Int Arch Occup Environ Health
DOI 10.1007/s00420-014-0971-4

REVIEW ARTICLE

Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis

Lage Burström · Tohr Nilsson · Jens Wahlström

Received: 14 November 2013 / Accepted: 1 August 2014

Abstract
Purpose The aim of this systematic literature review was to evaluate the association between whole-body vibration (WBV) and low back pain (LBP) and sciatica with special attention given to exposure estimates. Moreover, the aim was to estimate the magnitude of such an association using meta-analysis and to compare our findings with previous reviews.
Methods The authors systematically searched the PubMed (National Library of Medicine, Bethesda), Nioshtic2 (National Institute for Occupational Safety and Health (NIOSH, Morgantown), and ScienceDirect (Elsevier, Amsterdam) databases for records up to December 31, 2013. Two of the authors independently assessed studies to determine their eligibility, validity, and possible risk of bias.
Results The literature search gave a total of 306 references out of which 28 studies were reviewed and 20 were included in the meta-analysis. Exposure to WBV was associated with increased prevalence of LBP and sciatica [pooled odds ratio (OR) = 2.17, 95 % confidence interval (CI) 1.61–2.91 and OR 1.92, 95 % CI 1.38–2.67, respectively]. Workers exposed to high vibration levels had a pooled risk estimate of 1.5 for both outcomes when compared with workers exposed to low levels of vibration. The results also indicate that some publication bias could have occurred especially for sciatica.
Conclusions This review shows that there is scientific evidence that exposure to WBV increases the risk of LBP and sciatica.

L. Burström (✉) · T. Nilsson · J. Wahlström
Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine, Umeå University, 901 87 Umeå, Sweden
e-mail: lage.burstrom@envmed.umu.se

Keywords Vibration · Low back pain · Sciatica · Meta-analysis · Exposure · Publication bias

Introduction

Occupational exposure to whole-body vibration (WBV) from the operation of vehicles has long been acknowledged as one risk factor for low back pain (LBP) and sciatica. Sciatica presents with symptoms of pain, numbness, or tingling throughout the distribution of the sciatic nerve, thus radiating from the lower back into the legs. Several overviews and reviews on this relation have been presented and during the last 15 years eight systematic reviews (Bakker et al. 2009; Bernard 1997; Bovenzi and Hulshof 1999; Burdorf and Sorock 1997; Hoogendoorn et al. 1999; Lings and Leboeuf-Yde 2000; Waters et al. 2007; Vingård and Nachemsson 2000) addressing the association between WBV and LBP have been published in English (Table 1). The table shows which articles were included in each review and in cases where the authors assessed the quality of the articles the table shows how many of those meet the requirement of high quality.

In the reviews, a total of 57 articles (Anderson 1992; Barnekow-Bergkvist et al. 1998; Bongers et al. 1988a, b, 1990a, b, c; Boshuizen et al. 1990b, c, d, 1992; Bovenzi and Betta 1994; Bovenzi et al. 2002; Bovenzi and Zadini 1992; Brendstrup and Biering-Sorensen 1987; Brown et al. 1998; Burdorf et al. 1991, 1993; Burdorf and Zondervan 1990; Burton et al. 1996; Chernyuk 1994; Dupuis and Zerlett 1987; Futatsuka et al. 1998; Heliovaara 1987; Heliovaara et al. 1991; Hoy et al. 2005; Jensen and Tuchsen 1995; Johanning 1991; Kelsey et al. 1984; Kelsey and Hardy 1975; Kumar et al. 1999; Langauer-Lewowicka et al. 1996; Leclerc et al. 2003; Liira et al. 1996; Macfarlane

Published online: 21 August 2014

Table 1 Summary of previous systematic reviews and included articles in the, respectively, review

	Bakker et al. (2009)	Waters et al. (2007)	Bovenzi and Hulshof (1999)	Hoogendoorn et al. (1999)	Lings and Leboeuf-Yde (2000)	Vingård and Nachemsson (2000)	Bernard (1997)	Burdorf and Sorock (1997)
Bakker et al. (2009)	A 6 (HQ 6) Leclerc et al. (2003), Macfarlane et al. (1997), Manninen et al. (1995), Niedhammer et al. (1994), Pietri et al. (1992) and van Poppel et al. (1998)			Macfarlane et al. (1997), Manninen et al. (1995) and Pietri et al. (1992)		Pietri et al. (1992)		Pietri et al. (1992)
Waters et al. (2007)		A 13 (HQ 13) Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi et al. (2002), Brendstrup and Biering-Sorensen (1987), Burdorf et al. (1993), Burdorf and Zondervan (1990), Dupuis and Zerlett (1987), Hoy et al. (2005), Kumar et al. (1999), Miyashita et al. (1992), Schwarze et al. (1998) and Zimmermann and Cook (1997)	Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Brendstrup and Biering-Sorensen (1987), Burdorf et al. (1993) and Schwarze et al. (1998)		Bovenzi and Betta (1994), Burdorf et al. (1993), Miyashita et al. (1992) and Schwarze et al. (1998)	Boshuizen et al. (1990c, 1992) and Bovenzi and Betta (1994)	Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Burdorf et al. (1993) and Burdorf and Zondervan (1990)	Boshuizen et al. (1990c, 1992) and Bovenzi and Betta (1994)
Bovenzi and Hulshof (1999)			A 17 (HQ 17) Bongers et al. (1988a, b, 1990a, b, c), Boshuizen et al. (1990b, c, d, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Brendstrup and Biering-Sorensen (1987), Burdorf et al. (1993), Johanning (1991), Magnusson et al. (1996), Sandover et al. (1994) and Schwarze et al. (1998)		Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1993), Magnusson et al. (1996), Sandover et al. (1994) and Schwarze et al. (1998)	Bongers et al. (1990c), Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Johanning (1991) and Magnusson et al. (1996)	Bongers et al. (1988a, 1990c), Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1993), Johanning (1991) and Magnusson et al. 1996)	Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Johanning (1991) and Magnusson et al. (1996)

Table 1 continued

	Bakker et al. (2009)	Waters et al. (2007)	Bovenzi and Hulshof (1999)	Hoogendoorn et al. (1999)	Lings and Leboeuf-Yde (2000)	Vingård and Nachemsson (2000)	Bernard (1997)	Burdorf and Sorock (1997)
Hoogendoorn et al. (1999)				A 5 (HQ 4) Macfarlane et al. (1997), Manninen et al. (1995), Nuwayhid et al. (1993), Pietri et al. (1992), Riihimaki et al. (1994)		Pietri et al. (1992)	Riihimaki et al. (1994)	Pietri et al. (1992) and Riihimaki et al. (1994)
Lings and Leboeuf-Yde (2000)					A 21 (HQ 5) Anderson (1992), Barnekow-Bergkvist et al. (1998), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Brown et al. (1998), Burdorf et al. (1993), Burton et al. (1996), Chernyuk (1994), Futatsuka et al. (1998), Jensen and Tuchsen (1995), Langauer-Lewowicka et al. (1996), Liira et al. (1996), Magnusson et al. (1996), Masset and Malchaire (1994), Miyashita et al. (1992), Nehring and Wolf (1990), Sandover et al. (1994), Schwarze et al. (1998), Simon-Arndt et al. (1997), Smeathers and Wright (1990) and Xu et al. (1997)	(Bovenzi and Betta 1994; Bovenzi and Zadini 1992; Liira et al. 1996; Magnusson et al. 1996)	(Bovenzi and Betta 1994; Bovenzi and Zadini 1992; Burdorf et al. 1993; Magnusson et al. 1996; Masset and Malchaire 1994)	(Bovenzi and Betta 1994; Bovenzi and Zadini 1992; Liira et al. 1996; Magnusson et al. 1996)

Table 1 continued

	Bakker et al. (2009)	Waters et al. (2007)	Bovenzi and Hulshof (1999)	Hoogendoorn et al. (1999)	Lings and Leboeuf-Yde (2000)	Vingård and Nachemsson (2000)	Bernard (1997)	Burdorf and Sorock (1997)
Vingård and Nachemsson (2000)						A 14 Bongers et al. (1990c), Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991), Heliovaara (1987), Heliovaara et al. (1991), Johanning (1991), Kelsey et al. (1984), Kelsey and Hardy (1975), Liira et al. (1996), Magnusson et al. (1996) and Pietri et al. (1992)	Bongers et al. (1990c), Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991), Johanning (1991), Kelsey and Hardy (1975) and Magnusson et al. (1996)	Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991), Johanning (1991), Liira et al. (1996), Magnusson et al. (1996) and Pietri et al. (1992)
Bernard (1997)							A 19 Bongers et al. (1988a, 1990c), Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991, 1993), Burdorf and Zondervan (1990), Johanning (1991), Kelsey and Hardy (1975), Magnusson et al. (1996), Magora (1972), Masset and Malchaire (1994), Riihimaki et al. (1989, 1994), Skov et al. (1996), Toroptsova et al. (1995) and Walsh et al. (1989)	Boshuizen et al. (1990c, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991), Johanning (1991), Magnusson et al. (1996) and Riihimaki et al. (1994)

Table 1 continued

	Bakker et al. (2009)	Waters et al. (2007)	Bovenzi and Hulshof (1999)	Hoogendoorn et al. (1999)	Lings and Leboeuf-Yde (2000)	Vingård and Nachemsson (2000)	Bernard (1997)	Burdorf and Sorock (1997)
Burdorf and Sorock (1997)								A 13 Bongers et al. (1990c), Boshuizen et al. (1990c, d, 1992), Bovenzi and Betta (1994), Bovenzi and Zadini (1992), Burdorf et al. (1991), Johanning (1991), Liira et al. (1996), Magnusson et al. (1996), Pietri et al. (1992), Riihimaki et al. (1994) and Saraste and Hultman (1987)

In the diagonal, is indicated the numbers of articles (A) included in the review as well as the number of articles respective authors assessed meet the requirement of high quality (HQ). The rows indicate the articles that are common between the reviews

et al. 1997; Magnusson et al. 1996; Magora 1972; Manninen et al. 1995; Masset and Malchaire 1994; Miyashita et al. 1992; Nehring and Wolf 1990; Niedhammer et al. 1994; Nuwayhid et al. 1993; Pietri et al. 1992; Riihimaki et al. 1989, 1994; Sandover et al. 1994; Saraste and Hultman 1987; Schwarze et al. 1998; Simon-Arndt et al. 1997; Skov et al. 1996; Smeathers and Wright 1990; Toroptsova et al. 1995; Walsh et al. 1989; van Poppel et al. 1998; Xu et al. 1997; Zimmermann and Cook 1997) were included and the majority of these reviews demonstrated an association between WBV and LBP and sciatica. However, the criteria for including or excluding studies in the reviews varied among the different authors. Thus, studies included in one review might not have been found in another. All reviewers focused on "low back pain" based primarily on symptoms assessed with the Standardized Nordic questionnaire for the analysis of musculoskeletal symptoms (Kuorinka et al. 1987). A few reviewers also included "low back disorders", "low back morbidity", "sciatica", and "disability". The criteria for which study design is included in the reviews also varied. Bakker et al. (2009), for example included only prospective cohort studies. Moreover, some of the previous reviews included studies that lacked information on the vibration exposure while other reviews emphasized the evaluation of the quality of the exposure assessments. Five of the eight published systematic reviews included quality assessments of the original studies.

Many of the original studies compared WBV-exposed workers with manual labour or office workers not exposed to WBV. Selections of appropriate reference groups are crucial for the validity of the subsequent estimations of the relative risks. The differences between the exposed and non-exposed groups are sometimes considerable; not least of which is the static posture with restrained movements that vehicle driving entails. Only a few cases have investigators attempted to control for such differences by taking into account various influencing confounding factors. One strategy to overcome confounding factors between vibration-exposed and non-exposed workers has been to compare the same groups of vibration-exposed workers with varying exposure levels. Vingård and Nachemsson (2000) noted in their review that high-exposure helicopter pilots showed higher risks than low-exposure occupations. Waters et al. (2007) demonstrated in their meta-analysis of studies with different operator exposure groups that drivers with high vibration exposure were at higher risk than drivers with low vibration exposure. This result was consistent with the findings of Bovenzi and Hulshof (1999).

In spite of the large number of reviews, there is still a scientific need for a review with strict criteria on the estimates of exposure in relation to symptoms. We emphasized the importance of the exposure assessment in the current systematic review and included only studies that measured

or estimated the exposure to vibration and endeavoured to include prospective longitudinal studies.

Our aim was to provide a systematic literature review of the association between WBV and LBP and sciatica with special attention paid to exposure estimates. Moreover, the aim was to estimate the magnitude of such an association using meta-analysis and to compare our findings with previous reviews. Furthermore, the aim was to investigate whether the effect size might differ according to the possible risk of bias.

Materials and methods

Search strategy

The systematic literature review followed the preferred reporting items for systematic review and meta-analyses (PRISMA) guidelines (Moher et al. 2009) and was based on original scientific articles. The databases used for the search were PubMed (National Library of Medicine, Bethesda), Nioshtic2 (National Institute for Occupational Safety and Health (NIOSH, Morgantown) and ScienceDirect (Elsevier, Amsterdam). The reason for searching the slightly overlapping databases was that the databases index articles from partially different journals. The following search string was used to identify relevant studies in the databases: exposure (vibration, whole body, vibration exposure, occupation, driving and work), local (back), disease (low back pain, disc degeneration, spinal degeneration, lumbar disc, sciatica) and symptoms (pain, radiating pain). Our search was limited to studies in humans, and the search covered articles published until December 31, 2013. Only articles written in English were accepted, and we excluded case reports, letters, editorials, guidelines, and comments. We also searched the reference lists of the included studies.

Study selection

The article selection process was conducted according to the PRISMA guidelines, Fig. 1. Two of the authors independently examined all titles and abstracts. We scrutinized the full text of relevant papers and determined whether they met the inclusion criteria. We included articles with both exposure assessments of WBV estimated via database or measurements and health outcomes in the form of LBP or low back disorder and sciatica (Fig. 1). In case of disagreement, all three authors discussed each article until consensus was reached.

Possible risk of bias

Criteria focusing on the assessment of possible risk of bias for the methods (2–20 points) and exposure assessment (0–25 points) were used to assess the overall quality of the studies. Risk of bias in reported studies was assessed on the individual components of study design, confounding exposures and possible effect modification from various factors (Table 2). Possible bias in exposure was estimated according the precision in the estimates of current exposure time, previous acceleration, previous exposure and the quality of the technical measurements. The resulting estimation of the various components was added together and the studies ranked in accordance to sum of the estimation of possible bias. These criteria were modified from Bovenzi and

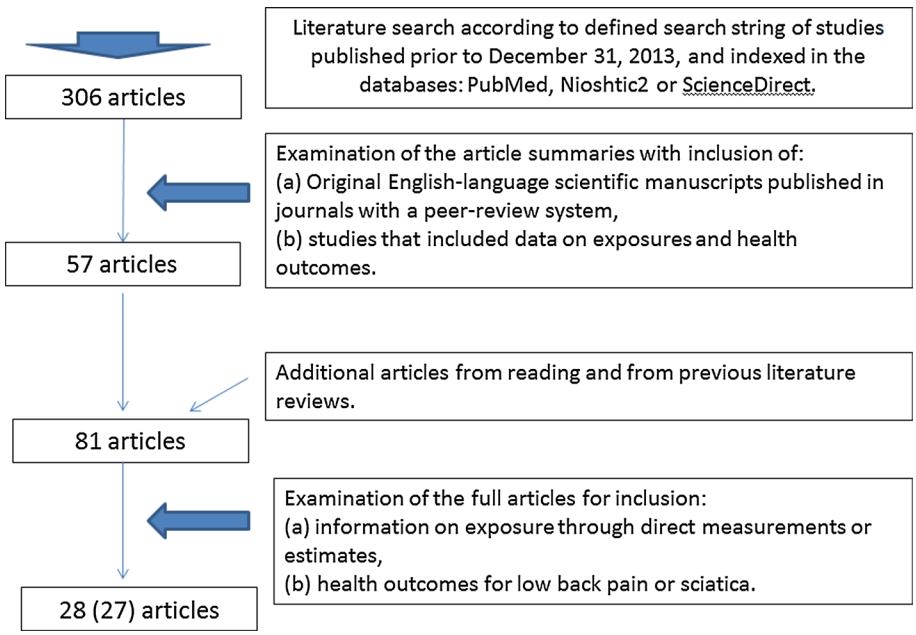

Fig. 1 Flowchart of the search strategy and selection of studies to assess the association between WBV and LBP or sciatica

Table 2 Criteria for the assessment of possible risk of bias

Criterion	Alternative	Score
Method		
Study design	Randomized controlled trial/cohort/case–control/cross section	8/6/4/2
Selection	Response rate higher than 70 % or falling off at follow-up less than 30 %	2/0
Control of individual confounding factors	Yes/no	2/0
Control of psychosocial confounding factors	Yes/no	2/0
Control for previous LBP complaints	Yes/no	2/0
Control for biomechanical exposure	Objective measures/subjective estimates/no information	4/2/0
Exposure		
Current exposure time (hours/day)	Objective measures/subjective estimates/no information	5/2.5/0
Information about previous acceleration	Objective measures/subjective estimates/no information	5/2.5/0
Information about previous exposure (years)	Objective measures/subjective estimates/no information	5/2.5/0
Information about previous exposure (hours/day)	Objective measures/subjective estimates/no information	5/2.5/0
Quality of technical measurements	Good/acceptable/bad	5/2.5/0

Hulshof (1999). Two of the authors independently assessed the risk of bias for the studies. In case of disagreement, the authors discussed the relevant criterion until consensus, but only minor disagreements in scores between the two authors occurred. The studies were classified as "low risk of bias" (score equal or higher than 10 for both methodology and exposure) or "unclear risk of bias" (score less than 10 for either methodology or exposure) based on the score.

Meta-analysis

Studies that reported a risk estimate (odds ratio) for LBP or sciatica were eligible for the meta-analysis. Furthermore, studies were also chosen although they did not report any risk estimates but they presented data that made it possible to calculate an unadjusted odds ratio. In order to study the influence of the magnitude of the vibration exposure on the outcome, studies on the same groups of vibration-exposed workers but with varying exposure levels were gathered. The lowest exposure group in each study was defined as "low exposure" and the highest exposure group as "high exposure". The comparisons of estimates have been made in accordance with Altman and Bland (2003).

We conducted random-effects meta-analyses and the tested the heterogeneity between the different studies using Cochran's chi-square (Q test) and the I^2 statistic (Ioannidis et al. 2007; Petitti 2001). The small-study effect and the risk of bias effect were assessed by cumulative meta-analysis and by subgroup analysis. For cumulative meta-analysis, the studies were ranked in descending order by grading scores. Publication bias was examined with funnel plots. Asymmetry of the funnel plots was assessed by three statistical methods: the rank correlation method (Begg and Mazumdar's test) (Begg and Mazumdar 1994), regression analysis (Egger et al.'s test) (Egger et al. 1997) and Duval and Tweedie's trim and fill method (Duval and Tweedie 2000).

All calculations were performed with the statistical programme Comprehensive Meta-Analysis Version 3.0 (Biostat, Englewood, USA).

Results

We identified 28 relevant studies on the associations between WBV exposure and LBP or sciatica. Of these, two were identical (Okunribido et al. 2006, 2008) and we excluded the second one to be published (Okunribido et al. 2008). This resulted in 27 articles being included in this review, and their assessments scores for exposure and method are given in Table 3. The table also indicates study design and used definition of LBP and sciatica within each study. The quality assessment resulted in 11 studies of low risk of bias and 16 of unclear risk of bias.

Seven studies could not be used in the meta-analysis. Boshuizen et al. (1990a) investigated the prevalence of LBP among three groups of drivers, but the study did not present data in such way that the data could be included in the meta-analysis. Tamrin et al. (2007) studied risk factors associated with LBP among bus drivers, but the study did not use a control group and the study did not reveal a significant association between measured WBV and LBP among the bus drivers. Noorloos et al. (2008) investigated whether body mass index increased the risk of LBP in a population exposed to WBV, but the study groups were similar to the ones analysed by Tiemessen et al. (2008), and therefore, this study was not included in the meta-analysis. Palmer et al. (2008) conducted a case–control study of patients suffering from LBP who were referred

Table 3 Identified studies and study design, outcome and definition [low back pain (LBP) and/or sciatica (Sc)], quality assessments score for exposure and method and total score and the risk of bias (low or unclear)

Study	Study design	Outcome	Exposure	Method	Total	Risk of bias
Bovenzi et al (2002)	Cross section	LBP/Sc LBP def/question about ache, pain, or stiffness in the lower part of the back during the previous 12 months Sc def/question about radiating pain in one or both legs in the previous 12 months	25	10	35	Low
Bongers et al. (1990c)	Cross section	LBP/Sc LBP def/question about regularly experience pain or stiffness Sc def/question about the back pain radiate to one of your legs	22.5	10	32.5	Low
Bovenzi (2009)	Prospective cohort (2 year)	LBP LBP def/question about pain or discomfort in the low back area with or without radiating pain in one or both legs, lasting l day or longer in the previous 12 months	15	16	31	Low
Bovenzi (2010)	Prospective cohort (2 year)	LBP LBP def/question about pain or discomfort in the low back area with or without radiating pain in one or both legs, lasting l day or longer in the previous 12 months	15	16	31	Low
Tiemessen et al. (2008)	Prospective cohort (1 year)	LBP LBP def/question about pain or discomfort in the low back area with or without radiating pain in one or both legs, lasting l day or longer in the previous 12 months	17.5	12	29.5	Low
Schwarze et al. (1998)[a]	Prospective cohort (4 year)	LBP LBP def/lumbar syndrome was defined as any kind of symptoms like lumbago or sciatica in the lumbar region and in the sacral area	15	14	29	Low
Bovenzi and Zadini (1992)	Cross section	LBP/Sc LBP def/low back symptoms: any low back complaint, i.e. leg pain, acute low back pain, or low back pain (12 months) Sc def/leg pain: radiating pain in one or both legs (12 months)	17.5	10	27.5	Low
Boshuizen et al. (1992)	Cross section	LBP/Sc LBP def/question about regularly experience pain or stiffness Sc def/question about the back pain radiate to one of your the past 12 months	15	10	25	Low
Bovenzi and Betta (1994)	Cross section	LBP/Sc LBP def/question about ache, pain or stiffness in the lower part of the back within the previous 12 months Sc def/question about lifetime experience of radiating pain in one or both legs	15	10	25	Low
Bovenzi et al. (2006)	Cross section	LBP LBP def/question about pain or discomfort in the low back area between the twelfth ribs and the gluteal folds, with or without radiating pain in one or both legs, lasting 1 day or longer in the previous 12 months	15	10	25	Low
Burdorf et al. (1993)	Cross section	LBP LBP def/LBP was defined as pain located in the lumbar region that had persisted for at least a few hours the past 12 months	10	14	24	Low
Johanning (1991)	Cross section	LBP/Sc LBP def/question about back complaints during last year Sc def/Sc was computed by a combination of different responses and defined as recurrent (more than three times per year) or lasting(more than 1 week) pain in the lower back and radiating down the leg to below knee level	15	4	19	Unclear
Palmer et al. (2012)[a]	Case–control	LBP LBP def/cases were a consecutive series of patients from the study population referred for MRI of the lumbar spine during 2003–2006 to the radiology department at the public hospital	5	12	17	Unclear

Table 3 continued

Study	Study design	Outcome	Exposure	Method	Total	Risk of bias
Boshuizen et al. (1990c)	Cross section	LBP/Sc LBP def/questions about back pain and LBP was defined as back pain lasting several weeks or longer, or back pain occurring more than five times a month, which lasted several days or longer.? Sc def/questions about back pain and "prolapsed disc" included workers with or without present back pain with a history of prolapsed discs	7.5	10	17.5	Unclear
Magnusson et al. (1996)	Cross section	LBP LBP def/Not clear stated but used modified Nordic questionnaire for the analysis of musculoskeletal symptoms (12 month or 7 days)	12.5	4	16.5	Unclear
(Milosavljevic et al. (2012)[a]	Cross section	LBP LBP def/LBP was defined as having had at least one episode in the past 12 months	10	6	16	Unclear
(Okunribido et al. (2006)	Cross section	LBP LBP def/questions about pain and/or symptoms past 12 months	10	6	16	Unclear
Palmer et al. (2003)	Cross section	LBP/Sc LBP def/was defined as back pain lasting a day or longer during the previous 12 months in an area between the twelfth ribs and the gluteal folds Sc def/sciatica were defined as LBP which radiated down the leg to below the knee.	7.5	8	15.5	Unclear
(Palmer et al. 2008)[a]	Case–control	LBP LBP def/cases were a consecutive series of patients from the study population referred for MRI of the lumbar spine during 2003–2006 to the radiology department at the public hospital	5	10	15	Unclear
Johanning et al. (2006)	Cross section	LBP/Sc LBP def/back pain lasting more than 1 day in the past 12 months Sc def/sciatica pain at least once a week in past year	10	4	14	Unclear
Hoy et al. (2005)	Cross section	LBP LBP def/questions about symptoms and pain in the back, during the last 12 months	7.5	6	13.5	Unclear
Joubert and London (2007)	Cross section	LBP LBP def/question about back pain during the past year	7.5	6	13.5	Unclear
Kumar et al. (2001)	Cross section	LBP LBP def/self reported regular ache back complaints	7.5	4	11.5	Unclear
Noorloos et al. (2008)[a]	Cross section	LBP LBP def/question about pain or discomfort in the low back area during the past 12 months?	7.5	4	11.5	Unclear
Tamrin et al. (2007)[a]	Cross section	LBP LBP def/question about aching, pain or discomfort during the past 12 months (low back and upper back)	7.5	4	11.5	Unclear
Boshuizen et al. (1990a)[a]	Cross section	LBP LBP def/the prevalence of low back pain lasting several days or longer	5	4	9	Unclear
Rozali et al. (2009)	Cross section	LBP LBP def/was defined as back pain or discomfort in the lower back region between the twelfth rib and gluteal folds, with or without radiating pain down one or both legs, lasting 1 day or longer in the previous 12 months	5	4	9	Unclear

[a] Not included in the meta-analysis

for magnetic resonance imaging (MRI). Cases were a consecutive series referred for a lumbar MRI because of LBP and controls were age- and sex-matched subjects who underwent X-rays for other reasons. Because the LBP leads to a referral for MRI, we judged that the data were not comparable with LBP found by general questionnaires, and

this study was not included in our meta-analysis. Palmer et al. (Palmer et al. 2012) also conducted a similar investigation on the same study group with the aim to study the relation between WBV and prolapsed lumbar intervertebral disc (PID) and nerve root entrapment among patients with LBP. In this case, we also judged that the data could not be included in the meta-analysis. Milosavljevic et al. (2012) found an association between WBV and LBP among quad bike users. However, the data were presented in such way so they could not be used in further analysis. Furthermore, the study by Schwarze et al. (1998) was omitted since they used a definition of "lumbar syndrome" that included both LBP and sciatica.

Meta-analysis of exposed versus unexposed groups

Figures 2 and 3 show the results of the meta-analysis of studies comparing risk for LBP and sciatica between groups exposed to WBV versus the reference group not exposed to WBV. The analysis has also been divided between studies of low and unclear risk of bias. Within the two risk of bias-groups, the studies have been ranked in descending order according to their total score (Table 3). For each study, the odds ratio, 95 % confidence interval (lower and upper limit), z value and p value are shown.

Among the included studies, comparisons between exposed and unexposed groups were conducted in 15 studies for LBP and 9 studies for sciatica. For the LBP outcome, the pooled estimate had an odds ratio of 2.17 (95 % CI 1.61–2.91) and the heterogeneity was 85 % ($p < 0.01$). Only small differences between studies of low and unclear risk of bias were observed (2.29 vs. 2.06) and heterogeneity [83 % ($p < 0.01$) vs. 88 % ($p < 0.01$)]. The results for the sciatica outcome (Fig. 3) gave a pooled odds ratio of 1.92 (95 % CI 1.38–2.67) and a heterogeneity of 70 % ($p < 0.01$). However, the pooled risk estimate for the studies with low risk of bias ($n = 5$) was 1.99 (95 % CI 1.31–3.02) and the heterogeneity was 39 % ($p = 0.16$), while the pooled risk estimate of the studies with unclear risk of bias ($n = 4$) was 1.82 (95 % CI 1.07–3.10) and the heterogeneity was 80 % ($p < 0.01$).

If the analysis were divided between studies with adjusted and unadjusted odds ratios, the outcome for LBP gave a pooled risk estimate for the studies ($n = 6$) with adjusted odds ratios of 2.96 (95 % CI 1.65–5.30) compared to 1.64 (95 % CI 1.36–1.96) for studies ($n = 9$) with unadjusted odds ratios. The corresponding pooled risk estimate for the sciatica outcome was 2.53 (95 % CI 1.88–3.39; $n = 5$) vs. 1.15 (95 % CI 0.97–1.37; $n = 4$).

The funnel plot of the studies included in our meta-analysis for LBP (15 studies) or sciatica (9 studies) and exposure to WBV is presented in Figs. 4 and 5, respectively. For the LBP outcome, the studies were distributed symmetrically around the estimated effect suggesting little effect of publication bias. Neither Begg's ($p = 0.37$) nor Egger's ($p = 0.07$) tests showed evidence of publication bias and

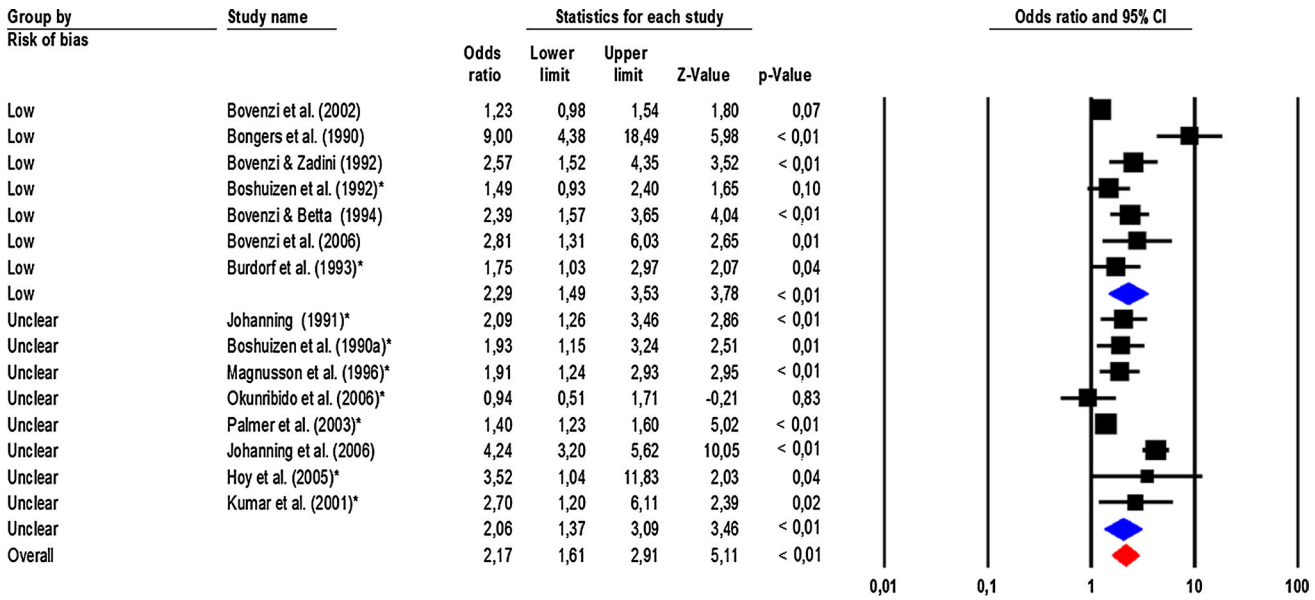

Fig. 2 Statistics and Forest plot from the random-effect meta-analysis on the occurrence of LBP between the groups exposed to WBV versus non-exposed reference groups. The sizes of the *dots* for the individual studies are proportional to the study weight. The *blue dots* indicate the subgroups of risk of bias (low, unclear) and the *red dot* indicates the overall summary. The studies have been sorted in order from highest to lowest scores in Table 2. *Asterisk* indicates that the study presented data that made it possible to calculate an unadjusted odds ratio (colour figure online)

Group by Risk of bias	Study name	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
Low	Bovenzi et al. (2002)*	1,57	0,79	3,15	1,28	0,20
Low	Bongers et al. (1990)	3,30	1,08	10,10	2,09	0,04
Low	Bovenzi & Zadini (1992)	1,95	1,15	3,31	2,48	0,01
Low	Boshuizen et al. (1992)*	1,11	0,54	2,25	0,28	0,78
Low	Bovenzi & Betta (1994)	3,90	1,75	8,70	3,32	< 0,01
Low		1,99	1,31	3,02	3,21	< 0,01
Unclear	Johanning (1991)	3,90	1,73	8,77	3,29	< 0,01
Unclear	Boshuizen et al. (1990a)*	1,62	0,88	2,98	1,56	0,12
Unclear	Palmer et al. (2003)*	1,09	0,90	1,32	0,90	0,37
Unclear	Johanning et al. (2006)	2,17	1,33	3,55	3,08	< 0,01
Unclear		1,82	1,07	3,10	2,20	0,03
Overall		1,92	1,38	2,67	3,88	< 0,01

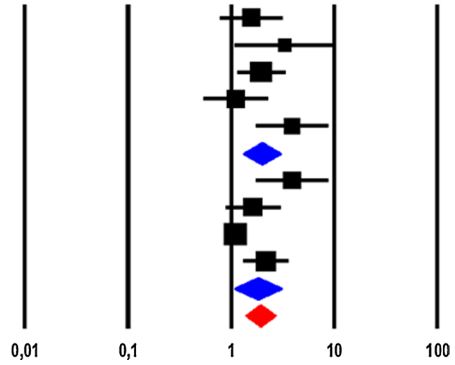

Fig. 3 Statistics and Forest plot from the random-effect meta-analysis on the occurrence of sciatica between the groups exposed to WBV versus non-exposed reference groups. The sizes of the *dots* for the individual studies are proportional to the study weight. The *blue dots* indicate the subgroups of risk of bias (low, unclear) and the *red dot* indicates the overall summary. The studies have been sorted in order from highest to lowest scores in Table 2. *Asterisk* indicates that the study presented data that made it possible to calculate an unadjusted odds ratio (colour figure online)

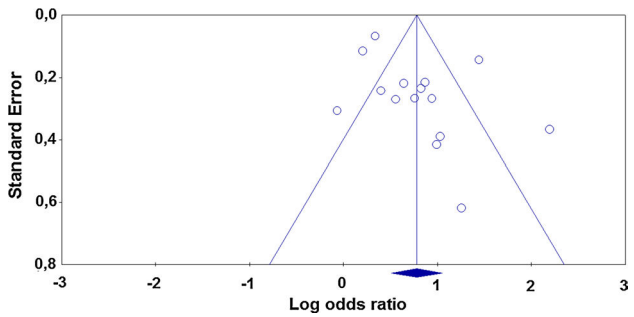

Fig. 4 Funnel plot with pseudo 95 % confidence limits for publication bias in studies of the association between the prevalence of LBP among groups exposed to WBV versus non-exposed reference groups

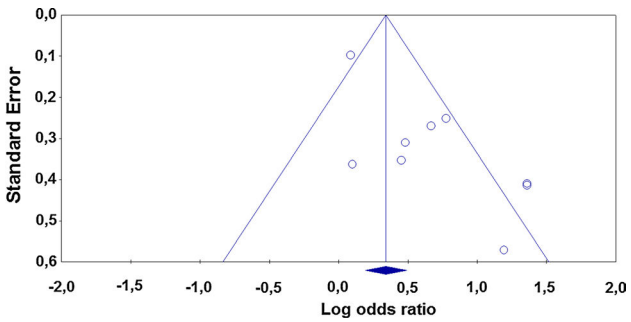

Fig. 5 Funnel plot with pseudo 95 % confidence limits for publication bias in studies of the association between the prevalence of sciatica among groups exposed to WBV versus non-exposed reference groups

the trim and fill method imputed no missing studies (random-effect model). For the sciatica outcome, there was an asymmetrical tendency suggesting that some medium sized and small studies with negative or null findings were not published. Only Egger's test ($p < 0.01$), but not Begg's test ($p = 0.47$), showed evidence of publication bias. The trim and fill method imputed three missing studies to the left of the mean (random-effect model).

Meta-analysis of low- and high- exposure groups

In Figs. 6 and 7, the exposure to WBV has been divided between groups with low and high exposures. The analysis has also been divided between studies of low and unclear risk of bias. For LBP, the pooled risk estimate was 1.51 (95 % CI 1.30–1.75) for the 13 included studies and the heterogeneity was 44 % ($p = 0.05$). The pooled risk estimates for the studies with low risk of bias and unclear risk of bias were similar (1.64 vs. 1.48), but the heterogeneity differed [62 % ($p = 0.01$) vs. 0 % ($p = 0.60$)].

The sciatic results showed a pooled risk estimate of 1.48 (95 % CI 1.19–1.84) for the six included studies and the heterogeneity was 0 % ($p = 0.58$). The odds ratio for the studies with a low risk of bias (OR = 1.82) was higher than that of studies with unclear risk of bias (OR = 1.44). The same pattern was found for the heterogeneity [9 % ($p = 0.35$) vs. 0 % ($p = 0.75$)].

The analysis of publication bias in the form of funnel plots for the LBP and sciatica outcomes shows that for both outcomes the studies are distributed symmetrically around the estimated effect, suggesting little publication bias (data not shown). For LBP, Begg's ($p = 0.04$) but not Egger's ($p = 0.12$) tests showed evidence of publication bias and the trim and fill method imputed four missing studies to the left of the mean. The corresponding values for sciatic

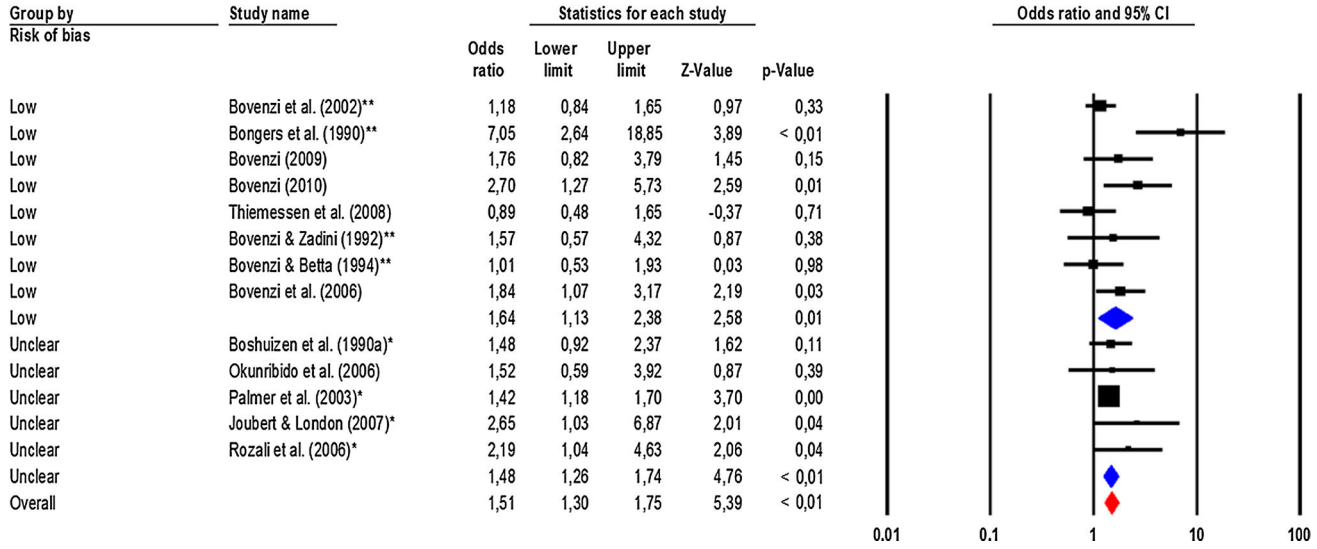

Fig. 6 Statistics and forest plot from the random-effect meta-analysis on the occurrence of LBP between the groups with low and high exposure to WBV. The sizes of the *dots* for the individual studies are proportional to the study weight. The *blue dots* indicate the subgroups of risk of bias (low, unclear) and the *red dot* indicates the overall summary. The studies have been sorted in order from highest to lowest scores in Table 2. *Asterisk* indicates that the study presented data that made it possible to calculate an unadjusted odds ratio. *Double asterisk* indicates that the study presented estimates that made it possible to calculate the difference between estimates (colour figure online)

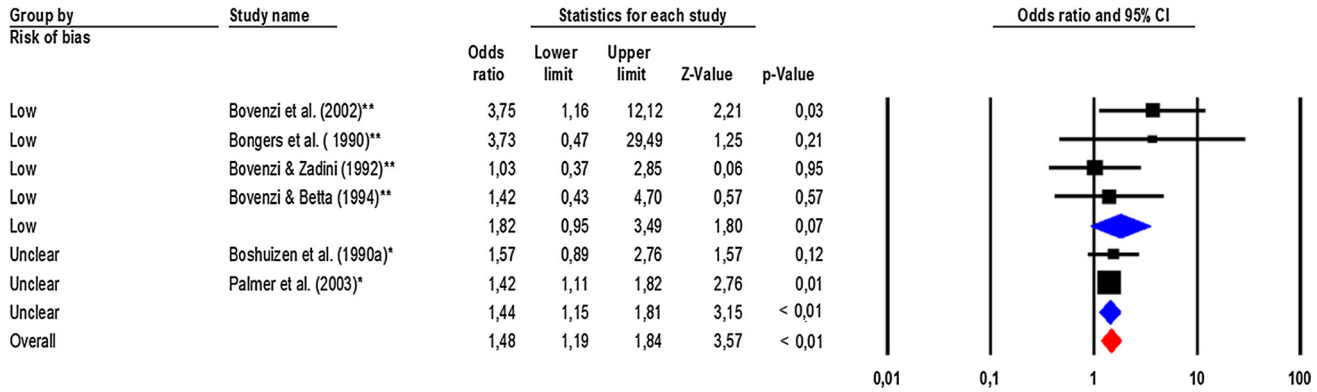

Fig. 7 Statistics and forest plot from the random-effect meta-analysis on the occurrence of sciatica between the groups with low and high exposure to WBV. The sizes of the *dots* for the individual studies are proportional to the study weight. The *blue dots* indicate the subgroups of risk of bias (low, unclear) and the *red dot* indicates the overall summary. The studies have been sorted in order from highest to lowest scores in Table 2. *Asterisk* indicates that the study presented data that made it possible to calculate an unadjusted odds ratio. *Double asterisk* indicates that the study presented estimates that made it possible to calculate the difference between estimates (colour figure online)

outcome were $p = 0.45$ and $p = 0.31$ for Begg's and Egger's tests, respectively, and the trim and fill method imputed one missing study to the left of the mean.

Discussion

This systematic literature review and meta-analysis shows that workers who are exposed to WBV have an increased risk of both LBP and sciatica compared to non-exposed groups. The pooled estimates of the risk are approximately doubled. It is interesting to note that our results are more or less the same as presented in the earlier reviews, (Bakker et al. 2009; Bernard 1997; Bovenzi and Hulshof 1999; Burdorf and Sorock 1997; Hoogendoorn et al. 1999; Lings and Leboeuf-Yde 2000; Waters et al. 2007; Vingård and Nachemsson 2000) although there has been a clear difference in the inclusion and exclusion criteria and that our review cover more resent published articles. Our use of more stringent criteria for inclusion has led to a slightly higher risk of LBP and sciatica due to WBV exposure compared with the previous reviews.

Our attempt to compare the same groups of vibration-exposed individuals by contrasting high exposure with low exposure showed a pooled risk estimate of about 1.5 for both LBP and sciatica that indicates a possible exposure–response relationship. However, in the included studies, the exposures occurred at many different levels and were quantified in different ways. This means that those who in one study were considered low-exposed might in another study be regarded as highly exposed.

Results of this review could have been biased by confounding exposures. Workers exposed to WBV often have exposure to prolonged sitting and to unfavourable working postures, and both of these factors can also cause LBP (Lis et al. 2007). Because these factors have a strong correlation with exposure to WBV, it has been difficult to consider these factors separately in the analyses and to assess whether they reinforce each other´s harmful effects. An indication of such confounding could be the somewhat smaller pooled risk estimates when comparing low- and high- exposure groups of workers as opposed to the pooled risk estimates found when comparing exposed workers to reference groups. Some of the studies included in the meta-analysis controlled for potential confounders in the estimates, but others did not. Our comparison of studies that controlled or not controlled for such confounding factors clearly demonstrate their significant impact since the adjusted risk estimates are more or less doubled compared with the unadjusted risk estimates. Moreover, the case definition for low back pain and sciatica differ between different studies and in many studies the outcomes did not include information on the frequency and severity of LBP or sciatica. Different recall periods and different case definitions were used, but the most commonly used outcome assessment was a questionnaire asking about LBP in the previous year. A limited number of prospective studies on the role of WBV in the occurrence of LBP or sciatica have also been published. Results from cross-sectional studies are particularly vulnerable to effects from "healthy worker" selection or "healthy worker" survival. This effect leads to the risk of exposure being underestimated. In our review, we found some examples of studies where the groups exposed for a short time had a higher risk than those who were exposed for a long time, and this indicates a possible "healthy worker" selection (Li and Sung 1999). Unfortunately, the proportion of prospective studies is too small to be able to make a comparison between the different study designs.

One of the strengths with this review is the strict exposure criteria for a study to be included in the final analysis. Inclusion of the study also required that there were either measurements or estimates of exposure in combination with defined health outcomes. This has resulted in excluding relevant studies based on clinical examinations with very high quality scores, but where no quantification of the exposure was presented. This can also be seen as a limitation because we have included studies that presented information about the vibration exposure in which the outcome and the exposure time have only been estimated by a questionnaire.

There might be a publication bias in favour of positive results between WBV and the studied effects. Publication bias arises when studies showing a statistically significant positive association are more likely to be reported or published than studies with a negative or null association. Publication bias is more likely to affect small studies, which tend to show larger risk estimates than larger studies. The results (funnel plots) indicate that some publication bias could have occurred for sciatica. In addition, we only included articles published in English language journals and there is scientific literature published in other languages that has been ignored. However, we believe from the consistent findings in other reviews that this "language bias" would not cause a significant shift in our final assessment. A further limitation for generalizing our results is that all of the risk estimates we have included in the meta-analysis only apply to male workers. Therefore, no conclusion about the risk for women exposed to WBV can be drawn.

In summary, this review shows that there is scientific evidence that exposure to WBV increases the risk of LBP and sciatica. The pooled odds ratio shows a doubled risk for both outcomes. Adverse posture and prolonged sitting correlate with exposure to WBV, but these potential confounders have only been taken into account in a small number of the reviewed studies. However, it is unlikely that the overall risk pattern can be explained by other confounding factors. The novel finding of this review is that it shows clear evidence in the literature that exposure to WBV also increases the risk of sciatica.

The results of the review shows that one should strive to have the lowest exposure to WBV as possible. Unfortunately there are insufficient data to determine what a "safe" level is for the whole body, i.e. a level at which risk is not increased. There is a need for further research on the relationship between dose and response that take into account possible interactions with other factors such as prolonged sitting and unfavourable working postures.

Acknowledgments The financial support of the Swedish AFA Insurance is gratefully acknowledged. We also acknowledge comments on the original manuscript in Swedish (Burström et al. 2012).

Conflict of interest The authors declare that there is no conflict of interest.

References

Altman DG, Bland JM (2003) Interaction revisited: the difference between two estimates. BMJ 326(7382):219

Anderson R (1992) The back pain of bus drivers. Prevalence in an urban area of California. Spine (Phila Pa 1976) 17(12):1481–1488
Bakker EW, Verhagen AP, van Trijffel E, Lucas C, Koes BW (2009) Spinal mechanical load as a risk factor for low back pain: a systematic review of prospective cohort studies. Spine (Phila Pa 1976) 34(8):E281–E293. doi:10.1097/BRS.0b013e318195b257
Barnekow-Bergkvist M, Hedberg GE, Janlert U, Jansson E (1998) Determinants of self-reported neck-shoulder and low back symptoms in a general population. Spine (Phila Pa 1976) 23(2):235–243
Begg CB, Mazumdar M (1994) Operating characteristics of a rank correlation test for publication bias. Biometrics 50(4):1088–1101
Bernard B (ed) (1997) Musculoskeletal disorders and workplace factors A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back. NIOSH, Cincinatti
Bongers PM, Boshuizen HC, Hulshof CT, Koemeester AP (1988a) Back disorders in crane operators exposed to whole-body vibration. Int Arch Occup Environ Health 60(2):129–137
Bongers PM, Boshuizen HC, Hulshof CT, Koemeester AP (1988b) Long-term sickness absence due to back disorders in crane operators exposed to whole-body vibration. Int Arch Occup Environ Health 61(1–2):59–64
Bongers PM, Boshuizen HC, Hulshof CT (1990a) Disability due to back disorders in crane operators in a metal construction company. short communication Academisch Proefschrift, Universiteit van Amsterdam
Bongers PM, Hulshof CT, Dijkstra L, Boshuizen HC, Groenhout HJ, Valken E (1990b) Back pain and exposure to whole body vibration in helicopter pilots. Ergonomics 33(8):1007–1026
Bongers PM, Boshuizen HC, Hulshof CT (1990c) Self reported back pain in drivers of wheel loaders. Academisch Proefschrift, Universiteit van Amsterdam
Boshuizen HC, Bongers PM, Hulshof CT (1990a) Back disorders and occupational exposure to whole-body vibration. Int J Ind Ergon 6(1):55–59
Boshuizen HC, Bongers PM, Hulshof CT (1990b) An explorative case-referent study of disability due to back disorders in relation to driving. Academisch Proefschrift, Universiteit van Amsterdam
Boshuizen HC, Bongers PM, Hulshof CT (1990c) Self-reported back pain in tractor drivers exposed to whole-body vibration. Int Arch Occup Environ Health 62(2):109–115
Boshuizen HC, Hulshof CT, Bongers PM (1990d) Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration. Int Arch Occup Environ Health 62(2):117–122
Boshuizen HC, Bongers PM, Hulshof CT (1992) Self-reported back pain in fork-lift truck and freight-container tractor drivers exposed to whole-body vibration. Spine (Phila Pa 1976) 17(1):59–65
Bovenzi M (2009) Metrics of whole-body vibration and exposure–response relationship for low back pain in professional drivers: a prospective cohort study. Int Arch Occup Environ Health 82(7):893–917. doi:10.1007/s00420-008-0376-3
Bovenzi M (2010) A longitudinal study of low back pain and daily vibration exposure in professional drivers. Ind Health 48(5):584–595
Bovenzi M, Betta A (1994) Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. Appl Ergon 25(4):231–241
Bovenzi M, Hulshof CT (1999) An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986–1997). Int Arch Occup Environ Health 72(6):351–365
Bovenzi M, Zadini A (1992) Self-reported low back symptoms in urban bus drivers exposed to whole-body vibration. Spine (Phila Pa 1976) 17(9):1048–1059
Bovenzi M, Pinto I, Stacchini N (2002) Low back pain in port machinery operators. J Sound Vib 253(1):3–20
Bovenzi M et al (2006) An epidemiological study of low back pain in professional drivers. J Sound Vib 298(3):514–539
Brendstrup T, Biering-Sorensen F (1987) Effect of fork-lift truck driving on low-back trouble. Scand J Work Environ Health 13(5):445–452
Brown JJ, Wells GA, Trottier AJ, Bonneau J, Ferris B (1998) Back pain in a large Canadian police force. Spine (Phila Pa 1976) 23(7):821–827
Burdorf A, Sorock G (1997) Positive and negative evidence of risk factors for back disorders. Scand J Work Environ Health 23(4):243–256
Burdorf A, Zondervan H (1990) An epidemiological study of low-back pain in crane operators. Ergonomics 33(8):981–987
Burdorf A, Govaert G, Elders L (1991) Postural load and back pain of workers in the manufacturing of prefabricated concrete elements. Ergonomics 34(7):909–918
Burdorf A, Naaktgeboren B, de Groot HC (1993) Occupational risk factors for low back pain among sedentary workers. J Occup Med 35(12):1213–1220
Burström L, Nilsson T, Wahlström J (2012) Systematiska kunskapsöversikter; 2. Exponering för helkroppsvibrationer och uppkomst av ländryggssjuklighet. In: Torén K, Albin M, Järvholm B (eds) Arbete och Hälsa, vol 46(2). Göteborgs universitet, Göteborg (In Swedish)
Burton AK, Tillotson KM, Symonds TL, Burke C, Mathewson T (1996) Occupational risk factors for the first-onset and subsequent course of low back trouble: a study of serving police officers. Spine (Phila Pa 1976) 21(22):2612–2620
Chernyuk V (1994) Effect of whole body vibration on diseases of the lumbar section of the spine in agricultural machinery opertors. Noise Vib Bull 28:75–77
Dupuis H, Zerlett G (1987) Whole-body vibration and disorders of the spine. Int Arch Occup Environ Health 59(4):323–336
Duval S, Tweedie R (2000) Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56(2):455–463
Egger M, Davey Smith G, Schneider M, Minder C (1997) Bias in meta-analysis detected by a simple, graphical test. BMJ 315(7109):629–634
Futatsuka M, Maeda S, Inaoka T, Nagano M, Shono M, Miyakita T (1998) Whole-body vibration and health effects in the agricultural machinery drivers. Ind Health 36(2):127–132
Heliovaara M (1987) Occupation and risk of herniated lumbar intervertebral disc or sciatica leading to hospitalization. J Chronic Dis 40(3):259–264
Heliovaara M, Makela M, Knekt P, Impivaara O, Aromaa A (1991) Determinants of sciatica and low-back pain. Spine (Phila Pa 1976) 16(6):608–614
Hoogendoorn WE, van Poppel MN, Bongers PM, Koes BW, Bouter LM (1999) Physical load during work and leisure time as risk factors for back pain. Scand J Work Environ Health 25(5):387–403
Hoy J et al (2005) Whole body vibration and posture as risk factors for low back pain among forklift truck drivers. J Sound Vib 284(3):933–946
Ioannidis JP, Patsopoulos NA, Evangelou E (2007) Uncertainty in heterogeneity estimates in meta-analyses. BMJ 335(7626):914–916. doi:10.1136/bmj.39343.408449.80
Jensen MV, Tuchsen F (1995) Occupation and lumbar disk prolapse. Ugeskr Laeger 157(11):1519–1523
Johanning E (1991) Back disorders and health problems among subway train operators exposed to whole-body vibration. Scand J Work Environ Health 17(6):414–419
Johanning E, Landsbergis P, Fischer S, Christ E, Gores B, Luhrman R (2006) Whole-body vibration and ergonomic study of US railroad locomotives. J Sound Vib 298(3):594–600

Joubert DM, London L (2007) A cross-sectional study of back belt use and low back pain amongst forklift drivers. Int J Ind Ergon 37(6):505–513

Kelsey JL, Hardy RJ (1975) Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral disc. Am J Epidemiol 102(1):63–73

Kelsey JL et al (1984) An epidemiological study of acute prolapsed cervical intervertebral disc. J Bone Joint Surg Am 66(6):907–914

Kumar A, Varghese M, Mohan D, Mahajan P, Gulati P, Kale S (1999) Effect of whole-body vibration on the low back: a study of tractor-driving farmers in north India. Spine (Phila Pa 1976) 24(23):2506–2515

Kumar A, Mahajan P, Mohan D, Varghese M (2001) IT—information technology and the human interface: tractor vibration severity and driver health: a study from rural India. J Agric Eng Res 80(4):313–328

Kuorinka I et al (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 18(3):233–237

Langauer-Lewowicka H, Harazin B, Brzozowska I, Szlapa P (1996) Evaluation of health risk in machine operators exposed to whole body vibration. Med Pr 47(2):97–106

Leclerc A, Tubach F, Landre MF, Ozguler A (2003) Personal and occupational predictors of sciatica in the GAZEL cohort. Occup Med (Lond) 53(6):384–391

Li CY, Sung FC (1999) A review of the healthy worker effect in occupational epidemiology. Occup Med (Lond) 49(4):225–229

Liira JP, Shannon HS, Chambers LW, Haines TA (1996) Long-term back problems and physical work exposures in the 1990 Ontario Health Survey. Am J Public Health 86(3):382–387

Lings S, Leboeuf-Yde C (2000) Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992–1999. Int Arch Occup Environ Health 73(5):290–297

Lis AM, Black KM, Korn H, Nordin M (2007) Association between sitting and occupational LBP. Eur Spine J 16(2):283–298. doi:10.1007/s00586-006-0143-7

Macfarlane GJ, Thomas E, Papageorgiou AC, Croft PR, Jayson MI, Silman AJ (1997) Employment and physical work activities as predictors of future low back pain. Spine (Phila Pa 1976) 22(10):1143–1149

Magnusson ML, Pope MH, Wilder DG, Areskoug B (1996) Are occupational drivers at an increased risk for developing musculoskeletal disorders? Spine (Phila Pa 1976) 21(6):710–717

Magora A (1972) Investigation of the relation between low back pain and occupation. 3. Physical requirements: sitting, standing and weight lifting. IMS Ind Med Surg 41(12):5–9

Manninen P, Riihimak H, Heliovaara M (1995) Incidence and risk factors of low-back pain in middle-aged farmers. Occup Med (Lond) 45(3):141–146

Masset D, Malchaire J (1994) Low back pain. Epidemiologic aspects and work-related factors in the steel industry. Spine (Phila Pa 1976) 19(2):143–146

Milosavljevic S, Bagheri N, Vasiljev RM, McBride DI, Rehn B (2012) Does daily exposure to whole-body vibration and mechanical shock relate to the prevalence of low back and neck pain in a rural workforce? Ann Occup Hyg 56(1):10–17. doi:10.1093/annhyg/mer068

Miyashita K, Morioka I, Tanabe T, Iwata H, Takeda S (1992) Symptoms of construction workers exposed to whole body vibration and local vibration. Int Arch Occup Environ Health 64(5):347–351

Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339:b2535. doi:10.1136/bmj.b2535

Nehring P, Wolf H (1990) Längsschnittstudie zur aufklärung des einfluses von ganzkörperschwingungen auf des gesundheitszustand von werktätigen, die mobile baumaschinen bedienen. TiefB Berufsgenossens 102:453–457

Niedhammer I, Lert F, Marne MJ (1994) Back pain and associated factors in French nurses. Int Arch Occup Environ Health 66(5):349–357

Noorloos D, Tersteeg L, Tiemessen IJ, Hulshof CT, Frings-Dresen MH (2008) Does body mass index increase the risk of low back pain in a population exposed to whole body vibration? Appl Ergon 39(6):779–785. doi:10.1016/j.apergo.2007.11.002

Nuwayhid IA, Stewart W, Johnson JV (1993) Work activities and the onset of first-time low back pain among New York City fire fighters. Am J Epidemiol 137(5):539–548

Okunribido OO, Magnusson M, Pope MH (2006) Low back pain in drivers: the relative role of whole-body vibration, posture and manual materials handling. J Sound Vib 298(3):540–555

Okunribido OO, Magnusson M, Pope MH (2008) The role of whole body vibration, posture and manual materials handling as risk factors for low back pain in occupational drivers. Ergonomics 51(3):308–329. doi:10.1080/00140130701637262

Palmer KT, Griffin MJ, Syddall HE, Pannett B, Cooper C, Coggon D (2003) The relative importance of whole body vibration and occupational lifting as risk factors for low-back pain. Occup Environ Med 60(10):715–721

Palmer KT et al (2008) Case–control study of low-back pain referred for magnetic resonance imaging, with special focus on whole-body vibration. Scand J Work Environ Health 34(5):364–373

Palmer KT et al (2012) Professional driving and prolapsed lumbar intervertebral disc diagnosed by magnetic resonance imaging: a case–control study. Scand J Work Environ Health 38(6):577–581. doi:10.5271/sjweh.3273

Petitti DB (2001) Approaches to heterogeneity in meta-analysis. Stat Med 20(23):3625–3633. doi:10.1002/sim.1091

Pietri F, Leclerc A, Boitel L, Chastang JF, Morcet JF, Blondet M (1992) Low-back pain in commercial travelers. Scand J Work Environ Health 18(1):52–58

Riihimaki H, Tola S, Videman T, Hanninen K (1989) Low-back pain and occupation: a cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. Spine (Phila Pa 1976) 14(2):204–209

Riihimaki H, Viikari-Juntura E, Moneta G, Kuha J, Videman T, Tola S (1994) Incidence of sciatic pain among men in machine operating, dynamic physical work, and sedentary work: a 3-year follow-up. Spine (Phila Pa 1976) 19(2):138–142

Rozali A et al (2009) Low back pain and association with whole body vibration among military armoured vehicle drivers in Malaysia. Med J Malays 64(3):197–204

Sandover J, Gardner L, Stroud P, Robertson N (1994) Some epidemiological issues regarding vibration and tractor driving. Paper presented at the United Kingdom informal group meeting on human response to vibration 19–21 September, Gosport

Saraste H, Hultman G (1987) Life conditions of persons with and without low-back pain. Scand J Rehabil Med 19(3):109–113

Schwarze S, Notbohm G, Dupuis H, Hartung E (1998) Dose-response relationships between whole-body vibration and lumbar disk disease: a field study on 388 drivers of different vehicles. J Sound Vib 215(4):613–628

Simon-Arndt CM, Yuan H, Hourani LL (1997) Aircraft type and diagnosed back disorders in US Navy pilots and aircrew. Aviat Space Environ Med 68(11):1012–1018

Skov T, Borg V, Orhede E (1996) Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in salespeople. Occup Environ Med 53(5):351–356

Smeathers JE, Wright V (1990) New engineering concepts and alternative materials for prostheses. Proc Inst Mech Eng H 204(4):259–261

Tamrin SB et al (2007) The Association between risk factors and low back pain among commercial vehicle drivers in peninsular Malaysia: a preliminary result. Ind Health 45(2):268–278

Tiemessen IJ, Hulshof CT, Frings-Dresen MH (2008) Low back pain in drivers exposed to whole body vibration: analysis of a dose–response pattern. Occup Environ Med 65(10):667–675. doi:10.1136/oem.2007.035147

Toroptsova NV, Benevolenskaya LI, Karyakin AN, Sergeev IL, Erdesz S (1995) "Cross-sectional" study of low back pain among workers at an industrial enterprise in Russia. Spine (Phila Pa 1976) 20(3):328–332

van Poppel MN, Koes BW, Deville W, Smid T, Bouter LM (1998) Risk factors for back pain incidence in industry: a prospective study. Pain 77(1):81–86

Vingård E, Nachemsson A (2000) Work-related influences on neck and low back pain. In: Nachemsson A, Jonsson E (eds) The scientific evidence of causes, diagnosis, and treatment. Lippincott Williams and Wilkins, Philadelphia, pp 97–126

Walsh K, Varnes N, Osmond C, Styles R, Coggon D (1989) Occupational causes of low-back pain. Scand J Work Environ Health 15(1):54–59

Waters T, Rauche C, Genaidy A, Rashed T (2007) A new framework for evaluating potential risk of back disorders due to whole body vibration and repeated mechanical shock. Ergonomics 50(3):379–395

Xu Y, Bach E, Orhede E (1997) Work environment and low back pain: the influence of occupational activities. Occup Environ Med 54(10):741–745

Zimmermann CL, Cook TM (1997) Effects of vibration frequency and postural changes on human responses to seated whole-body vibration exposure. Int Arch Occup Environ Health 69(3):165–179