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Reducing whole body vibration in forklift drivers

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Abstract. Forklift drivers in warehouses are often exposed to whole body vibration (WBV) during the total day. There is however an association between working as a forklift operator and the development of low back pain. In this study the exposure to WBV was measured in five forklift drivers who performed a standardised order picking task during 10 minutes. The effect of driving surface (uneven concrete vs. new flat concrete), driving speed (15 km/h vs. 8 km/h) and seat suspension (mechanical suspension vs. air suspension) was investigated. Improving the driving surface was the most effective preventive measure by reducing the whole body vibration with 39%, from 1.14 to 0.69 m/s^2. Lowering the speed limit resulted in a reduction of WBV with 26% (1.05 vs. 0.78 m/s^2). An air suspension seat was 22% more effective compared to mechanical suspension (1.02 vs. 0.80 m/s^2). On uneven concrete an air suspension seat performed even better by reducing the WBV by 29% (1.33 vs. 0.95 m/s^2). A combination of a new driving surface, limiting the maximum speed and the introduction of an air suspension seat reduced the whole body vibrations below the action limit of 0.5 m/s^2 as mentioned in the European directive. None of the interventions were effective enough on their own.

Keywords: whole body vibration, forklift driver, driving surface, air suspension seat, driving speed

1. Introduction

There is a significant relationship between working as a forklift operator and the development of LBP [22, 23]. The self-reported prevalence of low back pain was 63% in Japanese forklift drivers. This was twice as high as in the remaining blue-collar workers [17]. Review studies also revealed that the relative risk for low back pain was more than 2.0 for forklift drivers. This means that operators exposed to driving forklifts are greater than twice the risk of those not exposed to driving forklifts to experience low back pain [22, 23].

The factors that contribute to cause low back pain are diverse and might include prolonged sitting, poor postures and exposure to whole-body vibration (WBV). Long term occupational exposure to WBV is associated with an increased risk of disorders of the lumbar spine and the connected nervous system [2]. The risk for injury increases as the duration and the dose of WBV increases [20].

The current ISO 2631-1 WBV standard specifies that whole body vibration measurements should be made in each of the three applicable axes (x, y and z) in order to account for the nature of vibration, which involves both a magnitude and a direction [8]. The European directive mentions an action value of 0.5 m/s^2. When the measured amplitude is higher, preventive action is necessary. There is also a limit value, 1.15 m/s^2 that may not be exceeded. In five European countries LBP and spinal disorders due to WBV are currently recognised as an occupational disease. In Belgium a limit of 0.8 m/s^2 is used as criterion.

In this study forklift drivers worked in a warehouse, performing an order picking job. This consisted of transporting stacks of plywood from the warehouse to a central loading place. One hour recording of the whole body vibration revealed that the forklift drivers were exposed to an average acceleration of 1.09 m/s^2.

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This is above the action value as mentioned in the European directive. Ergonomic intervention should be undertaken.

In the literature several influencing factors on WBV in forklifts are mentioned:

- Track [4, 5, 12]
- Load [10, 12]
- Engine [12]
- Tyres [12, 18]
- Cab suspension [11]
- Seat suspension [1, 12, 14, 15, 17]
- Driving speed [5, 6, 10, 13]
- Driving behaviour [7, 13, 21]
- Body weight of driver [1, 12]
- Driving posture [16, 22]

They can be divided in three categories: the environment, the truck and the driver.

Levelling the track, adjusting the driving speed, using a suspended seat and inflated tyres are the main technical actions capable of reducing the vibration amplitudes to which the workers are exposed. The engine effect is rather small. Diesel and electric forklift trucks showed comparable acceleration amplitudes. The vibration also did not differ between the soft and hard cushion tyres. They tended to be smaller for the inflated tyres in a truck with seat suspension [12].

In a study with heavy haulage trucks, unloaded travel was also associated with the highest vibration accelerations. The decreased vehicle mass and increased driving speeds contributed to the high vibration accelerations [10].

Suspended cabs in forklifts are not common. In an experimental study a low frequency suspension system (spring and dampers) was placed between the driving cab and chassis of an existing forklift truck. The measurements showed that the attenuation of vertical accelerations was more than 50% [11]. The effectiveness of cab suspension can even be improved. In subway train cars the ones with air-cushioned suspensions showed 31% lower overall vibration levels than for the cars with spring-based suspension [14].

A mechanical suspended seat showed a lower vibration exposure in the vertical direction compared to a fixed seat without dampening [12]. The introduction of a suspended seat and pneumatic tires decreased the proportion of forklift workers with LBP by absolutely reducing whole body vibrations [17]. The WBV exposure on a mechanical suspension seat showed to be weight dependent. An air suspended seat however reduced the vibration level to a comparable magnitude for all weight classes of drivers. Overall the WBV values were 24% lower with an air suspended seat compared to mechanical suspension [1].

Driver characteristics have also an influence on the vibration exposure. Accelerations on the seat were the greatest for the worker weighing only 55 kg, while they were the smallest for the heaviest one [12]. There is also an effect of the driving behaviour [7, 13, 21]. The harmful effect of WBV on the spine can even be aggravated by the driving posture [16, 22].

The vibration exposure is mainly influenced by the roughness of the track, the speed and the quality of the seat. The purpose of this study was to determine the effect of flattening the driving surface, providing air suspension seats and reducing the driving speed. The aim was to decrease the current vibration level of 1.09 m/s^2 below the action level of 0.5 m/s^2. Therefore the effect of each preventive measure and the combined effects were investigated.

2. Methods

2.1. Subjects and forklifts

A total of 5 experienced forklift drivers participated in this study. The mean (SD) age and body weight of the subjects was 41.2 (8.7) years and 86.1 (11.9) kg respectively. The subjects had 6 to 13 years of experience operating forklifts. They drove during 8 hours a day, with only small breaks when taking a new pick list.

Each driver had his own Hyster 7.0 forklift truck, LPG powered with solid rubber tires. The forklift has a load capacity of 7000 kg and a two-speed electronic power shift.

2.2. Accelerometer

The exposure to WBV was measured using a seat pad accelerometer, model GA2005C, Castle Excieo C (Castle, Scarborough, United Kingdom). Following settings were used: sensitivity of 10 mV/g range + 50g, frequency of 0,5 – 3000 Hz + 5%, range of 0,02 – 100 ms-2 and log interval of 1s

The data were processed by VIBdataPro (Castle group), vibration analysis software. The WBV exposures were calculated according to the ISO 2631-1 (1997). Root mean square average weighted vibration

(A_w) was calculated. ISO 2631-1 suggests using the worst axis to predict potential health effects. This is the axis with the highest frequency-weighted root mean square vibration magnitude. The Belgian legislation also refers to this method.

2.3. Set up

The forklift drivers performed a standardised order picking task during 10 minutes. They had to pick up stacks of plywood in the warehouse and bring them to a central place where the stacks were loaded into a truck. Driving to the warehouse was always unloaded and in a forward direction, driving to the central place with the load occurred backwards with a twisted back and neck.

This picking task was repeated under different conditions: on an even and uneven driving surface, mechanical and air suspension seat, slow and fast driving speed.

2.3.1. Driving surface

The track of the warehouse consisted of concrete plates but they were not flat anymore. The surface was rough and uneven with shocks, bumps and jolts. The warehouse however had two departments. In one department the driving surface was renewed with a flat concrete floor. This made it possible to compare the two track conditions.

2.3.2. Seat suspension

The study examined the exposure to WBV using two different types of seat suspension: mechanical and air. The driver's seat with mechanical suspension (model MSG 65, Grammer, Amberg, Germany) has a vertical travel of 60mm and weight adjustment between 45 and 170 kg. This type of seat was standard available in the forklift trucks.

The air suspension seat with automatic weight adjustment (model Maximo XXL, Grammer) between 50 and 130 kg had a suspension stroke of 100 mm. This seat could also swivel 20° around a vertical axes in both directions. This swivelling mechanism was fixed to compare both seats more accurately.

2.3.3. Driving speed

The maximum driving speed was set at 15 km/h and 8 km/h. The drivers were asked to drive as fast as possible to the maximum limit. However, in the loaded condition the maximum speed of 15 km/h could not always be reached while driving backwards.

2.4. Statistical analysis

Repeated ANOVA methods were used to determine statistical significant differences. Differences were considered significant when p-values were less than 0,05.

3. Results

Table 1 shows the measured whole body vibration in the different test conditions. In fig. 1 the results are averaged for surface, seat suspension and speed.

3.1. Driving surface

The average vibration in the z-axis driving a forklift on a flat concrete surface was 0.69 m/s^2 compared to 1.14 m/s^2 while driving on the uneven surface. Flattening the surface reduced the vibration with 39%. This was the most effective preventive measure in this study (fig. 1).

The advantage of a good driving surface was even more pronounced when seating on a mechanical suspension seat. The reduction in whole body vibration was 46%. After the introduction of an air suspended seat the effect of the driving surface was significantly lower. On the even surface (0.65 m/s^2) the whole body vibrations were 32% lower in comparison to the uneven condition (0.95 m/s^2).

There was no interaction effect between the driving surface and the driving speed. At both speeds, the effect of improving the track was 40%.

However, the dose of vibration would still remain above the action value of 0,5 m/s^2 under real working conditions. Extra preventive measures remained necessary to prevent low back pain.

Table 1
Measured whole body vibration (SD)

Surface – suspension - speed	A_w in m/s^2
Even, mechanical, 15 km/h	0,86 (0,10)
Even, mechanical, 8 km/h	0,58 (0,07)
Even, air, 15 km/h	0,72 (0,09)
Even, air, 8 km/h	0,58 (0,08)
Uneven, mechanical, 15 km/h	1,52 (0,19)
Uneven, mechanical, 8 km/h	1,13 (0,15)
Uneven, air, 15 km/h	1,10 (0,15)
Uneven, air, 8 km/h	0,80 (0,10)

3.2. Seat suspension

An air suspended seat with automatic weight adjustment was evaluated to know the effect of this preventive measure in forklift trucks. Compared to a mechanical seat suspension (1.02 m/s^2) the root mean square acceleration was 22% lower with an air suspended seat (0.8 m/s^2).

The effect of suspension showed an interaction effect with the floor condition. A forklift seat with air suspension was the most effective while driving on uneven concrete reducing the vibrations with 28% (air: 0.95 m/s2 vs. mechanical: 1.33 m/s^2). This is significantly better than the 10% benefit of the air suspension seat on even concrete.

The positive effect was independent of the driving speed. On an air suspended seat the vibrations were 24% lower while driving fast compared to 20% lower while driving slow. On a flat surface there was even no meaningful difference between the two types of suspension (0.58 m/s^2) while driving slow.

3.3. Driving speed

With a mechanical seat suspension the effect of reducing the driving speed was 28% on the vibration values (1.19 m/s^2 at 15 km/h vs. 0.86 m/s^2 at 8 km/h). With an air suspended seat the favourable influence was 24% (0.91 at 15 km/h vs. 0.69 m/s^2 at 8 km/h). The effect of lowering the driving speed showed no significant difference between the uneven and even track.

A combination of a better driving surface, air suspension seat and lower driving speed was for the standard order picking task still not enough to reduce the vibrations below the action value (0.5 m/s^2). However, the vibration under real work circumstances (1.09 m/s^2) would be reduced to 0.37 m/s^2 by the combined effect of these interventions.

4. Discussion

4.1. Driving surface

Flattening the concrete surface reduced the vibrations the most effectively. After renewal of the track the vibrations were 39% lower. A previous study with forklift trucks already showed that the vibration exposure was mainly influenced by the roughness of the track. Driving in a forklift on smooth concrete showed 41% lower vibrations values compared to working on a rough paved track. These forklifts had seats without anti-vibration system and seats with a mechanical suspension [12].

This study showed also an interaction effect with the seat type. With a mechanical suspension the positive effect of a flat surface was even larger (46%). When the dampening of the seat is less pronounced, the underground gains importance. This was also found in other studies with different types of vehicles. With a comparable speed and seat in highway transport trucks or motorcycle riders, the road condition was the best predictor of the vibration exposure [4, 5].

Considering the vibration level of 1.09 m/s^2 under real working conditions, improving the driving surface would reduce the vibration to 0.59 m/s^2. Levelling the track alone was not effective enough. On the other hand, without an even floor the vibrations would never reach below the action value of 0.5 m/s^2 while driving with the forklift trucks in the warehouse.

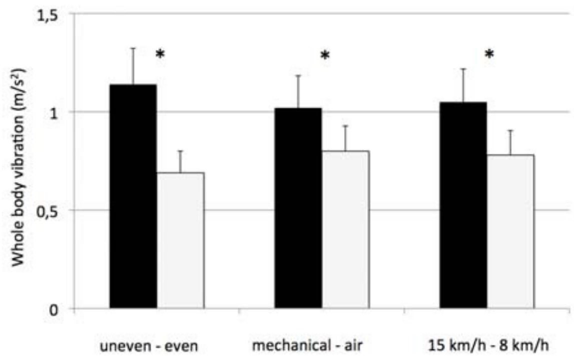

Fig 1. Average whole body vibration for each driving surface, seat suspension and driving speed (* p<0,05).

4.2. Seat suspension

The overall effectiveness of an air suspended seat compared to the mechanical suspension seat was 22%. The vibrations were reduced from 1.02 (mechanical) to 0.8 m/s^2 (air). These results are in agreement with a recent study [1] where an air suspension seat reduced the vibrations from 0.71 m/s^2 with a mechanical seat suspension to 0.54 m/s^2. The benefit is 24%, similar to this study.

However, in the mechanical seat WBV exposure appeared to be weight-dependent. The exposure decreased as the body mass of the drivers increased. A mechanical suspended seat is more effective for the heavy drivers. An air suspension seat on the contrary reduced the vibrations to a comparable level independent of the weight of the driver. This makes that the benefit of an air suspended seat over a mechanical suspension seat is also weight-dependent, being the most effective for lightweight drivers. For drivers with a body weight of less than 84 kg the vibrations were reduced with 49%, for the drivers weighing between 84 and 116 kg the reduction was 8%. The heavy drivers (>116 kg) however showed a 12% higher exposure to vibrations on an air suspended seat compared to the mechanical suspension. The body weight of the five drivers in this study varied between 72 and 102 kg. The light and medium weight of the drivers agreed with the positive effects of the air suspension seat.

An earlier study [3] however found no difference between seats with conventional suspension and those with air suspension. When the surface and speed were optimised in this study, the seat suspension had also no meaningful influence anymore on vibrations. An air suspension seat was more effective when the driving surface was uneven. This indicates that the seat suspension is the last line of defence against vibration. When the other preventive measures are lacking, the suspension of the seat becomes more important.

These results however do not conclude that a mechanical suspended seat would not be effective. Comparing a fixed seat without suspension and a mechanical anti-vibration system, the vibration exposure was 32% lower in favour of the seat suspension [12].

4.3. Driving speed

Lowering the speed limit from 15 km/h to 8 km/h reduced the vibration exposure with 26%. Driving with a loaded forklift with stacks of plywood however, the driving speed of 15 km/h was unrealistic. The drivers had to push the forklift to the maximum, especially on the rough surface. The gain under real working circumstances will be smaller.

The influence of driving speed is in agreement with other studies. When the driving surface and the type of seat are the same, then driving speed was the primary predictor of vertical vibration on the seat in train operators. The speed was the most significant factor influencing vibration exposure levels [13]. In taxi drivers there was even a quadratic-linear relationship between the average driving speed and the measured vertical acceleration [6].

5. Conclusion

A combination of the three preventive measures was effective in reducing the whole body vibrations below the action value of 0.5 m/s^2 under real working conditions. Improving the floor and lowering the speed are the first line of defence against vibrations. A combination of these interventions reduced already effectively the accelerations below the action value. Lowering the speed was however not interesting for the operators and the management. The job had to be done.

Finally the management decided to flatten the driving surface, an air suspension seat was implemented in the procurement procedure. In this way it was also possible to drive safely the whole day in the forklift at a normal working speed.

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