

Dose-response relationships for hand-transmitted vibration

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BRAMMER AJ. Dose-response relationships for hand-transmitted vibration. *Scand J Work Environ Health* 12 (1986) 284–288. Few dose-response relationships have been reported for signs and symptoms resulting from occupational exposure of the hand to vibration. For population groups whose members operate the same vibrating power tool or industrial process throughout the workday, a simple model may be constructed to provide functional dose-response relationships for the onset of episodes of finger blanching. In such groups, the latency interval for various population percentiles may be expressed in terms of a frequency-weighted, root-mean-square, component acceleration at a surface in contact with the hand. Of the two constitutive equations required by the model, one appears to be supported by epidemiologic data published since its derivation, but the second may require modification to be applicable to very short daily exposure durations.

Key terms: latency model, power tool, white finger hazard, work piece.

Although there have been many reports in the medical literature of neurological, vascular, and musculoskeletal disturbances among workers who operate hand-held power tools or industrial processes in which vibration enters the hands, there have been few dose-response relationships derived for the hand-arm vibration syndrome from epidemiologic data. Of these, only the work of Futatsuka et al (5), Griffin (6), and Brammer (2) attempts to summarize a broad range of data, though the relationships suggested by Futatsuka et al are based solely on vibration exposures that occurred in Japan.

A convincing set of functional relationships between exposing the hand to vibration and the development of the hand-arm vibration syndrome must allow for the possibility that the various components of the syndrome may develop independently, and hence progress at different rates. Several dose-response relationships may therefore be required (3). Furthermore, a successful, objective diagnostic test has not yet been established for any component of the syndrome. In consequence, dose-response relationships have to be based on subjective reports of signs and symptoms. They must also include the significant range in human response to vibration exposure, some individuals developing the syndrome much sooner than others.

In this paper, a model for the onset of vibration-induced white finger (VWF) is reviewed which takes into account these considerations. The ensuing dose-response relationships form the basis for those that appear in an appendix to the standard for hand-transmitted vibration developed recently by the International Organization for Standardization (ISO) (7). The compatibility of the relationships with epidemi-

ologic data published since their derivation is then explored.

Development of the hand-arm vibration syndrome

Model

A model for the development of the hand-arm vibration syndrome must be sensitive to the following factors: (i) the physical, biodynamic, and person-specific factors influencing the severity of vibration exposures experienced by persons nominally performing the same work (eg, methods of tool or process operation, work practices, hand grip, susceptibility, etc) (11); (ii) the limitations of epidemiologic data based on small numbers of workers and studies in which the change in group membership during the course of exposure is unknown; and (iii) the lack of information in most epidemiologic studies concerning the magnitude of vibration entering the hands and the duration of exposure each workday.

These considerations define the form of model employed, as is illustrated in figure 1, where the appearance of a given sign or symptom among members of a population group is shown as a function of exposure duration. To obtain these curves, the model assumes that all workers are performing essentially the same task throughout the workday using identical power tools or processes. The *exposure duration* is taken to be the number of workdays since the commencement of this activity (usually expressed in years). It does not include explicitly the time per day during which vibration enters the hands, as this time factor is infrequently reported in epidemiologic studies and, moreover, can be expected to vary from day-to-day in the normal course of work. In addition the model assumes, for the purposes of calculation, that the exposure of a population group may be characterized by

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a single *exposure rate*, formed from a single-valued measure of the magnitude of vibration coupled to the hands. Note that this assumption, though mainly a mathematical convenience, has the following two important consequences: (i) only a typical magnitude of the vibration coupled to the hands needs to be established for a population group, rather than the magnitude experienced by each person; and (ii) all variability in human response to vibration exposure must be expressed by other model parameters.

The expectation that the severity of vibration exposure differs among members of a population group, all of whom perform essentially the same work, is reflected in the range of exposure durations during which signs and symptoms appear in group members. This range is shown in cumulative form in figure 1. The frequency with which a given sign or symptom develops in group members, when expressed as a function of the exposure duration, would thus appear to provide a suitable measure of the typical, and range in, human response to vibration. In consequence the form of the distribution function must be included in the model.

Most epidemiologic data from which dose-response relationships can be constructed are expressed as the prevalence of a particular sign or symptom in a population group, and they include the exposure duration prior to its development. Clearly, a meaningful measure of a typical or average response of a population group to vibration, as well as the range in response, can only be obtained when a majority of persons are affected. This is the case in figure 1B, where the difference between the true median and the observed median response (ϵ) is small, but it is not the case in figure 1A. Hence the ability to construct dose-response relationships from epidemiologic data depends on the

prevalence of the sign or symptom under consideration, which is influenced by the rate workers enter and leave the job and the length of time they have been exposed to vibration. Control of these variables to exclude data from unrepresentative groups inevitably requires the imposition of rules for accepting data from epidemiologic studies.

Onset of finger blanching

Though the model may, in principle, be applied to any sign or symptom of the hand-arm vibration syndrome, dose-response relationships have only been constructed for the exposure duration prior to the onset of finger blanching, that is, for the latency interval (t_{L1}). This is primarily because epidemiologic studies rely on subjective reports of signs and symptoms, and the latency interval for finger blanching is the commonest sign that appears to be recalled with reasonable precision by most of those affected. For population groups whose members continue to perform the same work year after year, the frequency with which group members develop white fingers may be approximated by a normal distribution when expressed as a function of exposure duration (4). The function expressing the accumulating frequency of white fingers required by the model (figure 1) is then a cumulative normal distribution.

Considerable progress in constructing cumulative normal distributions for a variety of occupations in which different latency intervals are known to occur has been achieved by expressing the exposure rate in terms of a frequency-weighted acceleration. The frequency-weighting network employed for this purpose is that proposed by ISO (7); it is compatible with the known physiological, psychophysical, and subjec-

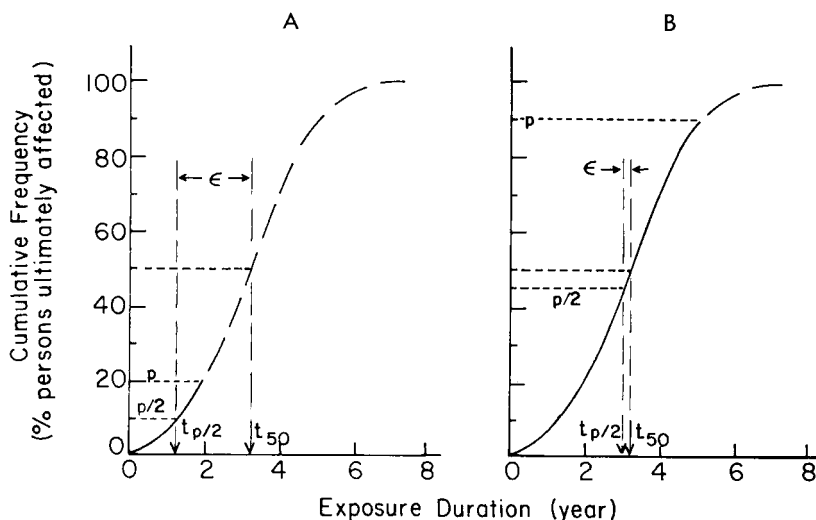


Figure 1. Development of a sign or symptom in members of a population group as a function of exposure duration. The observed cumulative frequency (p) defines an observed median exposure duration ($t_{p/2}$). The difference between the true median exposure duration, usually unknown but calculable when the cumulative frequency is 100 % (t_{50}), and the observed median exposure time is the error associated with not all persons ultimately affected possessing symptoms at the time of the epidemiologic study (ϵ).

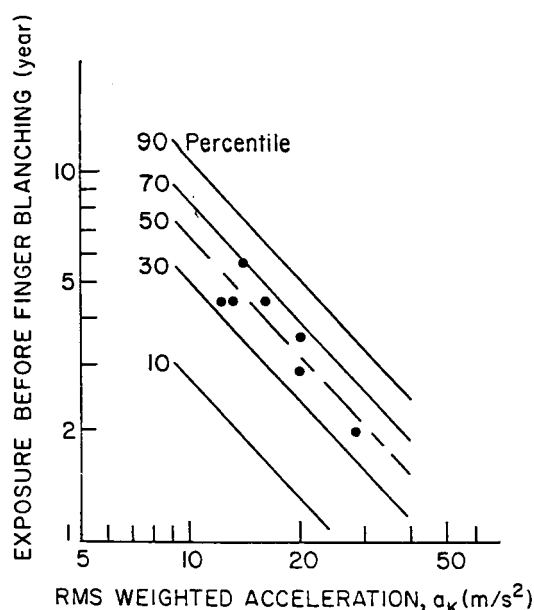


Figure 2. Duration of exposure prior to the onset of vasospasms in members of a population group exposed to a given frequency-weighted [root-mean-square (rms)] component acceleration, expressed as percentages of the total number of persons ultimately affected (2).

tive responses of the hand to vibration (2). To obtain a single-number measure of exposure rate, one of the three orthogonal components of vibration of a surface in contact with the hand is selected. It is usually the X component in the coordinate system specified by ISO (7), which records essentially the compression of flesh in the palm of the hand. The expression of exposure rates in terms of this frequency-weighted acceleration component (a_k) has only been attempted for population groups whose members operate a single type of power tool or industrial process throughout the workday.

The dose-response relationships so obtained are shown in figure 2 (3). They are believed to apply to occupations in which vibration enters the hand intermittently, and they give the duration of employment prior to the onset of episodes of finger blanching in selected percentiles of a population group exposed to a known, frequency-weighted, root-mean-square (rms), component acceleration. The curves are thus contours of the cumulative frequency of white fingers in a vibration-exposed population, expressed as percentages of the total number of workers ultimately affected.

Recent epidemiologic studies and the constitutive equations

The dose-response relationships of figure 2 are constructed from two constitutive equations, which, in turn, are derived from the results of epidemiologic studies of working populations. The two equations contain the parameters necessary to define fully a

cumulative normal distribution in terms of the component frequency-weighted acceleration. The first relates a representative value of a_k measured at a surface in contact with the hand to the mean latency interval for finger blanching in a population group ($\bar{t}_{LI}$) (2):

$$\bar{t}_{LI} = 78.7/a_k^{1.07} \quad (\text{eq 1})$$

This equation thus attempts to describe the average response of an exposed population group to vibration (given by the 50 percentile and t_{50} in figure 2 and 1, respectively).

The second equation defines the distribution function appropriate to the average group response. As the range of exposure times for the onset of episodes of finger blanching in members of a population group is taken to follow a normal distribution, it may be conveniently expressed in terms of the standard deviation (s). The distribution function may then be completely specified by its mean value $\bar{t}_{LI}$ and s (2):

$$s = 0.01 + 0.46\bar{t}_{LI} \quad (\text{eq 2})$$

These empirical equations were derived from the application of the following list of selection rules (adapted from reference 2) to every epidemiologic study of vibration-exposed persons published prior to 1980, virtually all of which were cross-sectional and retrospective in nature:

1. The group must consist of at least 30 persons whose full-time occupation involves the operation of a particular type of vibrating power tool or industrial process throughout the workday, at least 20 of whom must experience episodes of finger blanching.
2. The minimum prevalence of finger blanching within the group must be 50 % if the latency interval is less than six years, and 75 % if the latency interval is greater than six years.
3. On the average, the duration of vibration exposure for group members must exceed the latency interval reported by those affected.
4. A recognized experimental technique must be used to measure the vibration entering the hands of group members. (See, for example, reference 7.)

The rules attempt to exclude from the analysis population groups whose members' exposures may not be characteristic of a large population, by imposing a minimum acceptable group size (rule 1). Errors introduced by exposure conditions that result in a low prevalence of VWF within a group are limited by rules 1 and 2. The exclusion of population groups subject to a large influx and/or efflux of members is not treated explicitly (as no such information is provided in the original studies), but is the reason for rule 3 and for the increase in prevalence with longer latency intervals

in rule 2. Rules 1—3 have been applied to studies in which the average latency interval and its standard deviation were reported for a group of vibration-exposed workers, and rules 1—4 to those containing both the average latency interval and a measure of the tool or process vibration. The results of 14 studies were used to construct equation 2, but data from only seven population groups effectively satisfied all the selection rules and hence served as the basis for equation 1. The latter are shown in figure 2 by the filled circles, which generate the broken line for the 50 percentile.

Three additional studies that comply with selection rules 1—3 are now available with which to assess the functional form and accuracy of equation 2 (1, 8, 9). These are shown by the diamonds in figure 3. Although it is evident that the recent data appear to support the present form of the original equation (shown by the continuous line), namely, a linear increase in s with $\bar{t}_{LI}$, they suggest that a better fit to all the data would now be obtained with $s \approx 0.5\bar{t}_{LI}$.

There is only one additional study that satisfies all the present selection rules and so may be compared with equation 1 (9). It is shown by the diamond in figure 4 and appears to be in disagreement with the original constitutive equation.

Discussion

Although the recent epidemiologic data appear to confirm a linear increase in s with $\bar{t}_{LI}$, they do not appear to support the constitutive equation shown in figure 4. There are three possible reasons for the apparent incompatibility between equation 1 and the results of this recent study of miners using jack-leg rock drills. First, the vibration exposure experienced by this group of miners may differ in some significant way from those occurring in other population groups, the implication being that the selection rules are inadequate in their present form. Second, the frequency weighting used to relate the hazard posed by vibration at different frequencies may be inappropriate for this power tool. Finally, the first constitutive equation may be incorrect.

Several elements of the miners' vibration exposure warrant closer examination. The rock drill is an impact tool which generates repeated, short duration, large amplitude, low-frequency acceleration. It has been suggested that vibration with a large crest factor (ie, an impulse or, in this case, repeated impulses) is more hazardous than low crest factor vibration and hence results in a shorter latency interval for a given value of a_k (10). The crest factor does not appear to be the source of the discrepancy in this case, as inspection of figure 4 shows that the average latency interval reported by the miners is far in excess of that predicted by equation 1 for vibration of an unspecified crest factor with a frequency-weighted component acceleration of 16 m/s^2 . The daily duration of the miners' exposure to vibration was, however, extremely limited.

At most, each man spent no more than 2 h/d drilling (9). Furthermore, the jack-leg supports the drill once the hole is started, and it is not uncommon for the operator then to remove his hand from the handle and thereby further reduce his exposure duration. It could also be argued that the selection rules exclude studies such as this one, in which the activity involving vibration exposure is shared by two men, each man not then

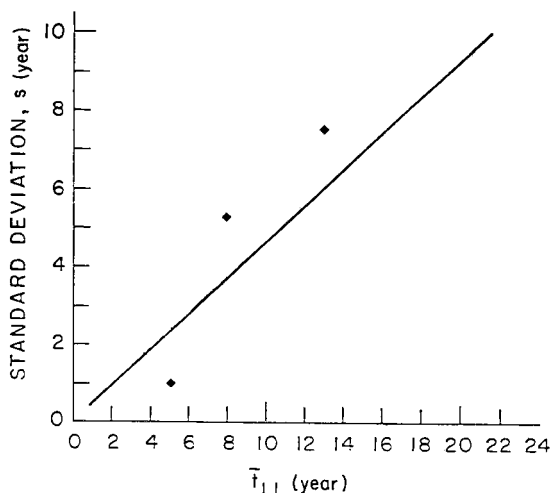


Figure 3. Constitutive equation 2: relation between standard deviation and mean exposure time ($\bar{t}_{LI}$) for members of a population group (straight line). Data published since the derivation of this equation are shown by diamonds (1, 8, 9).

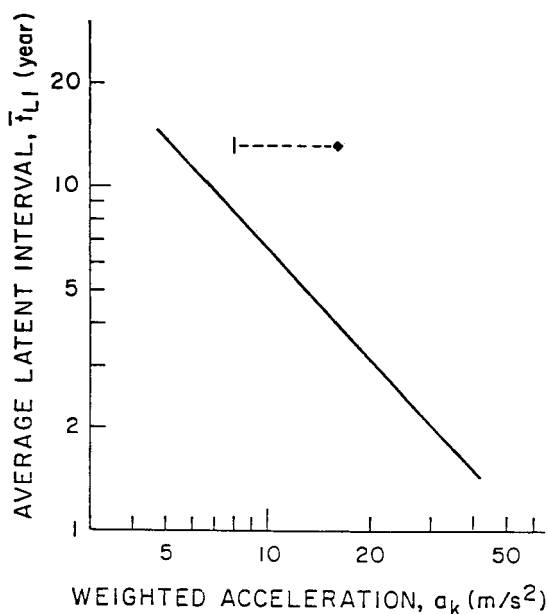


Figure 4. Constitutive equation 1: relation between mean latency interval and frequency-weighted [root-mean-square (rms)] component acceleration for population groups (curve). Data published since the derivation of this equation are shown by a diamond (9). The vertical bar shows the adjustment to a_k introduced by a 1-h daily exposure duration according to the procedure of ISO/DIS 5349.2:1984 (7).

strictly operating a power tool or industrial process throughout each workday.

Reference to the original data reveals that almost the entire contribution to the frequency-weighted acceleration occurs in the frequency bands corresponding to the drill impact frequency (31.5 and 40 Hz). Although it is possible that the frequency weighting used to establish equinoxious contributions to a_k at different frequencies overestimates the hazard at low frequencies, such a bias has not yet been confirmed elsewhere. Indeed, the original fit of the data to the constitutive equation would, in all probability, have been poor if the equinoxious contour were substantially in error.

Hence, of these alternatives, the slow development of VWF in this population group would appear to be mainly associated with the short daily exposure duration. Moreover, by not including the time exposed to vibration per day in the specification of exposure rate, equation 1 may well be in error for unusually short, or long, daily exposure durations. If the miners are assumed to have been exposed to vibration for 1 h/d, then the adjustment for this daily exposure duration proposed by the ISO standard would move the data point to the position of the vertical bar in figure 4. This placement is clearly in better agreement with the constitutive equation, though more epidemiologic data are evidently required to substantiate the effect of very short and very long daily exposure durations on the rate of development of VWF.

Conclusions

A simple model may be constructed to provide functional dose-response relationships for the onset of episodes of finger blanching in population groups whose members habitually operate the same power tool or industrial process throughout the workday. In such groups, the latency interval for various percentiles of the population group may be expressed in terms of a frequency-weighted, rms, component acceleration at a surface in contact with the hand.

Of the two constitutive equations, one appears to be supported by epidemiologic data published since the original derivation of the model, but its gradient may

require revision to $s/\bar{t}_{LL} \approx 0.5$. The second appears to require extension to allow for extremely short, and possibly long, daily exposure durations. More data are required to confirm these modifications.

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