jerk	153.82	119.18	455.76	455.76	8.935	9:37	> 24:00
	7	jerk	325.01	236.91	817.47	817.47	18.8	3:00	15:49
	1	No jerk	136.89	133.93	857.36	857.36	16.59	2:43	14:23
	1	jerk	401.2	374.41	1338.18	1338.18	27.64	1:07	5:56
	4	No jerk	168.38	133.03	735.21	735.21	15.92	3:42	19:34
Bajaj	4	jerk	522.84	312.77	1218.81	1218.81	25.135	1:20	7:07
	7	No jerk	117.08	131.65	731.15	731.15	14.31	3:44	19:47
	7	jerk	439.75	290.98	1006	1006	26.74	1:58	10:27

Table 3: RMS acceleration values, VDV, EAV and ELV for Piaggio and Bajaj Models of auto-rickshaws.

Qualitative Assessment

The results pertained to a qualitative assessment of effects of WBV on auto-rickshaw drivers are exhibited in Table 4, which reveals that 47.5% of the drivers complain about the pain in the neck as consequence of prolonged exposure to vibration. Out of these, 30.8% reported sometimes and 16.67% often when they drive for a long time in a day or over the worst road surface. The vibration exposure is also enhanced due to the poor suspension system and excessive engine noise. Out of all models, Mahindra auto-rickshaw drivers are less affected by neck pain compared to other drivers.

Body part	Response	**Mahindra**	**Atul**	**Piaggio**	**Bajaj**	**Total**	**% age**
Neck	Never	20	16	16	11	63	52.5
	Sometimes	6	11	7	13	37	30.83
	Often	4	3	7	6	20	16.67
Low back pain	Never	12	7	5	6	30	25
	Sometimes	12	14	13	12	51	42.5
	Often	6	9	12	12	39	32.5
Shoulder/arm pain	Never	11	9	9	10	39	32.5
	Sometimes	14	17	14	14	59	49.17
	Often	5	4	7	6	22	18.33
Wrist	Never	21	17	18	21	77	64.17
	Sometimes	9	12	12	7	40	33.33
	Often	0	1	0	2	3	2.5
Elbow	Never	28	29	28	28	113	94.17
	Sometimes	2	1	2	2	7	5.833
	Often	0	0	0	0	0	0
Ankles/feet	Never	26	28	24	22	100	81.97
	Sometimes	4	2	6	8	20	16.39
	Often	0	2	0	0	2	1.639
Knees	Never	24	23	21	29	97	80.83
	Sometimes	6	7	5	1	19	15.83
	Often	0	0	4	0	4	3.333
	Total	210	212	210	210	842	

Table 4: Frequency response of the effects of WBV in Questionnaire analysis.

Low back pain (LBP) is observed as the most common problem observed among vehicles drivers. It is because they have to drive in a sitting posture for longer hours, therefore the vibration exposure further enhances the occurrence of LBP, and moreover, wrong sitting posture during the driving hours could be another supplement factor. As far as the observations of the present study are concerned; about 75% of auto rickshaw drivers complained about the pain in the lower back due to exposure to WBV. Out of which (42.5%) complained about LBP experience for sometimes. Whereas, 32.5% driver complained about often pain in their lower back. The further reasons for exposure to WBV could be the improper maintenance of suspensions and engine and its mounting of vehicle, rough road conditions. Mostly, the drivers are continuously exposed to continuous but less magnitude of vibration for a long duration of time. On the other hand, they are also frequently exposed to the large magnitude of vibration for fewer spans of time or with poor suspension system, therefore it transmits the large magnitude of vibration to the driver's body. The RMS acceleration values of vibration are higher in case of Bajaj auto-rickshaw, so it may be a reason that Bajaj auto-drivers are more exposed to WBV.

In the case of hand-arm vibration (HAV) exposure, the vibration is mainly transmitted to the arms or shoulder through the steering wheel and some other manual control. The level of transmissibility upon the type of isolator provided flexibility and smoothness of steering. However, in the current scenario, the poor design, and material of isolation of steering wheel leads to higher HAV exposure. It is found that around 49.2% drivers complain about arms and shoulder pain sometimes. However, some of the drivers (18.33%) reported continuous pain in the upper limbs. The wrist is also repeatedly exposed to deviation in all directions during the driving, therefore during driving over rough road amount of vibration transmitted to hand is supplemented by ulnar and radial deviations with wrist extension and flexion, and it may cause a severe pain in the wrist of the hand. As such 33.33% reported about wrist pain for sometimes, if they drive for the long duration. Only a very few (2.5%) are suffering from continuous pain in their wrist. Some of the drivers (5.8 %) also complained about pain in the elbow sometimes for the long duration of exposure. It is also observed that 16.67 % of drivers feel some pain in the ankles for sometimes while driving on rough road condition or due to prolonged exposure to vibration or when they use breaks more frequently in a day. Only a few of the drivers 1.67 % are suffering from a continuous pain in their ankles. About 16.00 % are drivers reported knee pain for sometimes when they driving on rough road condition or due to prolonged exposure to vibration or when they using breaks many times in a day. However, a few of the drivers (3.33 %) reported a continuous pain in their knees. It may be possible if an accident occurred in the past or due to long experience.

The association of discomfort complaints in body parts w.r.t. age and experience of the drivers at a level of significance of 0.05 are tested using CHI-SQUARE test the same is shown in Table 5.

Parameters	Age of Driver	Experience of Driver
Total Score of all the Models	F=2.69, P=0.000	F=2.88, P=0.000
Neck	F=1.13, P=0.318	F=1.20, P=0.261
Shoulder/Arm	F=1.15, P=0.293	F=1.15, P=0.004
Low Back	F=3.41, P=0.000	F=2.48, P=0.001
Wrist	F=1.33, P=0.146	F=1.20, P=0.261
Elbow	F=1.27, P=0.188	F=1.82, P=0.022
Knees	F=2.05, P=0.004	F=2.58, P=0.001
Ankles/Feet	F=1.05, P=0.418	F=1.32, P=0.175

Table 5: Chi-Square test Results.

The results reveal those body responses, caused by exposure to whole body vibration are significantly associated with the age (F=2.69, P=0.000) and experience (F=2.88, P=0.000) of the drivers. The adverse effect of whole-body vibration is found on low back pain as it is reflected with significant influence of age (F=3.41, P=0.000) and experience (F=2.48, P=0.001) of the drivers. However, the pain in shoulder/arm and elbow is found significantly dependent on the experience of the driver with (F=1.15, P=0.004) and (F=1.82, P=0.022) respectively. The excess amount of WBV causes pain in the knees and it is significantly influenced by the age (F=2.05, P=0.004) and experience (F=2.58, P=0.001) of the auto-rickshaw drivers.

Conclusion

With the changing road condition from smooth to the rough surface, the RMS acceleration value and vibration dose value increase rapidly and the average time required reaching exposure action value decreases. Therefore, it is suggested the auto-rickshaw drivers should control the vehicle speed to suit the ground conditions to avoid excessive bumping and jolting. For the model D, the RMS acceleration value is higher than other models. As the number of passenger increases the induced magnitude of RMS acceleration and vibration dose decreases, and the average time required to reach exposure action value increases.

As far as prevalence of musculoskelatal disorders are concerned, low back pain is the most common response of the whole body vibration. The result shows the RMS acceleration value is higher in the case of Model D. Therefore, it can be stated that the concerned drivers are more susceptible to Low back pain. It is influenced by the exposure time duration, age and driving experience of the drivers.

References

1. Anon (2004) Whole-body vibration. Texas Workers' Compensation Commission, Worker's Health and Safety Division. Safety Education and Training Programs [sic]. Publication No. HS97-106B.
2. Stayner RM (2001) Whole-body Vibration and Shock: A Literature Review: Extension of a Study of Overtravel and Seat Suspensions. The University of Southampton, Institute of Sound and Vibration Research.
3. Newell GS, Mansfield NJ (2004) The exploratory study of whole-body vibration 'artefacts' experienced in a wheel loader, mini-excavator, car, and office worker's chair. In 39th United Kingdom Group Meeting on Human Responses to Vibration, pp: 15-17.
4. HSC (2003) Proposals for new control of vibration at work regulations implementing the physical agents (vibration) Directive (2002/44/EC) whole-body vibration. Consultative document. The Health and Safety Executive.
5. Teschke K, Nicol AM, Davies H, Ju S (1999) Whole Body Vibration and Back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators A Review of the Scientific Evidence. Occ Hyg 6: 1-3.
6. Yasobant S, Chandran M, Reddy EM (2015) Are Bus Drivers at an Increased Risk for Developing Musculoskeletal Disorders. J Ergonomic.
7. Sekulic D, Dedovic V, Rusov S, Obradovic A, Slaviša Šalinić (2016) Definition and determination of the bus oscillatory comfort zones. International Journal of Industrial Ergonomics 53: 328-339.
8. Scarlett AJ, Price JS, Stayner RM (2002) Whole-body vibration: Initial evaluation of emissions originating from modern agricultural tractors. HSE Contract Research Report.
9. HSE (2003A) In the driving seat. Advice to employers on reducing back pain in drivers and machinery operators. The Health and Safety Executive. Document ref. INDG242.
10. Paddan GS, Griffin MJ (2002) Effect of seating on exposures to whole-body vibration in vehicles. J Sound Vib 253(1): 215-241.
11. USACHPPM (2003) Just the facts...whole-body vibration. Guidance produced by the U.S. Army Center for Health Promotion and Preventative Medicine. Document ref. 65-022-0503.
12. Ismail AR, Nuawi MZ, Kamaruddin NF, Bakar RA (2010) Comparative assessment of the whole-body vibration exposure under different car speed based on Malaysian road profile. J app Sci 10(14): 1428-1434.
13. ISO2631-1 (1997) Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements. International Organization for Standardization. Geneva.
14. Bovenzi M (1994) Hand-arm vibration syndrome: diagnostic aspects, dose-response relationship and exposure limits. Med Lav 85(6): 463-473.
15. Vikas Kumar VH, Sarab, Veeresalingam Guruguntla (2013) Study of Vibration Dose Value and Discomfort due to Whole Body Vibration Exposure for a Two Wheeler Drive" Proc. of the 1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM2013), IIT Roorkee, India, pp: 947-952.
16. Özkaya N, Willems B, Goldsheyder D (1994) Whole-body vibration exposure: a comprehensive field study. American Industrial Hygiene Association 55(12): 1164-1171.
17. Bovenzi M, Betta A (1994) Low-back disorders in agricultural tractor drivers exposed to whole-body

vibration and postural stress. Applied Ergonomics 25(4): 231-241.

18. Malchaire J, Piette A, Muller I (1996) Vibration exposure on fork-lift trucks. The Ann Occ Hyg 40: 79-91.

19. Village J, Morrison JB, Leong DK (1989) Whole-body vibration in underground load-haul-dump vehicles. Ergo 32(10): 1167-1183.

20. Sujatha C, Rao PP, Narayanan S (1995) Whole–body vibration exposure in Indian buses. Int J Heavy Veh Sys 2(2): 160-173.

21. Kharat RM, Dhande KK (2015) Effect of vibration on the health of driver of three wheelers using Iso 2631. International Engineering Research Journal (SERJ) (2): 5029-5033.

22. Koley S, Sharma L, Kaur S (2010) Effects of occupational exposure to whole-body vibration in tractor drivers with low back pain in Punjab. Anthropologist 12: 183-187.

23. ISO 2631-2 (2001) Mechanical vibration and shock - Evaluation of human exposure to vibration - Part 2: Vibration in buildings (1 Hz to 80 Hz). The International Organization for Standardization. Geneva.

24. ISO 2631-5 (2001) Mechanical vibration and shock - Evaluation of human exposure to vibration - Part 5: Method for evaluation of vibration containing multiple shocks. The International Organization for Standardization, Geneva.

25. Hostens I, Ramon H (2003) Descriptive analysis of combine cabin vibrations and their effect on the human body. J sound vib 266(3): 453-464.