



A DECADE OF IMPROVEMENT IN WHOLE-BODY VIBRATION AND LOW BACK PAIN FOR FREIGHT CONTAINER TRACTOR DRIVERS

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(Accepted 8 May 1998)

The authors' study in 1983 revealed that the whole-body vibration of the tractor units of freight containers was most hazardous in the back-to-chest directions (x -axis). The allowable exposure time was considerably shorter than that for heavy duty trucks. The low back pain (LBP) among the drivers seemed to be due to the long working hours and the ergonomically unsound tractor design, as well as the vibration. A preventative measure was the introduction of a tractor cab suspended by an air spring instead of a steel spring. In 1992, a follow-up field study was conducted. A personal vibration exposure meter developed by us measured the whole-body vibration on eight tractors. Eighty-nine triplets matched with the age and the years of driving tractors answered a questionnaire evaluation of the ergonomics of their tractor units.

The comparison of the newest steel suspension vehicles to the old ones produced by the same motor company revealed that in the x -axis the vibration level had decreased by as much as 4 to 9 dB. Some tractors showed an increase in vibration in the buttocks-to-head direction (z -axis). However, such adverse changes seemed not to affect evaluations according to the fatigue-decreased proficiency boundary (FDP) and the exposure limit (EL) recommended in ISO 2631-1978. The present models, regardless of the type of suspension, changed the direction of the most hazardous vibration from the x -axis to the z -axis. However, the effect of the air-suspension was not so remarkable as expected. Among 40% of drivers seemed to exceed the FDP boundary during a day.

The questionnaire study showed an improvement in the ergonomic evaluation of the tractors. The air suspension models seemed to induce less LBP than the steel suspension models.

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1. INTRODUCTION

The introduction of freight container tractor trucks (tractors) into the international cargo transportation system started in 1967 in Japan. In the late 1970's, the complaint of low back pain (LBP) became prevalent among the drivers. In the early 1980's the compensating apparatus of the national government recognised several LBP cases as occupational diseases. Responding to the request of the concerned trade union to solve the problem, the authors conducted a study consisting of three parts. The first was the assessment of whole-body vibration of 10 tractors. It involved a monthly survey of the daily driving hours of 240 tractor drivers, and a time study of 28 man-days [1]. The second was a medical examination of 231 tractor drivers [2, 3]. The third was a questionnaire study among 549 tractor drivers of the ergonomic design of the tractors [4].

According to ISO 2631-1978 [5] and ISO 2631-1978/A1-1982 [6] the vibration levels of the tractors were more hazardous in the fore-aft direction or back-chest direction (x -axis)

[4]. The time study showed that the daily driving hours of more than 90% of drivers exceeded the allowable exposure time according to the fatigue-decreased proficiency boundry (FDP) [4]. Around one-third of the drivers exceeded the allowable exposure limit (EL) [4]. The results suggested that long exposure to severe vibration during work was one of the causal factors of LBP in the tractor drivers [1–4].

The union attempted to improve the working conditions according to the report of the authors' study. One of the improvements was the introduction of air suspension, instead of steel suspension for the tractor cab. Anecdotes told of the decrease of whole-body vibration and LBP prevalence after several years. The objectives of the present study were to address the problem relating to whole-body vibration and to identify what problems still remained. The study in 1992 consisted of the assessment of the whole-body vibration of the drivers and the ergonomic evaluation of the tractors through a questionnaire administered to the drivers.

2. METHODS AND SUBJECTS

2.1. MEASUREMENT OF WHOLE-BODY VIBRATION

A personal whole-body vibration exposure meter was developed following the earlier studies [1–4]. It recorded whole-body vibration during the usual work without the attendance of an operator to conduct the measurements. It consisted of a real-time analyzer, a preamplifier and a circular, semirigid pad (PV-62, Rion Co., Ltd.). The pad diameter was 210 mm, 12 mm in height with a weight of 400 g mounting three translational piezoelectric accelerometers as defined by ISO 5008 [7]. The analyzer allowed simultaneous measurement of power averaged (mean) levels in three axes and the maximum level after frequency weighting as defined by ISO 2631-1978 [5]. It also allowed the measurement of the total power levels in 1/3 octave bands in one axis.

In the present study, the circular pad was located between the buttock and the seat. The vibration meter analysed the 1/3 octave bands in the x -axis, because the previous study [4] had indicated it as the most hazardous direction. The time weighting was 0.125 s. The memory interval for instantaneous values was 40 s, so that a whole workday measurement was possible without the attendant operating the vibration meter. The system was put in a suitable place in the cab of a tractor and powered by an external battery.

The vibration meter measured the eight types of tractor selected by the union as the most familiar steel suspension and air suspension models of the same four Japanese motor companies as before. Several union drivers drove the tractors in four conditions. The conditions were two combinations of the length of the freight container (20 or 40 ft) and the loading conditions (laden or unladen). The vibration meter was used to measure the vibration once on the given route for each condition. Mean levels of whole-body vibration for each axis were calculated for each condition while driving on the route between Osaka and Kobe harbours. The distance was around 40 km. The route was almost the same as in the previous study [4]. One of the purposes of the present study was to compare the present whole-body vibration with the preceding evaluation. Only ISO 2631-1978 [5] and ISO 2631-1978/A 1-1982 [6] were available during the previous study [4]. Therefore, the vibration levels were acquired from the weighted r.m.s. acceleration through the weighting networks defined by ISO 2631-1978 [5]. A personal computer downloaded the memory from the vibration meter and the work time history recorded by the drivers for further analysis. It calculated the mean level for each axis for the same public road on the route as mentioned above. The mean level was converted to FDP and EL through ISO 2631-1978/A1-1982 [6]. The FDP and EL were compared between the old and new

models as well as between the present steel and air suspension models. The old and new models were compared for the steel suspension by motor company, size of the freight container, and laden condition.

The driving hours exceeding the mean allowable exposure time of FDP or EL was estimated from the driving hours in the previous study [1].

2.2. ERGONOMIC EVALUATION

The present ergonomic evaluation by the drivers used almost the same questionnaire as in the previous study [4]. The cases were the drivers of the air suspension vehicles. The controls were drivers of the steel suspension vehicles with ages and years driving a tractor differing from the cases by no more than 2 years. Corresponding controls were selected from the company wherever possible. Each case had two corresponding controls, so the study consisted of 125 triplets. The majority of the subjects had participated in the previous ergonomic questionnaire study [4]. The subjects checked their own tractors, usually assigned by their employers. We used χ^2 statistics to assess the differences in the rates of complaint of ergonomic items between the case and control groups. The same factors were used to test the differences of both rates from the rates in 1983, whose sample was the whole respondents of 549 tractor drivers [4].

3. RESULTS

3.1. WHOLE-BODY VIBRATION OF THE PRESENT AND OLD STEEL-SUSPENSION MODELS

In most cases, *x*-axis vibration showed levels less than or equal to those in the *y*-axis. Figure 1 shows the change of the mean vibration level and the FDP of the steel suspension models by motor company and loading condition. The abscissa shows the mean vibration

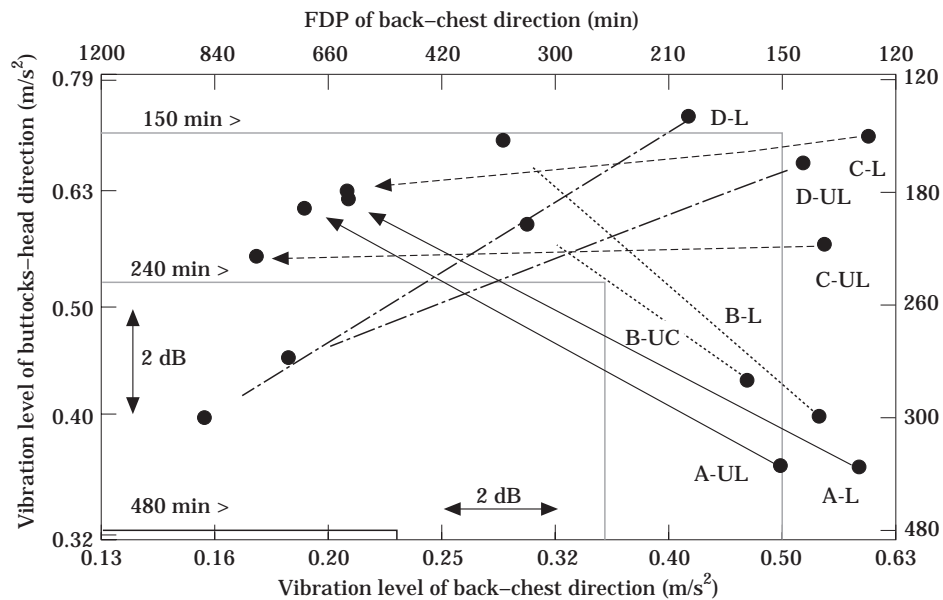


Figure 1. A decade improvement of whole-body vibration level of drivers' seats of the tractors pulling the 20 ft freight-container and corresponding allowable exposure time of fatigue-decreased proficiency boundary (FDP) defined by ISO 2631-1978 [5]. A,B,C,D name of motor company; L, laden container; UL, unladen container; level in 1983 → level in 1992; —, fatigue-decreased proficiency boundary (FDP).

levels and the FDP of vibration in the back-to-chest direction. The ordinate shows the mean vibration levels and the FDP of vibration in the buttocks-head direction. The grid lines in the graph show allowable minutes for the FDP as references. If an arrow in the graph directs to the left bottom corner, it means that the vibration level of the typical steel suspension model of the motor company decreased between the two studies. Different patterns of the arrow were classified by motor company (A, B, C and D) and loading condition (driving with laden or unladen container of 20 ft). As shown in Figure 1, all the arrows are directed leftward more consistently than directed downward. The decrease in the vibration level of fore-aft direction (x -axis) was as much as 4–9 dB when driving a 20 ft laden freight container. Some tractors showed an increase in the buttocks-head direction (z -axis). However, the decrease in the vibration level of x -axis vibration was so large that some adverse changes in the z -axis did not affect the FDP or the EL which were improved by the decrease in the vibration level in the x -axis.

3.2. WHOLE-BODY VIBRATION OF THE AIR-SUSPENSION AND THE STEEL-SUSPENSION MODELS

In most cases, the x -axis showed vibration levels less than or equal to those in the y -axis. Figure 2 shows the differences in the mean vibration levels and the FDP between the steel suspension models (circles) and the air-suspension models (stars). It shows the differences by motor company, length of container (20:20 ft and 40:40 ft) and loading condition (solid symbol: laden container and empty symbol: unladen container). The abscissa shows the mean vibration levels and the FDP of vibration in the back-to-chest direction. The ordinate shows mean vibration levels and the FDP of vibration in the buttocks-to-head direction. The grid lines in the graph show allowable minutes for the FDP as references. A circle and star pair connected by a line represents vehicles belonging to the same motor company (A, B, C or D) operated with the similar loading condition. If a star is nearer to the left bottom corner than the corresponding circle, the air suspension model had less vibration level in the x - and z -axes than the steel suspension model for the same motor company. If a star is on the zone nearer to the left bottom corner than the corresponding circle, the air suspension model had longer allowable exposure time than the steel suspension model. The air suspension model of the motor company "A" showed the largest increase in the FDP and allowed a driving period longer than 8 h per day. Other air suspension models did not allow driving more than 6 h per day. The comparison of both suspension models in Figure 2 under similar loading conditions showed that the dominant direction affecting the FDP changed from back-to-chest vibration (x -axis) to buttocks-head vibration (z -axis).

As shown in Table 1, the daily driving hours of more than 40% of the present drivers exceeded the FDP according to the distribution of the driving hours in the 1983 survey. The driving hours of a few percent of the present drivers exceeded the EL.

3.3. ERGONOMIC RESPONSES

The number of responses from the cases was 108 (response rate: 86.4%) and the number of available matched triplets was 89 (71.2%). The average ages of the drivers of air suspension and steel suspension vehicles were 46.9 and 46.8 years (38.4 in the 1983 study). The average years driving the tractor were 17.0 and 16.7 years (8.3 years). The average body heights were 167.5 and 167.2 cm (167.2 cm). The average weights were 67.1 and 67.2 kg (65.3 kg).

Figure 3 shows the principal result of the ergonomic evaluation by the drivers. The comparison of ergonomic items for the steel suspension model between 1983 and 1992

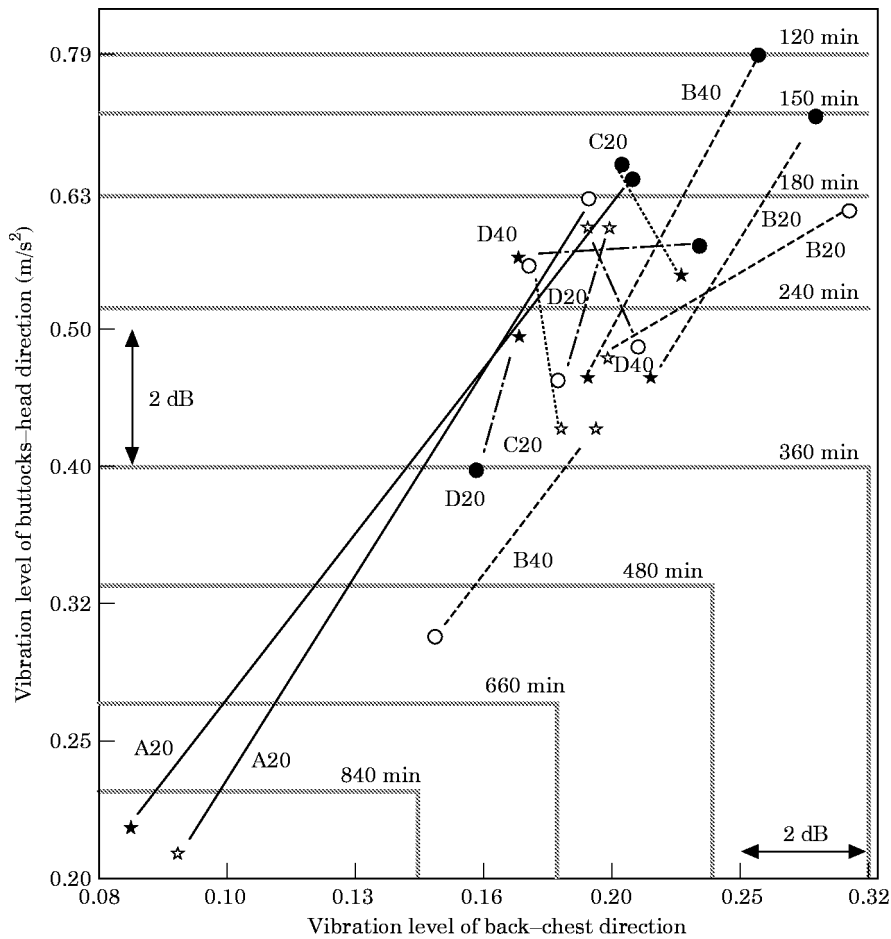


Figure 2. Comparison of the whole-body vibration level of drivers' seats between steel and air spring suspension models of the freight container tractor under different conditions. min: Allowable exposure time of the fatigue-decreased proficiency boundary (FDP) defined by ISO 2631-1978 [5]. ○, Steel-suspension and unladen; ●, steel suspension and laden; ☆, air-suspension and unladen; ★, air suspension and laden; —, FDP, 20:20 ft; 40:40 ft. Motor company: —, A; - - -, C; - · - · -, D.

showed a significant and considerable improvement in ratings of vibration. The present steel suspension models induced significantly fewer complaints of habitability, safety and ease of driving, low back problems, and dissatisfaction and desire to replace a tractor early with an improved model. The drivers of the air suspension models seemed to show the lowest rate of LBP in these months. They also showed the lowest rates of dissatisfaction with the current tractor and of desire to replace the tractor early with an improved model. However, they estimated as high a probability of getting LBP from tractor driving as those of the steel suspension models. There was no significant difference between them for fatigue, dullness or pain in the lower back during and after driving. The drivers of the air suspension models complained more about the following conditions than drivers of the steel suspension models: getting in and out of the cab, leg room around the seat, fit of the driver's seat to the body, and blind spots. Other complaints were comparable with the 1983 study.

4. DISCUSSION

The previous study [4] used an FM cassette tape recorder and needed an attendant to perform the measurements. However, it was difficult to get the co-operation of the employers of the drivers for the attendant to ride on the vehicle. Also, the previous study consumed long hours and a large work force to analyze the analogue data recorded. It was for these reasons that after the previous studies [1–4], the authors began to develop the personal exposure meter for whole-body vibration suitable to be used in the field without an attendant. The present study used the second prototype, which had a display screen and built-in printer because of technical difficulties in removing them in the construction of the commercial real-time analyser. However, its specifications and analyzing procedure were as defined by the same ISO standards as in the preceding study [4]. Therefore there could be no bias caused by the difference between the two methods employed [4].

Because of financial problems, only one exposure meter was available and it could store 1/3 octave bands in only one axis of vibration. Therefore, it was impossible to compare the differences in the frequency spectrum among the three axes.

As the ergonomic questionnaire study showed, motor companies might improve the vehicles in many ways in addition to introducing air suspension. Also, those responsible for the roads might improve and maintain the roads better. The present study did not measure and evaluate the tractors under the conditions defined by the standard such as ISO 500 [8], CEN/TC 150/WG8, Draft pr EN no. 73 [9], so it is difficult to say exactly what factors changed the whole-body vibration.

There was a limitation in the sampling method and the sample size because of financial problems and the lack of co-operation from the employers. Thus it was difficult to treat the acquired data statistically.

ISO 2631-1978 [5] and ISO 2631-1978/A1-1982 [7] were combined in ISO 2631 Part 1 [10] after the previous measurements [4]. It has been reported that the intent of the subcommittee might be best understood by a separate reading of the two original documents [11]. Therefore it was not necessary to discuss the present study according to ISO 2631 Part 1 [10]. ISO 2631/1-1997 [12] has updated the frequency weighting curves and the time-dependency for daily exposures. Some readers may be interested to examine the acquired data according to this standard. However, this was impossible because of the limitation of the stored data as mentioned above.

TABLE 1

Rate of person-days exceeding the mean allowable exposure time of FDP or EL; person-days and daily driving hours were derived from the time study

	1983	1992	
		Leaf spring	Air spring
FDP (%)			
Unladen	90.5	42.8	27.2
Laden	93.2	68.8	20.3
EL			
Unladen	29.3	2.6	0.6
Laden	45.7	4.8	0.7

FDP is the fatigue-decreased proficiency boundary and EL is the exposure limit defined by ISO 2631-1978 [5]. Laden/unladen: laden condition of a pulled container with 20 ft length.

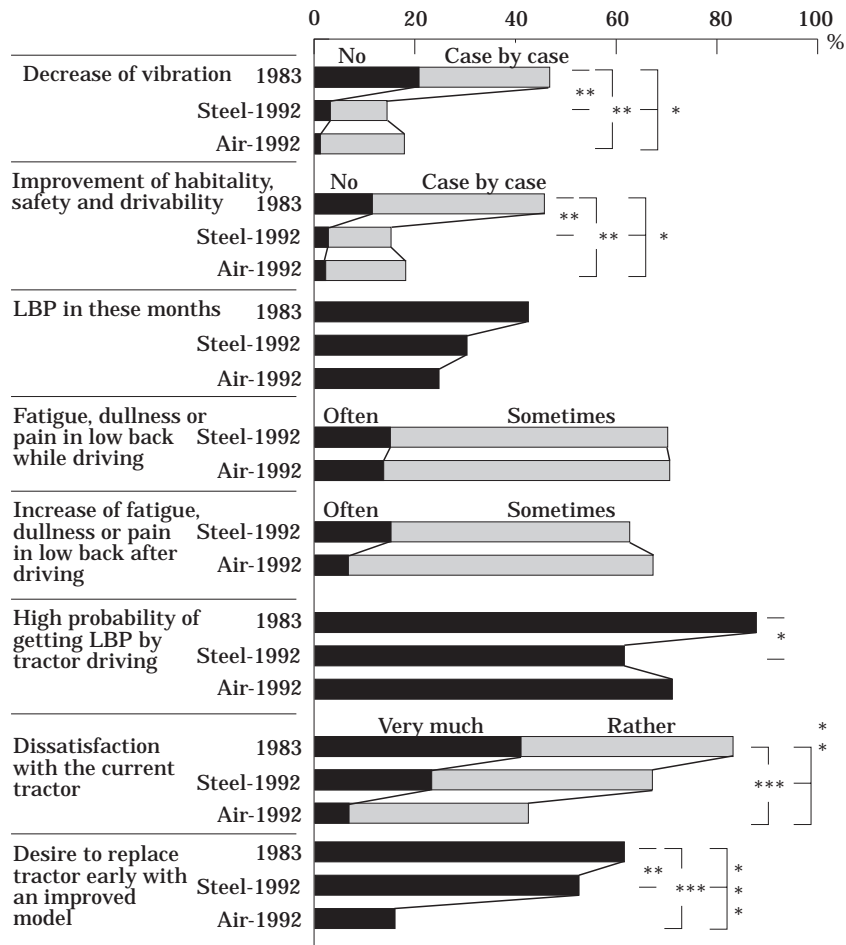


Figure 3. Subjective assessment by drivers on whole-body vibration and low back complaints. 1983: rate in 1983 whose sample was the whole respondents of 549 steel suspension tractor drivers [4]. Average age = 38.4 years. Average years driving a tractor 8.3 years. Steel-1992: Rate in 1992. $N = 178$ steel suspension tractor drivers matched with air suspension tractor drivers less than or equal to two years for age and years of driving a tractor. Average age = 46.8 years. Average years driving a tractor 16.7 years. Air-1992: Rate in 1992. $N = 89$ air suspension tractor drivers. Average age = 46.9 years. Average years driving a tractor = 17.0 years. *, $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$, χ^2 -test.

The FDP of the air suspension models did not always decrease compared to those of the steel suspension models, in some motor companies. There might be a bias caused by the limitations of the sample: the drivers of the air suspension models did not have a chance to compare their models with the steel suspension models. However, the subjective decrease of the vibration from the steel suspension models was as remarkable as for the air suspension models. There was no significant difference in the subjective decrease of vibration between both models.

Although the prevalence rates of LBP were not significantly different, the drivers of the air suspension models showed the lowest prevalence of LBP. There should be some bias such as an ageing effect on health during the past nine years. Therefore, the decrease of the LBP might be significant if it were possible to match it with the age. However, the drivers of the air suspension models complained of many ergonomically unsound conditions. This means that the ergonomic improvement was still not consistent.

In spite of some limitations mentioned above, the present survey suggested that the whole-body vibration had decreased on the whole, especially from the viewpoint of allowable exposure time. However, the daily driving hours of many drivers may still exceed the FDP and a small percentage of drivers may exceed the EL. Therefore, it is still necessary to decrease the vibration level or the driving hours to protect the drivers from the fatigue and hazards. It may be concluded that, to establish a policy on the effective decrease of whole-body vibration exposure, it is necessary to study the subject more systematically.

ACKNOWLEDGMENTS

The authors thank the participating drivers and their employers for their co-operation in this study. The authors also thank Rion Co., Ltd. for developing the personal exposure meter for whole-body vibration. The development was partly supported by a grant from the Japanese Ministry of Education (Grant No. 63870026).

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