# An evaluation of the effects of whole-body vibration on tractor and truck operators

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Tractors and trucks have an important role in Turkish forestry. The health and productivity of the operators of these vehicles are affected by the overload and stress put upon the spine and lowers back during the course of their work. The objective of this study was to present an ergonomic analysis of the whole-body vibration resulting from the towing tractors and trucks used in forestry operations in Turkey. Three types of seats on three makes of tractors were evaluated. In addition, two types of seats on three truck models were assessed on both asphalt and forest roads. The highest vibration values for all axes were obtained on a Kismet Erkunt tractor with an old seat lacking springs and on a 1995 model AS 950 truck with an old seat; the lowest values were measured on a John Deere towing tractor with a four-spring seat. According to the Tukey test, the best performance was seen with a four-spring seat for tractors and anew-style seat for trucks. Orthopaedic examinations and tests carried out on six forestry workers revealed that two of the three towing tractor operators and all three truck operators were suffering from lower back discomfort and herniations. Due to the stress overload put upon this anatomical region during the routine operation of trucks and tractors, old-style seats without suspension systems need to be replaced with new seats having springs.

**Keywords**: Ergonomics; Forestry; Harvesting; Seat; Transport; Turkey.

## Introduction

As in every country today, the protection of workers and occupational health and safety are among the most important labour issues in Turkey. This situation brings up the need for increasing studies on forestry labour conditions. Research conducted in this scope has revealed the previously unknown fact that vibrations are harmful to health. Vibration refers to the shaking transmitted to a person's body. The effects of vibration on the body differ in severity.

Controlling the low-frequency vibrations resulting from moving on rugged terrain is a difficult undertaking. In order to reduce the effects of this vibration, insulation systems consisting of dampers and elastic devices such as springs are used. An operator's seat equipped with an appropriate insulation system is very important for reducing the consequences of vibration. The seats on tractors used for various purposes in forestry have an important role in terms of vibration (Melemez and Tunay 2010). The main objective when designing and manufacturing a seat is to minimize the effects of vibration. In addition, the comfort of the seat is another point to be taken into consideration. Likewise, to improve the ride comfort of operator, seat vibration insulation systems should minimize these motions. In addition, in order to carry out their forestry activities, operators of towing tractors and trucks spend most of their time in the vehicles, and thus are exposed to long-term body vibrations which pose major health risks. The harmful effects of vibration on human health depend on factors such as the exposure period, vibration frequency and the area of the human body exposed to the vibrations (Eratak 2007). The workers' health, their safety, comfort, and working efficiency are also adversely affected by WBV exposure (Mayton et al. 2003, Jack and Oliver 2008). A person exposed to very intense, long-term, whole-body vibration (WBV) is at a significant health risk. It is thought that WBV can cause damage to the lower back and spinal column as well as to the digestive, urinary and reproductive systems in addition to accelerating pre-existing disorders (Ananymous 1997). One of the most common effects of vibration on human health is whiplash injury. Heavy lifting and sitting on ill-designed seats for long periods can also cause back injuries. In some cases, vibration and bad posture are the combined cause. For example, tractor drivers are exposed to very high WBV; in addition, they habitually sit in incorrect positions on poorly-designed seats (South 2004).

This study aimed to present an ergonomic analysis of the vibrations resulting from the towing tractors and trucks used in forestry activities in Turkey. The WBV transmitted to operators was measured and some recommendations offered to reduce the vibrations to which operators are exposed.

## Materials and Methods

This study was conducted during the routine activities of harvesting and transportation vehicles over the period of 2011-2013 in the Directorate of the Bartin Forest Enterprise of the

Zonguldak Regional Directorate of Forestry, which is one of the richest forested regions of Turkey.

For the measurements, the 1980 model International 444, the 2011 model Kısmet Erkunt and the 2010 model John Deere towing tractors were used, along with the 1988, 1992 and 1995 models of As 950 trucks, all of which are commonly used in forestry harvesting work. Vibration measurement surface is the surface of the operator's seat for harvesting and transport vehicles used in the study. For the WBV measurements, old seats which had lost their damping feature and new 2- and 4-spring tractor seats were used for the towing tractors; for the trucks, new-style seats were compared with the old ones in current use. The new seats were equipped with springs and damper systems and had back-forward adjustments. They could also be adjusted according to the weight of the operator (Figure 1).

**Figure 1. The study used type of seat.**

In this study which was carried out in order to put forward the importance of driver's seat in vibration insulation; driver's seat of tractor which was most commonly sold in market was used as experiment material and among these harvesting vehicles used in forestry; it was aimed to analyse vibration conducted to operator and the effect of this vibration on human health. According to this aim; first of all vibration measurements were done on current seats of each of these vehicles which are used in forestry harvesting works. Later on, the seats were unfixed and replaced with original new seats, procedures and numbers of measurements on applied on current seats were repeated on new ones (Table 1). Measurements were carried out only on forest road for towing tractor operators, and on two different road types being asphalt and unpaved forest road for truck operators.

**Table 1. The planning of measurements to study.**

<table>
<tr><th>VEHICLE TYPE</th><th colspan="12">SAMPLE NUMBER</th></tr>
<tr><th>Towing Tractors</th><th colspan="4">Old Seat</th><th colspan="4">2-Spring Seat</th><th colspan="4">4-Spring Seat</th></tr>
<tr><td>1980 model</td><td colspan="4">3</td><td colspan="4">3</td><td colspan="4">3</td></tr>
<tr><td>2010 model</td><td colspan="4">3</td><td colspan="4">3</td><td colspan="4">3</td></tr>
<tr><td>2011 model</td><td colspan="4">3</td><td colspan="4">3</td><td colspan="4">3</td></tr>
<tr><td></td><td colspan="12">TOTAL = 27</td></tr>
<tr><td colspan="13"></td></tr>
<tr><th>VEHICLE TYPE</th><th colspan="12">SAMPLE NUMBER</th></tr>
<tr><th rowspan="2">Truck</th><th colspan="6">Old Seat</th><th colspan="6">New Seat</th></tr>
<tr><th colspan="3">Asphalt Road</th><th colspan="3">Forest Road</th><th colspan="3">Asphalt Road</th><th colspan="3">Forest Road</th></tr>
<tr><td>1988 model</td><td colspan="3">3</td><td colspan="3">3</td><td colspan="3">3</td><td colspan="3">3</td></tr>
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<tr><td>1995 model</td><td colspan="3">3</td><td colspan="3">3</td><td colspan="3">3</td><td colspan="3">3</td></tr>
<tr><td></td><td colspan="12">TOTAL = 36</td></tr>
</table>

Twenty-seven different measurements for towing tractors, thirty-six different measurements for trucks were conducted on the seats and the forest harvesting vehicles. The factors affecting vibrations included tyre pressure (30 psi), weight of the operator (±85 kg), rate of headway (5 km/h) and slope values (5%). The same values were used for all vehicles which were compared.

For this study, the operator's seat level was accepted as the vibration measurement level for the harvesting and transportation vehicles. The triaxial accelerometer sensor was located between the driver contact points and the vibration source. The accelerometer was placed on the seat of the driver. During the test, the driver sat on the accelerometer (Ismail et al. 2010). In order to record the vibrations of the operator’s seat, the measurement was made with a Brüel & Kjaer 4447 vibration measurement device which takes measurements at three axes (Figure 2). The obtained results were compared with the daily exposure limit values in accordance with the ISO 2631 standard and the ergonomic comfort was assessed. The driver vibration exposure values and the maximum daily work periods were then measured. Finally, the effects of the vibrations resulting from the vehicles on the human body, particularly the spine and lower back areas, were evaluated.

**Figure 2. Brüel & Kjaer 4447 vibration measurement device with measurements to be made.**

In parameters related to WBV, the values of vibration transmitted to the operator from axes on the seat were found at (a) (1), x, y and z axes according to weighted averages. By turning the total vibration value ($a_t$) (2) and the measured vibration acceleration values into a reference 8-hour time slice, the vibration acceleration value ($A_8$) (3) was calculated using the following formulae:

$$\mathrm{a} = \left[ \frac{1}{T} \int_0^T a^2(t)dt \right]^{1/2} \quad \text{(ms-2)} \qquad (1)$$

$$\mathrm{a}_{\mathrm{t,\,health}} = \left[ (1.4 * a_x)^2 + (1.4 * a_y)^2 + (1.0 * a_z)^2 \right]^{1/2} \quad \text{(ms-2)} \qquad (2)$$

$$\mathrm{A}_8 = a_t \left[ T/T_0 \right]^{1/2} \quad \text{(ms-2)} \qquad (3)$$

At this point, $a_x$, $a_y$, and $a_z$ refer to (back-forth) rms acceleration values at x axis, (horizontal) rms acceleration values at y axis and (vertical) rms acceleration values at z axis, respectively. $T$ refers to the period of vibration exposure (s) and $T_0$ refers to the 8-hour period (28800).

In order to statistically present the success of the applied vibration measurement method and to discover whether the vehicle and seat type have any effects on the vibration values transmitted to operators, a multiple variance analysis was conducted via the SPSS 16 statistical package program. The Tukey test was then applied to identify different groups and to determine the best vehicle and seat type for operators.

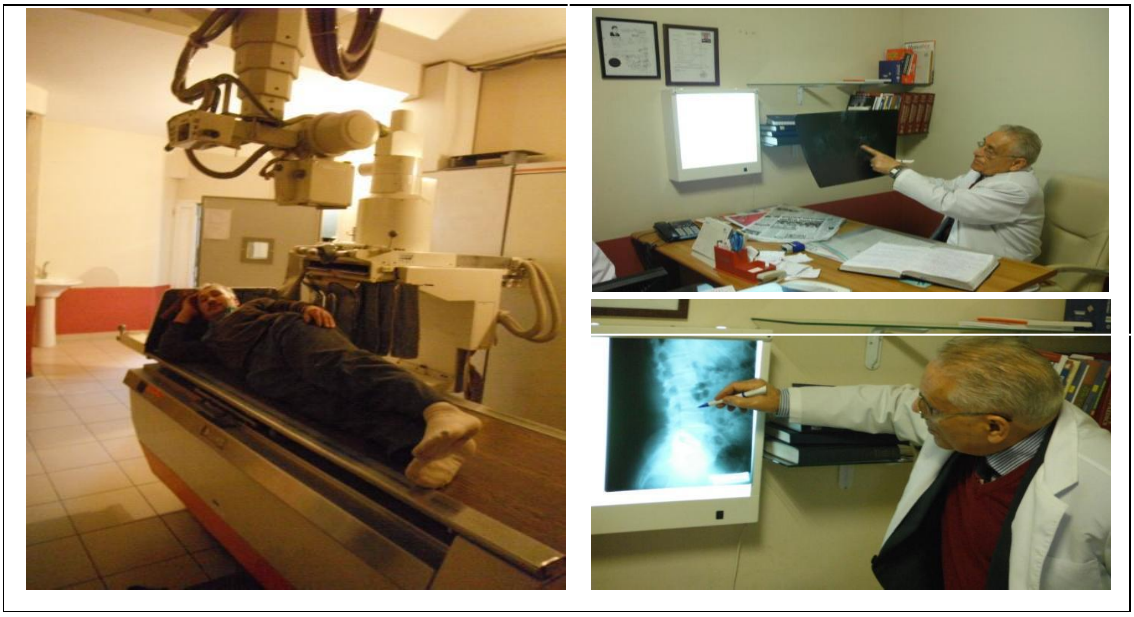

**Figure 3. The evaluation of radiological examinations by a specialist.**

Following the determination of the differences between vibration values, hospital examinations were conducted on six forestry workers (three towing tractor operators and three truck operators). At first stage, patients are pulled the general examination after their radiology examinations interpreted have been subjected by a specialist (Figure 3). The aim was to reveal the effects of vibration factors on the human body, particularly on the spine and lowerback (lumbar) area. For the diagnosis of medical problems, orthopaedic specialists carried out a general examination on the operators and then lowerback x-rays were taken. The results of the physical and radiological examinations were assessed by the physicians for the detection of any disorders along with the degree of their severity.

## Results

Whole-body vibration measurements were obtained for three makes of tractor with three seat types. Accordingly, in the currently-used(old-style)seats of the Kısmet Erkunt, John Deere and International towing tractors, the WBV values were found to be 0.68, 0.47 and 0.64, respectively. The highest WBV values for all axes ($a_x$=0.26 ms$^{-2}$, $a_y$ =0.26 ms$^{-2}$, $a_z$=0.46 ms$^{-2}$) were determined on the Kısmet Erkunt tractor. The lowest WBV values for all axes ($a_x$=0.14 ms$^{-2}$, $a_y$=0.10 ms$^{-2}$, $a_z$=0.22 ms$^{-2}$) were measured on the John Deere towing tractor with a suspended seat (Table 2). In previous studies where whole body vibration was calculated, average weighted acceleration and standard deviation values for 20-40 km/h driving speed was found to be 0.35 (SD 0.19) for X axis, 0.34 (SD 0.28) for Y axis and 0.54 (SD 0.23) $ms^{-2}$ for Z axis (Village et al. 2012).

Table 2. Vibration values transmitted to the operator while working with a towing tractor.

| **Tractor Type** | **Seat Type** | **X- axis** | **Y- axis** | **Z- axis** | **Total V** |
|---|---|---|---|---|---|
| **2011 model** | **Current** | 0.26 (0.04) | 0.26 (0.05) | 0.46 (0.07) | 0.68 (0.10) |
| | **Sliding** | 0.18 (0.06) | 0.20 (0.03) | 0.34 (0.02) | 0.51 (0.06) |
| | **Suspended** | 0.15 (0.05) | 0.12 (0.01) | 0.22 (0.06) | 0.35 (0.05) |
| **2010 model** | **Current** | 0.20 (0.02) | 0.16 (0.03) | 0.31 (0.04) | 0.47 (0.01) |
| | **Sliding** | 0.15 (0.04) | 0.08 (0.03) | 0.30 (0.07) | 0.39 (0.08) |
| | **Suspended** | 0.14 (0.02) | 0.10 (0.02) | 0.22 (0.05) | 0.33 (0.06) |
| **1980 model** | **Current** | 0.26 (0.04) | 0.18 (0.06) | 0.46 (0.08) | 0.64 (0.12) |
| | **Sliding** | 0.23 (0.05) | 0.21 (0.06) | 0.39 (0.12) | 0.59 (0.16) |
| | **Suspended** | 0.31 (0.04) | 0.18 (0.08) | 0.28 (0.03) | 0.58 (0.08) |

The total vibration values of the towing tractors were below the danger limit (1.15 $ms^{-2}$) stated in international standards. With the use of sliding and suspended seats, compared to the current seats, the total vibration values were reduced to below the warning limit (0.5 $ms^{-2}$) for each vehicle (Figure 4). During the first stage, total vibration values were measured for daily vibration exposure (8 h), and then the maximum work period was determined via the warning limit (0.5 $ms^{-2}$) set by international standards. The measurements were made using the lowest and highest vibration values. Maximum daily work periods were calculated for the towing tractor having the highest vibration values ($a_t$:0.68), the Kısmet Erkunt, and the results were as follows: 4.21 h (253 min) for the current seat, 7.75 h (465 min) for the sliding seat (2-spring) and >8 h (480 min) for the suspended seat.

Therefore, it can be seen that, considering the 8-hour work period, the suspended and sliding seats were more effective than the current seats which had lost their damping feature. The suspended seats had four springs and the sliding seats two springs. In addition, neither the suspended nor the sliding seats had lost their new damping features as had the old seats currently in use. These factors all contributed to the effectiveness of the suspended and sliding seats.

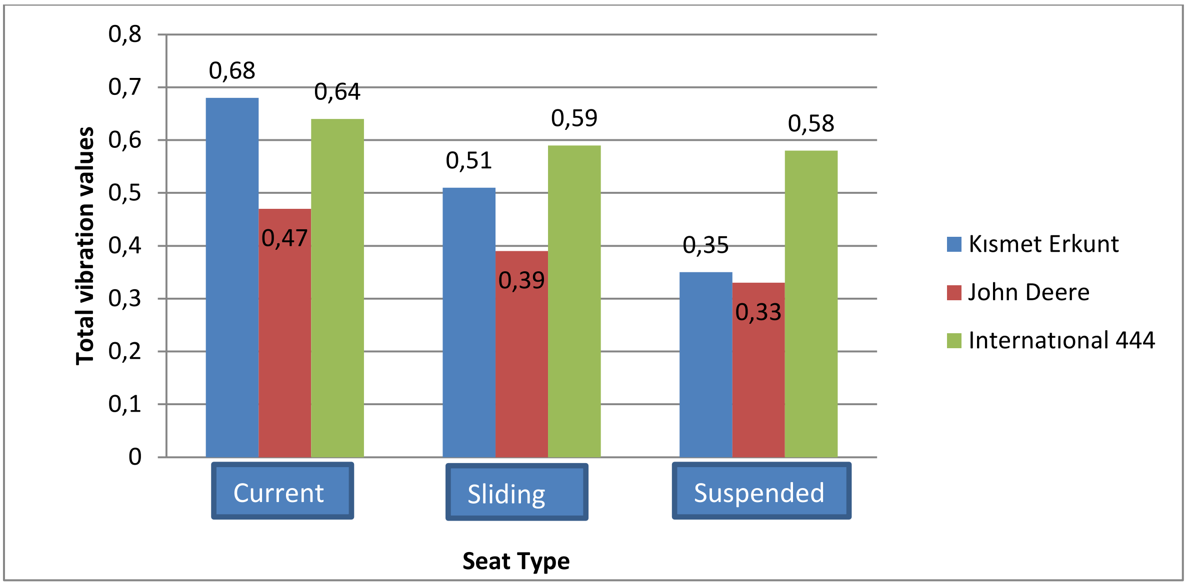


Figure 4. Vibration values to which the operator is exposed during work with towing tractors.

According to the variance analysis, it was determined that tractor and seat types having *P* values of 0.001 and 0.004 ($P<0.05$) had an effect on the total vibration value (Table 3). The Tukey test was conducted to identify different groups, and the results showed that, of the seat types, the 2- and 4-spring seats performed the best (Table 4) and of the tractor types, the 2010 model John Deere tractor exhibited the best performance (Table 5).

Table 3. The results of variance analysis for the towing tractors.

| **Variation Source** | **Sum of Squares** | **Degree of Freedom** | **Squares Mean** | **F Value** | **P Value** |
|---|---|---|---|---|---|
| **Tractor Type** | 0.18 | 2 | 0.090 | 10.78 | 0.001* |
| **Seat Type** | 0.13 | 2 | 0.065 | 7.755 | 0.004* |
| **Tractor x Seat** | 0.060 | 4 | 0.015 | 1.79 | 0.175 |
| **Error** | 0.151 | 18 | 0.008 | | |
| **Total** | 7.66 | 27 | | | |

Table 4. Summary of variance results for all axes.

| Variation Source | x-axis | | y-axis | | z-axis | |
|---|---|---|---|---|---|---|
| | F value | P value | F value | P value | F value | P value |
| Tractor type | 14.864 | 0.00* | 8.382 | 0.003* | 4.495 | 0.026* |
| Seat type | 3.742 | 0.044* | 3.083 | 0.071 | 13.523 | 0.00* |
| Tractor x Seat | 3.087 | 0.042* | 2.212 | 0.108 | 0.921 | 0.473 |

Table 5. The results of comparative tests of WBV values according to seat types.

| All axis accelerations | Seat type | Tukey test results | | |
|---|---|---|---|---|
| | | Group 1 | Group 2 | Group 3 |
| $a_x$ (back-forth) | Spring-free seat | | 0.2444 | |
| | 2-spring seat | 0.1967 | 0.1967 | |
| | 4-spring seat | 0.1867 | | |
| $a_y$ (horizontal) | Spring-free seat | | | |
| | 2-spring seat | | | |
| | 4-spring seat | | | |
| | Spring-free seat | | | 0.4256 |

| | | | | |
|---|---|---|---|---|
| $a_z$ (vertical) | 2-spring seat | | 0.3422 | |
| | 4-spring seat | 0.2411 | | |
| $a_t$ (total) | Spring-free seat | | 0.6189 | |
| | 2-spring seat | 0.4967 | | |
| | 4-spring seat | 0.4222 | | |

Most suspended seats are designed for isolation at the vertical axis (Donatı 2002). Vibration magnitude effective on Z axis direction is more dangerous for tractor drivers (Nishiyama et al. 1998). According to the results of the Tukey test, the z axis had the greatest vibrational effect. The spring-free (0.42ms$^{-2}$), 2-spring (0.34ms$^{-2}$) and 4-spring (0.24ms$^{-2}$) seats were placed in different groups and the best performance was seen in the 4-spring seats (Table 4).

Whole-body vibration measurements for the trucks were obtained with a separate assessment of three different truck models and two different seat types on both forest and asphalt roads. Accordingly, in the measurements of the currently-used seats on the 1995, 1992 and 1988 model AS 950 trucks, the WBV values were found to be 01.04, 0.95 and 0.80, respectively. The highest WBV values for all axes ($a_x$=0.46 ms$^{-2}$, $a_y$=0.29ms$^{-2}$,$a_z$=0.69 ms$^{-2}$) were obtained with the (old) current seat on the 1995 model AS 950 truck. The lowest WBV values for all axes ($a_x$=0.19 ms$^{-2}$, $a_y$=0.15 ms$^{-2}$, $a_z$=0.33 ms$^{-2}$) were determined with the new seat on the 1995 model AS 950 truck (Table 6). Similarly in the study which aims to reveal the efficiency of seat vibration insulation in 100 different vehicles in 14 different categories, highest vibration value was determined as 3.27 ms$^{-2}$ in excavator while it was determined as 1.04 ms$^{-2}$ in trucks (Paddan and Griffin 2002). In another study where vibration effect on two different models was emphasized it was determined that highest vibration magnitude for a model which has high load capacity (10 m) was found to be vertical vibrations (in Z direction) varying between 0.89-1.18 ms$^{-2}$ while highest vibration magnitude for a model which has lower load capacity (6 m) was found to be horizontal vibrations (in X direction) varying between 0.55-0.64 ms$^{-2}$ (Eger et al. 2005).

Table 6. Vibration values transmitted to operators during work using trucks.

| **Truck Type** | **Seat Type** | **Road Type** | **X- axis** | **Y- axis** | **Z- axis** | **Total V** |
|---|---|---|---|---|---|---|
| **1995 model** | **Current** | **Forest** | 0.46 (0.05) | 0.29 (0.07) | 0.69 (0.07) | 1.04 (0.08) |
| | | **Asphalt** | 0.43 (0.05) | 0.25 (0.03) | 0.71 (0.11) | 1.00 (0.13) |
| | **New** | **Forest** | 0.19 (0.06) | 0.15 (0.04) | 0.33 (0.09) | 0.48 (0.13) |
| | | **Asphalt** | 0.28 (0.03) | 0.18 (0.02) | 0.58 (0.03) | 0.75 (0.05) |
| **1992 model** | **Current** | **Forest** | 0.28 (0.02) | 0.26 (0.04) | 0.77 (0.07) | 0.95 (0.09) |
| | | **Asphalt** | 0.25 (0.02) | 0.24 (0.03) | 0.81 (0.07) | 0.95 (0.08) |
| | **New** | **Forest** | 0.34 (0.03) | 0.31 (0.05) | 0.48 (0.07) | 0.81 (0.10) |
| | | **Asphalt** | 0.25 (0.02) | 0.18 (0.01) | 0.54 (0.01) | 0.69 (0.02) |
| **1988 model** | **Current** | **Forest** | 0.24 (0.01) | 0.26 (0.01) | 0.62 (0.17) | 0.80 (0.14) |
| | | **Asphalt** | 0.18 (0.01) | 0.22 (0.01) | 0.76 (0.03) | 0.86 (0.04) |
| | **New** | **Forest** | 0.24 (0.02) | 0.21 (0.01) | 0.45 (0.07) | 0.64 (0.06) |
| | | **Asphalt** | 0.14 (0.01) | 0.17 (0.03) | 0.56 (0.08) | 0.65 (0.10) |

The total vibration values of the trucks are very close to the danger limit (1.15 $ms^{-2}$) stated in international standards. With the use of new seats, compared to the current seats, total vibration values decreased to below the warning limit (0.5 $ms^{-2}$) for all vehicles (Figure 5). Hence, considering the use of the seats over the 8-hour work period, the new seats showed better results compared to the current seats which had lost their damping ability. It was concluded that the functioning damping feature of the new seats had a positive effect on the outcome.

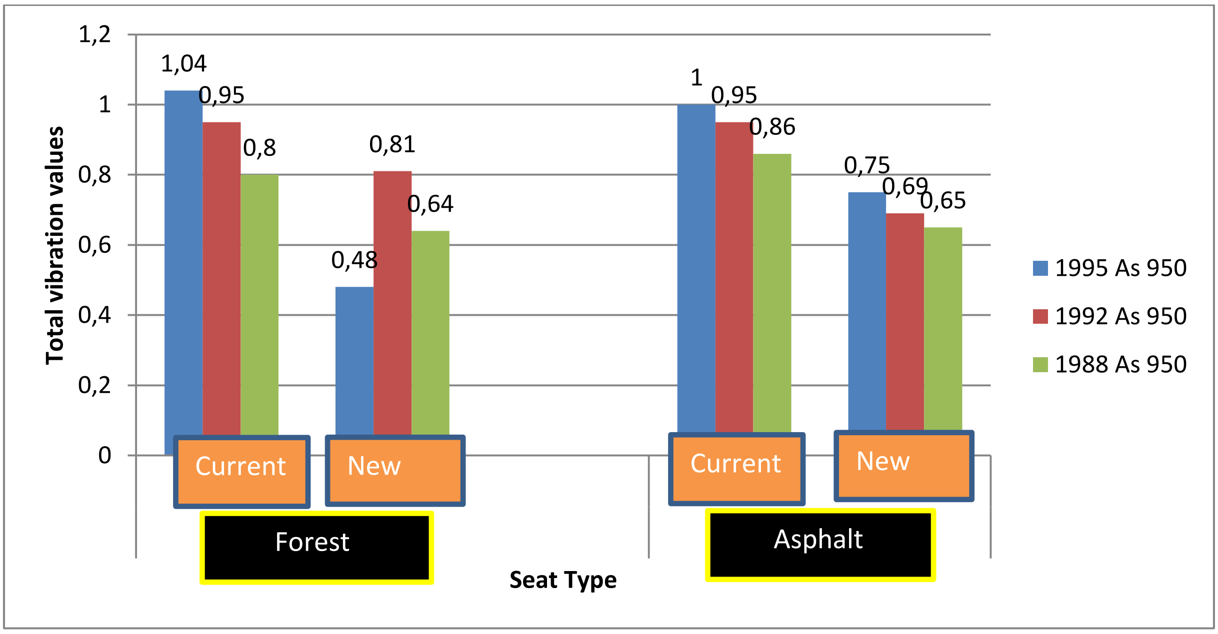


Figure 5. Vibration values to which the operator is exposed during work with trucks.

The total vibration values were measured for daily vibration exposure (8 h), and then the maximum work period was calculated via the warning limit (0.5 $mm^{-2}$) set by international standards. The measurements were made via the lowest and highest vibration values. Accordingly, the maximum daily work periods were determined, with the 1995 model AS 950 truck having the highest vibration values ($a_t$:1.04) on forest roads. The results were as follows: 1.88 h (113 min) for the current seats (without springs) and >8 h (480 min) for the new seats.

Table 7. The results of variance analysis for the trucks.

| **Variation Source** | **Sum of Squares** | **Degree of Freedom** | **Squares Mean** | **F Value** | **P Value** |
|---|---|---|---|---|---|
| **Truck Type** | 0.082 | 2 | 0.041 | 5.002 | 0.015* |
| **Seat Type** | 0.619 | 1 | 0.619 | 75.674 | 0.00* |
| **Road Type** | 0.008 | 1 | 0.008 | 0.918 | 0.347 |
| **Truck x Seat** | 0.092 | 2 | 0.046 | 5.621 | 0.010* |

| | | | | | |
|---|---|---|---|---|---|
| **Truck x Road** | 0.044 | 2 | 0.022 | 2.703 | 0.087 |
| **Seat x Road** | 0.005 | 1 | 0.005 | 0.599 | 0.446 |
| **Truck x Seat x Road** | 0.084 | 2 | 0.042 | 5.149 | 0.014* |
| **Error** | 0.196 | 24 | 0.008 | | |
| **Total** | 24.266 | 36 | | | |

*There is a statistically significant difference between the groups.

According to the variance analysis, it was determined that truck and seat types having *P* values of 0.015 and 0.000 ($P<0.05$) affected the total vibration value (Table 7). The Tukey test was conducted to identify the different groups and the results showed that of the seat types, the new seats performed better, and of the truck models, the 1988 and 1995 model AS 950 trucks exhibited the best performance (Table 8).

Table 8. Summary of variance results for all axes.

| Variation Source | X- axis | | Y- axis | | Z- axis | |
|---|---|---|---|---|---|---|
| | F value | P value | F value | P value | F value | P value |
| Truck type | 61.651 | 0.00* | 3.453 | 0.048* | 2.583 | 0.096 |
| Seat type | 40.127 | 0.00* | 21.539 | 0.00* | 76.176 | 0.00* |
| Road type | 11.804 | 0.002* | 12.718 | 0.002* | 14.036 | 0.001* |
| Truck x Seat | 53.951 | 0.00* | 6.246 | 0.007* | 1.228 | 0.311 |
| Truck x Road | 10.81 | 0.00* | 3.325 | 0.053 | 0.972 | 0.393 |
| Seat x Road | 0.104 | 0.75 | 0.403 | 0.531 | 1.846 | 0.187 |

*There is a statistically significant difference between the groups.

In order to evaluate the health problems of forestry workers (vehicle operators) related to lumbar and back complaints, radiological and physical examinations were made and the physicians who evaluated the examination results diagnosed the medical conditions and ailments of the forest workers. The health screening was carried out to investigate the general health effects of the vibration to which forest workers are exposed during forest harvesting work. The ages of the towing tractor operators were 48, 51 and 53 and they had worked in the forestry sector for 30, 20 and 30 years, respectively. Although each of the three towing tractor operators had suffered moderate back discomfort for 30, 20 and 30 years, respectively, none of them had undergone surgery for the treatment of back or lumbar problems. The truck operators were aged 44, 46 and 52 and they had worked in the forestry sector for 25, 15 and 30 years, respectively. Although all three truck operators had suffered moderate back discomfort for 10, 10 and 15 years, respectively, none of them had undergone surgery for the treatment of back or lumbar complaints either. Additionally, according to the towing tractor operators, their discomfort had not been severe, although they had been having these back problems from the time they first began working.

After orthopaedic specialists evaluated the examination and test results, it was found that two of the three towing tractor operators and all three truck operators were suffering from herniations related to their back and lumbar discomfort. The herniations were observed at L5-S1 and L4-L5 among the five lumbar vertebrae located in the lower back region (Figure 6). The discs between the vertebrae have the function of absorbing the shock on the spine. The degeneration of the lumbar discs is a consequence of stress overload and strain on this part of the back. In a similar study where effects of vibration on the spine were examined for 3 operators with different heights and weights, effects were observed on T12/L1, L3/L4 and L5/S1 discs and that highest pressure was observed in L5/S1 region (Seidel 2005).

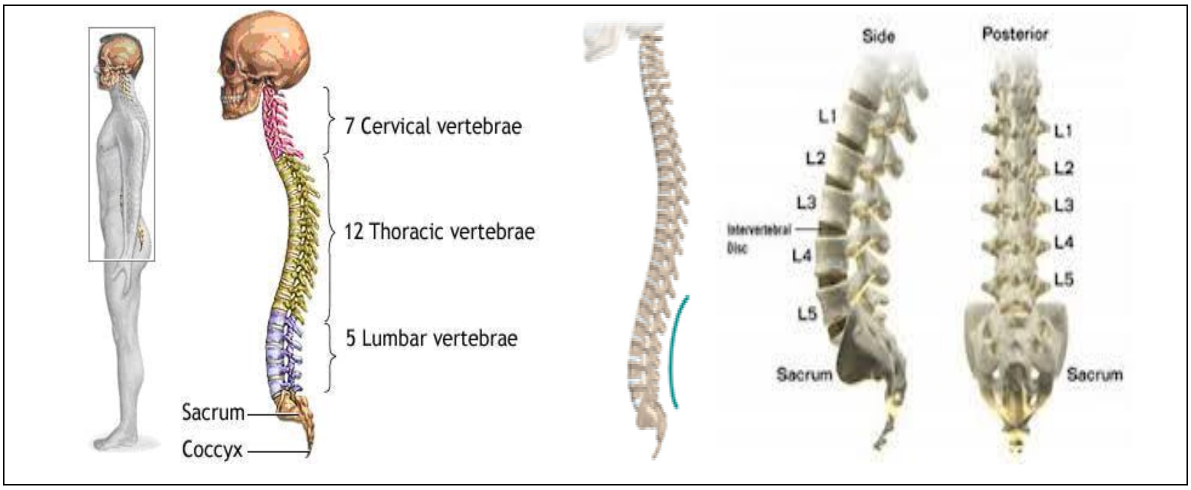


Figure 6. Lumbar vertebrae of the human spinal column.

Furthermore, apart from heavy lifting and sudden movements which put stress on the back, the factor of incorrect sitting and standing habits has been found to contribute greatly to back and lumbar problems. Operators must often make sudden unavoidable movements in order to prevent the vehicle from overturning in case of a breakdown. They control the vehicle via the pedals and the tambour system via the arms mounted in the tambour system. During the course of these manoeuvres, the operator often gets in the habit of incorrect sitting and standing positions.

A herniated disc was the most prevalent condition observed in the truck operators, and all truck operators mentioned having the intense foot pain caused by a herniated disc. Other contributing factors that were observed included the physical characteristics of the truck operators themselves, such as being heavier and taller than other operators, traits which exposed them to more heavy lifting and loading work than others (Figure 7).

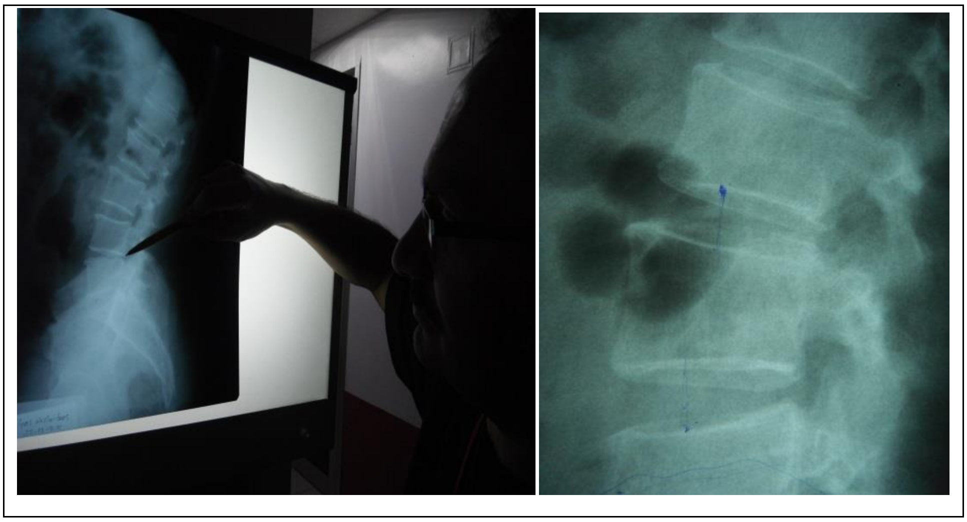

Figure 7. Radiological assessments.

**Discussion**

Following the investigation of the effect of vibration on towing tractors and trucks in three axes, it was observed that the greatest effect was on the Z (vertical) axis. These values can be reduced by the use of new sliding and suspended tractor seats and new truck seats. It was concluded that suspended 4-spring tractor seats and new truck seats give the best results when considering the issues of operator health and comfort.  In the test measurements with the trucks conducted on forest and asphalt roads in three axes, the X (back-forth) and Y (horizontal) axis values were higher on the forest roads compared to the asphalt roads. This case was just the opposite for the Z (vertical) axis; the Z axis values were higher on asphalt roads. In a similar study carried out by Melemez et al. (2013) on skidder tractor operators, it was observed that harmful effects of whole-body vibration on operators could be decreased with seat suspension system. Also showed a similar study conducted before that vibration effect can be decreased less than 100% by seat insulation in 75 vehicles out of 100 and it was stated that changing the vehicle set may be useful and meliorations in the sitting dynamics may decrease whole-body vibration exposure in many working environments (Paddan and Griffin 2002).

In addition, according to the calculation of maximum work periods through the warning limit (0.5 $ms^{-2}$) set by international standards, it was concluded that, without causing any health or comfort problems, work periods could be increased by means of seat changes for the three towing tractor makes and the three truck models observed in the study. By similar studies made earlier, vertical vibration measurements were made on new seats developed with vibration preventing suspension system in agricultural tractors in order to decrease the vibration and exposure values below limit values (Sreedhar et al. 2008). Vibration is acutely applied in periods varying between 5 and 30 seconds while it is applied chronically in periods varying between 10 days and 6 months and according to these results, studies which will determine the optimal vibration magnitude and application period which will cause positive effects in performance (related with the effect of vibration on performance) are necessary (Kin-Isler 2007). In another study where effects of body vibration were examined on driver operators in terms of comfort and health, it was observed that measured average rms values exceeded the limit values and that they increased the upper limit of health zone within 2,3 hours (Jack et al. 2010).

It was noted that two of the three towing tractor operators and all three truck operators were suffering from herniations related to back and lumbar discomfort. In a similar study where the role of gender and age in forecasting the exposed vibration was tested, it was determined that 36% of the participants have been exposed to occupational exposure against whole-body vibrating equipments at least once and that old age and male gender is effective on exposure (Harris et al. 2012). In a similar study where effects of vibration on the spine were examined for 3 operators with different heights and weights, effects were observed on

T12/L1, L3/L4 and L5/S1 discs and that highest pressure was observed in L5/S1 region (Seidel 2005). Poor sitting posture was an apparent contributing factor in the towing tractor operators as was the lifting work and carrying of heavy logs by the truck operators. Apart from these factors related to back and lumbar problems, sudden unavoidable movements of the operators, regardless of the level of their experience, can also have negative effects. As towing tractor operators are susceptible to health problems from the time they begin this work, necessary precautions should be taken within their first year at the job. The tambour system should be managed by buttons instead of by manual controls in order to prevent incorrect sitting posture.

Measurement and evaluation of vibration values in three axes, in particular vertical vibration values, should be carried out in order to avoid their adverse effects on the health and working performance of vehicle operators. It is a fact that operator comfort increases efficiency in machine use; therefore, old seats that have lost their damping features should be replaced with new ones; thus, operator satisfaction and performance efficiency will be improved. Attempts should be made to ensure that the optimum insulation of tractor and truck operator seats is implemented. In addition, the pressure of front and rear tractor tyres should be kept at the lowest appropriate level. Moreover, further action should be taken to repair rough road surfaces as operators are constantly exposed to the adverse effects of vibration due to such roads.

Tractor operators should be informed about the sources and health risks of vibration and instructed in ways to prevent its negative effects. Compulsory training should be established with the cooperation of forest enterprises and relevant labour safety units. In order to protect tractor operators from vibration, there should be a 10-minute break for every hour during the work period, and shift working opportunities should be offered when necessary. Attention should be paid on studies that will determine the optimal vibration magnitude and application period which will have positive effects on performance. Finally, in the forestry sector, purpose-built vehicles should be used rather than agricultural tractors.

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