Rheumatic effects of vibration at work

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Occupational exposures to vibration come in many guises and are very common at a population level. It follows that an important minority of working-aged patients seen by medical services will have been exposed to this hazard of employment. Vibration can cause human health effects which may manifest in the patients that rheumatologists see. In this chapter we identify the health effects of relevance to them, and review their epidemiology, pathophysiology, clinical presentation, differential diagnosis, and vocational and clinical management. On either side of this, we describe the nature and assessment of the hazard, the scale and common patterns of exposure to vibration in the community, and the legal basis for controlling health risks, and comment on the role of health surveillance in detecting early adverse effects and what can be done to prevent the rheumatic effects of vibration at work.

The nature and measurement of vibration at work

Vibration is an oscillatory motion, characterised by the frequency of the oscillatory cycle, its magnitude, and its direction. The average energy imparted is believed to reflect the potential for injury.

The magnitude of motion can be quantified in terms of its displacement or velocity, but is normally expressed in terms of its acceleration, and time-averaged (the so-called 'root mean square (r.m.s.) magnitude') to smooth out the effect of peaks and troughs. The frequency of motion is expressed in cycles per second (Hertz). Biodynamic investigations have shown that the response of the body to vibration is frequency dependent and to account for this, standards for exposure evaluation weight the frequencies of measured vibration according to the assumed effects at each frequency. Frequency weightings are applied to measurements taken in three axes at right angles to one another, sited at the boundary between the body and the vibration (e.g. using accelerometers mounted on the handle of a powered tool or the seat of a vibrating vehicle). 'Dose' of vibration is based on specific relations between time and vibration magnitude defined in ISO standards [1,2], allowing the daily vibration exposure to be re-expressed in terms of the equivalent acceleration that would impart the same energy over an 8-hour reference period (a notional average working day). This is called the $A(8)$ (m/s^2 r.m.s.). Partial doses from several sources can be summed to an equivalent daily dose: inventories of sources, data on vibration magnitude from equipment handbooks or suppliers' information sheets, and on-line ready reckoner calculators supplied in the UK by the Health and Safety Executive (HSE) [3] allows employers to estimate workers' exposures relative to control and surveillance standards set in European law.

In practice, two forms of vibration are distinguished: hand-transmitted vibration (HTV) from hand-held powered tools, with potential impacts on the upper limb, and whole-body vibration (WBV) from vehicles, and sometimes platforms, with potential impacts on the spine. For each type of vibration, two exposure limits are specified in UK and European legislation [4]:

(1) An Exposure Action Value (EAV), representing the daily amount of exposure above which employers must act to control exposure. For HTV this $A(8)$ is 2.5 m/s^2 r.m.s. and for WBV it is 0.5 m/s^2 r.m.s..

(2) An Exposure Limit Value (ELV), representing the maximum amount an employee may be exposed to on any given day: 5 m/s^2 r.m.s. for HTV and 1.15 m/s^2 r.m.s. for WBV. (Doses of WBV can also be expressed in other units, but for simplicity we ignore this in the present account.)

Health surveillance is required for workers who remain regularly exposed above the EAV. These values have been translated into guidelines based upon typical patterns of exposure. For example, use of hammer-action tools for > about 1 hour/day, or of some rotary-action tools for > 2 hours/day regularly is likely to exceed the ELV for HTV and the EAV may be breached by as little as 15 minutes/day of exposure to certain hammer-action tools [5]. (Some employers employ a 'traffic light' labelling system to identify tools with the worst characteristics.)

This summary of current approaches to risk assessment and control suggests a precise understanding of the exposure-response relationship, and a precise cut-off for safe practice. In fact, the ISO standard for HTV is predicated on the assumption that about 10% of a population exposed at the EAV will still suffer vascular effects over a period of about 12 years; and other formulae for summing the vibration dose accumulated over a lifetime have been found to approximate cross-sectional and longitudinal data on disease risks more closely than the official assessment standard. Similarly, the limit values for WBV have more to do with discomfort and tolerance than a well-described relationship between vibration dose and adverse health effects on the spine.

Common sources of exposure

Exposure to HTV arises from many sources, including chain-saws, hand-held grinders, concrete breakers, metal polishers, power hammers and chisels, needle scalers, scabblers, powered sanders, hammer drills, and even powered lawnmowers and motorcycle handlebars (Figure 1). Exposures are particularly common in the construction industry and in heavy engineering, but significant exposures can arise in many occupations, such as builders, metal-working and maintenance fitters, welders, foresters, shipbuilders, foundry workers and labourers. In one national survey it was estimated that about 1.2 million men and 40,000 women in Britain had weekly exposures that were high enough to justify health surveillance [6,7].

FIGURE 1 NEAR HERE, CAPTION:

Figure 1: Exposure to hand-transmitted vibration occurs in many forms (with permission of Prof KT Palmer)

The same survey put weekly occupational exposures to WBV in Britain at some 7.2 million in men and 1.8 million in women [8]. Thus, WBV and HTV are among the commonest of occupational hazards. Common sources of occupational exposure to WBV include cars and vans driven professionally, forklift trucks, lorries, tractors, buses and loaders; exposures also arise among operators of many other vehicles and machines, including excavators, bulldozers, armoured and off-road vehicles [8]. At-risk occupations range from travelling salesmen and delivery men through to bus and lorry drivers, farmers, soldiers, pilots, and police and emergency workers. In another British survey, 12% of men and 1% of women reported their job involving sitting or standing on a vibrating machine or vehicle, with higher prevalences in farming, forestry and road transport [9].

Rheumatic effects of hand-transmitted vibration on the upper limb

Some reported effects of HTV have a well-established occupational connection. These include secondary Raynaud's phenomenon (vibration-induced white finger or VWF), digital neuropathy, and carpal tunnel syndrome (CTS). For other disorders, the evidence base on occupational causation is less deep (e.g. Dupuytren’s contracture, tendonitis) or more contentious (e.g. osteoarthritis of the elbow and hand). The disorders of the upper limbs associated with HTV exposure are collectively called the ‘Hand-arm Vibration Syndrome’ (HAVS). In this account we focus principally on VWF, sensorineural dysfunction and CTS, although other effects are described in passing.

Vibration-induced white finger

VWF, like Raynaud's phenomenon (RP) from other causes, is characterised by episodic cold-induced finger blanching. Classically there is a sharp demarcation between normal and affected skin, the latter becoming numb, cold, and sometimes cyanotic with a bluish tinge, but fiery red and tingling in the recovery phase. As with RP more generally, non-classical patterns may also be seen (e.g. blanching that affects only the digit’s lateral or medial aspect rather than the more usual circumferential appearance).

A point of distinction is that the disease, initially distal in its development, often comes to affect those areas most closely in contact with the vibrating parts of the worker’s tools. However, this is not a sufficient and reliable enough basis to distinguish VWF from, say, primary RP. In practice there is no fool-proof way to make this determination. The diagnosis of VWF rests on a history of characteristic colour changes in the digits, provoked by cold in a worker with a history of substantial occupational exposure to vibration, and exclusion of causes other than vibration. But this process has limitations. It assumes, for example, that a person with another cause of RP cannot get VWF (which is doubtful). More significant, however, is the subjectivity of the approach: attacks are rarely witnessed by a clinician; workers may have trouble in describing their symptoms and how they have developed; some workers may have a vested interest in concealing or exaggerating their symptoms; idiopathic RP is quite common anyway; simple tests of cold challenge (e.g. immersing the hands in cold water) can be painful and unreliable.

Effort, therefore, has been expended in developing objective standardised methods of assessment [10]. Currently available methods for vascular disease include plethysmography, Doppler ultrasonography, direct capillaroscopy, skin temperature and skin re-warming rates after cold challenge and measurements of finger systolic blood pressure (FSBP) during cooling. The last of these has found the widest application. Taking a history of finger blanching at medical interview as the reference standard, a 'positive' vascular test during finger cooling to 10°C (FSBP $\geq$40% below that at 30°C) has been reported to have a sensitivity in the range of 74 to 99%, a specificity of 64 to 98%, a positive predictive value of 75 to 99%, and a negative predictive value of 94 to 97% for the detection of abnormal cold responsiveness in the digital arteries of vibration-exposed workers [11].

At present there are limited resources for standardised testing nationally and these are applied mostly in centres of excellence for purposes of research or to help adjudicate medico-legal disputes. However, some occupational health professionals use them to gauge severity and progression, and to supplement subjective impressions with objective measurements. Another approach has been to adopt simple clinic-based tests of dysfunction (especially to chart sensorineural effects) and colour charts (picture sets of affected and unaffected digits) to improve history-taking, Figure 2). The colour chart method offers considerable promise. Such charts are simple to use and understand independently of culture, quick to administer (only 2-3 minutes), cheap and capable of standardisation. They also perform well and have proved, in a longitudinal study of forestry and stone workers, to be a better predictor of digital arterial hyper-responsiveness to cold than did a medical history alone [12].

FIGURE 2 NEAR HERE, CAPTION:

Figure 2: Colour charts, showing a normal hand (top), Raynaud phenomenon (middle), and cyanosis and acrocyanosis (bottom).

[From http://www.vibrisks.soton.ac.uk; VIBRISKS - EC FP5 project no. QLK4-2002-02650]

Estimates of the prevalence of VWF depend on the method of ascertainment and the populations studied. However, in one British population survey of almost 20,000 working-aged adults it was estimated that there are more than 220,000 cases of VWF nationally with extensive blanching (affecting at least 15 phalanges) [13]. This figure is considerably higher than previously estimated by the HSE using a less representative sample, but not incompatible with the 100,000 medico-legal claims that have been processed among ex-miners from British Coal many of which were compensated within a programme of objective testing. High prevalences of VWF have been found in many occupational groups with high levels of exposure to HTV (Table 1) [14].

TABLE 1 NEAR HERE

The pathophysiological mechanisms underlying cold-induced Raynaud's phenomenon in vibration-exposed workers are complex. Some researchers have postulated that the response represents an exaggerated central sympathetic vasoconstrictor reflex, caused by prolonged exposure to vibration, whereas others have emphasized the role of vibration-induced local alterations in the digital vessels (e.g. thickening of the muscular wall, endothelial damage, functional receptor changes), [15]. Some investigators have implicated vasoactive substances, including endothelins, immunologic factors, and blood viscosity, in disease pathogenesis.

Sensorineural effects of hand-transmitted vibration

Users of powered vibratory tools often experience tingling in their digits, but symptoms are initially transient and disappear quickly after use. However, if exposures are high enough for long enough then they may develop at other times, to begin with in an intermittent way and thereafter in troublesome and prolonged spells that can affect sleep. Transient and then permanent numbness is another common pattern. In more advanced stages, clinical examination may reveal abnormalities of light touch, temperature, and pinprick, but before this the clinical approach lacks sensitivity and repeatability.

Electrophysiological tests indicate that a diffuse polyneuropathy of the digits and peripheral nerve entrapment can both arise. Objective methods of assessment include aesthesiometry (to measure two-point discrimination and depth perception), thermo-aesthesiometry and temperature probe tests (to detect thermal thresholds), vibrometry (which measures vibrotactile thresholds using a vibrating probe), and several standardised tests of dexterity [10]. Among simple office tests, the Semmes-Weinstein's monofilaments (which have hairs of constant length but varying diameter) provide a non-invasive and controlled reproducible force stimulus for evaluation of touch sensation at the palmar surface of the tip of the second and fifth fingers, and are used to assess the function of the median and ulnar nerves. Vibration-associated carpal tunnel syndrome is assessed in the usual fashion, by measurements of motor and sensory nerve conduction velocities and latencies.

Affected individuals often complain of clumsiness and impairment of fine finger movements and grip, and this may be a consequence of neuropathic and neuromuscular injury. Sensorineural and neuromuscular effects frequently coexist with vascular disease, although they can arise independently and progress at different rates.

The British National Survey of Vibration estimated that there are perhaps 300,000 cases of sensorineural HAVS in the UK [16], making this one of the commoner occupational hazards at a population level. The impact of disease varies across a spectrum from minor and temporary discomfort to permanent incapacity.

Clinical grading and prognosis of HAVS

Vascular and neurological components of HAVS are graded separately according to two scales with international currency, developed by a workshop in Stockholm [17,18] and advocated in the UK by the HSE and the Faculty of Occupational Medicine, London (Table 2) [19]. These scales are used for surveillance, research and medico-legal purposes, but especially to frame recommendations on career counselling and preventing disease progression.

TABLE 2 NEAR HERE

There is no established really satisfactory treatment for HAVS, although conservative measures (e.g. wearing of woollen gloves and warm clothing, avoidance of wet or draughty conditions), may alleviate some symptoms. In lieu of effective therapy, screening, early detection, and early withdrawal from exposure remain the most important practical interventions that can be offered. Additionally, by way of prevention, in many cases, industry has been able to substitute tools that interrupt the pathway of transmission of vibration (by isolation or vibration-damping), to improve the maintenance of tools, to redesign them to avoid the need to grip high vibration parts, and to restructure work or working patterns to reduce workers' total exposures. Advice on these issues is available in the UK from the HSE [20].

Until the 1960s, VWF was thought irreversible, but studies have now shown that vascular symptoms can improve on withdrawal from exposure, albeit slowly over many years. Workers with advanced disease are less likely to recover. By contrast, the neurological effects of HAVS do not improve with time, and loss of hand function is the main clinical endpoint to avoid.

Given the lack of treatment options, the poor prognosis in particular of neurological injury, and the benefits of withdrawal from exposure, the HSE and the UK's Faculty of Occupational Medicine have published several recommendations on counselling affected workers [19,20]. A balance may need to be struck between protecting a worker's health and limiting their earnings opportunities. In some workers disability will appear slight and the rate of disease progression will be slow. Thus, advice tends to be titrated to the severity of disease and rate of progression, and should consider also the individual's wishes, their length of remaining service, the scope to further limit exposures within the same job, the scope for redeployment to another job, and the employer's attitude to medico-legal risk. For those with mild stage 1 disease, work with vibratory tools is not ruled out, provided that health checks and counselling are on-going and proper consideration is given to control of vibration at source; at the other extreme, those with advanced stage 3 disease should discontinue exposure altogether. For those in-between, the best course of action is more finely balanced. At present, most experts feel that the dividing line between an acceptable and an unacceptable outcome lies somewhere along the continuum between early and late stage 2 disease, the challenge being not to allow progression from the former to the latter.

Young workers are another particular case. They should be encouraged to explore options for alternative employment, even if mildly affected, since otherwise they may have many years of exposure ahead, and since they have time in which to develop a different career pathway.

Vibration-associated carpal tunnel syndrome
Good evidence exists that HTV can increase the risk of carpal tunnel syndrome (CTS) (Table 3), although rather less information exists on the risk-conferring levels of exposure. In some studies about a fifth to a quarter of HTV-exposed workers who complained of persistent sensorineural symptoms in the digits and hands were found to have CTS [21,22].

TABLE 3 NEAR HERE

The clinical features of CTS, when vibration-associated, are not distinguishable from CTS from other causes. Diagnosis and clinical treatment are for CTS more generally, except in two respects: (i) it needs to be borne in mind that digital neuropathy affecting the medial digits may be confused with CTS (and they can both occur in the same individual); (ii) management should include consideration of withdrawal from the occupational exposure, although advice on this is less well developed than for HAVS. The prognosis following surgical release may also be less favourable relative to entrapment neuropathy from other causes [23,24], although evidence on this is somewhat limited.

The increased risk of CTS is thought to arise from a combination of factors. Vibration, ergonomic effects of forceful gripping, awkward postures, and repetitive movements, and increased static and dynamic muscle loading, can induce structural changes in the nerves just proximal to the wrist (e.g. disruption of myelin sheaths, interstitial and perineural fibrosis), and pressure effects can arise from perineural oedema and synovitis of finger flexor tendons at the carpal tunnel [25]. Whatever the mechanisms, markedly higher rates of CTS have been reported in response to the combination of HTV and physical overloading of the upper limb in some settings [26].

Vibration-associated Dupuytren's contracture

The relation between HTV and Dupuytren's contracture has been disputed [27], but evidence on risks has grown and recently a meta-analysis of studies published between 1951 and 2007 estimated a relative risk (RR) from vibration at work of 2.88 (95%CI 1.36 to 6.07), or 2.14 (95%CI 1.59 to 2.88) when analysis was confined to reports of higher quality [28]. RRs of 2 to 3, and a dose-response relationship, were reported in a cross-sectional study of Italian quarry drillers and stone carvers with many years of exposure to relatively high levels of HTV [22]; by about 5 to 11 fold in manual workers employed by private companies in France [29]; by almost two-fold in male users of powered tools from a different French survey who had been exposed for a median of 10 years [30]; by 2 to 3-fold in Italian men from a wide range of occupations, when exposed for >10 years [31]; by almost 2-fold in men claiming VWF, in comparison with men from a general surgical ward in an English hospital [32]; and by almost 3-fold among men from the National Vibration Survey with current weekly exposure above the HSE's action level [33]. In contrast, a British study involving over 97,000 miners and ex-miners seeking compensation for HAVS, found no relationship with years of exposure to HTV when analysed as a continuous variable [34], although the degree of exposure contrast within this medico-legal group was unclear.

If the association is accepted, it remains unclear whether its basis lies in vibration injury or more general physical trauma from manual activities in which vibratory tool users engage (elevated risks have also been found in other blue-collar jobs which do not entail exposure to HTV, but do involve heavy labour [28,29]). The distinction matters in terms of prevention, although the management of Dupuytren's contracture and the prognosis of the condition are unlikely to differ importantly by cause and from that for the disease in general.

Osteo-articular effects of vibration

In a few countries, such as France, Germany, and Italy, bone and joint diseases are considered to be occupationally-related to use of hand-held vibrating tools and state funding exists to compensate affected workers. In other countries, including the UK, the association is not yet accepted for compensation despite a listing for *Osteoarticular diseases of the hands and wrists caused by mechanical vibration* in the European Schedule of Occupational Diseases (2003). A well-known review has reported excesses of hand and carpal bone vacuoles and cysts, Kienböck's disease, navicular pseudoarthrosis, olecranon spurs, and osteoarthrosis of the wrist and elbow joints in exposed workers relative to controls [35]; but other researchers consider that such findings are incidental, non-specific, or related to ageing or the manual aspects of work, rather than vibration per se, so the matter is contended. Work with percussive tools (in coal mining, road construction, and foundries) is said to be more injurious, entailing as it does exposures to higher magnitudes of acceleration and lower frequencies (< 50 Hz) of vibration coupled with adverse ergonomic conditions (awkward posture of the hands and arms, high grip and push forces) that could potentially contribute to bone and joint damage.

Health surveillance in workers exposed to HTV

As mentioned above, a programme of health surveillance is mandated for those who remain regularly exposed to HTV above the EAV of 2.5 m/s^2 r.m.s. [4], the main aim being to aid early detection of HAVS and counselling/job modification (secondary prevention), but additionally also to provide a check on workplace controls (to aid primary prevention).

The main elements of a surveillance programme for HAVS comprise a system of symptom reporting, periodic health inquiry and examination, formal clinical assessment of suspected cases, the redeployment of affected individuals, and statutory record keeping. The HSE advocates a tiered approach, with basic lay screening (usually by questionnaire) and referral of symptomatic individuals to medical practitioner or occupational health service [36]; the Faculty of Occupational Medicine in the UK offers a syllabus against which doctors and nurses are trained and certificated to discharge this function and training is normally expected by the regulator.

Individuals with primary Raynaud's disease and CTS, if identified at the pre-employment stage, may be debarred from employment in exposed jobs, although the evidence base supporting this practice is limited.

Other points

In the UK, workers with HAVS may be entitled to a no-fault state-funded compensation benefit called Industrial Injuries Disablement Benefit under certain circumstances. This does not require a worker to surrender their job to be paid, but is conditional on their exposure and the severity of their symptoms (further details can be found at https://www.gov.uk/industrial-injuries-disablement-benefit/eligibility). Separately, employers have a statutory duty to notify cases to the enforcing authority (HSE or local authority) under the so-called "RIDDOR" Regulations.

Rheumatic effects of whole-body vibration

As with HTV, some reported health effects of WBV are well recognized, but others are more conjectural. Substantial evidence has accrued in relation to musculoskeletal symptoms in the lower back, radiating leg pain, sciatica and, to a lesser extent, early degeneration of the lumbar spine and herniated lumbar disc . Less often and less convincingly, associations have been described with neck-shoulder symptoms, autonomic disturbance, disorders of balance and digestion, and effects on menstruation and labour [37,38]). In this account we concentrate on back pain and sciatica.

Low back pain and sciatica

Low-back pain (LBP) is of course a symptom rather than a diagnosis, and is common across all occupations. It is also a fluctuating, rather than a fixed condition with a natural proclivity to recover, relapse, and recur over time. Non-occupational risk factors may contribute substantially to symptom reporting, as may physical activities in the workplace and bad ergonomics. Having said this, the symptom is reported more frequently by professional drivers than in suitable comparison groups, including other sedentary occupations. Similarly, radiating leg pain is more common, and a few studies have even confirmed symptomatic prolapsed inter-vertebral disc at surgery [39,40].

Occupations in which higher risks of spinal complaints have been reported are many, and include: drivers of cars, buses and coaches, goods vehicles, tractors, helicopters, fork-lift trucks, cranes, wheel loaders, freight containers, locomotives, and sundry off-road vehicles such as earth movers and excavators [37,41,42].

In summarizing the body of epidemiological evidence in the late 1990s, the US National Institute for Occupational Safety and Health described evidence on the association with LBP as 'strong' (15 of 19 studies positive) [43], while other systematic reviews have reached similar conclusions [42]. Although much of the research has been cross-sectional in design, with well-known potential limitations (such as the 'healthy worker' selection effect and errors in the assessment of prior exposures), findings have been generally consistent. Moreover, several investigators have reported a dose-response relationship with WBV [41,42] and studies of related outcomes, such as disability pensioning and prolonged sick leave attributed to LBP, have mirrored those on pain in their relations to driving activity [44,45].

A recently updated meta-analysis by one of the authors (MB) incorporated 13 cross-sectional studies published between 1987 and 2006. A summary prevalence odds ratio (POR) was found of 1.98 (95% CI 1.56-2.50) for LBP in the past 12 months in 24 groups of professional drivers exposed to WBV when compared with unexposed controls comprising administrative officers, manual workers and maintenance operators (Figure 3) [41,46-57]. In the same analysis, a summary POR of 1.67 (95% CI 1.25-2.23) was found for 12-month prevalence of sciatic pain in the professional drivers. Earlier meta-analyses have similarly found an excess risk of LBP and sciatic pain in professional drivers [42,58,59,60].

FIGURE 3 NEAR HERE, CAPTION:

Figure 3: Results of the meta-analysis of cross-sectional epidemiological studies of 12-month low-back pain in 24 groups of professional drivers exposed to WBV from industrial machines or motor vehicles compared with unexposed control groups. Point estimates of the prevalence odds ratio (POR) and 95% confidence intervals (95% CI) are given for each study after adjustment for age.

Driving involves exposure not only to WBV but also to several ergonomic risk factors which can affect the spine, such as prolonged sitting in a constrained posture (which raises intradiscal pressure) and frequent twisting with a non-neutral trunk position (e.g. looking behind when manoeuvring a fork-lift truck). Moreover, some driving occupations include heavy lifting and manual handling activities within the job description (e.g. drivers of delivery trucks). Therefore, the etiopathogenesis of low back complaints in drivers has been debated.

In a growing number of studies, however, special effort has been made to control for confounding by known causes of LBP. For example, in a cross-sectional study of 1,155 tractor drivers and 220 unexposed controls, cumulative exposure to WBV and postural load were found to be independently associated with 'chronic' LBP (daily experience of LBP or several episodes of LBP lasting more than 30 days in the previous 12 months), such that tractor drivers with high exposure to both factors had a more than threefold elevated risk of chronic LBP relative to subjects scoring low on these counts [54]. Analysis took account of many risk factors for LBP such as age, smoking habit, body mass index, recreational activity, mental health status and previous injuries to the back.

More significantly, in a recent prospective study of 537 professional drivers [61], the occurrence of low back symptoms could be related to internal forces caused by WBV and acting upon the spine. These were estimated from models that incorporated the static gravitational force acting on vertebral endplates, the vibration-related peaks of dynamic compression on vertebrae, individual characteristics of the drivers (e.g. age, body mass, body mass index, size of bony vertebral endplates), and their duration of exposure and typical working postures [62,63]. Two metrics for assessment of risk were derived, called the daily compressive dose S_{ed} (MPa) and the risk factor R (non-dimensional units), [ISO/CD 2631-5 2014]. After adjustment for potential confounders, S_{ed} and risk factor R were significant predictors of the occurrence of LBP, sciatic pain, and treated LBP over follow-up (Table 4). In the same study, herniated lumbar intervertebral disc (diagnosed by CAT or MRI), traumatic injuries to the lower back, and high physical workload other than when driving were also associated with low back symptoms, confirming the multifactorial nature of low-back disorders among professional drivers.

TABLE 4 NEAR HERE

Pathophysiology of WBV-related lumbar disorders

The field observations on LBP in drivers are lent support by various biodynamic and physiological laboratory experiments identifying a potential for WBV to cause mechanical overloading of the spine and muscle fatigue [64]. When WBV is measured on the seats of vehicles, it tends to show peaks of acceleration at frequencies of 2 to 6 Hz, a range which corresponds to the resonance frequency of the lumbar tract of the spine in a seated subject exposed to vertical vibration [64,65]. It is though that such resonance can cause large relative displacements between the lumbar vertebrae, with extra compressive load and shear stress on soft and bony tissues of the spine. In turn, as evidenced by cadaver experiments, mechanical damage and interference with tissue nutrition may lead to degeneration and microfractures of the vertebral endplates, increase of intradiscal pressure, and rupture of disc fibres [66,67], with resultant initiation and progression of intervertebral disc herniation [68,69]. Additionally, electromyographic studies have shown than WBV can induce fatigue in the paravertebral muscles of the lower back [65]. Thus, a degree of biological plausibility exists for a causal relationship between WBV and low back complaints.

Risk control

The dose-response relationship between WBV and LBP is less well established than that for HTV and VWF [59]. Nonetheless, current evidence on risk has prompted legally mandated EAVs and ELVs, as well as other requirements to mitigate risk.

In practice, injury potential is likely to be influenced on the one hand by the magnitude, duration, and pattern of WBV (which in turn depends on vehicle design, the cabin seating, the suspension, the road conditions, road speed and driving behavior) and on the other by personal factors (e.g. individual susceptibility, body posture, health status)., Article 4 of Directive 2002/44/EC requires employers within the EU to assess risks from these various perspectives and to eliminate or reduce them as far as reasonably practicable when the EAV is breached.

Approaches to control encompass administrative measures (e.g. adequate information and advice), organisational measures (e.g. training in safe working practices, work schedules with rest periods), and technical interventions (e.g. choosing vehicles with lower WBV and better ergonomic designs). In the UK, where Directive 2002/44/EC is implemented as the Control of Vibration at Work Regulations 2005 [4], the HSE advocates that drivers should adjust their seating, avoid rough uneven surfaces, moderate their speed to suit road conditions, take sufficient rest breaks and comply with training on "safer systems of work", while employers should maintain vehicle suspensions and site roadways, and take care in choice of seating for company vehicles. At least some of this advice can be offered by clinicians to workers in driving occupations who suffer recurrent back problems.

Health surveillance in workers exposed to WBV

The EU Directive also requires health surveillance if drivers are regularly exposed above the EAV for WBV (0.5 m/s^2 r.m.s.). The aims of surveillance are reportedly (i) to inform workers on the potential risks associated with exposure, (ii) to assess their health status and fitness for work, (iii) to diagnose WBV-induced disorders at an early stage, (iv) to give preventive advice to employers and employees, and (v) to assess the long-term effectiveness of preventive measures. Pre-employment medical screening and subsequent periodic clinical examinations at regular intervals are advocated.

In practice, however, this approach is not without problems and limitations. For example, 1) LBP is so common in the general population as to be expected in many workers, drivers and non-drivers alike; 2) no clinical presentation is specific of back problems attributable to WBV as compared with other risk factors; 3) since LBP is intermittent, recurring and relapsing, the value of regularly scheduled assessments can be questioned (perhaps its value lies most in establishing the frequency and severity of symptom episodes); 4) the added value of physician's examination over screening questionnaires is also questionable (the HSE recommends a simple system of health monitoring for workers at higher risk). Certainly, although prescribed in law, the value of health surveillance for WBV is less well established than that for HTV.

Investigation, treatment and career advice

LBP and radiating leg pain in a driver are essentially investigated and managed as for these symptoms more generally – symptomatically, to achieve pain relief, early mobilisation and restored function, with due caution regarding potential 'red flags' in the clinical presentation. Use of analgesics, anti-inflammatory drugs, muscle relaxants, rehabilitation programmes, some forms of "back school", progressive active back exercises, cognitive behavioural therapy, and organisational interventions may all be considered to have a role in some individuals and their care.

An added consideration, however, is whether to advise the worker to withdraw from exposure to WBV, either temporarily, during a symptomatic episode, or in the longer term. Again the preferred advice is less well developed than for the worker with HAVS who is heavily exposed to HTV. Decision making may be influenced by company medical policy or the legislation of a country: according to the EU Directive on mechanical vibration (article 8, paragraph 3c), if a worker is affected with a health disorder associated exposure to mechanical vibration "*the employer shall ….. take into account the advice of the occupational health care professional or other suitably qualified person or the competent authority in* *implementing any measures required to eliminate or reduce risk…., including the possibility of assigning the worker to alternative work where there is no risk of further exposure*”. However, withdrawal from driving duties can be double-edged. There is good evidence that the longer a worker is off work with LBP, the lower their chances of ever returning to work [70]; on the other hand, especially in the acute symptomatic stages, a worker with severe LBP may be better off not incurring shocks and jolting from driving an off-road vehicle; and if considerable discomfort becomes a daily accompaniment to professional driving, then the possibility of job redeployment may need to be considered in the longer term.

A final consideration is whether exposure levels can be reduced without a change of employment. Preventive measures that may assist this outcome (and which employers have an obligation to consider) are mentioned above.

Other points

In some countries (e.g. Belgium, France, Germany, and Italy), low back disorders arising in workers exposed to WBV to a qualifying extent (intensity and duration) are considered to be occupational caused and may be compensated as such by the state.

Practice points

- Many workers are regularly exposed to sources of hand-transmitted and whole-body vibration in their work
- Important adverse health effects of hand-transmitted vibration include secondary Raynaud's phenomenon, sensorineural digital neuropathy and carpal tunnel syndrome, as well as various muscular and articular effects; loss of hand function is the most important health end-point to prevent
- Professional drivers, exposed occupationally to whole-body vibration, suffer more low-back pain, radiating leg pain and sciatica than other workers
- The health effects of vibration are preventable or at least controllable, provided that intervention is early
- Workers with rheumatic effects of hand-transmitted vibration may need career counselling and even a change of employment
- In the UK, workers with hand-arm vibration may be able to claim a no-fault state-funded benefit (without needing to surrender their job)

Research agenda

- Although some positive progress has been made in recent years, there is an ever-present need to improve the vibration characteristics of hand-hold power tools, machines and vehicles encountered at work
- A better understanding is required of the exposure-response relationships between vibration and its various health effects
- There have been only a few studies of interventions to reduce the risk of back pain from whole-body vibration, and overall, rather few longitudinal investigations of risk and trials. Too much of the evidence at present comes from cross-sectional observational studies (of which there are many)
- Health surveillance is mandatory for workers with sufficient occupational exposure to vibration, but published evidence on its benefits (especially in relation to drivers with back pain) and cost-effectiveness is very limited at present

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Table 1: Prevalence of white fingers in men exposed and not exposed occupationally to hand-transmitted vibration. Prevalence ratios (PR) and 95% confidence intervals (95% CI) were adjusted for age, smoking, and drinking habits, assuming the controls as the reference category (adapted from ref. 14).

Groups	N	White finger (%)	PR (95% CI)
Controls	455	1.1	1.0
Grinders	100	9.0	8.1 (2.7-24.4)
Shipyard workers	132	12.1	10.3 (3.8-28.4)
Caulkers	65	23.1	18.6 (6.7-51.9)
Mechanics	140	15.0	13.0 (4.9-34.7)
Foundry workers	31	51.6	39.8 (14.3-111)
Construction workers	148	7.4	6.1 (2.1-17.8)
Quarry drillers	41	36.6	31.0 (11.2-85.9)
Forestry workers	165	23.0	20.0 (7.8-51.2)

Table 2:(a) The Stockholm workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome (Gemne et al 1987 [REF])

Stage*	Grade	Description
0		No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers.
3	Severe	Frequent attacks affecting all phalanges of most fingers
4	Very severe	As in stage 3, with trophic skin changes in the finger tips

* The staging is made separately for each hand. In the evaluation of the subject, the grade of the disorder is indicated by the stages of both hands and the number of affected fingers on each hand - for example: '2L(2)/1R(1)', '-/3R(4)', etc.

(b) Proposed sensorineural stages of the hand-arm vibration syndrome (Brammer et al 1987 [REF])

Stage*	Symptoms
0SN	Exposed to vibration but no symptoms
1SN	Intermittent numbness, with or without tingling
2SN	Intermittent or persistent numbness, reduced sensory perception
3SN	Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity

* The sensorineural stage is established separately for each hand

Table 3: Prevalence of symptoms and signs of carpal tunnel syndrome (CTS) in vibration-exposed stone workers and unexposed male controls. Prevalence odds ratios (POR) and 95% confidence intervals (95% CI) are adjusted for age, smoking and drinking habits, and previous injuries to the upper limb, assuming the controls as the reference category (adapted from ref. 22).

CTS		Stone workers			
	Controls (n=258)	Quarry drillers (n=145)	Stone carvers (n=188)	Stone cutters (n=237)	All stone workers (n=570)
Prevalence (%)	2.3	14.5	7.4	6.3	8.8
POR (95% CI)	1.0	5.6 (2.1-14.6)	3.2 (1.2-8.8)	2.3 (0.8-6.1)	3.4 (1.4-8.3)

Table 4: Relationships of 7-day low back outcomes to daily compressive dose S_{ed} and risk factor R in a three-year prospective cohort study of 537 professional drivers. The changes in odds ratio (OR*) and 95% confidence intervals (95% CI) for a change of 0.1 MPa in S_{ed} and 0.1 units in R factor are shown (adapted from ref. 61).

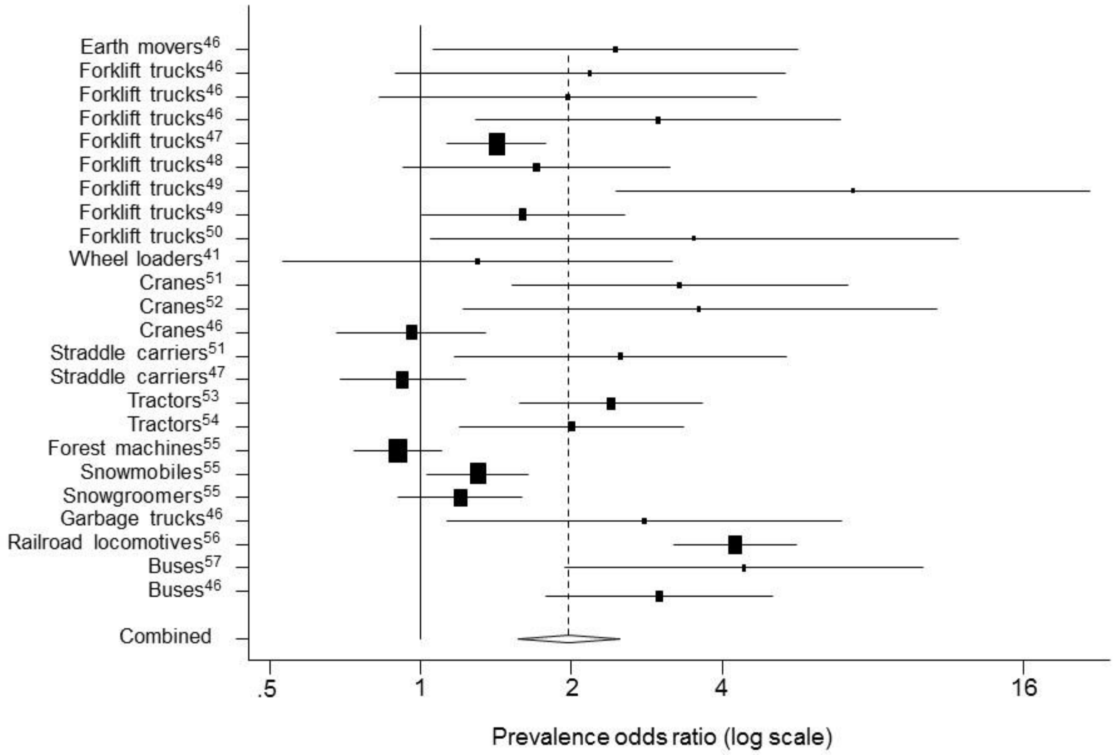
Predictors	LBP		Sciatic pain		Treated LBP	
	OR	95% CI	OR	95% CI	OR	95% CI
S_{ed} (MPa×10^{-1})	1.19	0.97-1.45	1.31	0.98-1.76	1.51	1.09-2.11
R factor (units×10^{-1})	1.26	1.10-1.45	1.36	1.12-1.66	1.44	1.16-1.78

*OR adjusted by age-at-entry, body mass index, years of full-time driving, physical work load, psychosocial work environment, herniated lumbar disc, lumbar trauma, and follow up time.

Low back pain (LBP): pain or discomfort in the low back area between the twelfth ribs and the gluteal folds, lasting one day or longer in the previous 7 days.
Sciatic pain: radiating pain in one or both legs (below the knee) in the previous 7 days.
Treated LBP: LBP treated with anti-inflammatory drugs or physical therapy in the previous 7 days.

Figure 1

Figure 2


Earth movers46
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Forklift trucks50
Wheel loaders41
Cranes51
Cranes52
Cranes46
Straddle carriers51
Straddle carriers47
Tractors53
Tractors54
Forest machines55
Snowmobiles55
Snowgroomers55
Garbage trucks46
Railroad locomotives56
Buses57
Buses46
Combined
.5
1
2
4
16
Prevalence odds ratio (log scale)

Figure 3