



***Whole Body Vibration  
and  
Low Back Pain***

**Literature Review**

Prepared for:

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# WHOLE BODY VIBRATION (WBV) STUDY

## EXECUTIVE SUMMARY

- ❑ The literature on Whole Body Vibration (WBV) and low back disorders (LBD) is diverse and confusing.
- ❑ The majority of the literature on this subject is poorly designed, uses inappropriate methods to address the 'causation' issue, does not adequately address potential biases and "confounders" and not infrequently makes inappropriate scientific, medical and epidemiological 'leaps' without appropriate support in view of the fact that low back pain is extraordinarily common in all populations of human beings.
- ❑ A prior report (unpublished, Teschke, 1997) is assessed as being uncritical from an epidemiological standpoint and lacks the rigour of other qualitative reviews.
- ❑ The attached report holds the literature to a much higher standard of analysis and is more appropriate given the significant clinical, financial and legal ramifications of this whole issue of WBV and LBD.
- ❑ The WCB should recognize that the epidemiology around WBV and LBD is in its infancy and until future prospective, long-term, cohort studies with appropriate measurements are undertaken, it is medically and epidemiologically reasonable to state that no significant body of work is available to conclude that WBV causes LBD.
- ❑ The WCB should continue to insist on holding any and all qualitative or quantitative systematic reviews of medically driven occupational issues to the highest standards available in the scientific community.

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# **Occupational Whole Body Vibration and Lower Back Disorders: A Review of the Published Evidence**

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## I. Summary

The object this review was to review the published evidence on the relationship of whole body vibration (WBV) to low back disorders (LBD) in the workplace. After a literature search, 33 studies met the study criteria and were included in the review<sup>(1-33)</sup>. Most studies (73%) were cross sectional in design and judged unable to assess causative relationships. Not a single study, completely met basic standard critical appraisal criteria that are normally used to assess the quality of research studies. These include appropriate study design, adequate study period, outcomes relevant to the hypothesis, statistically significant results, strengths of association and a lack of obvious bias and confounding in the study results.

The results, in general, were inconsistent, often negative and often showed stronger risks or similar risks for LBD in occupations with less WBV exposure that were used as control groups.

Two important factors that tend to obfuscate relationships in this area of research are a high frequency of LBD in humans and multiple factors that potentially relate to LBD.

Review criteria utilized in this review were relatively stringent to counter the potential for publishing bias and poor study design that other reviewers in this area of research have also pointed out.

Future research using long-term prospective cohort studies would hopefully, help determine causative relationships, safe levels of exposure for identified risks and loss of work data. This information is currently missing and may indicate a lack of ability or will to commit the necessary time or resources to this line of enquiry on the part of researchers in this area.

The conclusion of this review is that there is insufficient evidence to conclude that WBV is related to LBD. The more likely explanation is that LBD are related to multiple factors, many of which are non-occupational in nature and that the exact nature of these relationships is not understood at this time<sup>(43)</sup>.

## **II. Background**

### **II.A Whole-Body Vibration:**

Low back disorder (LBD) and low back pain are common conditions in humans. It is estimated that the incidence of life-time LBD is in the order of 60 to 70% and because of its widespread prevalence, the socioeconomic impact of this disorder is significant.<sup>(13,15,16)</sup> This has created a body of literature on the nature, impact and potential causes of LBD. Some of this research has focused on occupation as a risk factor where epidemiological data indicates a variation in the rate of low back disorders based on type of occupation. Over time, a number of theories have been put forward. Alternatively, occupations requiring heavy lifting, and those, which are sedentary in nature, have been identified as having increased risk.

Explanations for associations identified, have included systematic error due to weak study design, job selection bias, smoking, past trauma and other non occupational factors, as well as job related causes such as sitting in awkward positions and heavy lifting. One such hypothesis that has been proposed is that whole body vibration (WBV) is related to LBD.

A number of research studies and reviews have been published that have addressed this issue. They have tried to deal with the potential for a causative relationship. In addition, they have tried to address a number of related issues including trying to assess a cut-off level below which whole body vibration would not cause LBD and whether or not this relationship to LBD would have a socioeconomic impact in terms of time off work. This is the question central to the occupational issue, given that the incidence of LBD is so high in the general and working population. If up to two thirds of the workforce will have LBD at one time or another, it is more important to know whether or not time loss from work is related to WBV, in addition to whether or not it is a causative factor.

As an overview, the existing literature in the area of WBV in general lacks studies of quality<sup>(4,33)</sup>. A number of studies exist that are hypothesis generating in nature, in that they raise the possibility that a relationship between WBV and LBD may exist, but fall short of being able declare a

causative relationship. Still others have attempted to test the hypothesis of WBV causing LBD; but lack sufficient quality of study design for the results to be relied on. Reviews in the area of WBV and occupational risk factors have been published<sup>(34,35)</sup>, however, most of these are older reviews and may lack critical appraisal criteria that today would normally be associated with reviews assessing causative relationships. An unpublished review has been produced for the Worker's Compensation Board in 1999<sup>(36)</sup>.

A number of issues will be obvious to those reading this review, including the wide number of definitions of outcomes appearing in the literature, that are used to assess the relationship of WBV to back disorders. Composite classifications such as low back disorder, general outcomes such as low back pain and specific ones such as disc degeneration and sciatica all obfuscate relationships. Similarly, the issue of making a non-quantitative leap from the outcome of occupation to WBV without measurement data stands out in this review. Other issues will be raised.

## **II.B Appraisal Criteria:**

It is accepted in epidemiology, that the results of research studies can represent more than one state of affairs. They can represent a true set of results, or they can be due only to chance and not be true based on the type of study sample and measurements obtained. A third possibility is that results can be false, due to various sorts of systematic error. This third possibility can be based on confounding or various biases that may arise to systematically affect results. To deal with these issues, in any current review of the literature, it is necessary to establish a set of criteria on which to make judgements about the quality of published material that is to be reviewed<sup>(38)</sup>. These criteria must be able to assess the degree to which the available literature represents a true state of affairs, a possibility of chance error or the likelihood of being due to systematic error.

Fortunately, medical science and epidemiology in general have established accepted criteria that can be applied to these issues. The accepted way to deal with chance error is to reject hypotheses or study results where there is more than a certain probability of the study results being due to chance. The convention is to use p-values to assess point estimates and confidence limits to give some idea of the stability of the point estimate. If the p-value is greater than .05 or the confidence interval crosses 1 then the study results are

generally accepted as being not statistically different and no conclusions can be drawn about the results.

A host of issues come into play when setting criteria to assess the potential for systematic error. The most important of which is study design. Study designs range in terms of their ability to control for systematic error, from controlled intervention trials to case series in which no control group is available. In occupational medicine, where intervention trials are usually impractical then well designed prospective cohort studies with stringent and repeated exposure and health status measurements built into the design are probably the most acceptable in terms of controlling for potential biases. Studies with a decreased level of sophistication in design, such as retrospective studies, cases control studies and cross sectional studies are less able to establish causative relationships because of this propensity for systematic error to affect results. Recall bias for retrospective study designs and the inability to establish temporal relationships in cross sectional studies are just two of many powerful biases. In the case of cross sectional studies “cross sectional surveys, while easy and rapid to accomplish, do not establish the temporal sequence of events necessary for drawing causal inferences”<sup>(36)</sup>. Pauline Bongers in her longitudinal study on crane operators, which is one of the studies reviewed, mirrors this fact when she states “Because of the large number of dropouts due to lumbar spine disease in industry a longitudinal study design was chosen”.

Further and more specific criteria to apply to any review of epidemiological research would include: relevance of the exposure to the research question being reviewed, appropriateness of choice of outcomes, adequacy of the study period, and an assessment of the likelihood of confounding and bias occurring. Other outcomes that could independently explain study results should also be considered.

Finally, how positive the study results are (strength of the association), whether or not a dose-response relationship is seen and whether or not results are consistent across studies will impact on any assessment looking at causative relationships. The exception is in the case of consistency if there is a likelihood of systematic error in the study designs. In this setting, repetitive studies may show consistent relationships that are untrue. Note that, in general, study results tend to favor positive results as negative studies tend not be published. This publishing bias tends to increase chance error in results and artificially create consistency in study results.

## **II.C Purpose:**

The purpose of this review is to evaluate the published literature on occupational whole body vibration (WBV) to see if there is strong enough evidence to conclude that a causal relationship exists between WBV and low back disorders. Loss of work time due to this possible relationship will also be assessed, as this is the primary outcome of interest from the point of view of the Worker's Compensation Board. Thresholds are the third relationship that will be examined.

## **III Methods**

### **III.A Literature Search:**

A literature search of two available electronic data bases was conducted. These were the Medline database from 1966 to 2001 and EMBASE from 1998 to 2001 using the following Key Words: whole body vibration, occupational exposure, vibration, low back pain, sciatica, and lumbar. The search was restricted to human research and to articles in the English language.

In addition, an unpublished report reviewing the literature and prepared for the Worker's Compensation Board of B.C was included <sup>(36)</sup>. This report was supplied by the WCB and was used as a guide in assembling studies in this review.

### **III.B Inclusion/Exclusion Criteria:**

Controlled trials and epidemiological studies, which studied occupations involving equipment operation, or vehicles, where WBV occurs and where low back disorders were studied as an outcome, were included. Studies where the occupational description was too broad to identify those exposed to WBV were excluded, as were studies where WBV was artificially induced. These studies were excluded, as they are unlikely to duplicate the workplace experience.

### **III.C Evaluation Criteria:**

1. Study designs were assessed based on a hierarchy of study design <sup>(44,45)</sup>. In order of importance and ability to assess a causative relationship, they were assessed as follows. The highest order looked for were controlled trials followed by, prospective observational cohort studies, case control studies, other retrospective observational studies, cross sectional studies and case series in a descending order and ability to establish causative relationships.
2. Study outcomes were assessed in their ability to address the question of work loss and define the type of low back disorder being investigated.
3. Exposures were assessed as to the degree to which measurable WBV was being assessed or whether the surrogate outcome of occupation was being used. If WBV was being measured then a dose-response exposure was assessed.
4. The study period was assessed as to whether or not it was prospective, retrospective or at one point in time. The length of the study period was also assessed.
5. Results were assessed as to their statistical significance, strength of association, whether a dose-response relationship was seen, and whether multiple factors were seen to be associated with the exposure of interest.
6. Confounding and bias was assessed for each study.

## **IV Results**

A summary of the results are provided in Tables 1 and II. The results are presented in three parts. The first part presents summary appraisal results of the individual studies reviewed. Only results that have a significant and direct relationship to the causal relationship of whole body vibration and low back disorder are reported. The second part is an aggregated summary of the overall results of the review using appraisal criteria established in the methods section. Finally, two tables are presented to represent an overall view of the degree or lack of degree to which the results are positive and consistent for the hypothesis of WBV causing LBD.

### **IV.A Appraisal of individual studies relevant to review criteria:**

#### **IV.A.1 Prospective Cohort Studies:**

1. Pietri et al published a 1 year prospective cohort study looking at low-back pain in commercial travelers. Risk factors identified included smoking, psychosomatic factors and seat comfort. The weakness of this study in terms of the research questions posed is the short nature of the study, the lack of WBV as an outcome and the absence of data on work loss. The multiple risk factors identified do not support a specific relation of WBV to LBP.
2. Riihimaki et al undertook a 3 year prospective study and published in 1994, which examined sciatic pain in machine operators and carpenters v. office workers. Previous history of low back pain (LBP) increased risk 4 fold. The rate ratio adjusted for previous history and other covariates was 1.36 (95%CL .99 -1.9) for the machine operators and 1.5 (95% CL 1.1-2.1) for the carpenters. This argues against the WBV hypothesis as the confidence interval crosses 1 for machine operators indicating a non significant outcome while the larger effect is seen in the carpenters who have the lower exposure to WBV. Outcomes of WBV and work loss were not reported, therefore, causative relationships cannot be assessed based on these study results.

#### IV.A.2 Retrospective Cohort Studies:

3. Thorbjornsson et al has looked at psychosocial and physical risk factors in a cohort of subjects aged 18 to 34 years of age without low back pain (LBP) in 1969. They were part of a larger cross sectional REBUS study that occurred in 1969. This subset was re-examined in 1993 (n=783) looking retrospectively at risk factors for LBP. Dissatisfaction with leisure time and monotonous work were identified as risk factors. The authors concluded; “in this study, factors related to work had a long term effect only in interaction with leisure time factors”. This study did not show increased risk due to WBV exposure in the multivariate analysis.
4. Bongers, Boshuizen et al published a retrospective (longitudinal) cohort study in 1988 claiming that a combination of WBV and strained or unfavorable posture was “responsible” for the development of intervertebral disc degeneration. 743 crane operators were compared to 662 floor workers who were employed in a Steel Company in Holland. The review went back 10 years looking at age, nationality, shift work, calendar year, disability pension and reasons for leaving work. The authors claim that because more crane operators received a disability pension for degeneration disc disease (ICD 722.6) that WBV, unfavorable posture and climate were responsible. However, the following issues should be noted:
  - This is a study in a country where workers get a pension if they are 15% or more disabled from their job for over 1 year and other tasks are not available. This creates a potential for other factors such as job satisfaction to confound results. More crane operators quit their job (27% v. 23%) than floor workers over the course of the study. This could indicate a relative imbalance in job related satisfaction. This is supported by the reasons given for resigning: job dissatisfaction, financial reasons, work reasons and shift work. These would be potentially powerful confounders for those who might seek a pension rather than resigning their job. Crane operators did have more shift-work supporting the potential for this bias. It is interesting that, overall, the crane operators received more disability pensions than floor workers (18% v.14%) indicating as above that factors other than WBV may be driving the process.
  - The two groups compared were not equivalent for factors other than WBV. Not only did the crane operators do more shift work, they were older and had worked longer at their job than the floor workers. While

the authors tried to adjust for these factors in the analysis they failed to include and adjust for other factors such as smoking and sports activities that would likely be different between these groups given the age, years of employment and shift work differences.

- Less than half of both groups were still employed at the end of the study period (1984) indicating a large loss of information about over half of the subjects being studied. This creates an enormous potential for bias if a larger proportion of those with degenerative disc disease occurred in one group or the other in those who were lost to the study. This becomes a bigger problem if the study numbers are small, as is the case in this study.
  - The ability to make confident assumptions about causative relationships depends to a large degree not only on the size of the study in terms of sample size but also on the frequency of events. The lower the number of events, the less one is able to make generalizable statements. In the case of this study, the primary outcome reported by the authors was that an “incidence density ratio (IDR) exceeded 2 for disability because of degeneration of the intervertebral disc, after adjustment for age, nationality, shift work and calendar year”. Looking at Table 4 one sees that this is based on 14 cases in the crane operators and 3 in the control group. It would be entirely inappropriate to make a case for a causative relationship based on these small numbers even if potential biases could be controlled for. In terms of this review, it is interesting to note that no difference was found in disability pension rates between the two groups for back disorders in general (90% CL .84-2.07). This comparison was based on the larger numbers of 38 and 18 respectively.
  - There are other issues that affect the ability of this study to make claims about WBV. There is a lack of a measurable link between the occupation and WBV. There is exposure contamination in that 30% of floor operators were exposed to WBV 20% of the time. This relationship is more of an assumption on the part of the authors. The retrospective design has created an environment in which multiple biases can operate. Multiple testing has gone on without adjustment or a logical explanation for why the primary outcome is disc disorder and not all back disorders. This raises the possibility of post hoc analysis. Finally, if the primary hypothesis was originally the composite outcome of all back disorders, which would seem more appropriate, then this is a negative study, which argues against WBV.
5. Bongers, Boshuizen et al published a follow-up study on the above cohort of crane operators and floor workers. This study looked at the

absolute number of at least one spell of sickness absence from work of 28 days or longer. The results again showed no difference between the two groups for “ all back disorders” (90% CL .77-1.25) and this time with larger numbers, no difference for disc disorders as well (90% CL .74-2.07). Despite the authors’ claims, this argues against the hypothesis that WBV causes back disorders.

6. Boshuizen, Bongers et al published a second retrospective cohort study in 1990 looking at tractor drivers from a single company and comparing them to a reference company consisting of inspectors from another company and technical service workers in the company where the tractor drivers worked. The outcomes of interest were long-term sick leave and disability pensioning due to back disorders. Issues on the potential for biases to operate and confounding were similar to the earlier study by the same authors. The historical nature of the study, differences between the groups other than WBV exposure and the disability environment that exists in Holland all are potential sources of error in interpreting results. The authors demonstrated the reality of a selection bias with their comparison with and without including the reference company. “ The incidence of a first long-term sick leave due to back disorders was 3 per 100 person-years in tractor drivers and 2 per 100 person-years in the entire reference group. However, the incidence was not substantially increased in tractor drivers when the referents comprised only those working at the same company, suggesting selection bias”. The incidence of intervertebral disc disease was not significantly different in this study as opposed to the authors earlier study (90% CL .73-5.5). Again, this data is unstable as the numbers are so small (n= 17 v. n= 3). In terms of disability pensioning the reported results are “ far from statistically significant”.
7. Boshuizen, Bongers et al went on to publish a follow-up paper on this cohort. They sent out a postal questionnaire trying to establish a relationship to vibration dose and degrees of back pain. The response rate was 79%. The authors found that the prevalence of self-reported back pain is 10% higher in the tractor drivers, than in the reference population. However, 4 of 8 crude odds ratios looking at questions relating to a dose response relationship of vibration dose in years were not significantly different. For example there was no difference in those treated for back pain or those who had had a prolapsed disc. When adjusting for cofactors such as age and duration of exposure the vast majority of odds ratios of

vibration exposure and type of back pain were non significantly different. The authors point out that despite this lack of a demonstrated relationship “the highest prevalence odds ratios are found for the more severe types of back pain. These prevalence odds ratios do not increase with the vibration dose”. Despite the weakness of the study design, which has the same weaknesses, as described above plus the added weakness of a self reported questionnaire, the study argues against a dose-response relationship and a significant difference between groups.

#### **IV.A.3 Case Control Studies:**

8. Kelsey et al published a case control study in 1975 looking at the driving of motor vehicles as a risk factor for lumbar disc disease (LDD). This is an older study with a much weaker design than cohort studies. The authors identified 223 cases of LDD from those receiving lower back x-rays at three New Haven Hospitals during the years 1971-1973. They then found 494 controls and were able to match 217 controls to the cases. The cases and controls were interviewed. The object was, amongst other things, to establish the degree to which occupations involved driving. The response rate was 79%. A Mantel –Haenzel test of association for a comparison between the cases and the unmatched controls was significant and indicated a three-fold increase in risk. However, when the control group was adjusted for group differences by matching; the matched analysis combining surgical and probable cases produces an odds ratio of 2.55 ( $p > .05$ ) which is statistically not significant. This study in addition to the weaknesses associated with this type of study design as described previously, does not have WBV as an exposure but rather whether or not the job required sitting in a motor vehicle more or less than half time. The choice of half time appears arbitrary. In summary, this study has no features, which demonstrate a causative relationship between WBV, LBD and work loss.
9. Heliovaara et al published a case control study in 1987 looking at lumbar disc disease or sciatica. 592 men and women were compared to 2140 matched controls. As expected the risk of being hospitalized for herniated disc was lowest in professional and related occupations relative to all other occupations. Relative risks were elevated for occupations exposed to WBV and those not exposed to WBV. The maximal risk was “ highest among blue collar workers in industry and among motor vehicle drivers”.

This is a hypothesis generating study and no claims are made about WBV nor causal relationships. The authors point out that the occupational variation may “not be due to disease incidence but rather to greater likelihood of hospitalization”.

#### **IV.A.4 Cross Sectional Studies:**

The largest number of studies, in this review, are of a cross sectional design which, in general, as stated above, cannot be used to establish causation.

##### **IV.A.4.a Non Peer Reviewed Cross Sectional Studies:**

Four identified studies were excluded, as they did not appear to be published in a peer reviewed journal <sup>(39-42)</sup>.

##### **IV.A.4.b Peer Reviewed Cross Sectional Studies:**

###### **IV.A.4.b.1 Cross Sectional Studies where outcomes are multi-factorial and whole body vibration (WBV) was not an outcome:**

10. Frmoyer et al reported in 1979 that pregnancy, smoking, anxiety, depression, emotionally stressful occupations, lifting, carrying, pulling, pushing and twisting in addition to truck driving are all related to low back pain. There was no mention of WBV as an outcome and this study is a hypothesis generating study with no attempt to look at causation. It supports the notion of causes of LBD being multi-factorial.
  
11. Heliovaara et al published a large cross sectional study in 1991 looking at several factors for their “ association with the prevalence of chronic low-back syndromes, sciatica, and low back pain (LBP)”. Approximately, 5,000 subjects from the large Mini-Finland Health Survey project were examined and 5.1% were found to have sciatica while 11.6% were found to have LBP. Previous traumatic back injury, smoking, body height, and physical and mental stress at work all increased risk. The authors concluded “ many factors, independent of each other, determine the occurrence of chronic-low back syndromes”. This study does not support the notion that WBV is a major cause of chronic-low back syndromes.

12. Saraste et al published in 1987 showing that low back pain was related to lower education, physically heavy, monotonous or repetitive work and smoking. This supports a multifactorial cause of LBD. WBV was not an outcome looked at.
13. Nayha et al published in 1991 and reported that neck and shoulder pain was related to physical work in slaughtering reindeer but that “the association of back pain with the amount of work was weak”. WBV was not an outcome.
14. Burdorf et al published in 1993 and looked at sedentary workers using crane operators and straddle-carrier drivers as the occupations of interest. He compared them to office workers. Burdorf concluded that “in both occupations the daily exposure to whole-body vibration was low, and therefore not considered an important risk factor for low back pain”. The study “suggested” that non-neutral trunk posture may be a risk factor but, appropriately, stopped short of describing this as a causative relationship. This study does not support the use of these types of occupations in trying to identify a relationship between WBV and LBD.
15. Guo et al has published a study in 1995 showing that back pain is not only common, accounting for 25% of WCB cases but that it is common in a wide variety of jobs both with WBV exposure and in occupations where WBV is not present. The highest risk is for construction workers for males and for nurses’ aides in females. Industrial truck and tractor operators had similar but slightly lower relative risks of back pain than carpenters or construction workers with reputed lower WBV exposure. WBV was not an outcome of interest in this study.

#### **IV.A.4.b.2 Cross Sectional Studies with negative results where WBV is an outcome:**

16. Bongers, Boshuizen et al published a study in 1991 looking as a primary hypothesis at the dose response relationship of WBV to self-reported back pain. While younger less exposed drivers complained of more regular back pain than the reference group; “with increasing age, the difference in the prevalence of self-reported regular back pain between drivers and the reference group disappeared”. This argues against a dose response relationship, although, the authors feel that a “health-based

selection” bias may account for the unusual findings. Adjusted for age, there were no differences in 14-day sick leave, treatment for back pain or disc herniation between groups, which argues against a work loss hypothesis due to WBV.

17. Miyashita et al published in 1992 showing that fork lift operators (n=44) had more back pain, than office workers (p< .001). However, this difference was not seen in the two other groups looked at which had larger sample sizes (power shovel operators n=184, bulldozer operators n=127) and which also were exposed to WBV. Further, as 10 primary outcomes were assessed in 4 groups (30 tests), without a description of the statistics that were employed, then this result in forklift drivers must be discounted because of multiple testing without adjustment. The authors looked at Raynaud’s phenomenon, as a measure of local vibration, and found that this was more prevalent in the control group of office workers.
18. Masset et al in 1994, published a large cross sectional study looking at low back pain (LBP) in blue-collar workers in Belgium. The study showed the high prevalence of LBP in workers in that “66% of the workers, younger than 40 years, already had experienced lumbar problems during their lives”. The authors undertook multivariate logistic regression to show “ exposure to whole body vibrations were not associated with an increased prevalence of LBP”. The largest association was for heavy efforts of the shoulders (OR=1.62, p =.01) with a very small increase in risk for vehicle driving (OR=1.15, p<.01).
19. Xu et al in 1997 published another large study that was a re-analysis of a Danish survey. The full multivariate model adjusting for age and educational level showed a odds ratio of 1.23 (p=.122) for WBV as a risk factor for LBP. This is statistically a non significant finding. The unadjusted and reduced model gave a similar result in that the 95% confidence limit included 1.
20. Johanning et al looked at subway train operators and found higher rates of hearing loss, gastrointestinal problems and sciatica. “ A cumulative dose-response relationship could not be statistically demonstrated”. This study was particularly weak in the low response rate and the dissimilarity of the control group (switchboard operators).

21. Magnusson et al published a large two country study (USA and Sweden) looking at truck drivers, bus drivers and sedentary workers. The outcomes of interest were based on measuring WBV exposure, stress at work, work loss and a variety of complaints including low back, neck and shoulder pain. As expected, truck drivers had the highest exposure to WBV both daily and long term. However, work loss due to low back pain was lowest in this group in both countries. Not only was it significantly less than bus drivers but it was lower than sedentary workers (3.8 days v 18 days and 4.8 days). Approximately, half of the entire cohort complained of LBP. There was a non-significant increase in the percent of truck drivers that had LBP compared to sedentary workers (56% v. 42%). The authors concluded “inability to work seems affected by stress at work”.
22. Riihimaki et al published a study in 1989, looking at low back trouble (LBT), in machine operators (exposed to WBV), carpenters (not exposed) and office workers (not exposed). The lifetime incidence of LBT was the same for machine operators and carpenters (90%). It was lower for office workers (75%). Occasional LBT occurred equally in all three groups. Frequently occurring LBT was reasonably similar in machine operators and carpenters (30% v. 23%). The 12 month prevalence of LBT was “82% for the machine operators, 79% for the carpenters, and 61% for the sedentary workers”. These results argue against WBV as a causative factor in LBT. This study has undertaken multiple comparisons using univariate Chi square statistics without adjusting for these comparisons. Therefore, any interpretation of p-values given in this study are invalid other than to hypothesis generate.
23. Froom et al published a study in 1984 looking at helicopter pilots in Israel. While the authors found that helicopter pilots had a fourfold increase in spondylolisthesis (SLL) over cadets or transport pilots, they concluded that “although SLL is associated with LBP, the pain has little clinical significance”.
24. Walch et al published in 1989, a retrospective postal survey on 545 randomly selected adults. The outcomes looked at were factors related to low back pain. 65% of men had had LBP. A Cox proportional Hazards model was used to examine lifetime LBP, low back pain on the birthday prior to onset of symptoms and unremitting low-back pain on the

birthday prior to symptoms. Lifting or moving weights of 25kg. or more, were significant in all three categories. Driving a truck, tractor or digger did not increase risk for any of these outcomes adjusted for other activities. Similarly, using vibrating machinery had 95% confidence limits that cross 1 for all three analyses. The authors conclude that LBP is related to “heavy lifting and prolonged car driving”. This argues against WBV in heavy equipment operators.

25. Burdorf et al published a small sample size study in 1990 on 49 crane operators comparing them to 281 workers in a control group in the same factory. Only 67% of crane operators agreed to be in the study (n=33) and so no conclusions can be drawn between the index and the control groups. What is relevant is the authors’ multivariate logistic regression showing the “ strong influence of back straining factors in the past (previous employment) on the present probability of LBP. The authors conclude the study provides evidence “ to strongly recommend persons with a history of back complaints not to seek employment as crane operators”.

#### **IV.A.4.b.3 Cross Sectional Studies with positive outcomes where WBV is an outcome:**

26. Brendstrup et al published a study in 1987 on low back trouble in fork-lift drivers. 240 fork lift drivers were compared to two comparison groups ( unskilled workers and the working Glostrup men). The outcomes of interest were the frequency of LBT in the preceding year and absence from work. The frequency of LBT was not significantly different when compared to unskilled workers but was higher than the Glostrup working men. Work absence was higher for fork-lift drivers than for the other two groups. The weakness in this study over and above the weak cross sectional design is the lack of evidence of the appropriateness of using the Glostrup working men as the control group. In fact the study “ set up a reference group which resembled the fork-lift drivers as much as possible” in the second unskilled workers control group. In this comparison, no difference was detected. This weakens the claims of the author that “fork-lift driving may be a contributory cause for low back trouble”. WBV was not an outcome studied.

27. Dupuis and Gerlett published in 1987, comparing 352 operators of earth-moving machines to 315 workers who were not exposed to WBV. This study demonstrates the problem with cross sectional design in that 71% of operators had already had x-rays of the spine v. only 48% in the control group by the time of the study. Clearly, the potential for an uncover bias with respect to the amount of investigations or an incomparability of groups are at issue here. If more operators have had x-rays then more disease of the spine exists or is likely to be found in this group. All subsequent analyses follow from this, especially the comparisons for those x-rayed in both groups. The problem is we have no idea if this difference is real. It may be due health selection factors, in that those seated may work may be able to work with a back disorder, while more physical jobs such as a labor job may require one to change jobs, if a back disorder develops. This study appears, on appraisal, not to be set up to make claims about a causative relation of WBV to LBD.
28. Bongers, Boshuizen et al in 1990 published the results of a survey questionnaire on 163 helicopter pilots compared to 297 non-flying air force officers. This study showed that total flight time was related in a dose response relationship to risk for chronic back pain. This relationship became significant over 2000 hours of flight time. The authors were unsure if this effect was due to constrained posture or a combination of this and WBV.
29. Liira et al published a study in 1996 on the 1990 Ontario Health Survey, looking at long-term back problems and physical work exposures. This study involved a household-based population survey and only “reports the prevalences of reported long-term back problems”. This study is, therefore, hypothesis generating by its nature and not attempting show causative relationships. A logistic regression model was used for the analysis showing significant odds ratios for a variety of factors including age, smoking, blue collar occupations, working in awkward positions, bending and lifting, lifting light objects, lifting heavy objects and operating vibrating equipment. The authors emphasize that “Low back pain is multi-factorial in origin”.
30. Burdorf et al published a further study in 1991, looking at 114 concrete manufacturing workers exposed to heavy physical work, bending and

twisting and vibration due to operating vibrotables. These concrete workers were compared to 52 maintenance engineers. The prevalence of back pain in the 12 months preceding the investigation was 59% in the index group and 31% in the control group. 44% of concrete workers had the onset of back pain after starting work at the present factory v. 31% of the control group. This indicates support for the notion that a health selection bias such as the one discussed in the study Burdorf in 1990 was driving the results. Burdorf concluded in this study that working in a bent/twisted position may contribute to the prevalence of back pain and that WBV, “due to operating vibrotables, is a second risk factor for back pain”. The sample size in this study is too small to generalize any conclusions drawn to settings outside of this study.

31. Bovenzi et al published a study in 1994, on 1155 tractor drivers looking at LBP. They were compared to 220 revenue officers. Dose response relationships for postural loads and vibration were looked at for a variety of factors. The interviews were conducted at the residence of the subjects by teams. Postural load questions about awkward positions at work were highly related to LBP but the results cannot be interpreted. This is because of the potential for recall bias. Those interviewed with back problems would be much more likely to remember sitting in awkward positions at work than those without back pain in a dose response type of fashion. Secondly, the control group of revenue officers would likely be very different in terms of socioeconomic factors, lifestyle factors and previous employment factors. This tends to invalidate conclusions about a causative relationship between WBV and LBP that might otherwise be derived from this study. The authors found a host of risk factors for lifetime LBP, transient LBP and chronic LBP including age, occupation as a tractor driver as compared to a revenue officer, previous trauma and educational level. This was in addition to a dose-response relationship for total vibration dose. Trends were seen for the prevalence of recent and chronic LBP as well as for sciatica. Sick leave was increased but a non-significant trend related to vibration dose was seen. The same relations were seen for postural load. It is interesting that in this study known factors for risk such as smoking and previous jobs at risk were not significant.

32. Bovenzi et al published a smaller study in 1992, comparing 234 bus drivers to 125 maintenance workers and found bus drivers were at

increase risk for LBP. However, “low back symptoms occurred at exposures that were lower than the health based exposure limits proposed by the International Standard ISO 263/1”. Prolonged sitting in a constrained position was also increased risk. In the control group, only 8% had previous jobs with heavy physical demands compared to 21.3% in the bus drivers. This once again demonstrates the difficulty in interpreting cross sectional studies in terms of finding control groups that are similar to index groups except for the exposure of interest. If the groups are not similar as in this case, validity of the results cannot be ensured.

33. Netterstrom et al conducted a study that was published in 1989 on bus drivers in Denmark. The prevalence of frequent low back pain was somewhat higher in bus drivers (57%) than in the control group (40%). Increased risk was also shown for lumbar disc herniation. The authors conclude that “sedentary position and whole-body vibration may be contributory causes” but point out that “this might lead to a notion that people with LBT applied for jobs as bus drivers to avoid heavy manual labour. That this should be the case cannot be ruled out, especially since the prevalence of frequent lumbar pains was relatively high in the younger groups as well”. WBV was not an outcome nor was loss of time from work. Once again, the cross sectional nature of the design and the non comparability of the control group (all Danish men) somewhat limit the interpretation of these findings.

#### **IV.B Appraisal of aggregated review results relevant to study criteria:**

There were 33 epidemiological studies identified that appeared to be published in peer reviewed journals, dealing with the potential causal relationship of whole body vibration, occupation and various defined low back disorders. The majority of studies identified, 73% (24/33), were of a cross sectional design. There were 2 case control studies and 5 retrospective cohort studies. Only 6% or 2/33 of the identified research studies were prospective cohort studies. Of the prospective cohort studies, (the design most capable of assessing causative relationships of studies reviewed), 1 study was of too short a duration to generalize results as the study period was only 1 year's duration. Therefore, only 1 study or 3% of those accepted to be reviewed were prospective and of sufficient duration to be assessed as not being classed as weak in terms of trying to answer the research question of a causative relationship of WBV to LBD.

With regards to outcomes studied, most studies (28/33 or 85%) did not study WBV directly, but used the surrogate outcome of occupation. Of those that did look at WBV directly (5/33 or 15%), all were of the cross sectional design. Over the entire 33 studies reviewed, negative outcomes in terms of not reaching statistical significance were reported in a surprising number of studies for a variety of comparisons. Of those studies reviewed, 17/33 (52%) or half of studies reported negative findings. For example in the only prospective cohort study with an adequate study period, Riihimaki showed that carpenters, who had presumably less WBV exposure than machine operators, were more at risk than machine operators for sciatica. This represents a negative result for the hypothesis of WBV. For the machine operators, the relative risk for sciatica was 1.36 with 95% confidence limits of .99-1.87. This is a negative study result from a statistical significance point of view. Bongers, Boshuizen et al in their series of retrospective cohort studies show statistically negative results for all back disorders and disc disorders. Cross sectional studies reviewed also reported negative results. Boshuizen's study in 1991 on tractor drivers, showed a lower incidence of leave due to back trouble over 1-year in drivers v. the reference group (45 v. 56). In this study, the higher prevalence of self-reported regular back pain in younger drivers was not seen in older drivers. Xu's random sample of 5185 Danish employees gives an odds ratio of 1.23 for "vibration affecting the whole body" with a highly non-significant p-value of .122.

Most studies (31/33 or 94%) were unable to demonstrate a dose-response relationship or the design did not permit a dose-response relationship to be investigated. Of the 2 studies that did show a dose-response relationship, both were cross sectional in design. Further, the potential for confounding, study bias and multi-factorial relationships as alternate explanations for the relationship of low back disorder to occupation were evident in a majority of studies (82%). For example, selection bias was indicated as a reasonable explanation of results in several studies including those published by Boshuizen, Netterstrom and Burdorf. Low back disorders appeared often to occur at increased frequency in situations where WBV was occurring at low exposures (eg. Bovenzi) or in occupations with less WBV exposure than the occupation being investigated (eg. Riihimaki, Walch). The literature reviewed, as a body, indicated a number of other non work related factors that were associated with LBD in workers: leisure time factors, smoking, pregnancy, anxiety, depression, lower education, age, and pre-existing low back disorder. Similarly, a number of work related exposures were identified as being potential alternate explanations for associations between

occupations and LBD. These included sedentary work, heavy physical work, monotonous work, repetitive work, awkward sitting, bending, lifting, stress at work and blue-collar occupations in general.

Loss of work information was assessed in 8/33 or 24% of studies. Of these several studies reported negative results. Bongers et al failed to show significantly more sickness absence from work of 28 days or longer for all back disorders nor for disc disorders. Froom also found that LBP due to spondylolithesis had little clinical significance in terms of loss of work, while Magnusson found that truck drivers had less loss of work due to LBP than sedentary workers. Of the other 2 authors who published studies dealing with work loss, Guo showed a similar risk of work loss due to back pain for equipment operators in comparison to 15 other high risk occupations most of which did not involve WBV exposure. The final author, Brendstrup, found a higher absence from work for fork-lift drivers.

Strengths of association for WBV exposure were not tested for in most studies. In the 6 studies where this association was looked, at there was a high degree of variability with a range in relative risk of no association to 39.5.

Strengths of association for occupation were looked at in more than half of the studies. Again, there was a wide range in results ( RR's 1.15 to 4.8).

TABLE

Author(s)	Year	Study design	Study design weak for assessing causation	Study period short or retrospective	WBV exposure not directly studied	Negative Statistical results for relevant outcomes	Dose response relationship not looked at or not demonstrated	Confoundr/bias shown or declared as potential explanations	Multi-factorial outcomes other than WBV shown
Pietri	1992	cohort	no	yes	yes	no	yes	yes	yes
Riihimaki	1994	cohort	no	no	yes	yes	yes	no	no
Thorbjornsson	1998	cohort	yes	yes	yes	no	yes	yes	yes
Bongers,Boschhuizen	1988	cohort	yes	yes	yes	no	yes	yes	yes
Bongers,Boshuizen	1988	cohort	yes	yes	yes	yes	yes	yes	no
Bongers,Boshuizen	1990	cohort	yes	yes	yes	yes	yes	yes	no
Bongers,Boshuizen	1990	cohort	yes	yes	yes	yes	yes	yes	no
Kelsey	1975	casecontrol	yes	yes	yes	yes	yes	no	no
Heliiovaara	1987	casecontrol	yes	yes	yes	no	yes	yes	yes
Frymoyer	1979	crosssectional	yes	yes	yes	no	yes	yes	yes
Saraste	1987	crosssectional	yes	yes	yes	no	yes	yes	yes
Heliiovaara	1991	crosssectional	yes	yes	yes	no	yes	yes	yes
Nayha	1991	crosssectional	yes	yes	yes	yes	yes	yes	yes
Burdorf	1993	crosssectional	yes	yes	yes	yes	yes	yes	yes
Guo	1995	crosssectional	yes	yes	yes	yes	yes	yes	yes
Froom	1984	crosssectional	yes	yes	yes	yes	yes	n/a	n/a
Riihimaki	1988	crosssectional	yes	yes	yes	yes	yes	yes	no
Walsh	1989	crosssectional	yes	yes	yes	yes	yes	yes	yes
Burdorf	1990	crosssectional	yes	yes	no	no	yes	yes	yes
Bongers,Boshuizen	1991	crosssectional	yes	yes	yes	yes	yes	yes	yes
Johanning	1991	crosssectional	yes	yes	yes	no	yes	no	yes
Miyashita	1992	crosssectional	yes	yes	yes	yes	yes	no	no
Masset	1994	crosssectional	yes	yes	no	yes	yes	yes	yes
Magnusson	1996	crosssectional	yes	yes	yes	yes	yes	yes	yes
Xu	1997	crosssectional	yes	yes	no	yes	yes	yes	yes
Brendstrup	1987	crosssectional	yes	yes	yes	yes	yes	yes	no
Dupuis	1987	crosssectional	yes	yes	yes	no	yes	yes	no
Netterstrom	1989	crosssectional	yes	yes	yes	no	yes	yes	no
Bongers,Boshuizen	1990	crosssectional	yes	yes	no	no	no	yes	yes
Liira	1990	crosssectional	yes	yes	yes	no	yes	yes	yes
Burdorf	1991	crosssectional	yes	yes	yes	no	yes	yes	yes
Bovenzi	1992	crosssectional	yes	yes	no	no	yes	yes	yes
Bovenzi	1994	crosssectional	yes	yes	no	no	no	yes	yes

TABLE II

Author(s)	Year	Study design	main outcome(s)	Loss of work time studied	Prospective	Adequate prospective study period	WBV exposure studied	positive results of outcomes relevant to review	dose reponse relationship demonstrated	Strength of association of WBV exposure	Strength of association of occupation
Pietri	1992	cohort	LBP	no	yes	no	no	yes	no	not tested	1.5 to 2.1
Riihimaki	1994	cohort	Sciatica	no	yes	yes	yes	no	no	negative	1.4
Thorbjornsson	1998	cohort	LBP	no	no	no	yes	no	no	negative	not tested
Bongers, Boshuizen	1988	cohort	LBD/Disc degn	yes	no	no	yes	yes	no	not tested	2
Bongers, Boshuizen	1988	cohort	LBD/Disc degn	yes	no	no	no	no	no	not tested	not significant
Bongers, Boshuizen	1990	cohort	LBD/Disc degn	yes	no	no	no	no	no	not tested	1.16
Bongers, Boshuizen	1990	cohort	LBD/Disc degn	no	no	no	yes	no	no	1.38 to 3.9	not tested
Kelsey	1975	casecontrol	Disc disease	no	no	no	no	no	no	not tested	2.55
Heliavaara	1987	casecontrol	Sciatica	no	no	no	no	yes	no	not tested	4.8
Frymoyer	1979	crosssectional	LBP	no	no	no	no	yes	no	not tested	not tested
Saraste	1987	crosssectional	LBP	no	no	no	no	no	no	not tested	not tested
Heliavaara	1991	crosssectional	LBP/Sciatica	no	no	no	no	no	no	not tested	not tested
Nayha	1991	crosssectional	LBP/Sciatica	no	no	no	no	no	no	not tested	not tested
Burdorf	1993	crosssectional	LBP	no	no	no	no	no	no	not tested	2.51 to 3.29
Guo	1995	crosssectional	LBP	yes	no	no	no	no	no	not tested	2
Froom	1984	crosssectional	SLL	yes	no	no	no	no	no	not tested	not tested
Riihimaki	1988	crosssectional	LBT	no	no	no	no	yes	no	not tested	1.3
Walsh	1989	crosssectional	LBP	no	no	no	no	no	no	not tested	.6 to .7
Burdorf	1990	crosssectional	LBP	no	no	no	no	yes	no	not tested	3.6
Bongers, Boshuizen	1991	crosssectional	LBP/Sciatica	yes	no	no	no	no	no	not tested	not tested
Johanning	1991	crosssectional	Sciatica	no	no	no	no	yes	no	not tested	3.9
Miyashita	1992	crosssectional	LBP	no	no	no	no	no	no	not tested	not tested
Masset	1994	crosssectional	LBP	no	no	no	yes	no	no	no association	1.15
Magnusson	1996	crosssectional	LBP	yes	no	no	yes	no	no	no association	not tested
Xu	1997	crosssectional	LBP	no	no	no	yes	no	no	no association	not tested
Brendstrup	1987	crosssectional	LBT	yes	no	no	no	no	no	not tested	not tested
Dupuis	1987	crosssectional	LBD/Disc degn	no	no	no	no	yes	no	not tested	not tested
Netterstrom	1989	crosssectional	LBP/Disc degn	no	no	no	no	yes	no	not tested	not tested
Bongers, Boshuizen	1990	crosssectional	CBP	no	no	no	yes	yes	yes	1.4 to 39.5	not tested
Liira	1990	crosssectional	LBP	no	no	no	yes	yes	no	1.71	1.37
Burdorf	1991	crosssectional	BP	no	no	no	no	yes	no	not tested	2.8
Bovenzi	1992	crosssectional	LBP	no	no	no	yes	yes	no	not tested	2.99
Bovenzi	1994	crosssectional	LBP	no	no	no	yes	yes	yes	1.69 to 2.63	2.12

## **V Discussion**

A number of theories into causes of low back disorder have been proposed over the last few decades. Some have been tested in animal models and under laboratory conditions. Epidemiological research looking at these associations in populations has had the advantage of looking at the issue under more real working and living conditions, as opposed to these artificially created conditions such as laboratory conditions. These epidemiological studies tend to support the notion that the causes of low back disorder are multi-factorial and their relationships to outcomes poorly understood<sup>(43)</sup>. This review supports that point of view. This area of research is complicated not only by the existence of a multitude of potential causes and their inter-relationships; but also by the extremely high frequency of LBD in humans. Since this condition appears to be ubiquitous in human beings, it is extremely difficult to isolate putative exposures from other potential causes and confounders. In relation to occupation, there is a strong tendency for workers to self select employment on the basis of psychosocial and physical factors that, in themselves, predict on the incidence of low back disorder. Any attempt to assess causes in the workplace, must adequately control for these factors, which include, pre-employment low back conditions, leisure activities including sports that are differentially played by various occupations, smoking, family history, level of education, depression and a host of other factors not related to employment.

This review has focused on critically appraising the existing epidemiological literature on low back disorder and whole body vibration as a potential cause. Given this environment of high frequency of the disorder, the apparent multiplicity of potential causes and the importance of the question in terms of cost to society, it was seen as important to assess the quality of the studies reviewed and their ability to draw conclusions about causation. In addition, it was also seen as important to apply the normally accepted criteria for assessing causation. It would have been relatively easy to be less stringent and be open to making the mistake of attributing causation to relationships, which in fact are mere associations.

### **V.1 Critical Appraisal of studies reviewed:**

Most studies were cross sectional in design and, therefore, by themselves unable to make assessments about causative relationships. As described in the results, many confounders and bias's were uncovered supporting the notion that these were weak designs for assessing causation. Many times,

results were negative and conflicted with the hypothesis that WBV caused LBD. Many times associations other than WBV were uncovered.

Case control and retrospective cohort studies had similar weaknesses in design with potential bias's explaining results seen, negative results, and a lack of a link of the outcomes to WBV as an exposure.

Finally, the studies, with a design most likely to be able to draw causative conclusions about the relationship of WBV to low back disorders, also had serious methodological flaws. The first study by Pietri was of too short a study period (1 year). In addition, it had irrelevant outcomes in that there was no information on WBV or work loss. The study also identified other risk factors such as smoking, psychosomatic factors and seat comfort. The other prospective cohort study by Riihimaki also failed to study WBV or work loss as outcomes of interest and reported statistically negative results. This study showed that carpenters with less WBV tended to have increased risk than machine operators.

In conclusion, not one study met the review criteria of; adequate design and study period, appropriate outcomes assessed, inferentially positive results, and a lack of obvious bias and confounding.

## **V.2 Assessment of the epidemiological studies applying rules of causation:**

### 1. Strength of Association

Most strengths of association seen were relatively weak as demonstrated by the high frequency of relative risks (RR) whose confidence limits crossed 1 and so were statistically non significant findings. Even despite these negative statistical results, most RR's reported were in the range of 1.2 to 2.0. This is relatively weak when compared to RR's seen in the epidemiological literature on such health hazards as smoking.

### 2. Consistency of results

There was a good deal of inconsistency in results to support the theory that WBV causes LBD. The reporting of negative results was common. In addition, unexpected results, where occupations with lower WBV were at higher risk for LBD, were reported several times. Explanations for a number of outcome results including self selecting for occupations involving driving for those with pre-existing LBD argued against a consistent relationship.

### 3. Temporal Relationship

As most studies were cross sectional in design, the ability to assess temporal relationships of exposure to WBV to the development of LBD was lacking. This problem of the inability to establish a temporal relationship was echoed in many of these studies, most notably those studies where job selection bias was demonstrated. The 2 prospective studies, able to examine temporal relationships, without issues related to recall bias or cross sectional design weakness, also failed to adequately demonstrate temporal relationships for other reasons, including the length of the study period and the demonstration of the confounding effect of a previous history of LBD.

### 4. Dose Response relationship

Only 2 of 33 studies demonstrated a dose-response relationship. As discussed above these relationships were demonstrated in studies with cross sectional designs that contained a number of design flaws that made the results inconclusive in terms of interpretation.

### 5. Specificity

There was a clear lack of specificity of a one-to-one relationship between WBV and LBD. It was not demonstrated that WBV exposure was both “necessary and sufficient”<sup>(37)</sup> to cause LBD in any of the studies reviewed.

In summary, it appears that current epidemiological literature does not support the notion that whole body vibration causes low back disorder. This inability to demonstrate a causative relationship despite decades of research by multiple researchers is remarkable. Criteria to assess future research in this area must be stringent, as with this much research activity, there is likely a strong bias in terms of publishing positive results. This publishing bias could strongly skew study results in favor of the relationship of WBV to LBD. Future research should be limited to prospective long-term cohort studies, which use sophisticated measurements of both exposure to WBV and the degree of LBD over the course of the study. A crucial measurement would be identifying subjects as being condition free at the start of the study. This would require a commitment in terms of time and resources, on the part of investigators, that has, to this point in time, been missing in this area of research.

## VI References

- 1 Pietri F, Leclerc A, Boitel L, Chastang JF: Low-Back pain in commercial travelers. *Scand J Work Environ Health* 1992; 18:52-58.
- 2 Riihimaki H, Viikari-Juntura E, Moneta G, Kuha J: Incidence of sciatic pain among men in machine operating, dynamic physical work, and sedentary work. *Spine* 1994; 19: 138-142.
- 3 Thorbjornsson BCO, Alfredsson L, Fredriksson K, Koster M: Psychological and physical risk factors associated with low back pain: a 24 year follow up among women and men in broad range of occupation. *Occup Environ Med* 1998; 55: 84-90.
- 4 Bongers PM, Boshuizen HC, Hulshof CT, Koemeester AP: Back disorders in crane operators exposed to whole-body vibration. *Int Arch Occup Environ Health* 1998; 60: 129-137.
- 5 Bongers PM, Boshuizen HC, Hulshof CT, Koemeester AP: Long-term sickness absence due to back disorders in crane operators exposed to whole-body vibration. *Int Arch Occup Environ Health* 1988; 61:59-64.
- 6 Boshuizen HC, Hulshof CT, Bongers PM: Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration. *Int Arch Occup Environ Health* 1990; 62:117-122.
- 7 Boshuizen HC, Bongers PM, Hulshof CT: Self-reported back pain in tractor drivers exposed to whole-body vibration. *Int Arch Occup Environ Health* 1990; 62:109-115.
- 8 Kelsey JL, Hardy RJ: Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral disc. *American Journal of Epidemiology* 1975; 102:63-73.
- 9 Heliovaara M: Occupation and risk of herniated lumbar intervertebral disc or sciatica leading to hospitalization. *Journal Chron Dis* 1987; 40: 259-264.

- 10 Frymoyer JW, Pope MH, Costanza MC, Rosen JC: Epidemiologic studies of low back pain. *Spine* 1980; 3:419-423.
- 11 Heliövaara M, Mäkelä M, Knekt P, Impivaara O: Determinants of sciatica and low-back pain. *Spine* 1991;16:608-614.
- 12 Saraste H, Hultman G: Life conditions of persons with and without low back pain. *Scand J Rehab Med* 1987; 19: 109-113.
- 13 Nayha S, Videman T, Laakso M, Hassi J: Prevalence of low back pain and other musculoskeletal symptoms and their association with work in Finnish reindeer herders. *Scand J Rheumatol* 1991; 20: 406-413.
- 14 Burdorf A, Naaktgeboren B, de Groot HC: Occupational risk factors for low back pain among sedentary workers. *J Occup Med* 1993; 35:1213-1220.
- 15 Guo H, Tanaka S, Cameron LL, Seligman PJ: Back pain among workers in the United States: national estimates and workers at high risk. *Am J Ind Med* 1995; 28: 591-602.
- 16 Froom P, Froom J, Van Dyk D, Caine Y: Lytic spondylolisthesis in helicopter pilots. *Aviation Space Environ Med* 1984; 55: 556-557.
- 17 Riihimäki H, Tola S, Videman T, Hanninen K: Low-back pain and occupation: a cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. *Spine* 1989; 14: 204-209.
- 18 Walsh K, Varnes N, Osmond C, Styles R: Occupational causes of low-back pain. *Scand J Work Environ Health* 1989; 15: 54-59.
- 19 Burdorf A, Zondervan H: An epidemiological study of low back pain in crane operators. *Ergonomics* 1990; 33: 981-987.
- 20 Bongers PM, Hulshof CT, Dijkstra L, Boshuizen HC: Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics* 1990; 33: 1007-1026.

- 21 Johanning E: Back disorders and health problems among subway train operators exposed to whole body vibration. *Scand J Work Environ Health* 1991; 17: 414-419.
- 22 Miyashita K, Morioka I, Tanabe T, Iwata H: Symptoms of construction workers exposed to whole body vibration and local vibration. *Int Arch Occup Environ Health* 1992; 64: 347-351.
- 23 Masset D, Malchaire J: Low back pain: epidemiologic aspects and work related factors in the steel industry. *Spine* 1994; 19: 143-146.
- 24 Magnusson M, Pope M, Wilder DG, Areskoug B: Are occupational drivers at an increased risk for developing musculoskeletal disorders? *Spine* 1996; 21: 710-717.
- 25 Xu Y, Back E, Orhede E: Work environment and low back pain: the influence of occupational activities. *Occupational and Environmental Medicine* 1997; 54: 741-745.
- 26 Brendstrup T, Biering-Sorensen F: Effect of fork-lift truck driving on low back trouble. *Scand J Work Environ Health* 1987; 13: 445-452.
- 27 Dupuis H, Zerlett G: Whole-body vibration and disorders of the spine. *Int Arch Occup Environ Health* 1987; 59: 323-336.
- 28 Netterstrom B, Juel K: Low back trouble among urban bus drivers in Denmark. *Scand J Soc Med* 1989; 17: 203-206.
- 29 Boshuizen HC, Bongers PM, Hulshof CT: Self-reported back pain in fork-lift truck and freight-container tractor drivers exposed to whole body vibration. *Spine* 1992; 17:59-65.
- 30 Liira JP, Shannon HS, Chambers LW, Haines TA: Long-term back problems and physical work exposures in the 1990 Ontario health survey. *Am J Public Health* 1996; 86:382-387.
- 31 Burdorf A, Govaert G, Elders L: Postural load and back pain of workers in the manufacturing of prefabricated concrete elements. *Ergonomics* 1991; 34: 909-918.

- 32 Bovenzi M, Zadini A: Self-reported low back symptoms in urban bus drivers exposed to whole body vibration. *Spine* 1992; 17: 1048-1059.
- 33 Bovenzi M, Betta A: Low-back disorders in agricultural tractor drivers exposed to whole body vibration and postural stress. *Applied Ergonomics* 1994; 35: 231-241.
- 34 Bovenzi M, Hulshof CT: An updated review of epidemiological studies on the relationship between exposure to whole-body vibration and low back pain. *Int Arch Occup Environ Health* 1999; 72: 351-365.
- 35 Lings S, Leboeuf-Yde C: Whole-body vibration and low back pain: a systemic, critical review of the epidemiological literature 1992-1999. *Int Arch Occup Environ Health* 2000; 73: 290-297.
- 36 Teschke K, Nicol AM, Davies H, Ju S: Whole body vibration and back disorders among motor vehicle drivers and heavy equipment operators: a review of the scientific evidence. Unpublished 1999.
- 37 Mausner JS, Kramer S: Mausner and Bahn epidemiology- an introductory text. Philadelphia, Saunders, 1985, pp 177; 180-191.
- 38 Industrial Diseases Standing Committee: Protocol for the assessment of medical/scientific information. Workers' Compensation Board of British Columbia 1993.
- 39 Chernyuk V: Effects of whole body vibration on disease of the lumbar section of the spine in agricultural machinery operators. *Gigienda Truda* 1992; 28: 75-77.
- 40 Barbieri G, Mattioli S, Grillo S, Geminiani AM: Spinal diseases in an Italian tractor drivers group. *Agricultural Health and Safety: Workplace, Environment, Sustainability*. CRC Press 1995; pp 319-332.
- 41 Ruppe K, Mucke R: Functional disorders at the spine after longlasting whole body vibration. *Advances in Industrial Ergonomics and Safety*. London, Taylor and Francis, 1993, pp 483-486.

- 42 Kompier M, de Vries M: Physical work environment and musculoskeletal disorders in the busdriver's profession. *Musculoskeletal Disorders at Work*. London, Taylor, 1987, pp 17-22.
- 43 Crites Battie M, Videman T, Gibbons LE, Fisher LD: 1995 Volvo Award in clinical sciences: Determinants of lumbar disc degeneration: A study relating lifetime exposures and magnetic resonance imaging findings in identical twins. *Spine* 1995; 20: 2601-2612.
- 44 Sackett D, Haynes B, Tugwell P: *Clinical Epidemiology. A Basic Science for Clinical Medicine*. Little Brown and Company, 1985.
- 45 Checkoway W, Pearce N, Crawford-Brown D: *Research Methods in Occupational Epidemiology*. Oxford University Press, 1989.