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March 1988

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T. Haines

McMaster University, Hamilton, Ontario

J. Chong

McMaster University, Hamilton, Ontario

A. B. Verrall

McMaster University, Hamilton, Ontario

J. Julian

McMaster University, Hamilton, Ontario

Charles D. Bernholz

University of Nebraska-Lincoln, cbernholz2@unl.edu

See next page for additional authors

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Authors

T. Haines, J. Chong, A. B. Verrall, J. Julian, Charles D. Bernholz, R. Spears, and D. C. F. Muir

Aesthesiometric threshold changes over the course of a workshift in miners exposed to hand-arm vibration

T HAINES, J CHONG, A B VERRALL, J JULIAN, C BERNHOLZ, R SPEARS,
D C F MUIR

From the Occupational Health Program, McMaster University, Hamilton, Canada

ABSTRACT The objective of this study was to investigate whether aesthesiometric threshold changes occur over the course of a workshift in vibration exposed hard rock miners relative to workers unexposed to vibration during the shift. The subjects were 99 miners and 40 smelter workers; four subjects declined to participate and nine were excluded from the analysis because of apparent failure to comprehend the testing procedure. Two point discrimination and depth sense aesthesiometry were conducted at the beginning and at the end of the workshift in all digits of both hands excluding the thumbs. In addition to the use of a vibrating tool during the shift, age, digital temperature, signs of arm injury, presence of fingertip callus, and handedness were documented. In the analysis the difference between postshift and preshift readings was studied in relation to these variables, particularly exposure to the jackleg drill during the shift. With the exception of exposure of the jackleg drill, no associations were observed between these variables and change over the workshift in aesthesiometric results, on both unadjusted comparison of means and backward elimination regression analysis. A statistically significant association, however, was found between the use of a jackleg drill and change in two point discrimination and in depth sense aesthesiometric results over the course of the shift, for the right hand. Evidence of the occurrence of a learning effect, particularly for two point discrimination aesthesiometry, was observed. The occurrence of an effect in the right, but not the left, hand reflects dominant handedness and relatively greater vibration exposure in the right hand in our subjects. This study supports the incorporation of an exposure free interval before aesthesiometric testing of vibration exposed workers.

It is well established that occupational exposure to hand-arm vibration is associated with an increased risk of developing secondary Raynaud's syndrome*—with the incidence varying with vibration frequency and acceleration as well as duration of exposure. The resulting vasospastic disorder is most commonly referred to as "vibration white finger" (VWF). Occupational hand-arm vibration exposure has been linked to other manifestations as well, with the result that, as an overall descriptor for these, the term "vibration syndrome" (VS) has been put forward.²

Apart from VWF, peripheral neurological disturbances are the most prominent and scientifically best delineated element of VS.²

*Raynaud's syndrome is the terminology recently proposed by Blunt and Porter¹ as an alternative to the terms "disease" and "phenomenon."

Various tests of neurological function have been undertaken among workers exposed to vibration. Of these, two point discrimination (TP) and depth sense (DS) aesthesiometry have been among the most often used. Several vibration exposed populations have been surveyed by this procedure and have been shown to have a deficit, relative to comparison groups, of sensory function in the tips of the fingers.³⁻⁵ In addition, there is evidence that TP and DS aesthesiometry can detect VS with an acceptable degree of accuracy (T Haines, J Chong, unpublished data).

In the conduct of aesthesiometry Taylor advises that workers should have been away from vibration exposure for at least 16 hours at the time of testing.⁶ The reason for this recommendation is the concern that a temporary vibration induced shift in sensory threshold of the fingers may invalidate the results of testing for chronic sensory changes.

There has, however, been little investigation of short

term changes in tactile perception in relation to vibration exposure. An increase in the threshold for perception of vibration exposure. An increase in the threshold for perception of vibratory stimuli has been shown by Lidstrom⁷ and by Nishiyama and Watanabe⁹ after exposure to hand-arm vibration in a laboratory setting. Also in volunteers in a laboratory setting, Verberk *et al* have shown a reduction in two point discrimination but not in depth sense or vibratory perception, after exposure for 80 minutes to a plane sander (weighted acceleration 1.20m/s^2).⁹

The purpose of the present field study was to investigate whether aesthesiometric threshold changes occur over the course of a workshift in hard rock miners exposed to vibration relative to workers unexposed to vibration during the shift.

Materials and methods

This investigation was carried out in the context of a larger study of respiratory status and hand function among miners and smelter workers of the International Nickel Company, Sudbury, Canada.

The subjects of this main study consist of miners in the job codes with the greatest drilling exposure—driller, drift driller and stope leader, and of smelter workers on the workplace's "sulphur dioxide" register. The latter group is seldom exposed to hand-arm vibration.

All measurements in the main study were carried out at the beginning of shifts. The measurements included, in addition to aesthesiometry, pulmonary function testing and the administration of detailed questionnaires.

For purposes of the present investigation subjects were recruited as follows. All miners who had participated in the main (preshift) study and who had used a vibrating hand tool during the following shift were asked to have postshift testing. Because of limited time between the end of the mining shift and departure of the lift for the surface, it was not possible to study, at the end of the shift, all miners who had participated in the main study but had not used a vibrating hand tool during that particular workshift. Among this group, consecutive men returning from the stopes were selected until a preset quota was reached (set on the basis of the time interval until departure of the lift).

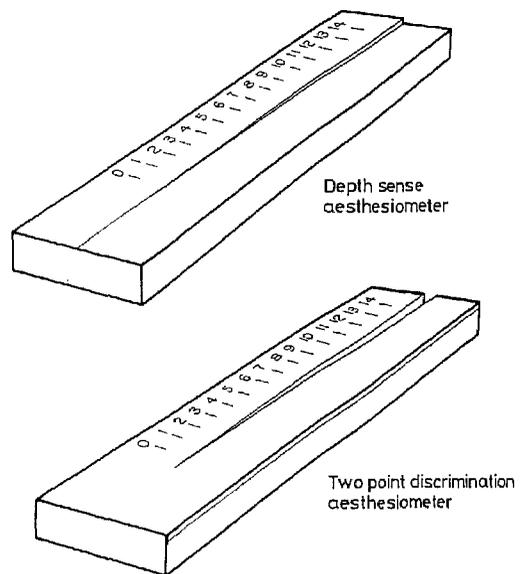
Among smelter workers who had participated in the main (preshift) study, subjects were selected randomly to be asked to have postshift testing, on the basis of the last digit of their employment serial numbers. Again, time imposed limitations in terms of the number that could be studied at the end of the shift because of subjects from the next shift arriving for the preshift testing of the main study. When a quota of subjects (based on the estimated time available for postshift

testing) was reached, selection was stopped.

Ninety nine miners and 40 smelter workers were asked to participate in postshift testing. Four miners declined; none had drilled during the shift (in each case, concern was expressed about missing the lift to the surface). No smelter workers refused.

The data in this investigation were collected, between 5 and 16 April 1984 in miners' lunchrooms underground and in a heated building adjacent to the smelter building. All subjects were male.

Two point discrimination and depth sense aesthesiometry were conducted using apparatus based on Renfrew's original conception^{10,11} as modified by Carlson *et al.*¹² Carlson's evaluation of the modified apparatus indicated that the modifications result in enhanced sensitivity to the presence of deficits in sensory function.¹² The instruments are illustrated in the figure. The depth sense aesthesiometer has a "split surface commencing at a zero point marked 5 cm from one end. . . . Half of the split surface remains level and the other half slopes at a rate of 1 mm/10 cm of horizontal distance. The total horizontal sensory length is 15 cm, making a maximum differential between surfaces of 1.5 mm. This provides a single edge for the perception of depth sense."¹³ The two point iscrimination aesthesiometer has a "5 mm deep wedge-shaped channel incised in the longitudinal surface. Beginning 5 cm from one end the wedge progressively spreads at a rate of 0.4 mm/cm for the remaining 15 cm of longitudinal length."¹³ Graduations in millimetres of horizontal distance are marked on each instrument.



Two point discrimination and depth sense aesthesiometers

We followed precisely the procedures and equipment devised by Carlson *et al*¹² to reduce differences among subjects in finger pressure and positioning and to enhance the comfort of the subject; these are not described in more detail here.

As described by Carlson *et al*, the starting position for each measurement was chosen variably on the initial 5 cm planar surface of the instruments. Subjects were instructed to look to one side during the measurements and to indicate verbally when the sensation of a double edge or ridge was first noted. The instruments were moved by the examiner (JC) under the subject's stationary finger at the approximate rate of 1 cm a second. The one difference in our procedure relative to that of Carlson is that the aesthesiometers were pushed toward, rather than pulled away from, the subjects.

Before the day of testing, most of the miners had been previously tested by aesthesiometry on one occasion, one year earlier. None of the smelter workers had previously had aesthesiometry. The apparatus and procedure were explained to the subjects in groups and also individually by the examiner. Trial runs on randomly selected fingers were repeated until, in the examiner's judgement, the subject has adequately grasped the concept of the testing.

Digits 2, 3, 4, and 5—that is, excluding the thumb—of both hands were tested before and after the shift. At the time of testing, evidence of any previous injury at or distal to the elbows was noted. In addition, an assessment by inspection and palpation of the presence or absence of fingertip callus was made. The temperature of index fingertips was documented by a Comark 3009 digital thermometer. Subjects' age and handedness were recorded. The type of vibrating tool, if any, used during the shift was noted. The time interval between pre-shift and post-shift measurements varied from five to six hours for miners and from 6.5 to 7.5 hours for smelter workers.

In the analysis the difference between post-shift and pre-shift readings, measured in millimetres of horizontal distance, was studied in relation to the variables described above, particularly exposure to vibrating tools. Statistical procedures included Pearson correlation, *t* tests, and backward elimination regression analysis; significance testing used a two tailed alpha level of 0.05.

Results

Despite the attention given to instructing subjects, it was apparent that a few of them remained confused as to how to participate in the testing. The following procedure was adopted to assess the degree to which subjects comprehended the procedure and thus were able to provide meaningful data. For each of the eight

individual fingers studied, the differences over the shift for two point discrimination and for depth sense were determined. Then, the differences between these differences ($\Delta TP - \Delta DS$) were determined, for each finger; any subject with ($\Delta TP - \Delta DS$) beyond two standard deviations from the overall mean ($\Delta TP - \Delta DS$) in more than one out of the eight fingers studied was excluded from the analysis. The rationale for this approach is Carlson's finding of a strong correlation between TP and DS¹²; widely discrepant differences in TP and in DS, when occurring in more than one finger, were taken as evidence of failure to comprehend the procedure. On this basis, four miners and five smelter workers were excluded from the analysis.

Table 1 gives the study population. Of the 91 miners included in the analysis, 28 used a jackleg drill during the shift under study.

Table 2 shows the mean age and index temperature (at shift start) among miners who did and did not drill and among smelter workers. As a group the smelter workers were older than the miners. No significant differences in pre-shift index temperature were noted.

In table 3 are shown the proportions, in each of

Table 1 Study population, refusals, and exclusions from analysis

	Approached for participation	Refusals	Exclusions from analysis*	Totals in analysis
Miners	99	4	4	91
Smelter workers	40	0	5	35
				126

*See results section for explanation of exclusions.

Table 2 Mean age and index temperatures (°C) (At shift start)

	Smelter workers	Miners who did not drill	Miners who drilled
Age (years)	48.9	41.1	41.1 (p=0.002)
Index temperature:			
Left	28.8	29.3	29.5
Right	28.7	29.1	29.1

Table 3 Proportion (%) with callus, with previous injury, right handed, and using slusher or other tools

	Smelter workers	Miners who did not drill	Miners who drilled
Callus present	17	70	68 (p < 0.001)
Evidence of previous injury:			
Left	20	11	0 (p = 0.03)
Right	6	14	7 (p = 0.43)
Right handed	94	97	86 (p = 0.14)
Use of slusher	0	25	36
Use of other vibrating tools	6	5	4

these groups, of presence of callus, evidence of previous laceration or other injury, handedness, and use of the slusher and other vibrating tools. The slusher is a machine used in the stopes to draw ore to the chute, which is associated with hand-arm vibration of much less intensity than that of the jackleg drill. Callus was present in a higher proportion of miners than smelter workers. The presence of signs of previous injury to the arm did not vary consistently among the groups. There were no distinct differences in handedness. A slusher was used in the stopes by some miners who drilled and some who did not drill. Two smelter workers (6%) briefly used a type of drill during the shift to dislodge metal from a drain.

We examined the relation between change over one shift in TP and DS results and age, preshift index temperature, presence of calluses, evidence of previous injury, handedness, and use of vibrating tools other than the jackleg drill. Calculation of Pearson correlation coefficients and *t* test statistics yielded no statistically significant associations. For example, workers who used a slusher during the shift had a mean change in TP aesthesiometry of the right hand (summed over the four fingers) of -21.2 mm, whereas those who did not use one had a mean change of -24.6 mm; the corresponding figures for DS aesthesiometry were -25.3 and 0.8 mm, respectively. These differences were not statistically significantly different for either test in any finger.

As shown in tables 4 and 5, however, an association was apparent between use of the jackleg drill and change in TP and DS aesthesiometric results over the course of the shift, for the right hand. Comparison of miners who did not drill during the shift with smelter workers, in terms of change over the shift in aesthesiometric results, showed no statistically significant difference for either test in any finger. It should be noted that the mean changes (postshift—preshift values) in TP and DS in the right hand are *negative* in sign in smelter workers and miners who did not drill

Table 4 Mean change over one shift in two point discrimination aesthesiometry (mm)

	Smelter workers	Miners who did not drill	Miners who drilled
In combined fingers:			
Left	-34.2	-23.3	-12.5 (p=0.46)
Right	-39.4	-26.6	3.5 (p=0.01)

Table 5 Mean change over one shift in depth sense aesthesiometry (mm)

	Smelter workers	Miners who did not drill	Miners who drilled
In combined fingers:			
Left	-4.5	5.9	18.6 (p=0.53)
Right	-0.4	-21.6	25.9 (p=0.04)

during the shift. Thus, on the whole, the aesthesiometric results of these subjects *improved* during the shift. On the other hand, the mean changes in the right hand in miners who drilled are *positive* in sign—indicative of a *decrement* in sensory function.

Finally, backward elimination regression¹³ analysis was carried out. The purpose was to examine the influence of age, index temperature, presence of callus, evidence of previous injury, and handedness, in relation to that of drill use, with respect to changes in TP and DS over a workshift. In this type of analysis the "variables retained in the equation" are those that exert independent effects on the dependent variables—that is, change in TP and in DS.

Tables 6 and 7 show that jackleg drill ("drill") use was found to be the only variable measured in this study that was associated with changes over the course of a workshift in TP and DS aesthesiometric results. Again the effect appears limited to the right hand. The regression coefficients (not shown in the tables) associated with the variable drill were all positive in sign—indicative of a negative influence by jackleg drill use on fingertip sensory status. The very low R² values indicate that drill use accounts, however, for little of the variability in the measured aesthesiometric changes.

Regression analysis was used also to determine whether any interaction existed between use of a drill and aesthesiometric level at the start of the shift. This analysis showed no evidence that the effect of using a drill depended on a subject's initial aesthesiometric status.

Table 6 Backward elimination regression of change over one shift in two point discrimination aesthesiometry

	Variables retained* in the equation	R ²
In combined fingers:		
2nd & 3rd, left hand	—	—
4th & 5th, left hand	Drill (p=0.02)	0.04
All left	—	—
2nd & 3rd, right hand	Drill (p=0.01)	0.05
4th & 5th, right hand	Drill (p=0.06)	0.03
All right	Drill (p=0.01)	0.06

*See results section for variables entered in the regression analysis.

Table 7 Backward elimination regression of change over one shift in depth sense aesthesiometry

	Variables retained* in the equation	R ²
In combined fingers:		
2nd & 3rd, left hand	—	—
4th & 5th, left hand	—	—
All left	—	—
2nd & 3rd, right hand	Drill (p=0.03)	0.04
4th & 5th, right hand	Drill (p=0.04)	0.03
All right	Drill (p=0.01)	0.05

*See results section for variables entered in the regression analysis.

Discussion

The results of this study demonstrate the occurrence in the workplace of aesthesiometric threshold shift related to hand-arm vibration associated with the use of a jackleg drill.

The absolute values of this shift, as evident from tables 4 and 5, are small. The main reason for this is that acute changes in finger sensitivity are, in fact, relatively small in terms of impact on exposed subjects; as with temporary noise induced audiometric shift, the changes in threshold may frequently be "subclinical" or not readily apparent to the affected individual.

Another reason for the small observed magnitude of aesthesiometric shift in this exploratory study is that we made no attempt to standardise for total duration of drill use during the shift or for time interval between last drill use and time of postshift testing (this interval was a minimum of 30 minutes).

A third reason for the small observed positive shifts was the occurrence of a learning effect among our subjects. There was no opportunity in this investigation to train the subjects comprehensively to the point where the effect of learning at time of retesting would have been eliminated. That a learning effect occurred is evident in the mainly negative changes in non-drilling subjects in tables 4 and 5.

We analysed our data with respect to whether the observed changes in non-drilling subjects were different from zero (two tailed $\alpha = 0.05$). For TP, but not for DS aesthesiometry, the changes were statistically significantly less than zero for both hands. Thus TP aesthesiometry was relatively more susceptible to a learning effect in our study.

Brubaker *et al*¹⁴ studied the vibration exposure of jackleg drillers in British Columbia and found a mean four hour weighted acceleration of about 20 m/s² (ISO-DIS 5349-2¹⁵)—considerably higher than the threshold levels that have been suggested to prevent the onset of vibration white finger in workers with lifetime vibration exposure.¹⁶ Preliminary evaluation by similar methods has been conducted on two representative jackleg drills used by Inco miners—the Joy AL60 and the Ingersoll-Rand JR300. The results, for both four foot and eight foot steel, indicate acceleration levels somewhat higher than those reported by Brubaker *et al* and a comprehensive vibration exposure survey is planned. As noted earlier, however, the intent of the present study was not to study vibration doses but to investigate whether short term vibration associated aesthesiometric threshold shift could be shown to occur in the field.

Although, clearly, miners who used a jackleg drill were aware of their exposure, this awareness is unlikely to have affected their performance in the testing. No overt behaviour suggestive of this possibility was

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observed among the subjects. In addition, the standardising refinements introduced to aesthesiometry by Carlson *et al*¹² as well as the variable zero starting point make the possibility of systematic error of this type very slight. Further, the occurrence of an effect in the right but not the left hand—reflecting dominant handedness and relatively greater vibration exposure in the right hand in our subjects—supports the validity of our observations.

Although aesthesiometry is not yet routinely conducted among vibration exposed subjects, there is evidence that TP and DS aesthesiometry is useful in the clinical detection of vibration syndrome (T Haines, J Chong, unpublished data). Further laboratory and field research will be beneficial in elucidating the relation between duration and intensity of exposure and aesthesiometric changes as well as the exposure free interval necessary to allow return to baseline status. In clinical surveillance using aesthesiometry the possibility that learning effects may occur should be taken into consideration.

We appreciate the cooperativeness of the Joint Health and Safety Committee of the International Nickel Company of Canada/United Steelworkers of America, Local 6500, in making it possible to carry out this study in the context of a busy production schedule. We are grateful to the miners and smelter workers who participated in this study.

This study was supported by the Joint Health and Safety Committee of the International Nickel Company of Canada/United Steelworkers of America, Local 6500.

Requests for reprints to: Ted Haines, MD Occupational Health Program, McMaster University, 1200 Main Street West, Hamilton, Ontario L8N 3Z5.

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