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Limitations of epidemiology when investigating occupations with a potential for significant vibration exposure and PD A11, Hand-arm vibration syndrome

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Limitations of epidemiology when investigating occupations with a potential for significant vibration exposure and PD A11, Hand-Arm Vibration Syndrome

Summary

Hand-Arm Vibration Syndrome (HAVS) is a disorder consisting of vascular and sensorineural components resulting from of exposure to Hand Transmitted Vibration (HTV). The main feature of the vascular component of HAVS, previously referred to as vibration white finger (VWF), is cold-induced sharply demarcated, episodic finger blanching (fb). The sensorineural component consists of symptoms of numbness, tingling, loss of dexterity and reduced sensory perception of the fingers. The majority of cases present with both components but 'vascular only' and 'sensory only' HAVS is recognised.

The Social Security (Industrial Injuries) (Prescribed Diseases) Regulations 1985 set out certain criteria by which claims for Industrial Injuries Disablement Benefit (IIDB) must be tested. These include, among other things;

- whether the claimant has the prescribed disease defined in Schedule 1 of the Regulations (sometimes called the 'diagnosis question');
- whether claimants have had the associated occupational exposure set out in the schedule (the 'occupational question') and;
- whether or not the development of the disease should be presumed to be "due to the nature of employment".

The attribution to occupation often depends on research evidence that work in the prescribed job or with the prescribed occupational exposures causes the disease on the balance of probabilities, effectively is it 'more likely than not' and referred to as the 'causation question'. In epidemiological terms this requires a more than doubling of relative risk.

Although the Industrial Injuries Advisory Council may find evidence of HAVS case reports in the literature associated with some occupations, there is often a paucity of good quality epidemiological studies providing robust and direct evidence of a doubling of relative risk. In these circumstances the Council is unable to recommend inclusion of an occupation or exposure from a vibrating tool to the list of Prescribed Diseases in Schedule 1.

The Command paper CP 868, '*Hand arm vibration syndrome and assessment of vibration exposure'* reviewed two alternative approaches to assessing vibration exposure and exposure equivalence to those vibrating tools on the current list that have passed the 'causation question'. The recommendation was to extend the list of tools in Schedule 1 of PDA11 despite the limited direct evidence of a doubling of relative risk in some tools.

This position paper reviews the epidemiology on HAVS in more detail and outlines its limitations with regard to some occupational groups and vibrating tools.

This report contains some technical terms, the meanings of which are explained in a concluding glossary.

The Role of the Industrial Injuries Advisory Council (IIAC) and prescription

1. IIAC is an independent statutory body established in 1946 to advise the Secretary of State for Social Security on matters relating to the IIDB scheme. Much of the Council's time is spent considering whether the list of prescribed diseases for which benefit may be paid should be expanded or amended. The Council searches for a practical way to demonstrate in the individual case that the disease can be attributed to occupational exposure with reasonable certainty. For this purpose, 'reasonable certainty' is interpreted as being based on the balance of probabilities.

2. Some occupational diseases are relatively simple to verify, as the link with occupation is clear-cut. Some only occur due to particular work, or are almost always associated with work, or have specific medical tests that prove their link with work, or have a rapid link to an exposure, or other clinical features that make it easy to confirm the work connection. However, many other diseases are not uniquely occupational, and when caused by occupation, are indistinguishable from the same disease occurring in someone who has not been exposed to a hazard at work. In these circumstances, attribution to occupation depends on evidence that work in the prescribed job or with the prescribed occupational exposures causes the disease on the balance of probabilities. The Council thus looks for evidence that the risk of developing the disease associated with a particular occupational exposure or circumstance is more than doubled. (Previous reports of the Council explain why this threshold was chosen.)

3. This position paper outlines a brief history of the epidemiology leading to the recommendation for prescription in 1981, subsequent epidemiology and systematic reviews. It outlines the limitations encountered in the more recent epidemiology in some occupational sectors with regular exposure to vibration magnitudes known to have the potential to cause HAVS (the definition of vibration magnitude is covered in Appendix 1).

Brief epidemiological history of HAVS

4. Pneumatic vibrating tools were introduced into French Mines in 1839 but it was not until the early part of the twentieth century that reports of 'dead fingers' started to appear in the literature (Loriga 1911, Hamilton 1918). Other vibrating tools were then used increasingly in a variety of industries such as foundries, quarrying, ship building and aircraft manufacturing. Chain saws were introduced to forestry in the mid-twentieth century with reports of VWF appearing in the literature a decade later.

5. Many of these early epidemiological studies concentrated on the prevalence or incidence of VWF and often failed to study a control population. This type of cross-sectional study has limitations including population turnover rate and healthy worker effect having an influence on reported symptom prevalences (Wasserman 1991) i.e., those unaffected remaining and those leaving because of symptoms having an impact on their ability to work. Vibration magnitudes of similar tools can vary between studies because of differences in workplace tool maintenance programs or workpiece hardness making comparisons problematic. In addition, variation in the diagnostic criteria used also made these early studies prone to ascertainment bias.

6. Following the work by Agate (Agate, 1949) it has generally been accepted that vibration is the cause of VWF, and cold exposure is merely a trigger to attacks of

finger blanching. However, one study found that a modest difference in the mean environmental temperature was associated with a significant difference in subjective experience of finger blanching in the vibration exposed (Burström, 2010). Laboratory studies have since demonstrated that short-term exposure to HTV can reduce skin temperature (Pettersson, 2018). A more recent prevalence study proposed that exposure to cold in the workplace may be a contributory factor in the overall development of HAVS (Gerhardsson, 2021) and may possibly act synergistically with vibration (Cooke, 2022). Therefore, whilst cold exposure may increase the reported finger blanching in prevalence studies a contributory role in causation cannot be ruled out.

7. The latent interval or time between first exposure to vibrating tools and the onset of finger blanching (fb) was initially thought by epidemiologists to be a '*much better indicator of hazard*' and correlate of vibration exposure in a group (Pelmear, 1998). However, there is a broad range of latent intervals reported within and between studies for the same tasks. This may result from a number of factors including variety of tool handling techniques or individual susceptibility to HTV. Also, the mean latency is not necessarily the same as mean duration of exposure before symptoms develop again because of study group turnover (Griffin 1990).

8. Against this background and informed by two reports (Stewart 1970, Taylor 1975-pre-publication) the Council reported on the 'Vibration Syndrome' in 1970 (Cmnd 4430) and again in 1975 (Cmnd 5965) but failed to add to the prescribed list of physical agents or 'A' diseases. One of their concerns related to distinguishing VWF from the background rate of constitutional white finger or Raynaud's Disease. The concept of vibration dose arose then as a possible assistance to diagnosis;
'…insistence on a minimum period of exposure to vibration, or on exposure to a given level of vibration over specified period of time i.e. to a minimum overall 'dose' of exposure, would go some way to solving the problem of diagnosis.' Cmnd 4430 1970.

9. A rationale for not prescribing was covered in an article published in the BMJ (McCallum 1971) highlighting some of the problems influencing exposure comparisons:'….*many other factors such as whether the tool is held in the hand and applied to the job or the job held in the hand and applied to the tool, personal susceptibility and skill, and the hardness of the metal being worked (Reynard,1954) complicate the problem.'*

10. The combined epidemiological evidence, particularly the publication of *'Vibration White Finger in Industry'* (Taylor, 1975), led the Council to recommend prescription for 'Vibration White Finger' in 1981 (Cm 8350). The current list of tools and occupations in Schedule 1 of PD A11 has essentially remained unchanged since. Although the 'research literature was studied' and advice was sought from the Health and Safety Executive (HSE) the actual epidemiological evidence forming the basis for the list was not reported in Cm 8350.

11. Despite many studies not reporting a control population, the background prevalence of Raynaud's phenomenon is known to range from 5-10% in men and 10-20% in women. It generally commences at a young age and is associated with a family history and smoking (Garner 2015). Using stricter criteria i.e., a description of clearly demarcated finger blanching and carefully excluding underlying conditions, the lifetime prevalence of Raynaud's phenomenon approximates to 5% (Palmer, 2000,

Garner 2015). Prevalence studies of vibration white finger (VWF) in excess of 10% would therefore represent a doubling of the background risk.

12. As stated above the early reports in vibration exposed workers were mainly prevalence studies; summary tables of prevalences were later collated by Griffin in a 'Handbook of Human Vibration' (Griffin 1990). The reported prevalences for VWF in categories of tools encompassing percussive metal working tools, grinding and rotary tools, pneumatic hammers and drills used in mining and chain saws ranged from approximately 20% to 100%. A non-exhaustive summary from referenced studies and adapted from Griffin's Handbook (Appendices 6-9) with the recorded latency is shown in Table 1. It is noteworthy to highlight the very high prevalence percentages which offset some of the concerns regarding the weakness of this type of study for assessing relative risk as outlined above and the range of latency periods encountered. The available data on shoe pounding machines were limited.

Table 1: Prevalence and latency of VWF (1930-1981)

Authors /year	**Vibrating tools or tasks**	**Population, n**	**Prevalence, %**	**Latent period, yrs**
Pneumatic tools				
Syring 1930	Pneumatic chisel	90 fettlers	61	2-10
McLaren 1937	(a) Pneumatic tools/riveters (b) iron/steel caulkers/fitters	(a) 20 (b) 19	100 58	(a) <2
Hunter 1945	(a) Caulkers (b) Fettlers (c) Riveters	(a) 36 (b) 108 (c) 78	(a) 75 (b) 71 (c) 62	(a) 2-5 (b) 2-5 (c) 2-5
Marshall 1954	Pneumatic hammers	31	94	0.25-2
Grinding and rotary tools				
Agate 1949	Flex shaft grinder/polisher	278	66	2
Dart 1946	High speed rotary burring	112	67 (pain)	<2.5
Biden-Steele 1947	Electrically driven tools	282 300	67 40	0.5-2
Taylor 1975	Hand-held grinders	245	22	18

Taylor 1975	Pedestal grinders	306	52	2.12
Percussive hammers and drills-mining				
Hamilton 1918	Pneumatic hammer	36 stonecutters	89.5	1.2-1.5
Ashe 1964	Jag-leg drill	42	100	1-9
Miura 1966	Jag leg hammer	70	37	0.5-11
Chain Saws				
Grounds 1964	Chain saws	22	91	1-6
Hellstrom 1970	Chain saws	264	54	8
Taylor 1971	Chain saws	142	44	1-8
Pykko. 1974	Chain saws	118	40	4
Shoe pounding				
Ejrup 1955	Shoe pounding-up	15	-	-

13. In addition, it should be noted that the prevalence data on finger blanching ranging between 30-70% from studies of high vibration magnitudes between 1946 and 1977 was used to construct the ISO 5349-1 dose-response model (Brammer 1986). The latter model was reviewed in CP 868.

14. An extended list of vibrating tools was recommended by the Council in 1995 (Cm 2844), again adapted from Griffin's 'Handbook of Human Vibration' (table 14.9) and using the same main categorisations (Griffin 1980, 1990). This list was not adopted however. A further review by the Council in 2004 found that in *'…no instance did there appear to be a sufficient weight of epidemiological evidence to modify the terms of occupational coverage'* (Cm 6098, 2004).

15. Emerging evidence in the 1980s regarding the sensory symptoms indicated the presence a separate but concurrent component to vibration disorders which led to the now internationally recognised terminology of hand arm vibration syndrome, HAVS.

16. A recent systematic review and meta-analysis by Nilsson et al of studies between 1945 and 2016 attempted to update the risk prediction model for vascular, sensory and entrapment neuropathy (carpal tunnel syndrome, CTS) in vibration exposed workers (Nilsson 2017). Whilst accepting limitations of the various studies, the estimated odds ratios where there was low risk of bias ('higher quality'), were 6.9 for Raynaud's phenomenon (95% CI 4.2- 11.3),7.4 (95% CI 4.3-14.2) for neurosensory symptoms and 2.9 for CTS (95% CI 1.7- 5). The study showed a 10% prevalence of Raynaud's phenomenon after 6 years exposure to a daily vibration magnitude, A(8) of 10 ms^{-2} and 2 years for neurosensory symptoms suggesting that for sensory symptoms the latency was three times shorter than for Raynaud's phenomenon (For definition of A(8) see Appendix 1).

17. Table 2 gives a summary of informative epidemiology on vibrating tools, prevalences of VWF and latent intervals published since prescription for 'Vibration White Finger ' was introduced in 1985 (following Cm 8350, 1981) suggesting more than a doubling of relative risk. This table was compiled following a literature search to reflect some of the reported prevalence rates but is not intended to be exhaustive given the extensive literature on this topic. Papers increasingly reported HAVS rather than just VWF separating out sensory symptoms (including carpal tunnel syndrome) so percentage prevalence of sensory symptoms are also reported here.

Table 2: Prevalence and latency of VWF plus sensory symptoms (1985-2016)

Authors /year	**Vibrating tools or tasks**	**Population, n**	**Prevalence, % VWF**	**Latent period, yrs**	**Prevalence % Sensory symptoms**
Bovenzi, 1985	Chipping hammers and grinders	67 46 (controls)	20.9 0	9.2	65.6
Brubaker, 1987	Chain saws (including some anti-vibration)	71 (longitudinal study)	50.7 (1979-80) 57.7 (1984-85)	4.2	67.6 56.3
Nilsson, 1989	Platers	89 61 (controls)	42	4 (10%centile)	
Letz, 1992	Shipyards; chipping hammers, grinders, burrs	103 115 53 controls)	70.9 (full time) 33 (part time) 5.7(non-exposed)	(8400 hrs)	83.5 50.4 17

Bovenzi, 1994	Stone workers;road breakers, angle grinders, percussive hammers	570 258	30 (stone workers) 4.3 (controls)	16.5 (Drillers) 12.7 -16.1 (Stone carvers)	40 16.3 (controls)
Virokannas, 1995	Railway maintenance tampers	252	14	-	39
Bovenzi, 1998	Multiple	822 445	17.2 (9 - 51.6) 1.1(referents)	-	-
Palmer, 1998	Compressor gun, rock drills, wacker plate	153	24	13.3	46
McGeoch, 2000	Welders, fitter, platers, dressers	180	33	19.1 (2-40)	62
Bylund, 2001	Various including dental drills	370 women	54	9.2	91
Kákosy, 2003	Chipping hammers, grinders	154	78.9	-	65.3
Barregard, 2003	Car mechanics; nut runners	806	14	15	25
Burström, 2006	Welding plating, grinding	87	39	11.6	47
Burström, 2010	Construction	19,251	13.4 8.4 (referents)	-	-
Sauni, 2008	Metalworkers	530 (133 respondents)	49	-	66
Nilsson, 2017	Meta-analysis	52 studies	22 (0-53)	-	43 (17-79)

Gerhardsson2020	Impact wrenches	30 men 8 women	30 50	10 5	70 88

Other occupations with potentially significant vibration exposure.

18. There are a number of hand-held vibrating tools used today that have rarely or never featured in any epidemiological studies. The weighted vibration magnitudes of these tools may be equivalent to those tools where strong epidemiological evidence exists. The limited evidence for some of these occupations has been previously reviewed by the Council (e.g., Information note 'Prescribing for Hand arm Vibration Syndrome and risk from motorcycle handlebars' 2017). Whilst these exposures may be of equivalent weighted vibration magnitudes, the intermittency or duration of use may not be sufficient to lead to cases of HAVS.

19. Palmer et al, following a large postal survey in 2001 (12,204 men aged 16-64yrs and 906 from the armed forces), concluded that *'little attention has been paid to the risks of vibration injury in construction workers, woodworkers, motor mechanics, and laborers, or to the risks from mowers, jig saws and several other common vibratory tools.'*

20. Case studies have been reported for several occupations e.g., gardeners, dentists and orthopaedic surgeons, some with reported measurement data but with limited associated epidemiology. Appendix 1 has a link to vibration magnitudes reported by the HSE for the purpose of information for employers to carry out risk assessments. Some commonly used tools for comparison with those reported in tables 1 and 2 and paragraphs 26-43 are taken from the HSE seventy fifth percentile vibration magnitudes:

    Road breakers 14 ms^{-2}
    Pneumatic hammers 25 ms^{-2}
    Chipping hammers on welds 31 ms^{-2}
    Impact wrenches 5-10 ms^{-2}
    Angle grinders 4-9 ms^{-2}
    Rock drills in mining 26 ms^{-2}
    Chipping hammers in mining 20 ms^{-2}
    Chains saws 7 ms^{-2}

Gardeners

21. The Health and Safety Executive reviewed the evidence and accepted that there exists a risk from hand transmitted vibration in Amenity Horticulture such as Local Authority or Landscape gardeners HSL 2011 and HSE INDG296 480: https://www.hse.gov.uk/pubns/indg480.htm In guidance to employers the HSE referred to 'initial recommended values' of vibration magnitudes estimates for assessing risks from horticultural tools:

    Pedestrian-controlled mower 6 ms^{-2}
    Ride-on mower 5 ms^{-2}
    Hedge trimmer 7 ms^{-2}

Brush cutter 5 ms^{-2}
Strimmer 7 ms^{-2}
Chainsaw 7 ms^{-2}

For example vibration magnitudes of 5 ms^{-2} and 7 ms^{-2} are likely to be at or above the HSE Exposure Action Value (EAV) after one and a half hours and one hour and likely to be above Exposure Limit Values (ELV) after three to six hours use respectively.*

22. Bernardi et al (2018) studied six brush cutters and showed an average ahv (acceleration hand vibration) of 4.36 ms^{-2} for mowing heads and 10.56 ms^{-2} for a brush knife.

23. Gardening was selected as one of four industries to administer a self-assessment Disability Arm Shoulder and Hand (DASH) questionnaire (HSL RR667, 2008). The response rate was low (n= 243, 14%) so the findings may be an over-estimate but the proportion reporting white finger on cold exposure was 30.4 % in gardeners (n=35) compared with 9.1% for manufacture of basic metals (n=11), 16% for construction (n=106) and 22% for motor vehicle repair (n=91).

24. A questionnaire and observational study of 204 workers using hand-held grass cutters concluded that there was under reporting of HAVS in the agricultural sector having found a prevalence of vascular disorder of 84.3% in the left hand and 79.9% in the right hand and similar sensorineural disorders in 82.8% and 79.4% respectively (Azmir, 2015). A further cross-sectional study of 168 workers using grass cutters found prevalence ratios of vascular and sensory symptoms between low and high exposures of 3.63 (95% CI 1.41-9.39) and 4.24 (95% CI 2.18-8.27) respectively (Azmir, 2016).

Dentists and dental hygienists

25. Vibrating tools used by dentists and hygienists are of higher frequency (potentially >1000 Hz). The frequency thought to be the most damaging to the hand arm system is disputed, but increasingly thought to include higher frequency ranges (Gerhardsson 2020). It is possible that the risk from these higher frequency rotary tools is underestimated due to the weighting system used when measuring vibration magnitudes in accordance with ISO 5349-1. In addition, it is possible that prolonged pinch grip or ‘tripod’ grip (thumb, index and middle finger), similar to holding a pen, may increase transmission of vibration. However, in a small study of HTV of dental hand-pieces, Rytkönen found that neither the water/air injection or grip force by fingers had any significant effect on the vibration transmission (Rytkönen, 2001).

26. A study of nine dentists and controls (Lundstom, 1985) demonstrated a reduction in vibration perception thresholds for the dentists compared to controls suggesting a possible negative influence on human tissues.

*The Control of Vibration at Work Regulations 2005 has an Exposure Action Value EAV A(8) of 2.5 ms^{-2} and an Exposure Limit Value ELV of 5 $ms^{-2.}$ (See Appendix 1)

27. An early study by Biden-Steele on factory workers using electrically driven cutting tools similar to dental-type drills found 67% and 40% prevalence of VWF (n = 282

and 300) with an average latency 23 months but sometimes as short as 6 months (Biden-Steele, 1947)

28. Ekenvall studied the sensory perception (vibration, temperature and pain) in the hands of dentists (Ekenvall et al 1990) in long term (> 10 years clinical dentistry, n=26) and short term (< 5 years clinical dentistry, n=18) exposure to high frequency vibration and found neurological symptoms in the long-term exposure group and differences between second and fifth digits.

29. Akesson investigated digital neuropathy in female dental personnel (30 dentists and 30 dental hygienists) using high frequency drills and compared them with non-exposed (30 dental nurses and 30 dental assistants). The exposed groups had more sensorineural symptoms and significant abnormalities in vibrotactile sensitivity and grip strength (Akesson,1995).

30. A study of 370 women seeking compensation under the Swedish Labor Market Insurance between 1988-1997 reported the highest prevalence amongst dental hygienists, dental nurses or dentists comprising 30% of the total (Bylund, 2001, see table 2).

31. Another study by Rytkönen found that whilst the daily vibration exposure of dentists was below the EAV an occupational history of extended dental filling and root canal treatment (questionnaire, n=295) was associated with finger symptoms (Rytkönen et al 2006).

32. Chowdhry et al (2017) undertook a review of a number of studies published on dentists and dental hygienists and concluded that such workers were at risk of developing vibration related disorders.

33. It should be remembered that sensory symptoms presenting in vibration exposed workers may be carpal tunnel syndrome (CTS) which should always be excluded. A study of 106 dentists found 17.9% prevalence of CTS with an odds ratio of 2.5 (CI:1.23-4.10) for vibration exposure greater than two hours a day (Maghsoudipour, 2021).

Orthopaedic Surgeons

34. Orthopaedic surgeons use pneumatic and electric powered saws for cutting bone particularly in large joint replacement surgery.

35. Cherniack undertook a small case study of five patients using pneumatically powered surgical instruments and found they developed symptoms of Raynaud's phenomenon and upper extremity paraesthesias following 7-32 months of exposure from bone harvesting (Cherniack 1994).

36. Roberts et al (2001) reported vibration magnitudes of 9.7ms^{-2} and 10.7 ms^{-2} for pneumatic oscillating saws. A further postal questionnaire study comparing symptoms of 891 orthopaedic surgeons with 663 gynaecologists reported more sensory symptoms and problems with manipulative dexterity in the former (Roberts et al 2007). Demographic profiles made it difficult to compare vascular symptoms.

37. Daily usage and A(8) values will vary widely and depend on the duration of procedures and number of operations but it is feasible that the HSE Exposure Action Value (EAV) could be exceeded in approximately 30 minutes of daily use of these tools.

38. Mahmood et al (2017) returned to the topic looking at battery powered saws used on cadavers and found weighted root mean squared magnitudes of vibration of 11.3 ms^{-2}. Accepting that usage will vary between surgeons and the number of operations per day but for a magnitude of 11.3 ms^{-2} it would take 23 minutes to reach the EAV and 1 hr 33 minutes to reach the ELV.

39. Daily vibrating magnitudes from oscillating saws used to remove plaster casts have been reported in a small study of four different tool types to be between 5.3 ms^{-2} and 15 ms^{-2} (Lembo 2016).

Conclusion

40. Whilst there is extensive historical epidemiology supporting a doubling of relative risk for tools in Schedule 1 of PD A11 this Position Paper demonstrates that there are limited epidemiological data on other tools that may have equivalent vibration magnitudes. Claimants with symptoms suggestive of HAVS should have detailed occupational and clinical histories undertaken to determine whether workers in these and other occupations with a potential for equivalent vibration magnitudes have been exposed to sufficient intensity and duration of vibration to develop HAVS.

Glossary

Prevalence: is the proportion of a particular population found to be affected by a medical condition (typically a disease or a risk factor such as smoking). It is derived by comparing the number of people found to have the condition with the total number of people studied, and is usually expressed as a fraction, as a percentage, or as the number of cases per 10,000 or 100,000 people. It is the total number of cases of a disease in a given area during a given time period.

Prevalence Ratio: If the prevalence is the same, the ratio will equal 1.0. If disease prevalence is higher in those with the exposure (placed on top in the ratio), the ratio will be greater than 1.0. If the prevalence is lower in those with the exposure, the ratio will be less than 1.0.

Meta-analysis: A statistical procedure for combining data from multiple studies. When the treatment effect (or effect size) is consistent from one study to the next, meta-analysis can be used to identify this common effect. The effect may be summarised as a meta-estimate of relative risk (meta-RR).

Confidence Interval (CI): The Relative Risk reported in a study is only an estimate of the true value of relative risk in the underlying population; a different sample may give a somewhat different estimate. The CI defines a plausible range in which the true population value lies, given the extent of statistical uncertainty in the data. The commonly chosen 95% CIs give a range in which there is a 95% chance that the true value will be found (in the absence of bias and confounding). Small studies generate much uncertainty and a wide range, whereas very large studies provide a narrower band of compatible values.

Risk: The probability that an event will occur (for example, that an individual will develop disease within a stated period of time or by a certain age).

Relative Risk (RR): A measure of the strength of association between exposure and disease. RR is the ratio of the risk of disease in one group to that in another. Often the first group is exposed and the second unexposed or less exposed. A value greater than 1.0 indicates a positive association between exposure and disease. (This may be causal, or have other explanations, such as bias, chance or confounding.)

Confounding: Arises when the association between exposure and disease is explained in whole or part by a third factor (confounder), itself a cause of the disease that occurs to a different extent in the groups being compared.

Bias: In statistics it is a researcher’s tendency to underestimate or overestimate the value of a parameter. This occurs when a researcher collects an inadequate amount of data or misinterprets the implications of a study's result. Statistical bias, which can be intentional or unintentional, can also occur when a model isn’t completely representing the population.

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Appendix 1

Vibration magnitudes are assessed in accordance with ISO 5349-1. An average acceleration (a) is recorded as a root mean square or rms level and expressed as ahv in ms^{-2}, (where h means hand transmitted and v vibration). As some frequencies are thought to be more damaging a frequency weighting (Wh) is also applied to the measurements. In addition vibration occurs in 3-axis (x,y,z) and as each is presumed to be equally damaging, a total vibration value of the three axis is calculated ($ahv = \sqrt{ahvx^2 + ahv^2 + ahvz^2}$).

The resulting daily vibration magnitude is referred to as A(8) where:

$A(8) = ahv\sqrt{T/T0}$ where T is the total daily duration of exposure to vibration and T0 an 8 hour equivalence.

Annex C of the standard shows the relationship between A(8) and duration exposure in years (Y) based epidemiological studies of workers using vibrating tools (frequency range 30 Hz to 50 Hz) that produces 10% finger blanching in a group. The standard notes that acceleration values derived from these studies were the dominant, single-axis, frequency-weighted component acceleration and applied a correction factor to take account of the total vibration value. The standard also notes that symptoms of hand-arm vibration are rare in persons exposed to an 8-h energy-equivalent vibration total value, A(8), at a surface in contact with the hand of less than 2 ms^{-2} and unreported in A(8) values of less than 1ms^{-2}. The latter being regarded in civil cases as a 'de minimus' or threshold level. Although some experts have disputed this as a 'safe level'. Cases of HAVS from long term exposure to A(8) vibration magnitudes of between 2 and 2.5 ms^{-2} have been reported (Burström 2006).

The Control of Vibration at Work Regulations 2005 Exposure Action Value EAV A(8) of 2.5 ms^{-2} acknowledges a potential 10% prevalence of finger blanching after 12 yrs regular use.

Vibration magnitudes reported by the Health and Safety Executive for commonly used tools:

https://www.hse.gov.uk/vibration/hav/source-vibration-magnitude-app3.pdf