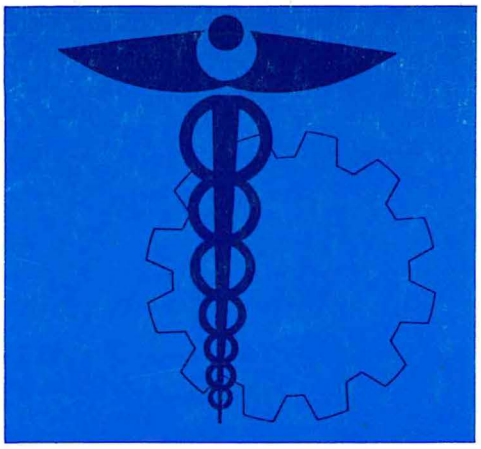


Relationship Between Whole Body Vibration & Morbidity Patterns Among Heavy Equipment Operators

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RELATIONSHIP BETWEEN WHOLE BODY VIBRATION AND MORBIDITY PATTERNS AMONG HEAVY EQUIPMENT OPERATORS

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ABSTRACT

A survey of the relationship between whole body vibration and morbidity patterns among heavy equipment operators has been conducted. Approximately 3900 claims for medical services were collected over a 20 month period extending from August 1971 to March 1973. The claims were coded according to the 8th Revision of the ICDA code and were statistically analyzed. Results suggest the existence of a selection process in which members of the exposed group leave jobs which subject them to whole body vibration when they become afflicted with certain disease conditions such as ischemic heart diseases, obesity of a non-endocrine origin, and certain musculoskeletal diseases, such as displacement of the intervertebral discs.

I. INTRODUCTION

It has been recognized that exposure to vibration can potentially produce various undesirable physiological and psychological effects on the human body [1]. The nature and extent of these effects depend upon the amplitude, frequency, intensity, and duration of the vibration. A good deal of basic knowledge has been developed in connection with acute vibration effects primarily by the military and space agencies. But, little is known about the effects of long-term or "chronic" vibration. This is especially true in the case of low frequency, (i.e., $\leq$ 100 HZ) high amplitude vibration of the type experienced by operators of heavy construction equipment. A major reason for the paucity of data in this area has been the unavailability of assessable information on morbidity experience patterns among large populations exposed to vibration of this type.

Local No. 3 of the International Union of Operating Engineers* headquartered in San Francisco, California, has over the past several years modernized and automated its membership and health plan record keeping systems to the point where it appeared possible to extract meaningful morbidity experience data by both age group and job classification. Because of our previous successful relationship with this large local union and their interest in occupational health problems,

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*Identification of the participating union contained herein has been done with their knowledge and written consent.

a project was planned and proposed to NIOSH for the study of morbidity patterns among this occupational group. The specific goal of the Study was to identify any unusual morbidity experience which might be associated with chronic exposure to whole body vibration.

Data Sources

All of the basic information reported in this Study was gathered from the records of Local No. 3 or from C.W. Sweeney & Co.,* the firm which administers their health and welfare plan. This plan covers Northern California which is defined in the Union's "Master Agreement" to be, ". . . that portion of the State of California above the northerly boundary of Kern County, the northerly boundary of San Luis Obispo County, and the westerly boundaries of Inyo and Mono Counties." Under the health and welfare plan eligible members and their dependents select their own physician and then submit a claim for his services to Sweeney & Co. for reimbursement. Expenses for hospital, surgery, diagnostic X-ray, laboratory, maternity, drugs, glasses, hearing aids, etc. are also reimbursed either in whole or in part. Although the plan also covers dental fees and claims are submitted to Sweeney & Co. for dental services, for the purposes of this Study these claims were not coded unless they involved hospitalization.

Eligibility for medical benefits through this program depends on time worked per month under the collective bargaining agreements. In fact, virtually all eligible workers are Union workers. In order to become eligible for benefits initially, a man must accumulate 300 hours

*Identification of the firm administering the health and welfare plan has been made with their knowledge and written consent.

in 3 calendar months. Thereafter, 100 hours per month maintain his or her eligibility status. It is possible to accumulate up to 1,200 hours which can be drawn upon during periods of unemployment and of work outside the collective bargaining agreements. For example, there are men who routinely work in construction six months or less per year and otherwise work in a variety of non-construction jobs.

Every month each employer must submit a contribution to the health plan for workers in his employ. This report lists each man employed and the hours worked. The contribution is calculated in cents per hour per man. In addition, this report includes the job class of each worker. The job classification system, which includes approximately 400 separate titles, was started in 1969 and at the time the Study began about 60% of eligible men were so classified. The estimate of the proportion classified at the termination of the Study is 70%. It is quite possible for men to work under multiple job titles over a several months period, a fact which was initially worrisome and which will be discussed below.

The claim handling process provided the other primary source of data for the Study. At the beginning of the Study, Sweeney & Co. were processing about 1,000 new claims per week. These claims included dependents, however. No reliable estimate was available concerning the weekly number of claims for members only.

When any eligible member receives medical service, his personal physician fills out the Health Plan's standard claim form, which includes such information as the date of the occurrence of the health problem, the physician's diagnosis of the problem and treatment given.

This form is then submitted to Sweeney & Co. for processing and payment. Claims are not paid without a doctor's diagnosis. Workers in the Claim Department do not do any medical record coding or other compilation of diagnostic data. For this reason, the Project hired accredited record technicians who were trained to code from the International Classification of Diseases, Adapted (ICDA). The coders worked at Sweeney & Co. and were included in their claim routing schedule.

Compensation cases are handled completely separately from those covered under the Health and Welfare Plan. No attempt was made to investigate compensable cases. In general, it was felt that the lack of association of vibration exposure to specific disease categories and the focus on disease rather than traumatic injury would result in most cases of interest appearing under the health plan rather than under compensation procedures. Also, the strong tendency of men to seek their own physician's advice suggests that the Health Plan may well cover cases which are, in fact, compensable.

Initial Study Design and Data Handling

Shortly after the initiation of the contract with NIOSH, the Project obtained the advice of Dr. Phillip Enterline of the University of Pittsburgh on several aspects of the Study design. Dr. Enterline traveled to Berkeley and met with Project personnel and with representatives of Local No. 3 and of Sweeney & Co. These meetings centered on the detailed nature of the available data with particular reference to job classifications and possible indices of exposure. It was found that there were two possible exposure indices: Union initiation date and pension credits.

The pension plan, also administered by Sweeney & Co., is set up such that one quarter of a pension credit is earned for each 300 hours worked. This scheme has been in effect since 1959. The nomenclature in use calls those pension credits accumulated since 1959 "future pension credits." Credit was given for work before 1959 based on initiation date, these credits being termed "past pension credits." Past credits are based on initiation date because no hourly employment records were kept prior to 1959. Total pension credits are the sum of past and future credits.

After much discussion, it was decided to use total pension credits, hereafter referred to simply as "pension credits," as the most reliable variable which, combined with job class, could be used as an index of duration of exposure to whole body vibration.

For the purposes of this study, total pension credits were divided into 8 groups. See Table I-1.

TABLE I-1

Pension Credits	Pension Credit Group
0 - 0.9	1
1.0 - 4.75	2
5.0 - 9.75	3
10.0 - 14.75	4
15.0 - 19.75	5
20.0 - 24.75	6
25 or more	7
Unknown	8

A major question to be answered during the Study then became the reliability of current job class as an indicator of overall work history. That is, does the fact that a man operates a dozer in 1972, for example, indicate that he has done so for most of his career in construction? In general, the Union personnel felt this to be a reasonable assumption. At early meetings, this assumption was clearly perceived to be a matter for verification during the Study.

Basing his decision on the nature and reliability of the available data, Dr. Enterline suggested the use of an internal control group. This group could be composed of eligible members working in job classes not subject to whole body vibration but otherwise working on job sites generally similar to those of machine operators.

Specifically, the objective of the Study was to contrast the claims experience of the eligible members exposed to whole body vibration against the claims experience of a control group, eligible under the same health and welfare plan, who were not so exposed. Because of the availability of the age and pension credit distributions for eligible members in the appropriate job classes the initial study design envisioned applying age and/or pension credit adjustment procedures to remove the influence of any dissimilarities in the distributions of these variables between the exposed and control populations.

Following the initial planning meetings and the hiring of the coders, attention was turned to data handling procedures. It was decided that Sweeney & Co., through their subsidiary, Electronic Tabulating Co. (ETC), would generate the basic sets of data cards in a format suitable for the IBM 1130 computer available at the School of

Public Health in Berkeley. ETC prepared two types of data cards referred to as "claim" cards and "matrix" cards (Figure A1-1 [Figure 1, Appendix 1]). A claim card was prepared for every claim coded. All data on the claim card was provided by our coders except job class and pension credit information which was automatically entered from Sweeney's records by ETC. Each claim card contained room for multiple ICDA codes. This provision resulted from the early discovery that doctors frequently included on one diagnosis form multiple problems which often appeared to be quite unrelated. For each month ETC produced a matrix card for each combination of job class and pension credit group containing at least one person. These data plus all the claim cards were then processed on the School of Public Health's 1130 computer and stored on magnetic discs.

Considerable effort was required in file management because of the large amounts of data. A variety of programs were developed for this aspect of the data handling problem. The other principal programming effort for the 1130 involved the development of the master program to produce the tables in the format suggested by Dr. Enterline. This program allowed the specification of the exposed and control group by job class, the ICDA disease group by code number and the time interval of interest. The program will accept up to 10 ICDA code groups per run. Two tables are output. Typical examples can be seen in Figures I-1 and I-2.

For example, consider the cell of Figure I-1 defined by pension credit group 5 and 45-54 year old age group. The four numbers in this cell are:

25 8

468 904

These numbers represent:

1. 25 - the number of claims for all diagnoses in the 0.1-136.9 category submitted during the period 8/71 to 3/73 on behalf of men in the exposed group who are between 45-54 years of age and who have accumulated between 15.0 and 19.75 pension credits (Table I-1).
2. 8 - the corresponding number of claims submitted on behalf of members of the control group.
3. 468 - the man-months of eligibility for health plan benefits accumulated by all members of the exposed group, during the period 8/71 to 3/73, who are between 45-54 years of age and possess 15.0 to 19.75 pension credits.
4. 904 - the corresponding number of man-months of eligibility accumulated by members of the control group.

With regard to the eligibility figure, it is difficult to estimate the average number of men working in each group for the twenty-month period. For example, the 904 man-months accumulated by the control group defined above would correspond to 904/20 = 45 men if they all worked the entire 20 months of the study period. This is probably a reasonable estimate since the work history survey presented in Section III indicates that for the control group the average number of months/year worked in construction is about 9-10 and this should be enough to accumulate sufficient eligibility credits to cover the remaining months of the year.

The bottom row and right-most column of Figure I-1 are the marginal sums. For example, all men in the exposed group possessing 15.0-19.75 pension credits (group 5) accounted for 44 claims for diagnoses within the 0.1-136.9 classification and 5075 man-months of

VIBRATION STUDY NIOSH-SCHOOL OF PUBLIC HEALTH UC BERKELEY

DATA FOR PERIOD 8 71 TO 3 73

ICDA DISEASE CODE GROUP 0.1 TO 136.9

PENSION CREDIT GROUP	AGE GROUP															
	UNKNOWN		00-24		25-34		35-44		45-54		55-64		OVER 65		Total	
	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C
1	0	0	0	2	6	21	2	13	12	10	11	11	0	0	31	55
	3657	5571	273	651	79	314	49	111	845	368	73	578	153	394	4856	7336
2	0	0	1	2	1	0	2	0	1	0	0	0	0	0	4	0
	167	594	111	267	36	135	136	87	71	92	23	78	49	34	482	1020
3	0	0	1	0	10	25	3	14	3	5	2	6	0	0	18	50
	1574	1779	928	1423	533	1057	665	1023	366	341	656	708	611	710	4405	5618
4	0	0	0	1	11	10	17	16	16	10	1	5	0	0	45	41
	2535	2364	1500	1679	895	962	652	1133	821	953	661	1007	794	1031	6358	7450
5	0	0	0	0	6	10	13	13	25	8	0	6	0	1	44	38
	1997	2184	1701	1270	1031	641	636	768	468	904	562	488	381	1062	5075	6047
6	0	0	0	0	4	1	4	3	7	6	13	7	0	0	28	17
	1523	1329	1653	1221	565	318	458	338	261	334	349	204	571	499	3727	3022
7	0	0	0	0	0	0	0	3	7	9	8	9	0	0	15	21
	871	951	658	409	250	194	315	287	332	126	430	279	185	431	2383	2268
8	0	0	0	0	0	0	0	0	7	3	9	3	0	0	16	6
	724	476	490	326	469	136	404	171	248	390	580	117	259	145	2684	1435
Total 9	0	0	2	5	38	67	41	62	78	51	44	47	0	1	201	228
	13048	15248	7314	7246	3858	3757	3315	3918	3412	3508	3334	3459	3003	4306	2496	2849

FIGURE I-1

VIBRATION STUDY NIOSH-SCHOOL OF PUBLIC HEALTH UC BERKELEY

DATA FOR PERIOD 8 71 TO 3 73

ICDA DISEASE CODE GROUP 0.1 TO 136.9

PC GROUP	1+2	3	4	5	6	7	8
OBSERVED CLAIMS	35	18	45	44	28	15	16
EXPECTED CLAIMS	39.04	32.63	30.40	38.26	22.50	40.87	16.77
NORMAL SCORE	-0.64	-2.56	2.64	0.92	1.15	-4.04	

PEAK METRIC = 0.6926E 01

SMR	89.63	55.15	147.98	115.00	124.41	36.69	95.35

RC = -0.085

	EXPOSED	CONTROL	VARIANCE	STATISTIC
AGE ADJUSTED RATE	0.1379E 00	0.1488E 00	0.1920E-03	-0.7859

FIGURE I-2

eligibility. These totals are the result of summing the individual cell entries over each age group. (However, these sums do not include the 0-24 year age group as will be discussed below.) Similarly, all men in the exposed group in the 45-54 age group accounted for 78 claims and 3412 man-months of eligibility where summation is over all pension credit groups.

The figure in the right-hand corner of the table is the grand total of each of the four cell entries. In this case only, the denominator is given in man-years. For example, the control group as a whole accumulated 2849 man-years of eligibility for benefits and submitted 228 claims for diagnoses included in the ICDA classifications 0.1 to 136.9.

The information shown in Figure 1-2 includes the observed claims in the exposed group and the expected number of claims from the control group for each pension credit group summed across all age groups. The expected number of claims for the control group is computed by multiplying the control group claims in each cell of Figure I-1 by the control/exposed eligibility ratio for that cell and then summing the observed and expected claims for each age group. Neither the unknown age group nor the 0-24 age group are included in this summation. The unknown age group has no claims in any case but the 0-24 age group is excluded for reasons discussed subsequently. For example, the observed and expected numbers of claims for pension credit group 4 of Figure I-2 are obtained from the data of Figure I-1 by summing,

$$\text{Expected} = 10\left(\frac{895}{962}\right) + 16\left(\frac{652}{1133}\right) + 10\left(\frac{821}{953}\right) + \ldots$$

$$\text{Observed} = 11 + 17 + 16 + \ldots.$$

The master program also calculates standardized morbidity ratios for each pension credit group based on the above data. Two separate statistical quantities are calculated to allow the investigation of trends in morbidity experience as a function of pension credits. These quantities are discussed in Section IV. The final data output on Figure I-2 shows the age adjusted claim rates and the statistic calculated to contrast these rates. The hypothesis test based on this statistic is discussed in Section IV.

Placement of Coders

At the beginning of September 1971, two part-time accredited record technicians (ART) were hired to code all active members' claims being processed by Sweeney & Co. Since there is considerable lag between the time of occurrence of a man's illness and the time at which his claim has been processed and is ready for payment, it seemed most feasible to begin our data collection on diagnoses which were made in the month of Agust 1971. This we did.

The Study's coders were inserted into the claims processing system at the point where the claim was ready to be turned over to the insurance company for payment. In order that claims would not be prevented from receiving prompt payment, it was agreed that the coders would code all claims available each day. Accordingly, each morning the coder went through the claims processed by Sweeney's employees the previous day and extracted the folders for members only from those for their dependents. They added to these claims all members' claims which had been disallowed for reasons other than work-incurred disabilities. From the physician's diagnosis in each claim folder, using Revision 8 of the ICDA Code, they recorded on prepared sheets each

illness and each treatment along with identifying data and age of the claimant. At the end of their workday, they placed the day's coded sheets (Figure AI-2) in a drawer to be picked up and keypunched by one of Sweeney's employees.

From time-to-time, there were diagnoses in these claim folders which were not sufficiently explicit to be coded with confidence. In these cases, the coder sent a form letter to the physician's office requesting further clarification of the diagnosis (Figure A1-3).

The last month for which the coders recorded diagnoses was March 1973, providing the Study with a total of 20 months data.

II. CHRONOLOGICAL DEVELOPMENT

In early January 1972 the first claim cards were delivered by ETC. At this point it was determined that about 90% of a given month's claims would be processed three months after the end of the given month. For example, 90% of the total claims made for services in August 1971 were received by November 30, 1971.

The claims coded covered the period of August 1971 through March 1973. The procedures followed in coding these claims were basically as follows: Only claims of active male members of the Union were coded. All paid claims were coded, as were all disallowed claims unless the claims were for work-incurred disabilities. Accidents were coded using "E" codes. No operations were coded. The date assigned to the diagnosis was that of the last visit listed on each claim sheet. If subsequent visits were obviously for the same problem, but not specifically so labeled, the original diagnosis was coded. Otherwise, a letter was sent to the physician requesting a current diagnosis. Occasionally, there was uncertainty as to the identity of the attending physician as well as no stated diagnosis. In these cases, the "Y" codes were used. If lab work or X-rays were done in a period covered by a diagnosis, they were not coded separately under the assumption that they were a part of the treatment. Once in awhile, when these indications were lacking, the R4.1 code for physical therapy was used.

When multiple diagnoses appeared on a claim, all of these diagnoses were coded. The diagnoses were always coded in order, as found on the claim form. If separate diagnoses with separate dates were sent in on the same claim form, each was coded separately.

A rather large number of claims came in for members who were seeing chiropractors often for several times over a period of months. When a chiropractor submitted repeated claims, the code Y104 (orthopedic aftercare) was sometimes used after the original diagnosis had been coded. It is worth noting here that chiropractic has its own terminology and disease entities which do not always translate well into the ICDA codes.

Not infrequently, the term "chest pain" was given as a diagnosis for a claimant. It was felt by the coders that the code 783.7 (pain in chest) being a symptom referable to the respiratory system might be misleading, therefore, in these cases the physician was written and a clarification of the diagnosis requested. When such a diagnosis was identified as being of unknown etiology, the code 796.9 (unknown morbidity) was used.

Due to a variety of difficulties, ETC did not deliver the first denominator data until April 1972. These data covered the five months from August through December 1971. It was immediately apparent that several problems existed with this information. Predominant among them was the large number of man-months of eligibility assigned to either the unknown age or unknown pension credit classifications. Discussions with ETC personnel were held in which it was decided to run an actuarial update, that is, to update the files used to assemble the denominator data with information on birthdates of new members and accumulated pension credit data. There existed some optimism that this procedure would result in substantial improvements in the quality of the denominator data. This update required preparation of an entirely new set of matrix cards for August to December 1971 plus the cessation of

deliveries of new matrix cards until the change was completed. At this point, ETC purchased a new computer and the changeover caused considerable delay. The new denominator data were not received until September 1972.

In the meantime, Project personnel turned their attention to the question of work histories. Local No. 3 personnel evidenced an interest in conducting their own work history survey of their entire membership. They were happy to consult with us in the preparation of their query so that the results would be relevant to both of our needs. The survey was conducted by the Union using their Union newspaper in July 1972. Regrettably, this event coincided with the National Presidential Election Campaign and a Union election both of which were receiving wide coverage in the Union newspaper, and response was very poor. It became clear that a sample of the membership would have to be reached by mail in such a way that some followup would be possible. This circumstance and the results of our efforts to properly define the exposed and control groups suggested that we focus our attention on those groups as they were defined in November 1972. Our interest in these job classes was discussed with the Union for their guidance in their conduct of this new survey.

The mailing of the new work history forms by the Union took place in the early spring of 1973. Five hundred and fifty of these were mailed and ultimately, 169 were returned after followup efforts. The results of this survey are discussed in the next section of this report.

Returning to the problems with the denominator data, we found that the effect of the actuarial update was almost negligible. That is, no appreciable reduction was achieved in the unknown categories. Again,

it became necessary to focus our attention on the exposed and control groups only and to attempt to improve the situation by contacting individuals to ascertain their age and/or pension credit status. This procedure involved the production of the appropriate listings by ETC, obtaining addresses and/or phone numbers, etc. The size of the initial listing convinced us that only the specific exposed and control groups could be handled in this way. Therefore, we elected to await the work history results to finally identify the exposed and control groups. This was completed in April 1973 and in May 1973, ETC listed all men in the job classes of interest whose age or pension credits were unknown through December 1972. We decided to focus on unknown age. However, only 90 men were identified in this category.

At this point we were approaching the end of the contract period with no further resources to devote to more extensive work in cleaning up the denominator data, particularly in view of the need to produce an entirely new set of matrix cards for the 20 months of the Study. It was possible, however, to determine the ages of 73 of the 90 men through Union records not held by Sweeney & Co. Given this reduction in the numbers of men of unknown age, a reasonable cleanup of the denominator data was expected. ETC was instructed to prepare a new set of matrix cards for August 1971 through March 1973, that is, for the entire Study period.

The results presented in the following sections of this report are based on the final update of the age data held by Sweeney. It will be seen that the denominator problem still exists in that 35% of the man-months of eligibility in the exposed group and 37% in the control group fall in the unknown age class. The figures for the unknown pension credit class are 8.5% and 4.2% for the exposed and

control groups, respectively. The effect of these unknown data on the Study will be discussed in Section V. The best that can be said of this situation is that the percentages for the two groups are not markedly different. Also the unknown age percentage is substantially greater than the unknown pension credit figure as could be expected, since age does not figure in monetary transactions for these groups as do pension credits.

The final percentage of unknown ages was surprisingly high and it appears that the reason for the persistence of these large percentages in the unknown age classes is connected with the procedure used in obtaining job class data. If the computer does not find a job class for a man in a particular month it searches backward in time for the most recent job class. If found, this class is used for the current month. If none is found, the search is begun forward in time. For example, a man may have no job class record for twelve months of the Study and in month 13 a job class is reported. If this man was eligible for benefits for all thirteen months his eligibility for the entire period would be recorded under the job class reported in month 13.

Originally, it was expected that a set of matrix cards would be produced each month and delivered to the Project. However, as noted above, the first delivery was comprised of five months data. In the effort to cleanse the data, the procedure was initiated in which the entire denominator data set was rerun after each cleansing attempt. This then allowed the possibility of the forward job class search. The last denominator rerun covered the entire 20 months of data collection. Therefore, the job class search routine maximized the

denominator eligibility figures for a given job class but simultaneously resulted in the large number of unknown ages. As mentioned above the impact of the large number of unknowns on the results is discussed in Section V.

III. WORK HISTORY SURVEY

The principal object of the work history survey was to establish the adequacy or inadequacy of current job class as an indicator of overall work history. In particular, this number was the only available means of classifying a man as a member of the control or exposed group and, as a consequence, its reliability for this purpose was central to the Study design.

Two separate queries were utilized by the Union for members of the exposed group (A) and the control group (B). ETC produced listings of all members of these groups and a random sample was selected from each. Five hundred and fifty queries were mailed, 325 to members of the control group and 225 to members of the exposed group. These two forms are included in Appendix I as Figures A1-4 and A1-5.

Ultimately, 169 forms were returned. A followup was necessary to achieve this total. Fortunately, the respondents appeared to be representative of the groups with respect to current job and age except that no response was received from men 24 years old or under. Histograms of the age distribution of the respondents are shown in Figure III-1. Similarly, histograms of the number of years in the construction industry are shown in Figure III-2. Interestingly, the hypothesis that the age distribution of the respondents was the same was accepted at the 5% level on the basis of a chi-square test calculated according to Equation 1:

$$X^2 = \frac{\Sigma(OBS_{Vib} - EXP_{Vib})^2}{EXP_{Vib}} + \frac{\Sigma(OBS_{Con} - EXP_{Con})^2}{EXP_{Con}} \quad (1)$$

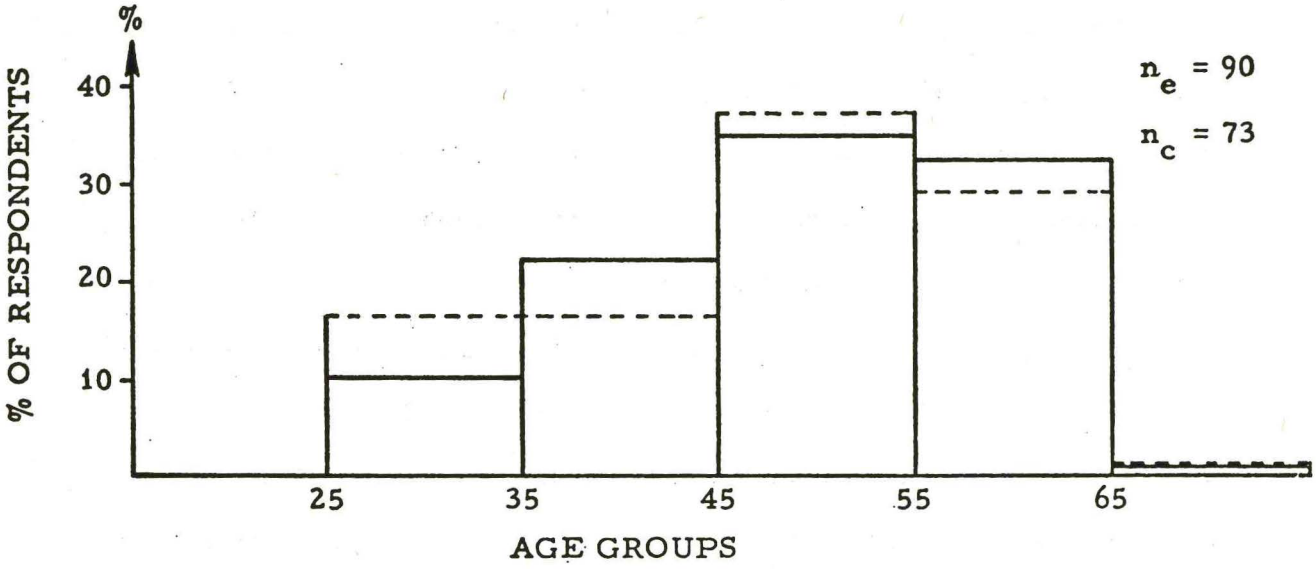


FIGURE III-1. AGE DISTRIBUTION OF SURVEY RESPONDENTS

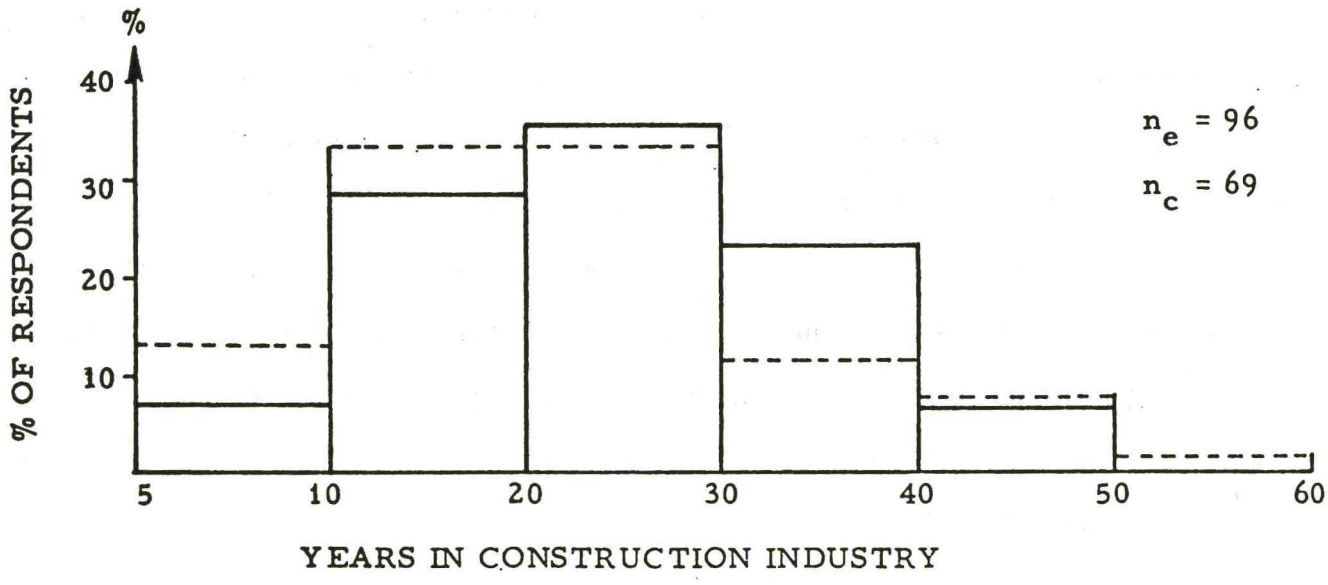


FIGURE III-2. CONSTRUCTION INDUSTRY EXPERIENCE OF SURVEY RESPONDENTS

——— EXPOSED GROUP -------- CONTROL GROUP

A similar test showed no difference between exposed and control group respondents in the number of years spent in the construction industry.

The age result appears to be at variance with the eligibility data which indicate that the exposed group may have a higher proportion of men under 25 whereas the control group has a higher proportion of men over 65 years of age. However, in the middle age groups, 25-34, 35-44, 45-54, and 55-64, the eligibility data show little difference in the percentage of eligible man-months accumulated by members of the exposed and control groups. This fact suggests that the age distribution of the respondents is probably representative of the middle age groups of each of the Study populations.

Figure III-3 shows histograms of the average months per year worked by the respondents. Here a marked difference can be seen. A substantial proportion of the control group respondents work a 12-month year whereas few of the exposed group appear to do so. This is consistent with the known effects of weather on the industry in that the control group includes a number of jobs which can be done indoors. Figure III-3 also shows a rather uneven distribution of working time among the control group. In any case, there is a clear difference between the two groups in this regard. This result tends to substantiate the choice of pension credit as opposed to initiation date as being a more meaningful index of exposure time to the occupational stresses relevant to this Study.

With respect to the job classification issue the first result was that the respondents do not appear to be familiar with the numerical job classification system. Only one or two answers out of the 169 gave actual job numbers in response to the question regarding current job classification. However, on the more important issue of time spent

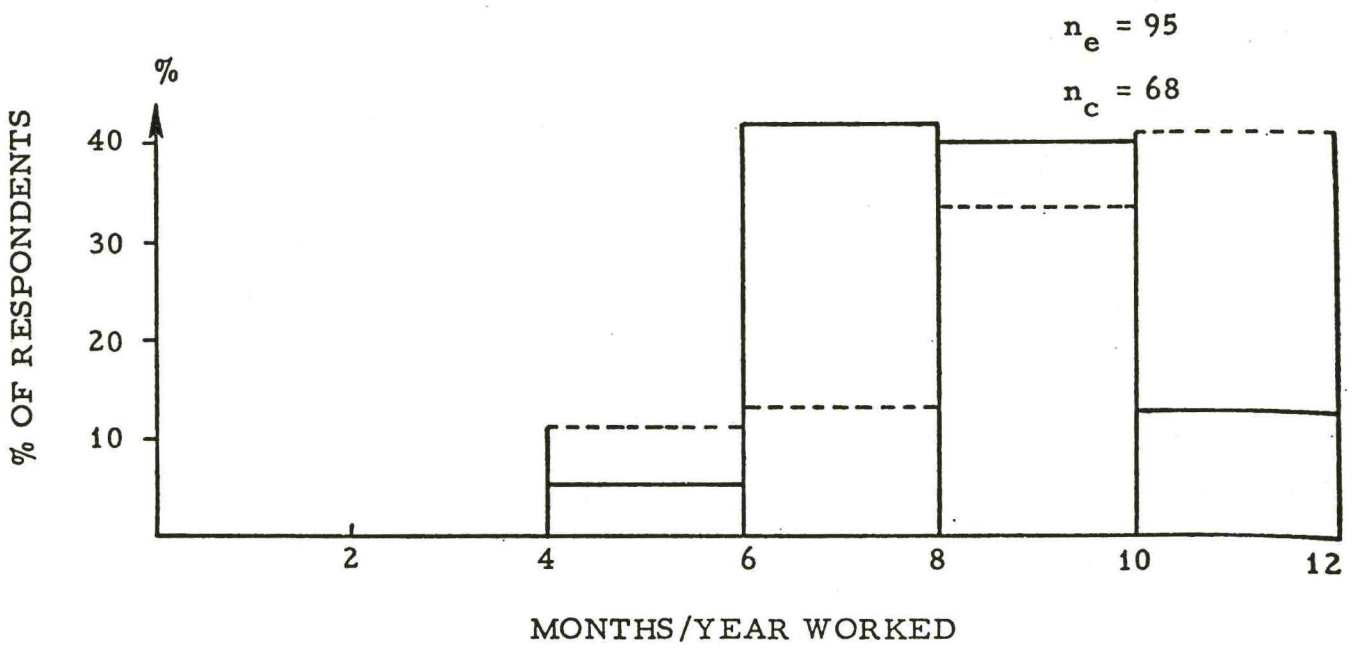


FIGURE III-3. WORKING TIME OF SURVEY RESPONDENTS

——— EXPOSED GROUP

- - - - - - CONTROL GROUP

operating the various machines the answers were precise and usually internally consistent. Figure III-4 shows the summed years of exposure on all vibrating machines versus years in the industry. This figure shows the most important result of the survey in that there is a clear difference between the two groups. There are some men in the control group who have had significant exposure but virtually no men classified as exposed have had under 5 years of exposure. This result led us to define the exposed group more precisely as being composed of those men who had experienced a total cumulative exposure of 5 years or more on vibrating machines. As a result of this definition, it was decided to exclude from consideration the under 25 age group. This was done because of our interest in health effects resulting from long-term exposure and because we knew nothing of the work histories of the group under 25 years of age. In addition, few claims were received from this group. Eligibility and claims data for this group are displayed on the master program computer output but these data are not included in the statistical calculations.

A further change suggested by the results displayed in Figure III-4 was that a correction to the final statistic might be incorporated to account for misclassifications. This correction, based on the survey results, would have, if used, the effect of increasing any difference in claims experienced between the groups because of the larger number of misclassifications of exposed workers as controls. This correction was <u>not</u> incorporated in the calculations but the effect of misclassification is discussed in Section IV.

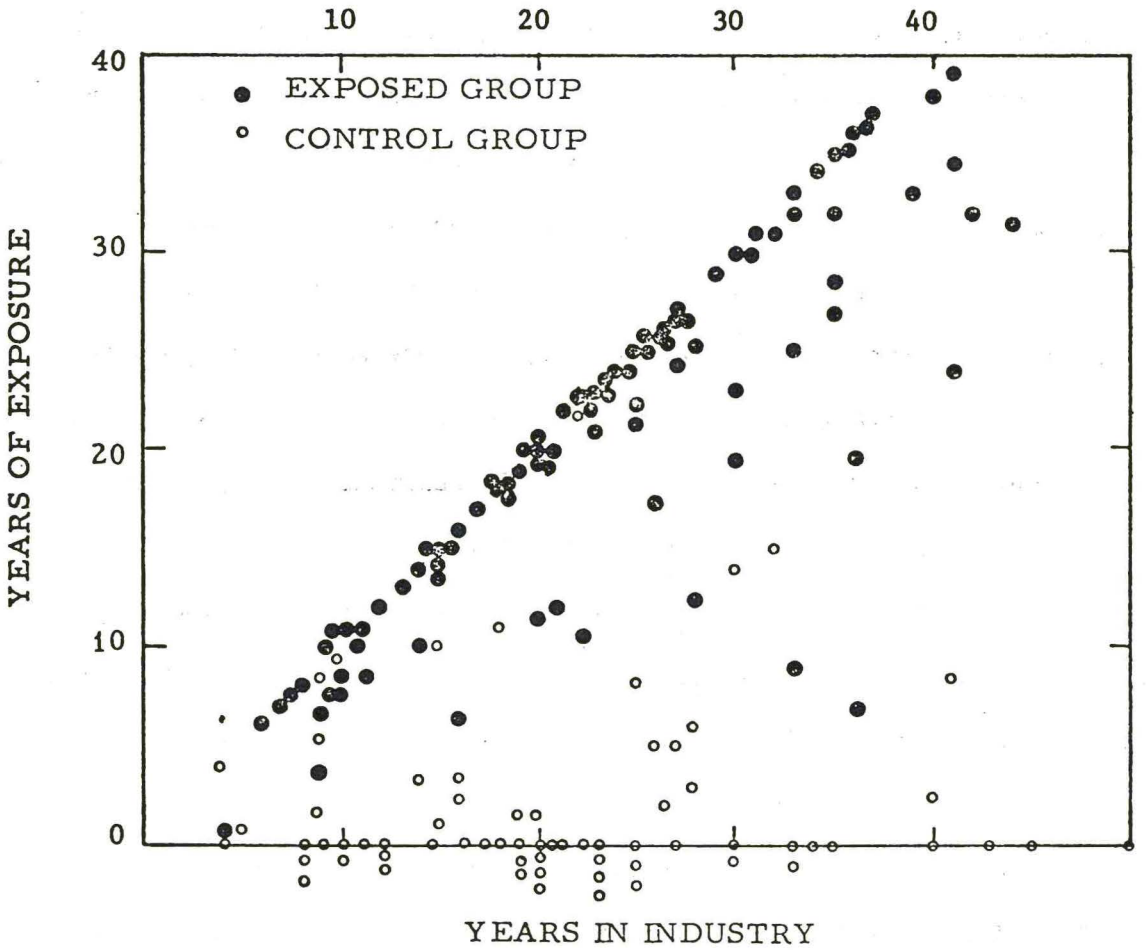


FIGURE III-4. EXPOSURE OF SURVEY RESPONDENTS

The final issue investigated via the survey concerned the variety of machines operated by a man over a career in the industry. It had been suggested that men tended to work a single type of machine or at least preferred to do so. The raw data did indicate that operators usually did work the greatest proportion of their time on a single type of equipment. However, time spent on other types was usually substantial. Figure III-5 shows the number of machines operated for periods in excess of 6 months for 3 groups of respondents of differing total experience in the industry. There appears to be little difference in the number of machines operated as a function of experience. The mean number of machines operated for all respondents is 5.8 with a median of 6. This result confirmed our prior judgment that it would not be possible to develop any realistic exposure index from the data available to us and also that it would be impossible to partition the exposed group on the basis of type of machine operated and investigate their morbidity experience separately.

As a result of the work history survey the job classes shown in Table III-1 (page 28) were finally selected as encompassing a majority of the significant whole-body vibration exposures sustained by the Study population.

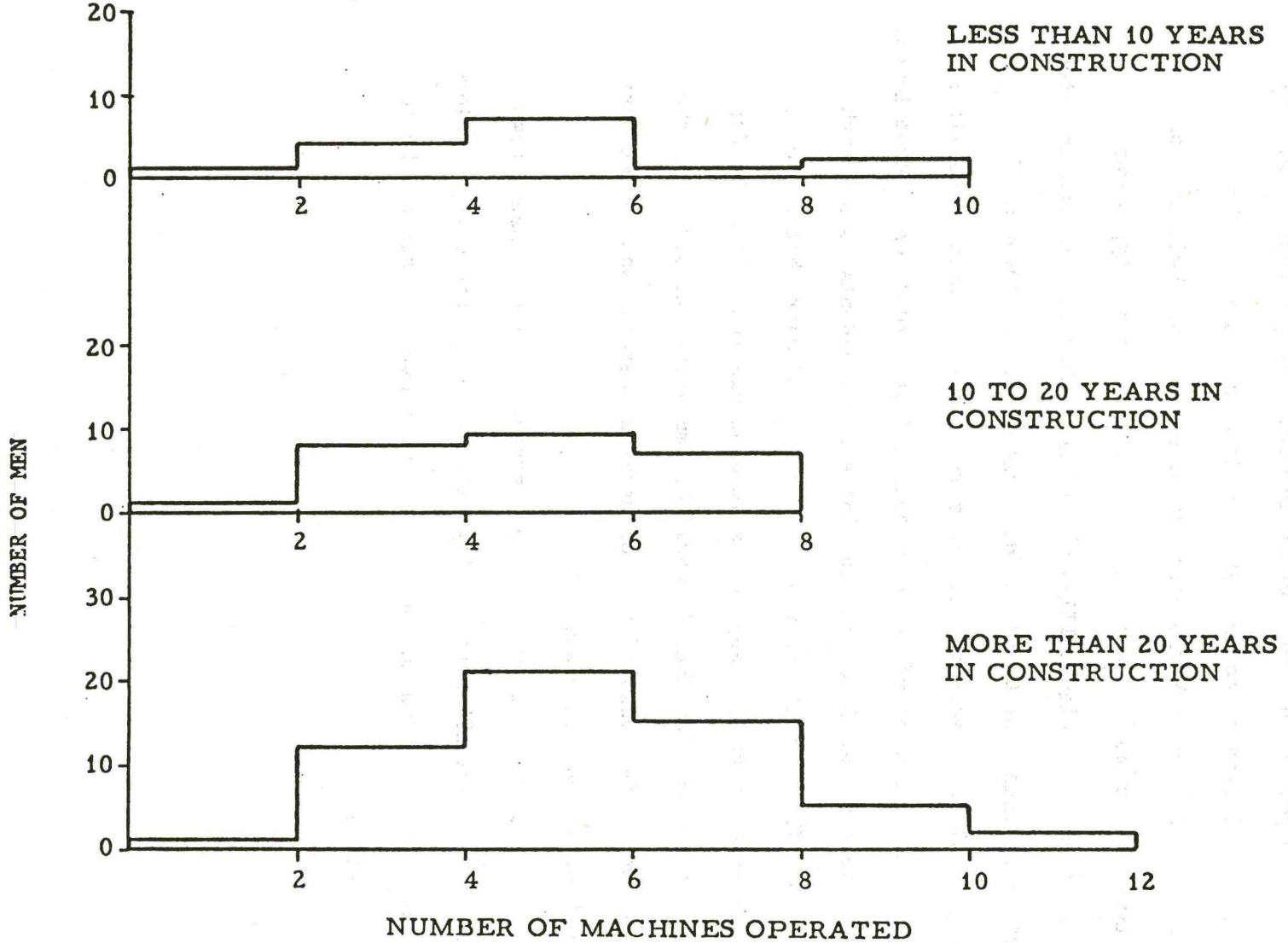


FIGURE III-5. WORK EXPERIENCE OF SURVEY RESPONDENTS

TABLE III-1

JOB CLASSES – EXPOSED GROUP

2361	Dozers
5051	Multi-Engine Earth Machine
5501	Pavement Breaker
5531	Pavement Breaker Truck Mounted
5801	Power Blade Operator
5821	Power Blade Operator
6081	Push Track-Type Dozer
6471	Rubber Tired Scraper Self Loading
6481	Rubber Tired Earth Moving
6491	Rubber Tired Earth Moving 2
6501	Rubber Tired Dozer
6521	Rubber Tired Earth Moving 2
6911	Self Propelled Compactor Single Engine
6941	Self Propelled Compactor
7011	Self Propelled Compactor With Dozer

JOB CLASSES – CONTROL GROUP

3221	Gradesetter Grade Checker
3311	Heavy Duty Repairman
3373	Heavy Duty Repairman Helper
3401	Heavy Duty Repairman and/or Welders
3731	Inspector Tech.
3761	Instrument Man
3771	Instrument Man Tech.
5173	Oiler
5383	Partsman Heavy Duty Repair Shop
7123	Signalman
7491	Soil Tester
7501	Soil Tester Tech.

IV. STUDY DESIGN

As described previously, the decision was made very early in the study to use an internal control group. That is, the morbidity experience of the exposed group was to be contrasted with a control group composed of men working under the same collective bargaining agreements and, therefore, eligible under the same health and welfare plan. Insofar as possible the job classes comprising the control group were selected with the objective of matching the occupational environments of the exposed and control groups except for the vibration exposure. For example, oilers, gradesetters and soil testers usually work on sites where substantial machine operations are in progress. As a result, these men are subjected to an environment similar to that of the operators in many important respects.

Another critical factor in selecting an internal control group was the nature of the data itself. The "numerator" data consists of the number of claims processed during the Study period by the health plan for a given set of job classes. As discussed in Section II, a "claim" is in some ways a quantity unique to this Study because of the ground rules we adopted at the outset. For example, multiple visits to a physician can appear as a single claim if the physician submits his bill for a set of visits at one time and one diagnosis covers all the visits. On the other hand, if the physician elects to bill the health plan after each visit multiple claims will appear. Therefore, in the context of this Study a claim is a well-defined entity and is consistent for both the exposed and control groups, but these data are not easily compared with normal population incidence rates of various diseases. Similarly, the denominator data, man-months of eligibility

for health plan benefits, is a measure of the population at risk but, again, not a measure easily related to standard epidemiological data sets.

Although we selected an internal control group to make factors other than exposure to vibration equivalent, we devoted our efforts to trying to ascertain if any bias could occur due to differences in claims handling, job class reporting or similar problems between the exposed and control groups. The only factor identified was related to the seasonal nature of the work and the suspicion that medical problems that are treated by elective surgery, for example, tend to be postponed until the winter months. This effect might be found in the exposed group to a somewhat greater degree than in the control group because as noted in Section III, men in the exposed group are not as likely to be working during the winter months. However, any significant bias due to such factors was diminished by extending the data collection period over 20 months.

Figure IV-1 again shows the basic data set as output by the master program. Recall that in any given age group - pension credit group cell four numbers are seen. These are the actual number of claims and the man months of eligibility for all members of the exposed (E) and control (C) group members in that cell. The bottom row and rightmost column are the marginal sums of both claims and eligibility. As discussed in reporting the results of the work history survey the 0-24 age group is not included in the marginal summation nor in the grand total in the lower right corner of the table. For the grand total figure only, the eligibility numbers are given in man years. Note that for a given set of job classes and a given period, the eligibility numbers are fixed regardless of disease code group.

VIBRATION STUDY NIOSH-SCHOOL OF PUBLIC HEALTH UC BERKELEY

DATA FOR PERIOD 8 71 TO 3 73

ICDA DISEASE CODE GROUP 140.0 TO 239.9

PENSION CREDIT GROUP	AGE GROUP														Total	
	UNKNOWN		00-24		25-34		35-44		45-54		55-64		OVER 65			
	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C
1	0	0	1	0	3	0	2	1	2	4	5	2	0	0	12	7
	3657	5571	273	651	79	314	49	111	845	368	73	578	153	394	4856	7336
2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
	167	594	111	267	36	135	136	87	71	92	23	78	49	34	482	1020
3	0	0	0	0	2	0	3	3	2	5	0	0	0	0	7	8
	1574	1779	928	1423	533	1057	665	1023	366	341	656	708	611	710	4405	5618
4	0	0	0	0	0	3	5	5	10	2	0	6	0	0	15	16
	2535	2364	1500	1679	895	962	652	1133	821	953	661	1007	794	1031	6358	7450
5	0	0	0	0	0	0	1	1	0	4	2	5	0	0	3	10
	1997	2184	1701	1270	1031	641	636	768	468	904	562	488	381	1062	5075	6047
6	0	0	0	0	0	0	2	1	10	4	7	4	0	0	19	9
	1523	1329	1653	1221	565	318	458	338	261	334	349	204	571	499	3727	3022
7	0	0	0	0	0	0	1	0	4	1	2	9	0	0	7	10
	871	951	658	409	250	194	315	287	332	126	430	279	185	431	2383	2268
8	0	0	0	0	0	0	0	0	2	0	12	2	0	0	14	2
	724	476	490	326	469	136	404	171	248	390	580	117	259	145	2684	1435
9	0	0	1	0	5	3	14	11	30	20	29	28	0	0	78	62
	13048	15248	7314	7246	3858	3757	3315	3918	3412	3508	3334	3459	3003	4306	2496	2849

FIGURE IV-1

The only processing of the raw data used to produce the array shown in Figure IV-1 is the classification of the actual age and pension credit values into six age groups and 8 pension credit groups and the coalescing of all claims for specific diseases into the ICDA group specified.

We now turn to the statistical questions surrounding the use of these data to identify differences in morbidity experience between these two groups. Focusing attention on an individual cell in the table it is usually found that the number of claims is small. Further, as the diagnostic group becomes more specific the number of claims diminishes. A typical illustration of this can be seen in the data presented in Figures IV-1 and IV-2 which show the data for all neoplasms, 140.0 - 239.9 and a subset of this group, benign neoplasms of bone and cartilage 213.0 - 214.9. In general, the number of claims in a cell was felt to be too small to attempt to base contrasts on the individual cell data. Rather, attention was directed at appropriate summations over age or pension credit groups.

Age Adjustment

The first contrast of the claims experience of the exposed and control groups involves age adjustment of the data. Age adjustment implies that the data is adjusted so that the populations to be compared appear to have the same age distribution. Stated differently, the age adjustment removes the influence of differences in the age distribution in the two populations. The method to be described is referred to as the direct method [2].

Let x_{ij} be the number of claims received from the j^{th} age group of the i^{th} population. Let n_{ij} be the man-months of eligibility amassed

VIBRATION STUDY NIOSH-SCHOOL OF PUBLIC HEALTH UC BERKELEY

DATA FOR PERIOD 8 71 TO 3 73

ICDA DISEASE CODE GROUP 213.0 TO 214.9

PENSION CREDIT GROUP	AGE GROUP															
	UNKNOWN		00-24		25-34		35-44		45-54		55-64		OVER 65		Total	
	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C
1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	1
	3657	5571	273	651	79	314	49	111	845	368	73	578	153	394	4856	7336
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	167	594	111	267	36	135	136	87	71	92	23	78	49	34	482	1020
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1574	1779	928	1423	533	1057	665	1023	366	341	656	708	611	710	4405	5618
4	0	0	0	0	0	0	2	0	3	0	0	0	0	0	5	0
	2535	2364	1500	1679	895	962	652	1133	821	953	661	1007	794	1031	6358	7450
5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
	1997	2184	1701	1270	1031	641	636	769	468	904	562	488	381	1062	5075	6047
6	0	0	0	0	0	0	1	0	0	1	1	0	0	0	2	1
	1523	1329	1653	1221	565	318	458	338	261	334	349	204	571	499	3727	3022
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	871	951	658	409	250	194	315	287	332	126	430	279	185	431	2383	2268
8	0	0	0	0	0	0	0	0	0	0	2	1	0	0	2	1
	724	476	490	326	469	136	404	171	248	390	580	117	259	145	2684	1435
9	0	0	1	0	0	0	4	0	3	2	3	2	0	0	10	4
tal	13048	15248	7314	7246	3858	3757	3315	3918	3412	3508	3334	3459	3003	4306	2496	2849

FIGURE IV-2

by the j^{th} age group of the i^{th} population. Then, for two populations, designated I and II, the data from row 9 of Figure IV-1 can be entered in columns (2), (3), (5), and (6) of Figure IV-3 and comprise the basic data set for the adjustment process. We now define the age specific claim rate as $r_{ij} = x_{ij}/n_{ij}$, where i is again the population subscript and j the age group subscript. The age specific rates are calculated and entered in columns (4) and (7) for populations I and II, respectively.

The next step is the definition of a standard population and the application of the separate age specific rates to this standard population. In this study the standard population was defined as the sum of the exposed and control populations, i.e., $n_j^* = n_{1j}^* + n_{2j}$, as indicated in column (8) of Figure IV-3.

The final step is to apply the age specific rates to the standard population. That is, a hypothetical number of cases are calculated for populations I and II by the relations $x_{ij}^* = r_{ij}\, n_j^*$. These results are entered in columns (9) and (10) of Figure IV-4. Denoting the sums of columns (2), (3), (5), and (6) by N_1, X_1, N_2 and X_2, respectively, the crude claim rates are defined as $R_1 = X_1/N_1$ and $R_2 = X_2/N_2$. Denoting the column sums of columns (8), (9), and (10) by N^*, X_1^* and X_2^* the age adjusted claim rates for the two populations are $R_1^* = X_1^*/N^*$ and $R_2^* = X_2^*/N^*$. These two quantities, R_1^* and R_2^* are the final results and can be regarded as reflecting the morbidity experience of the two populations independent of differences due to dissimilar age distributions.

The Test Statistic Applied to Age Adjusted Data

Resulting from the adjustment process is an estimate of the age adjusted claim rate for a specific set of disease classifications

	POPULATION I			POPULATION II			STANDARD POPULATION		
Column (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Age Group	Exposure Man-Months	Claims	Age Specific Claim Rate	Exposure Man-Months	Claims	Age Specific Claim Rate	Exposure Man-Months	Hypothetical Claims Population I	Hypothetical Claims Population II
1	n_{11}	x_{11}	$r_{11}=x_{11}/n_{11}$	n_{21}	x_{21}	$r_{21}=x_{21}/n_{21}$	$n_1^*=n_{11}+n_{21}$	$x_{11}^*=r_{11}\cdot n_1^*$	$x_{21}^*=r_{21}\cdot n_1^*$
2	n_{12}	x_{12}	$r_{12}=x_{12}/n_{12}$	n_{22}	x_{22}	$r_{22}=x_{22}/n_{22}$	$n_2^*=n_{12}+n_{22}$	$x_{12}^*=r_{12}\cdot n_2^*$	$x_{22}^*=r_{22}\cdot n_2^*$
3	n_{13}	x_{13}		n_{23}	x_{23}				
4	n_{14}	x_{14}		n_{24}	x_{24}				
5	n_{15}	x_{15}		n_{25}	x_{25}				
6	n_{16}	x_{16}	$r_{16}=x_{16}/n_{16}$	n_{26}	x_{26}	$r_{26}=x_{26}/n_{26}$	$n_6^*=n_{16}+n_{26}$	$x_{16}^*=r_6\cdot n_6^*$	$x_{26}^*=r_{26}\cdot n_6^*$
TOTAL	N_1	X_1	$R_1=X_1/N_1$	N_2	X_2	$R_2=X_2/N_2$	$N^*=N_1+N_2$	X_1^*	X_2^*

$N_1 = \sum_{j=1}^{6} n_{1j}$ $\quad X_1 = \sum_{j=1}^{6} x_{1j}$ $\quad R_1$ = Crude Rate, Population I $\quad R_1^* = X_1^*/N^*$

$N_2 = \sum_{j=1}^{6} n_{2j}$ $\quad X_2 = \sum_{j=1}^{6} x_{2j}$ $\quad R_2$ = Crude Rate, Population II $\quad R_2^* = X_2^*/N^*$ Age Adjusted Rates

FIGURE IV-3

for both the control group R_c^* and the exposed group R_e^*. We desire to know if R_c^* and R_e^* can be judged to reflect different morbidity experience among members of the two groups. Phrased differently, we desire to know if $R_e^* - R_c^*$ differs significantly from zero. The test statistic used in detecting any such differences was,

$$Z = \frac{(R_e^* - R_c^*) - E(R_e^* - R_c^*)}{\sqrt{\text{Var}\,(R_e^* - R_c^*)}} \quad . \tag{1}$$

Under the null hypothesis $E(R_e^* - R_c^*) = 0$. Then, by noting that Var $(R_e^* - R_c^*) = \text{Var}\, R_e^* + \text{Var}\, R_c^*$ the statistic may be expressed,

$$Z = \frac{R_e^* - R_c^*}{\sqrt{\text{Var}\, R_e^* + \text{Var}\, R_c^*}} \tag{2}$$

Using the notation of the age adjustment discussion the variance can be shown to be approximated by:

$$\text{Var}\, R_e^* + \text{Var}\, R_c^* = \frac{1}{N^{*2}} \sum_{j=1}^{m} n_j^{*2} \left(\frac{X_{1j}}{n_{1j}^2} + \frac{X_{2j}}{n_{2j}^2} \right) \tag{3}$$

where m is the number of age groups used in the adjustment process [3]. The approximation on which the formula rests is, in our case, that

$$\frac{1 - 5_{ij}}{1 + 5r_{ij}} \approx 1 \tag{4}$$

where r_{ij} is the age specific claim rate. In all cases encountered in the study this approximation is very good.

Figure IV-4 shows the second page of the output of the master program which corresponds with Figure IV-1. The four numbers at the bottom of the Figure are, respectively, R_e^* (exposed), R_c^* (control), Var $(R_e^* - R_c^*)$ (variance) and $Z = (R_e^* - R_c^*) / \sqrt{\text{Var } (R_e^* - R_c^*)}$ (statistics).

Although the claim rate R is not a proportion it can be so considered. That is, R can be interpreted as analogous to the number of men making claims divided by the number of eligible men where the denominator units are in man-years. In reality, multiple claims in a single year by some men do occur and could, in theory, allow R to exceed one. But, since R never approaches one, the usual statistical interpretation of R as a proportion supports the contention that under the null hypothesis Z is normally distributed with mean zero and unity variance. In this case, and because of the rather large samples, the appropriate test of the hypotheses that the exposed and control group do not differ in morbidity experience for a particular disease classification is accomplished with reference to the distribution of the normal variate rather than the t distribution. Although we are particularly interested in positive values of Z, i.e., in cases where the exposed group shows worse morbidity experience, a two-tailed test was selected so that differences in experience of either sign would be investigated. Under this test a value $|Z| > 1.96$ indicates a significant difference at the 5% level. However, this test focuses on a single contrast. This study was one in which multiple contrasts were made and the data "dredged" rather than the case in which a single condition is selected for study and the question of differences in experience posed for that condition only. Therefore, in making a large number of comparisons we would expect a certain number of false positives, even when no true differences exist. That is, if 50 single

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DATA FOR PERIOD 8 71 TO 3 73

ICDA DISEASE CODE GROUP 140.0 TO 239.9

PC GROUP.	1+2	3	4	5	6	7	8
OBSERVED CLAIMS	13	7	15	3	19	7	14
EXPECTED CLAIMS	9.19	7.31	11.32	8.65	11.32	16.50	9.91
NORMAL SCORE	1.25	-0.11	1.09	-1.92	2.28	-2.33	

PEAK METRIC = 0.8824E 01

SMR	141.42	95.67	132.39	34.65	167.78	42.40	141.20

RC = -0.257

	EXPOSED	CONTROL	VARIANCE	STATISTIC
AGE ADJUSTED RATE	0.5364E-01	0.4042E-01	0.6329E-04	1.6617

FIGURE IV-4

contrasts are made between two populations whose morbidity experience does not differ we would expect some numbers of Z values to exceed 1.96 purely by chance. This issue is central to the proper interpretation of the results of this study and will be discussed in detail in the results section. At the same time, however, a value of $|Z| > 1.96$ can be regarded as at least interesting and perhaps may even reflect potential causative mechanisms leading to an observed association for the particular disease classification in question.

The Effect of Unknowns in the Eligibility Data on the Z Statistic

The Eligibility data for men of unknown age is shown in row 9, column 1 of Figure IV-1. There are 13,048 man-months of eligibility in this class for the exposed group and 15,248 for the control group. However, there are no claims for men of unknown age. If we consider the unknown category as just one more age category for purposes of the age adjustment procedure, these unknowns will not affect the Z statistic because of the absence of any claims in that category. That is, whether or not the unknown age group is included in the adjustment procedure the Z value is unaltered because of the absence of claimants of unknown age.

The fact that there are no claimants of unknown age does not imply that a knowledge of the ages of all eligibles might not alter the results. As stated in previous sections, substantial efforts were undertaken to reduce the number of eligible man-months in the unknown age category but, to little avail. At this point we shall consider the possible effects of the unknowns on the results.

In order to ascertain the possible effects of the large eligibility figures in the unknown age group let us combine equations (2) and (3) and introduce the notation from Figure IV-3 that $R_e^* = R_1^* = X_1^*/N^*$ and $R_c^* = R_2^* = X_2^*/N^*$, then we may write:

$$Z = \frac{\frac{X_1^*}{N^*} - \frac{X_2^*}{N^*}}{\sqrt{\frac{1}{N^{*2}} \sum_{j=1}^{m} n_j^{*2} \left(\frac{X_{1j}}{n_{1j}^2} + \frac{X_{2j}}{n_{2j}^2} \right)}} \qquad (5)$$

As before

$$X_1^* = \sum_{j=1}^{m} (n_{1j} + n_{2j}) \frac{X_{1j}}{n_{1j}} \qquad (6)$$

$$= \sum_{j=1}^{m} (1+\sigma_j) X_{1j} \qquad (7)$$

where, $\sigma_j = \frac{n_{2j}}{n_{1j}}$. Also

$$X_2^* = \sum_{j=1}^{m} (n_{1j} + n_{2j}) \frac{X_{2j}}{n_{2j}} \qquad (8)$$

$$= \sum_{j=1}^{m} \left(\frac{\sigma_j + 1}{\sigma_j} \right) X_{2j} \qquad (9)$$

Then, multiplying through by N^* in equation (5) and substituting (7) and (9) into (5) yields:

$$Z = \frac{\sum_{j=1}^{m} \left[(1+\sigma_j) X_{1j} - \left(\frac{1+\sigma_j}{\sigma_j} \right) X_{2j} \right]}{\sqrt{\sum_{j=1}^{m} n_j^{*2} \left(\frac{X_{1j}}{n_{1j}^2} + \frac{X_{2j}}{n_{2j}^2} \right)}} \qquad (10)$$

But, since $n_j = n_{1j} + n_{2j}$

$$\frac{n_j^{*2}}{n_{1j}^{*2}} = \left(\frac{n_{1j} + n_{2j}}{n_{1j}}\right)^2 = (1 + \sigma_j)^2 \qquad (11)$$

Similarly,

$$\frac{n_j^{*2}}{n_{2j}^{2}} = \left(\frac{1 + \sigma_j}{\sigma_j}\right)^2 \qquad (12)$$

Substituting (11) and (12) into (10) yields

$$Z = \frac{\sum_{j=1}^{m} \left[(1 + \sigma_j) X_{1j} - \left(\frac{1 + \sigma_j}{\sigma_j}\right) X_{2j}\right]}{\sqrt{\sum_{j=1}^{m} \left[(1 + \sigma_j)^2 X_{1j} + \left(\frac{1 + \sigma_j^2}{\sigma_j}\right) X_{2j}\right]}} \qquad (13)$$

Equation (13) shows that the age adjusted statistic depends only on the actual claims data in each group, X_{ij} and X_{2j} and on the cell eligibility ratios $\sigma_j = n_{2j}/n_{1j}$. Therefore, if the actual age distribution of the eligibles of unknown age is such that the ratios of n_{2j}/n_{1j} are unchanged for each j, then the age adjusted Z is unaltered.

Although we do not have any information on the possible distribution of ages among the unknown group, it can be seen from equation (13) that the true distribution of the ages of the unknowns

need not be distributed as that of the knowns. For example, it might be that most unknowns are older men because of less attention to record keeping years ago. Then, the fact that no changes would occur in the eligibility figures for the younger age groups, and all of the unknowns went into the one or two older groups, would not disturb the values of Z if the σ_j ratio for the older groups remain unaltered.

The final comment on this issue is that the functional dependence of Z on σ_j as indicated in equation (13) shows that pathological behavior can be expected only when σ_j gets very small and therefore $(1 + \sigma_j)/\sigma_j$ very large. For the age adjustment data in this problem $.974 \leq \sigma_j \leq 1.434$, $j = 1,5$. Therefore, since the age distribution of the unknowns would have to differ substantially between the exposed and control groups to have an appreciable effect on the Z statistic, and since results of the work history survey showed no indication of dissimilarities between the age distribution of the respondents and that of the eligibility figures, we do not feel that the effect of the unknowns is appreciable. Further, we can conceive of no reason why bias on the basis of job class should appear in the unknown age group.

The Misclassification Problem

In reviewing the results of the work history survey it was mentioned that there were significant numbers of men classified as "control" who had experienced five years or more exposure as a result of having operated one or more machines defined as producing exposure to whole body vibration. In fact, 14 of the 69 control group respondents, or 20%, were misclassified by the five or more years of exposure criterion. On the other hand, only two of the 96 respondents classified

as "exposed" had experienced less than five years of exposure and were thereby misclassified. Assuming the survey respondents to adequately reflect the experience of their respective populations one may expect the 20% misclassification rate to definitely affect comparisons between the exposed and control groups. In particular, if differences in morbidity experience do in fact exist misclassifications tend to mask this difference. Taking the claim rate difference resulting from the age adjustment procedure as an example, it can be shown that the difference in rates corrected for misclassification is related to the uncorrected difference by the formula

$$\hat{R}_e^* - \hat{R}_c^* = (R_e^* - R_c^*)\left(\frac{1}{1-\theta}\right)$$

where R_e^* and R_c^* are the corrected rates a and $\theta = P(V|C_n) + P(C|C_v)$, the sum of the misclassification probabilities. Since $(1-\theta)$ is less than or equal to unity

$$\hat{R}_e^* - \hat{R}_c^* \geq R_e^* - R_c^*$$

The ultimate implication of misclassifications is that conclusions based on the uncorrected data will be conservative [4] [5]. That is, if a significant difference is found, based on the contaminated data, then a true difference exists. However, since misclassifications tend to diminish the power of the statistical test, real differences may in fact exist that are not detected as statistically significant.

Contrasts Based on Pension Credit Grouping

As recounted above, the age adjustment procedure allows for contrasts between the exposed and control populations after accounting for effects arising from differences in the age distributions of

the two populations. In the case of pension credits, however, a different problem is posed. We wish to determine if there exists a trend in the claims data which might indicate a progressive change in morbidity experience between the exposed and control groups as a function of time on the job, that is, a progressive change which might be related to exposure to whole body vibration.

The first method selected to explore the possibility of a pension credit related trend was to first compute the standard morbidity ratio (SMR) for each pension credit group as follows:

$$SMR_k = \frac{\sum_{j=1}^{5} X_{1jk}}{\sum_{j=1}^{5} \frac{n_{1jk}}{n_{2jk}} X_{2jk}}$$

where summation is over the five age groups. The notation is as in the age adjustment discussion except for the addition of the third subscript denoting the pension credit group. In essence, the SMR is computed by calculating an expected number of claims in each cell of the data matrix on Figure IV-1, summing observed and expected claims over each age cell and forming the ratio of the summed exposed group claims to the expected control group claims. This procedure compensates for age differences in each pension credit group.

Since each pension credit group from one through seven reflects an increasing work experience in the union one might expect that a disease causally related to whole body vibration exposure would result in a set of SMR's which would progressively increase in value with pension credits. That is, the SMR measures the relative claim experience for each pension credit group and, if exposure causes increased morbidity we would expect the SMR to increase with the

exposure measure, i.e., pension credits.

A simple statistical technique suitable for assessing the degree of correlation between exposure, as measured by pension credits, and morbidity is the Spearman Rank Correlation Coefficient, r_s. This statistic has values between -1 and +1, a value near +1 meaning an increase in morbidity with increased exposure. To illustrate the use of this measure of correlation, suppose the SMR data are as shown below for a particular disease group:

Pension Credit Group	SMR
1	.11 (1)
2	.27 (3)
3	.24 (2)
4	1.05 (5)
5	.91 (4)
6	1.13 (6)
7	1.34 (7)

Next to each SMR figure is the rank of that value where (1) denotes the smallest and (7) the largest SMR. By definition the pension credit groups are ranked in order of increasing pension credits, i.e., these values are ranked exposure classes. If exposure is closely correlated with morbidity as measured by the SMR we expect the difference in the ranks to be near zero. The value of the statistic is computed as:

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^2}{N^3 - N}$$

where N is the number of observations and d_i the difference in ranks squared.

Peaking Behavior

As will be seen in the Results Section, the Spearman test seldom suggested exposure related trends in the morbidity data. However, in plotting the SMR values versus pension credits it was noticed that some disease conditions showed what was subsequently termed "peaking" behavior. Figure IV-5 shows two examples of peaking and it was found that this pattern was seen rather more often than would be expected by chance. A plausible explanation for such behavior is that certain disease conditions may lead to a preferential selection out of the exposed category due to the rigors of machine operation. For example, a man with a heart condition would, one suspects, be much less likely to continue operating a rubber tired scraper than to continue in a job as an oiler. Therefore, if actual causation were present one might expect to see a rise in the SMR as exposure increases until a point is reached where significant selection out occurs. This would be followed by a decline in the morbidity ratios in the highest exposure categories as measured by time on the job.

The immediate question which arises concerns the likelihood of observing peaking behavior by chance when there is, in fact, no difference in morbidity rates between the exposed and control groups as a function of experience. Various approaches to this problem were investigated with the final decision being to develop a special statistic and to determine its distribution under the null hypothesis by simulation. Rather than work directly with SMR's we decided to use a measure which could be assumed to be normally distributed under the null hypothesis. Essentially, the SMR is the ratio of observed claims among the exposed

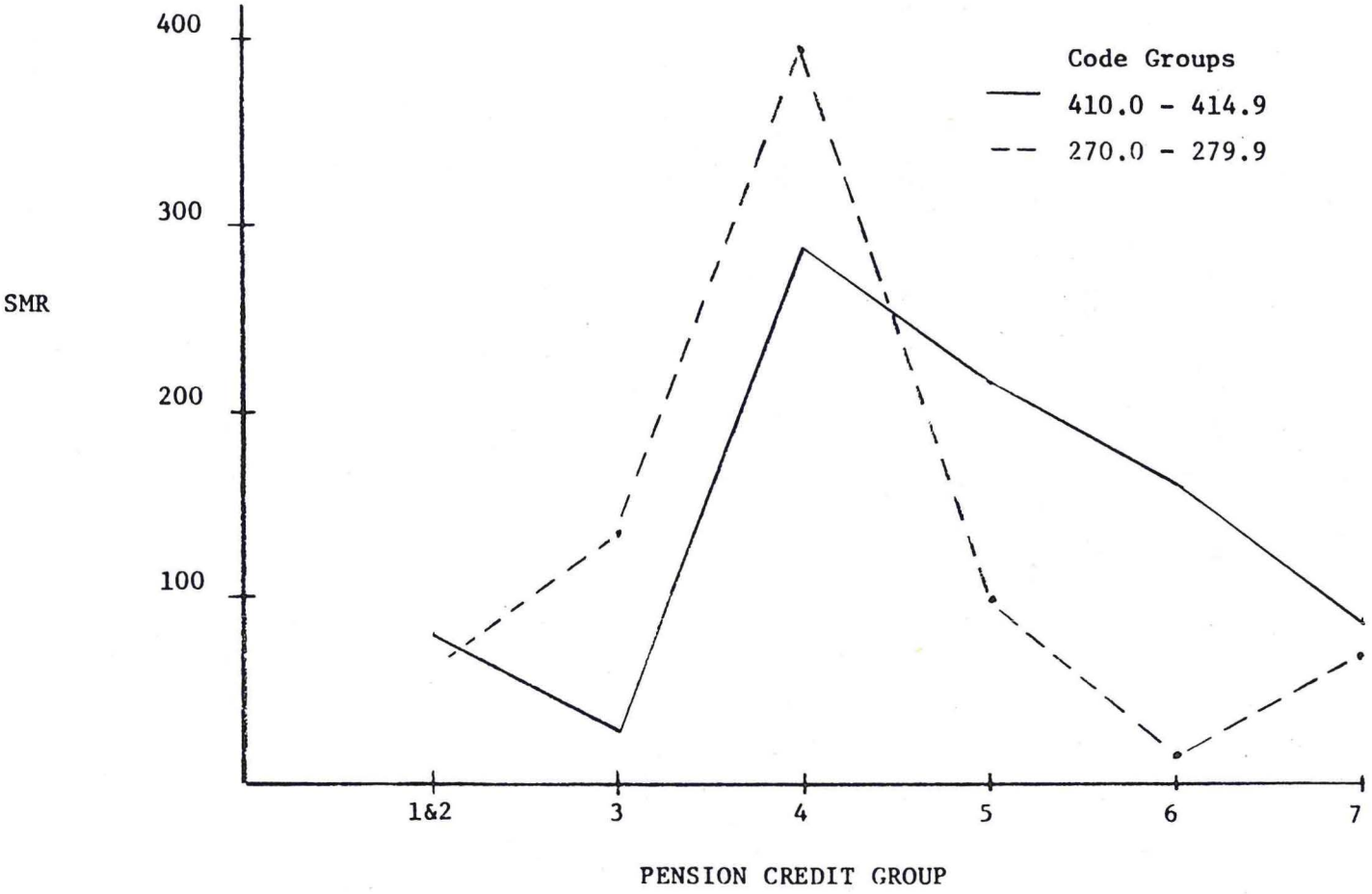

400
300
200
100
SMR
Code Groups
410.0 - 414.9
270.0 - 279.9
1&2
3
4
5
6
7
PENSION CREDIT GROUP

Figure IV-5

group to expected claims based on the control group experiences. In symbolic terms, this can be written as $SMR_j = O_j / E_j$. Following Armitage [2], it is possible to consider the variable $W_j = (O_j - E_j)/\sqrt{E_j}$ as a standardized normal deviate if E_j is not too small. That is, under the null hypothesis W_j has zero mean and unity standard deviation for each pension credit group, i.e., j = 1,7. Under this assumption it is possible to consider the appropriate definition of a peak, develop a measure of peakedness and find the distribution of this measure, the latter step being possible by simulation procedures.

A variety of definitions of peakedness as well as measures of peak height are possible. In developing our definitions we first decided to consider only peaks in exposed group morbidity. That is, for a given ICDA category a peak is defined by the maximum value of W_j. However, if the maximum occurs for pension credit group 1 or 7, that is, at the extremes of exposure, it does not constitute a proper peak. One additional condition for peakedness turned out to be necessary. This is referred to as the "mountain-valley" condition which is a condition excluding double peaking of the type shown in Figure IV-6a The specific rule was that if a second local peak existed it had to be outside a band of width delta below the absolute maximum for a true peak to exist. Figure IV-6b shows an acceptable second peaking by this definition.

Given that a peak exists, it is necessary to develop a measure of the degree of peakedness. The measure adopted is:

$$P_e = \frac{\sum_{i=o}^{m-k-i} \left| W_{m-i} - W_{m-i-1} \right| (i+1) + \sum_{i=o}^{n-m-1} \left| W_{m+i} - W_{m+i+1} \right| (i+1)}{}$$

where m denotes the index or pension credit group corresponding to the peak, k the index of the left base and n the index of the right base of the peak. For example, in Figure IV-6c a peak occurs at pension

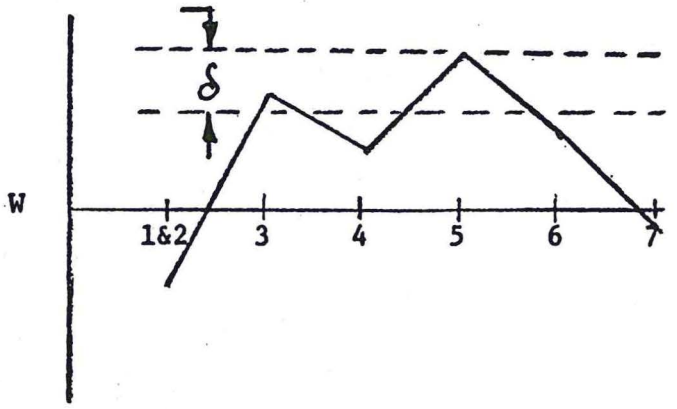


Figure IV-6a

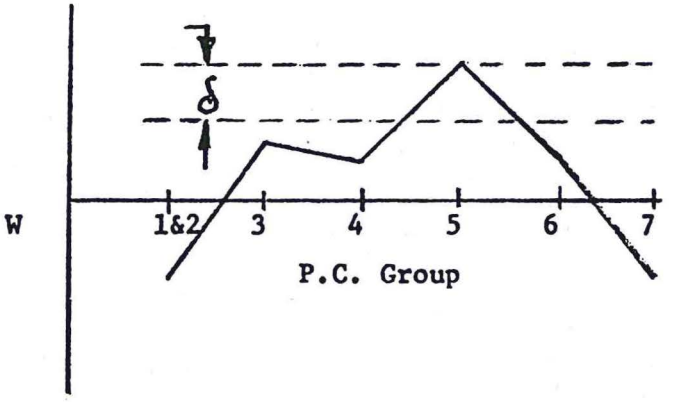


Figure IV-6b

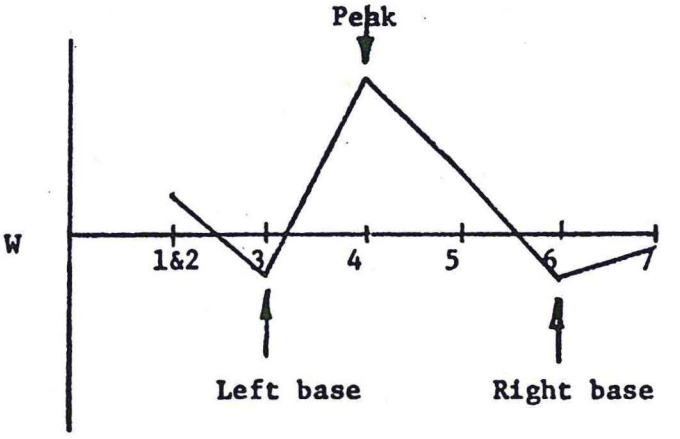


Figure IV-6c

credit group 4 and the bases occur at 3 and 6. Therefore m = 4, k = 3 and n = 6.

In essence, the peak metric is the sum of the first differential altitude segments on either side of the peak given unity weighting plus the second segments given double weighting, etc.. The precise choice of weighting is arbitrary but the effect of our choice is to weight regular peaks more highly than those with just a single outlying point. In Figure IV-7, for example, two patterns are shown where the maximum value of W_j is identical. The calculation of P_e for these cases is shown in Table IV-I. Note that P_e is larger for the more regular curve as is, in fact, desired.

The distribution of P_e under the null hypothesis can be estimated by computer simulation [6]. The program utilizes a random number generation routine which results in the selection of six random numbers from a normal zero-one distribution. (For both the SMR and P_e calculations pension credit groups 1 and 2 were merged so that each resultant group represented a five pension credit increment [See Table I-1]. This resulted in six pension credit groups.) These six values define a curve that might arise under the hypothesis that no difference in morbidity experience would be observed for the different exposure classes. The program then checks for peaking behavior by the following procedure:

1. Find Wmax
2. Determine if Wmax is at extremes of exposure
   a. If so no peak exists
   b. If not proceed to step 3
3. Check for existence of second peak within band of width delta from Wmax

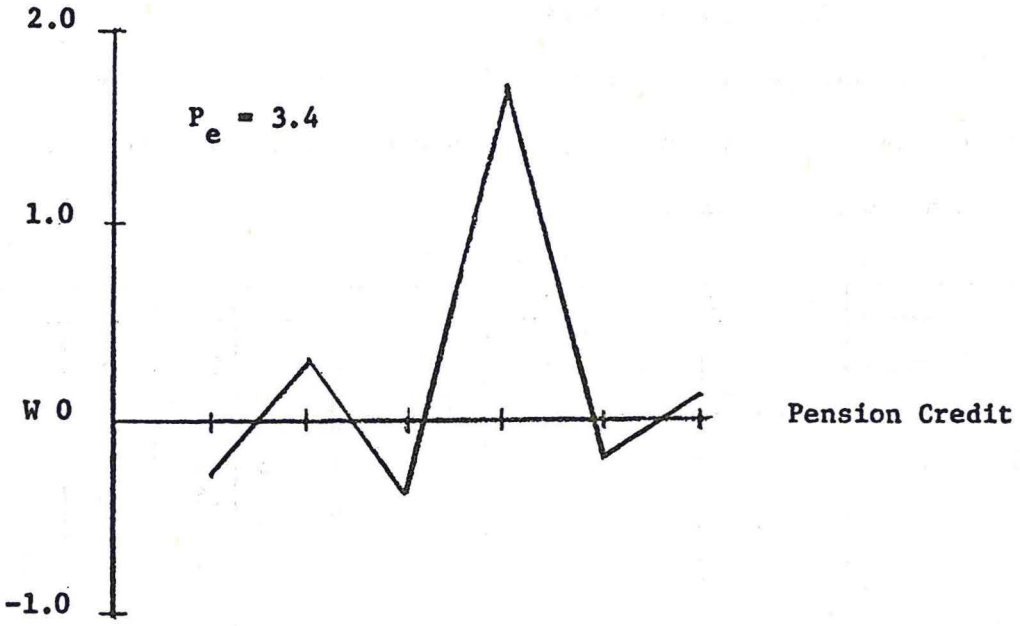


Figure IV-7a

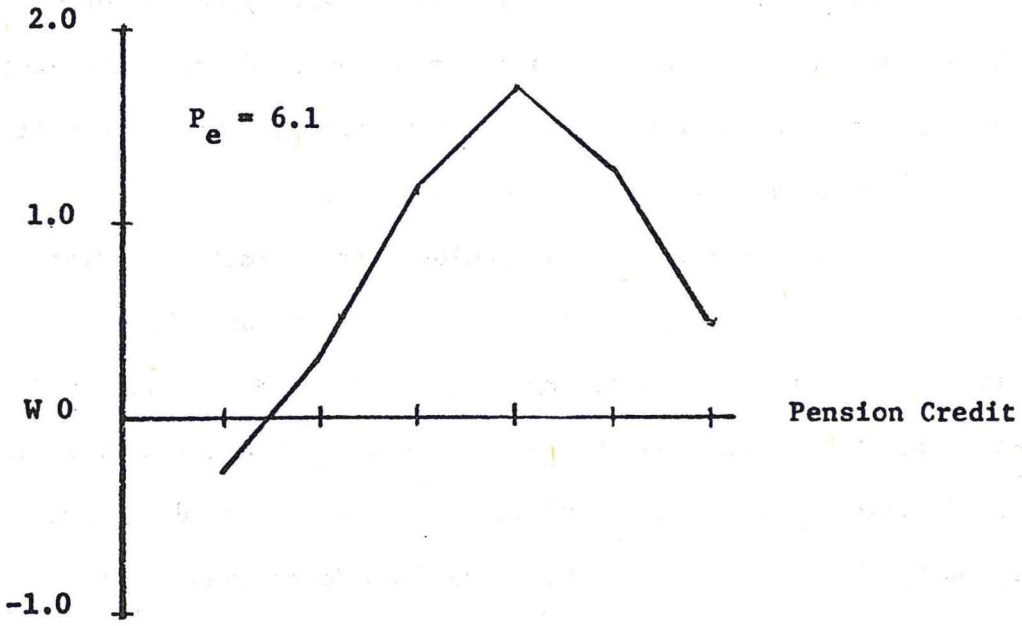


Figure IV-7b

a. If so no peak exists

b. If not, peak exists, proceed to step 4

4. Calculate peak metric according to equation on page 48.

A repetition of this process results in a set of sample values of P_e generated under the null hypothesis.

TABLE IV-1

	IV - 7a				IV - 7b			
P. C. Group	W	ΔW	Wt	Wt x ΔW	W	ΔW	Wt	WtxΔW
1 and 2	-.3				-.3			
						.6	3	1.8
3	-.4				.3			
						.9	2	1.8
4	.2				1.2			
		1.5	1	1.5		.5	1	.5
5	1.7				1.7			
		1.9	1	1.9		.4	1	.4
6	-.2				1.3			
						.8	2	1.6
7	.1				.5			
P_e = ΣWeight x ΔW				3.4				6.1

The distribution of P_e depends on the number of points defining the curve, six in this case, and the mountain-valley parameter delta. A value of delta = 1.0 was used in the runs reported below and experience showed this value to be a reasonable choice although mountain-valleys were quite uncommon in the actual morbidity data.

The Monte Carlo experiment employed to estimate the distribution of P_e found 740 peaks in 2949 trials. Hence, the probability of the occurrence of peaking behavior, P_p, is $.219 < P_p < .282$ with 95% confidence. Given that peaking behavior exists, the cumulative distribution function of P_e can be estimated from its sample distribution function $S_n(P_e)$, where n = 740, using confidence bands derivable from the Kolmogorov Statistic [7]. In this case the 95% confidence band about $S_{740}(P_e)$ is $\pm 1.36/\sqrt{740}$ or ± 0.05. A smoothed version of the sample distribution function derived from our simulation is shown

in Figure IV-8 together with the confidence band width. The entire cumulative distribution function $F(P_e)$ lies in the interval

$$S_n - 0.05 \leq F(P_e) \leq S_n + 0.05$$

with 95% confidence.

If one is only interested in a particular percentile of the distribution function $F(P_e)$, tolerance sets, another distribution-free technique, can be employed. For example, extrapolating from the graph of Murphy [8] for n = 740, we can state that 95% of the distribution of P_e lies below the 25th largest value from the random sample of 740 with 95% confidence. In our simulation experiment the value of this order statistic was 11.37, which will be utilized as a conservative estimate of the 95th percentile of $F(P_e)$. Therefore, if we find a value of P_e from the morbidity data such that $P_e > 11.37$ we may state that the probability of this occurrence under the null hypothesis is less than 0.05.

In summary, the three statistics Z, r_s, and P_e were calculated for each ICDA disease grouping of interest. The Z statistic tests for differences in morbidity rates on an age adjusted basis without reference to experience. The Spearman Rank Correlation coefficient tests for trends in the standardized morbidity ratios as a function of exposure and P_e is used to test for peaking behavior as related to exposure. Each of these statistics is printed on the master program standard output Figure IV-4, except in cases where no peak occurs. In such cases either "no peak" is printed or no reference to peaking will be found. The latter case occurs when the expected number of claims for some pension credit group is zero. Then, $W_i = O_i - E_i / \sqrt{E_i}$ and SMR = O_i / E_i are infinite and the SMR is set equal to 9999.99 for purposes of calculating r_s which does not depend on the actual magnitude of W_i.

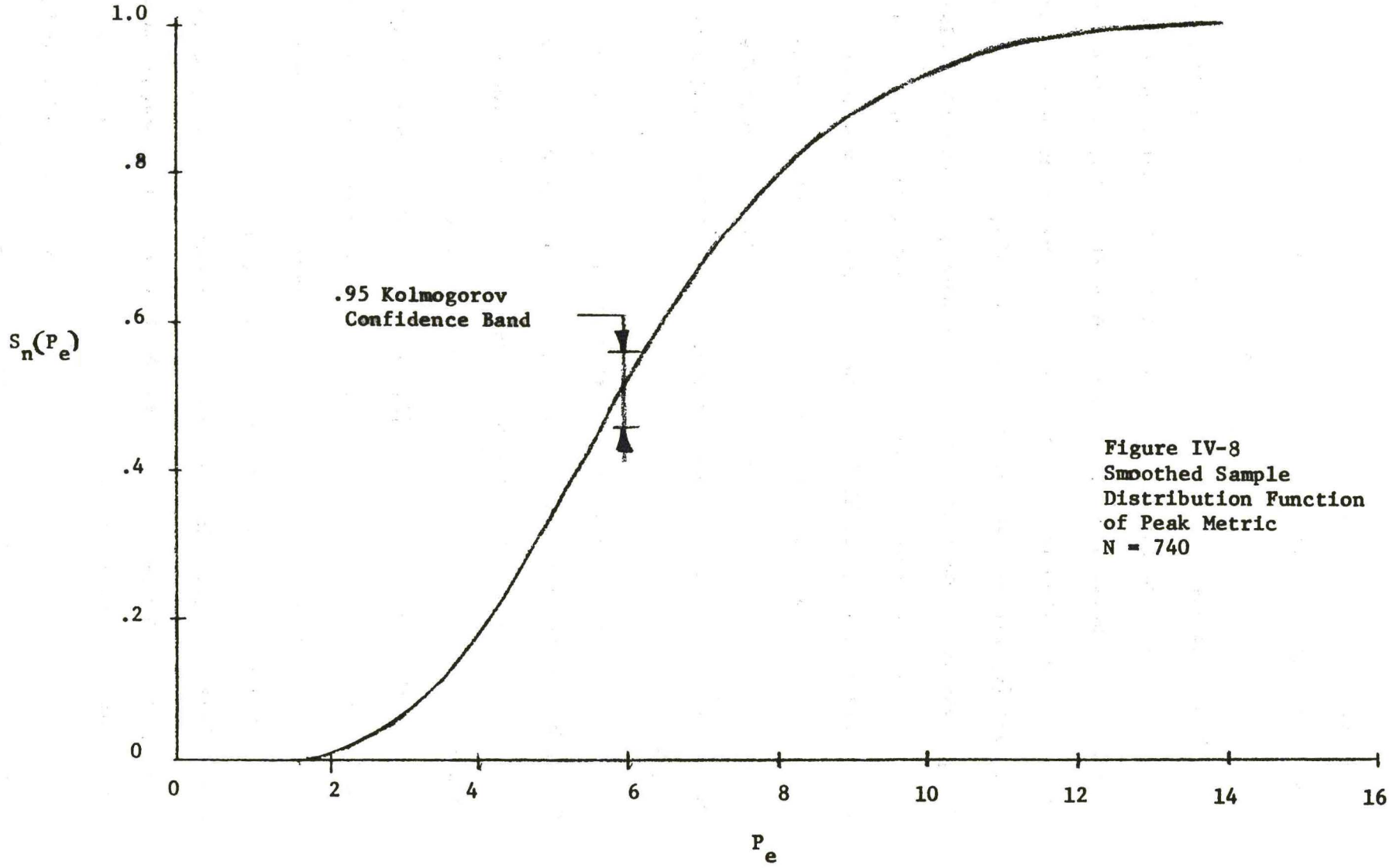


Figure IV-8
Smoothed Sample
Distribution Function
of Peak Metric
N = 740

V. RESULTS AND DISCUSSION

Preface

As a preface to presenting the results of the study it must be recalled that the objective was to attempt to identify any unusual morbidity experience among a population exposed to whole body vibration. Furthermore, the objective was to develop hypotheses concerning causative relationships between morbidity and exposure rather than to rigorously test pre-existing hypotheses. As a consequence, virtually all disease code groupings containing a sufficient number of claims to allow sensible interpretation were investigated. Of this set one may expect a certain number of false positives to occur simply by chance in the absence of any exposure-related causation. For example, the testing of the age adjusted rates by the Z statistic at the 95% confidence level will result, on the average, in one false positive in twenty independent trials. That is, even if no true difference exists in the morbidity experience of the two groups, statistical fluctuations are to be expected from which we would erroneously conclude that a difference exists about one time in twenty tests.

In this Study, separate tests were made for about forty different disease categories. Further, because of the possibility of multiple diagnoses per claim, two tests on non-overlapping ICDA categories cannot be assumed independent. There are statistical methods of rigorously treating the multiple comparison problem and several were investigated. However, it was decided that a focus on hypothesis development rather than hypothesis testing would be more productive than further statistical analysis. This decision, however, requires one to constantly keep in mind

the statistical nature of the results and the possibility of falsely placing too much credence in positive results.

Statistical considerations aside, it is also necessary to insert the standard caution appropriate to epidemiological studies of this sort. That is, the finding of a positive relationship between exposure and morbidity experience is termed an association and cannot be attributed to a cause and effect relationship without the eventual specification of a mechanism of action. The literature of epidemiology includes classic examples of strong associations which subsequently turned out to be spurious in nature. To reiterate, even the strongest statistical association cannot be considered proof of causation.

Results

The principal set of results are those contrasting the morbidity experience of the exposed and control groups for the set of secondary disease groupings given in the detailed list of three digit categories of the 8th Revision of the ICDA codes. In some cases these groupings were consolidated; for example, all infective and parasitic diseases (0.1 - 136.9) were treated together. In other cases, codes were not considered when ordinarily associated with female disease conditions, prenatal morbidity, congenital conditions, or other inappropriate factors.

Of the remaining groupings, a number showed very small total numbers of claims. This necessitated the establishment of a claim number cutoff below which no reasonable contrast was thought to be possible. The cutoff rule used was that disease groupings showing less than ten total claims from the exposed group would not be considered. The rationale for basing the cutoff rule on the exposed group claims rests on our interest in excess morbidity among this group. For example, 15 claims from the exposed and none from the control group may well be of interest for rare disease conditions.

Table V-1 presents the three statistics discussed in Section IV for 38 separate ICDA code groupings. Also shown are the total claims in each category for the exposed (n_e) and the control (n_c) groups. The values of Z, r_s, and P_e at the 95% level are 1.96, .829 and 11.37, respectively.

If a peak exists the value of the peak metric is listed under P_e in the Table. If the value is in parentheses this indicates that the expected number of claims was less than five for some pension credit group and that the assumption of normality under the null hypothesis is questionable. That is, in these cases, the sample size places the interpretation of a large value of P_e in question. The symbol "-" denotes that for some pension credit group the expected number of claims is zero. The symbol "*" indicates that no peak existed and the symbol "**" that the mountain-valley condition was violated. A total of approximately 3900 claims were processed on behalf of members of the exposed and control groups in the 20 months of the study.

Discussion

Reviewing the results of Table V-1, first with respect to the Z statistic, it can be seen that the only strikingly large values are those for cerebrovascular disease and fractures of the limbs. However, in the former case the result is based on only 12 claims, all of which were submitted on behalf of members of the exposed group. Because of the small number of claims in this case it was possible to check the number of individuals responsible for the twelve claims. Five individuals were responsible for these twelve claims. As a consequence, the meaningfulness of this Z statistic in terms of vibration-effect association is highly suspect. The results for accidents are discussed separately below.

TABLE V-1

ICDA CODE	DESCRIPTION	Z	r_s	P_e	n_e	n_c
0.1 - 136.9	Infective and Parasitic Diseases	-.786	-.085	6.926	201	228
170.0 - 174.9	Malignant Neoplasm of Bone, Connective Tissue, Skin, and Breast	.545	.771	--	12	10
180.0 - 189.9	Malignant Neoplasm of Genitourinary Organs	.307	.151	--	10	9
210.0 - 228.9	Benign Neoplasms	.225	.257	(9.986)	31	31
240.0 - 246.9	Diseases of Thyroid Gland	-.428	-.028	(11.99)	15	19
250.0 - 258.9	Diseases of Other Endocrine Glands	1.942	.142	(25.60)	46	31
270.0 - 279.9	Other Metabolic Diseases	1.943	-.257	22.69	75	57
350.0 - 358.9	Diseases of Nerves and Peripheral Ganglia	.629	-.371	--	40	37
400.0 - 404.9	Hypertensive Disease	-.313	-.428	(23.78)	51	57
410.0 - 414.9	Ischemic Heart Disease	1.709	.371	18.84	84	67
420.0 - 429.9	Other Forms of Heart Disease	-.967	-.142	(7.276)	32	42
430.0 - 438.9	Cerebrovascular Disease	3.464	--	--	12	0
450.0 - 458.9	Diseases of Veins and Lymphatics, and Other Diseases of Circulatory System	.142	.485	(16.13)	35	34
460.0 - 466.9	Acute Respiratory Infections, Except Influenza	-.505	.371	(13.23)	49	57
470.0 - 474.9	Influenza	1.178	-.085	--	22	16

(Table V-1, continued)

ICDA CODE	DESCRIPTION	Z	r_s	P_e	n_e	n_c
480.0 - 486.9	Pneumonia	-.265	.085	--	20	23
490.0 - 493.9	Bronchitis, Emphysema, and Asthma	.012	.314	*	73	76
500.0 - 508.9	Other Diseases of Upper Respiratory Tract	-1.079	-.085	(15.78)	43	56
510.0 - 519.9	Other Diseases of Respiratory System	-.595	.314	--	13	17
530.0 - 537.9	Diseases of Esophagus, Stomach, and Duodenum	.685	-.600	*	73	68
550.0 - 553.9	Hernia of Abdominal Cavity	.622	.200	*	37	34
560.0 - 569.9	Other Diseases of Intestine and Peritoneum	.602	-.600	(25.64)	31	28
570.0 - 577.9	Diseases of Liver, Gallbladder and Pancreas	-.362	.753	--	14	17
590.0 - 599.9	Other Diseases of Urinary System	-.999	-.542	**	28	38
600.0 - 607.9	Diseases of Male Genital Organs	2.051	.371	*	75	55
680.0 - 686.9	Infections of Skin and Subcutaneous Tissue	-.309	.257	--	19	22
690.0 - 698.9	Other Inflammatory Conditions of Skin and Subcutaneous Tissue	-1.605	-.028	(11.61)	30	46
700.0 - 709.9	Other Diseases of Skin and Subcutaneous Tissue	-.940	.600	9.205	54	67
710.0 - 718.9	Arthritis and Rheumatism, Except Rheumatic Fever	.788	.085	10.59	108	103
720.0 - 729.9	Osteomyelitis and Other Diseases of Bone and Joint	-.313	.142	16.07	116	128

(Table V-1, continued)

ICDA CODE	DESCRIPTION	Z	r_s	P_e	n_e	n_c
730.0 - 738.9	Other Diseases of Musculoskeletal System	-.271	-.085	13.00	52	58
810.0 - 828.9	Fracture of limb	2.822	-.085	--	75	48
830.0 - 845.9	Dislocations, Sprains and Strains of Joints	-.4729	-.257	*	75	87
850.0 - 877.9	Intracranial Injuries, Internal Injuries, Lacerations of Head, Neck, Trunk	1.286	-.257	(16.54)	31	23
880.0 - 887.9	Laceration and Open Wound of Upper Limb	-.5920	.142	13.47	90	103
910.0 - 929.9	Superficial Injuries, Contusions	.7669	-.085	16.46	167	163
940 - 949.9	Burns	1.407	.273	--	10	5

The only other Z statistic which shows a significant difference in age adjusted morbidity rates at the 95% level is that for diseases of the male genital organs. This category includes prostatitis and presents one of the few results in which a reasonably convincing mechanism can be postulated since the condition is assumed by some physicians to be causally related to physical trauma. Further, it should be recalled that the misclassification problem has the effect of diminishing actual differences so the true value of Z might be supposed to be higher than the value given in Table V-1. This relationship definitely should receive specific study in the future.

There are several other Z values which approach significance. In each of these cases prominent peaking behavior is also noted and discussion of these conditions will be deferred to a later paragraph.

Turning to the question of trend in differential morbidity experience as a function of exposure it can be seen that no value of the Spearman rank correlation coefficient is significant at the 95% level. Admittedly, the test employed is not exceedingly powerful and more sophisticated analysis could be brought to bear on the data. However, there is very little in these data that suggests that the SMR is a monotonically increasing function of exposure for any disease condition.

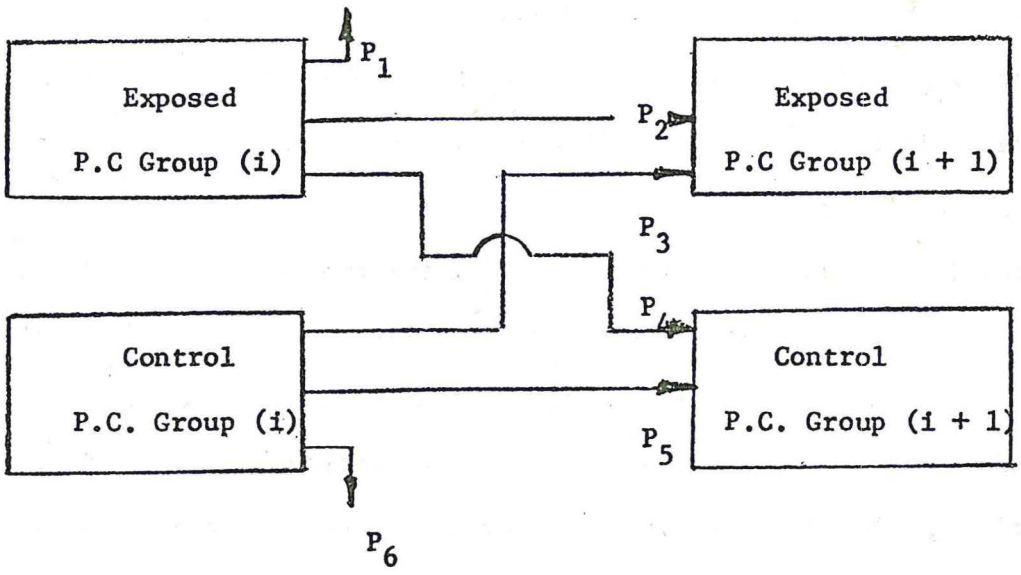
The lack of any indication of exposure-related trends in the morbidity data stimulated the search for other possible patterns and led to the identification of peaking behavior. As can be seen from Table V-I, peaking behavior is seen more often than would be expected by chance if each ICDA group contained independent data. Of the 38 runs listed in Table V-I, 20 show peaking behavior versus about 9 expected by chance under independence. However, as indicated by the figures in parentheses, peaking was often seen to occur where the expected

number of claims in at least one of the six pension credit groups was less than five. In such cases the assumptions underlying the estimation of the distribution of P_e are of questionable validity and the large peak metrics cannot be regarded as possessing the same degree of significance as similar values based on larger sample sizes. On the other hand, the peaking metric was selected so that a single outlier, as might result from a small E_i , is unlikely in itself to cause a large P_e value. That is, large values of P_e usually arise because of the regularity of the peak, not because of a single outlying value of W_i.

In those cases of peaking behavior where E_i is always greater than 5, "other metabolic diseases" shows a peak metric of 22.69 which is well above the estimate of the 95th percentile of P_e. Interestingly the Z statistic has a value of 1.943 which is only slightly less than the 95%value of 1.96. In conjunction with the P_e value of 22.69 these data are of interest. A breakdown of the 270.0 -279.9 category shows that most claims are for either "gout" (274) or "obesity not specified as of endocrine origin" (277).

Gout suggests an interesting example of a possible rationale underlying peaking behavior. A model of possible changes in job status for members of the exposed and control groups is shown in Figure V-1.

FIGURE V-1



Using this model the members of the exposed group in pension credit group i who are afflicted with a particular disease can be considered to have probability P_1 of leaving the study group entirely, probability P_2 of making the transition to the exposed group in pension credit group i+1 and probability P_4 of moving into the control group in P.C. group i+1. A similar set of probabilities exists for the control group. If P_5 is much greater than P_2 for those afflicted with the disease in question, it is likely that the SMR for P.C. group i+1 will decrease from the value for group i. For example, if a man has gout such a difference might be due to the fact that gout is quite painful and machine operation would certainly be uncomfortable. Moreover, machine operation is likely to be much more uncomfortable to the afflicted than would be continued employment as an oiler, gradechecker or other control group job.

If the disease is, in fact, caused by the exposure, the effects of exposure, followed by the selection mechanism outlined above, will lead to peaking behavior. Note that transition from the exposed group to the control group (P_4) will accentuate peaking behavior, but it is not necessary since movement out of the Study population (P_1) will also produce this phenomenon.

Clearly, the more debilitating or painful the disease, the less likely that a man in the exposed group will continue in such arduous employment regardless of the cause. If there does exist a causal relationship between whole body vibration and a severe disease condition, at any early age, however, peaking behavior in the morbidity profile is a plausible expectation. Therefore, potentially causal relationships exhibiting peaking behavior should also show a positive association between exposure to whole body vibration and the disease condition in question as measured by the Z statistic. Unfortunately, peaking behavior will tend to diminish the association reflected by the Z value as well as to destroy the linear trend with time of exposure as measured by the Spearman Rank Correlation coefficient. Peaking behavior itself, however, is at least an indication of an adverse effect from those jobs which expose the worker to whole body vibration whether or not it is due to that cause.

Peaking behavior also occurs in the case of ischemic heart disease (410.0 - 414.9). Again, P_e substantially exceeds its 95th percentile value and again the Z statistic is high, Z = 1.709, although not exceeding the 95% level of 1.96. Clearly, most disease conditions listed under ischemic heart disease would appear to be sufficiently severe to strongly mitigate against continued employment as an operator of the machines included in the exposed group and therefore suggest the strong possibility of retirement or job change for medical reasons.

The values of the Z and P_e statistics for ischemic heart disease are the most disturbing findings of this study. The data certainly do not present an overwhelming degree of association but the severity of the disease, coupled with the peaking behavior and the suggested excess of claims on an age adjusted basis, are sufficient evidence to merit further specific study.

Another facet of the exposure related results is illustrated by the data on diseases of the male genital organs. As previously noted, the age adjusted claim rate for the exposed group significantly exceeds that of the control group. However, no peak occurs in the experience related contrast. This data is consistent with what would be expected for an acute condition which, once cured, did not result in an increased likelihood of recurrence.

It is for diseases of the musculoskeletal system that the peaking phenomenon gives further suggestive results. For ICDA categories 720.0 - 729.9 and 730.0 - 738.9 the P_e values are 16.07 and 13.00, respectively. Both of these categories contain a variety of conditions which range from back pains to specific clinical conditions such as "displacement of intervertebral disc." Both categories certainly contain painful and debilitating complaints which might easily cause a man to seek employment not involving whole body vibration.

The Z statistic however shows no indication of a higher disease rate among the exposed population for either of these two categories of musculoskeletal diseases. Nonetheless, selection out of the exposed jobs is apparent. The pattern for the two code groups is remarkably similar, both peak in P.C. group 5 and for both the left base of the peak occurs at P.C. group 3 and the right base at P.C. group 7.

The number of claims in these two groups also suggested the possibility of investigating more specific diagnoses within the two categories. Two smaller code groups "displacement of intervertebral disc" (725) and "synovitis, bursitis and tenosynovitis" contained 72 and 83 claims, respectively. Both showed peaking behavior with metrics of 15.16 (725) and 17.00 (731). However, both of these smaller categories possessed fewer than five expected claims in one or more P.C groups. Nonetheless, the shape of the two curves was similar to that of the larger categories in both cases.

The final examples of peaking behavior occurred in two accident categories, "lacerations and wounds of the upper limb" and "superficial injuries and contusions." In neither case was the Z statistic significant. However, a Z value of 2.822 occurred for "fractures of the limbs" but in this case no peaking behavior was seen. In all three of these categories the number of claims was relatively high as indicated in Table V-I. These data present a most confusing picture and no plausible explanation has been developed. However, the large number of accidents and the presence of the experience related peaks do suggest a possible explanation of peaks in some other disease categories. As mentioned previously, claims often contain multiple diagnoses, sometimes for conditions which appear to be quite unrelated. It may be that a man seeks medical attention for an accident and mentions some secondary complaint which causes the physician to order laboratory tests or other diagnostic procedures unrelated to the original cause of the visit. For example, our data suggest that a peak may exist for diabetes in pension credit group 6 although the sample size is too small to support more than a suspicion. It might be that adult-type diabetes was diagnosed incidentally and that the peak is a result of the excess

number of men in the exposed group who sought medical attention for accidents or other unrelated complaints. Fortunately, future analysis of the existing data base may be able to shed some light on this question.

Conclusions

With the exception of diseases of the male genital organs, there is no persuasive evidence for the existence of increased age adjusted morbidity rates among men exposed to whole body vibration over the control population when experience is not taken into account. Further, on the basis of these data there appear to be no disease conditions for which the standardized morbidity ratio tends to increase continually with exposure to whole body vibration.

There does exist evidence of a selection process in which members of the exposed group leave jobs which subject them to whole body vibration when they become afflicted with certain disease conditions. It appears that among such diseases are obesity, gout, ischemic heart disease and musculoskeletal diseases included in the ICDA categories 720 - 729 and 730 - 738. In each of these cases, the shape of the curve relating relative morbidity to exposure to whole body vibration is consistent with the pattern that would occur if a causative mechanism and a selection process were operating. However, with the exception of the musculoskeletal diseases for which increased incidence as measured by the Z statistic was not found causative mechanisms are not readily apparent. Therefore, these results constitute suggestive associations which should receive further specific study.

A final word of caution is necessary with regard to peaking behavior. The unusual incidence of this phenomenon in the data stimulated the more detailed study of the statistical aspects of this finding as well as possible explanations. To then apply the peaking statistic to the original data can be justifiably criticized as a form of circular reasoning. In defense of the procedure it can only be said that a selection process makes sense for severe or painful diseases and that the existence of such a process is yet another hypothesis which awaits independent confirmation in the future.

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APPENDIX

FIGURE A1-1

IBM

INTERNATIONAL BUSINESS MACHINES CORPORATION

GX24-6599-0
Printed in U.S.A.

MULTIPLE-CARD LAYOUT FORM

Company OPER. ENG. LOC. 3

Application VIBRATION STUDY by _____ Date _____ Job No. _____ Sheet No. _____

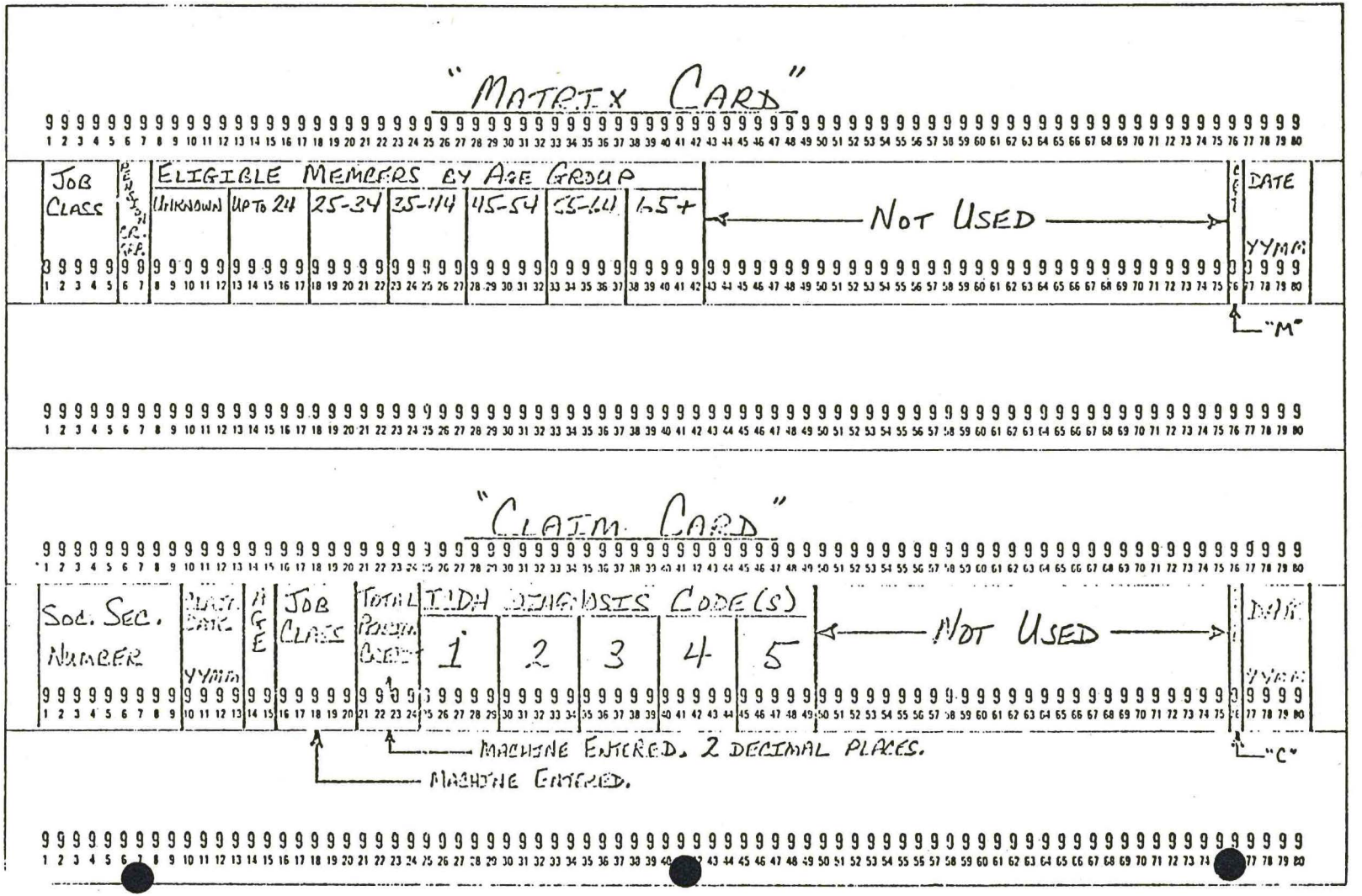


FIGURE A1-2

PAGE 1

O. E. VIBRATION STUDY

PUNCH "C" IN COL. 76 ALL

STUDY DATE MO. YR.

PUNCH IN COLS. 77-80 ALL

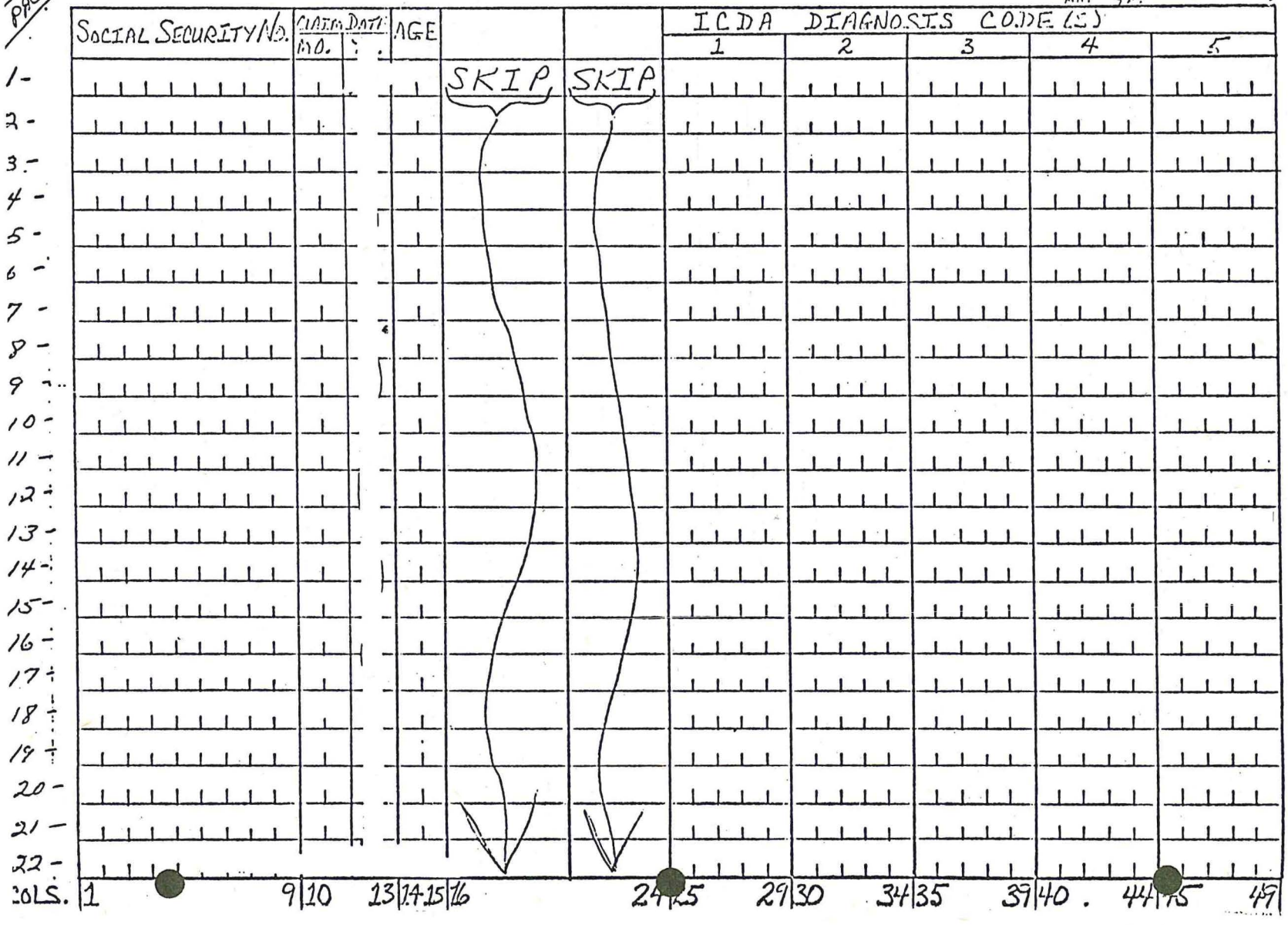


FIGURE A1-3

C. W. SWEENEY & COMPANY
Consultants and Administrators
Group Insurance Plans . Pension Programs
209 GOLDEN GATE AVENUE . SAN FRANCISCO 94102
Telephone 863-3235
AREA CODE 415

November 13, 1972

Dr.

RE: Name:_____

Claim No:_____

Diagnosis dated:_____

Stated diagnosis:_____

_____

Dear Dr.

_____For coding purposes we require a more specific diagnosis.

_x___May we have a current diagnosis of the patient's condition.

_____Please fill in the requested information below and return this form to us.

_____

_____

_____

_____

Thank you for your cooperation.

Coding Desk

(Mrs.) Ruth E. Clyatt, ART

FIGURE A1-4

FORM A

NAME _____

AGE _____

1. In your job experience, which do you feel has been the most damaging to your health: noise, heat, fumes or dust? _____

_____.

2. How many years have you worked in the construction industry? _____years.

3. What is your current job classification? _____.

4. On the average, how many months of the year do you work in construction? _____months.

5. Below are listed a number of machines, As nearly as you can remember, give the total amount of time you have spent operating each of these machines since you started working in the construction industry. If you have never worked on a particular machine, put zero.

SELF-PROPELLED COMPACTOR	_____Yrs._____Months
DOZER	_____Yrs._____Months
RUBBER-TIRED DOZERS	_____Yrs._____Months
LOADERS, RUBBER-TIRED OR TRACK TYPE	_____Yrs._____Months
RUBBER-TIRED SCRAPER, SELF LOADING	_____Yrs._____Months
TRENCHING MACHINE	_____Yrs._____Months
PORTABLE CRUSHING & SCREENING PLANTS	_____Yrs._____Months
COMBINATION BACKHOE AND LOADER	_____Yrs._____Months
BLADE OPERATOR	_____Yrs._____Months
OTHER	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months

FIGURE A1-4 (Continued)

FORM A - 2 - NAME _____

6. The same machines are listed below, As nearly as you can remember give the total amount of time you have spent operating each of these machines DURING THE PAST YEAR. If you did not work on a particular machine in the past year, put zero.

SELF-PROPELLED COMPACTOR _____Months

DOZER _____Months

RUBBER-TIRED DOZERS _____Months

LOADERS, RUBBER-TIRED OR TRACK TYPE _____Months

RUBBER-TIRED SCRAPER, SELF LOADING _____Months

TRENCHING MACHINE _____Months

PORTABLE CRUSHING & SCREENING PLANTS _____Months

COMBINATION BACKHOE AND LOADER _____Months

BLADE OPERATOR _____Months

FIGURE A1-5

FORM B

NAME _____

AGE _____

1. In your job experience, which do you feel has been the most damaging to your health: noise, heat, fumes or dust?

_____.

_____

_____

_____

_____

_____

_____

2. How many years have you worked in the construction industry?

_____years.

3. What is your current job classification? _____

_____.

4. On the average, how many months of the year do you work in construction? _____months.

5. Have you ever spent time operating a machine since you have been in the construction industry? _____. If yes, answer Question Number 6. If no, skip to Question Number 7.

FIGURE A1-5(Continued)

FORM B - 2 - NAME _____

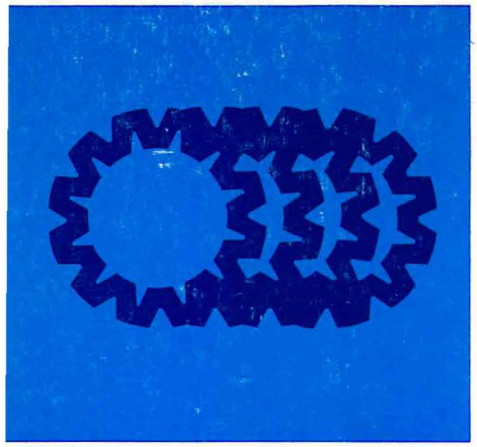
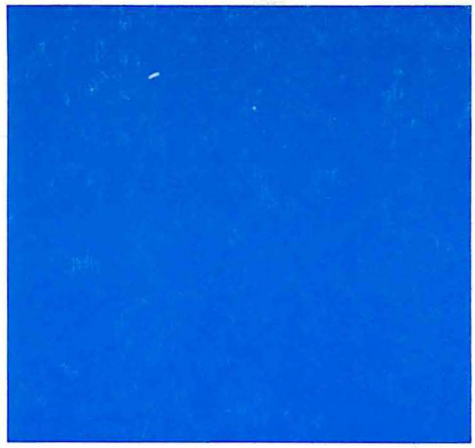
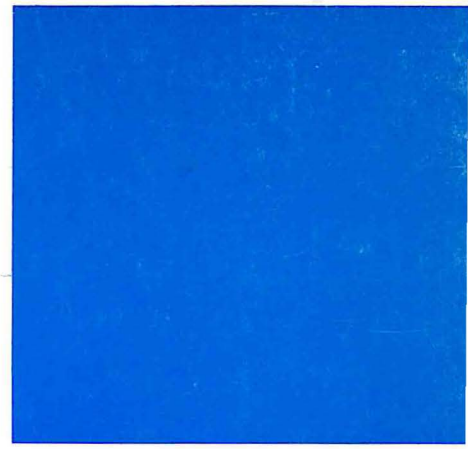
6. Below are listed a number of machines, As nearly as you can remember, give the total amount of time you have spent operating each of these machines since you started working in the construction industry. If you have never worked on a particular machine, put zero.

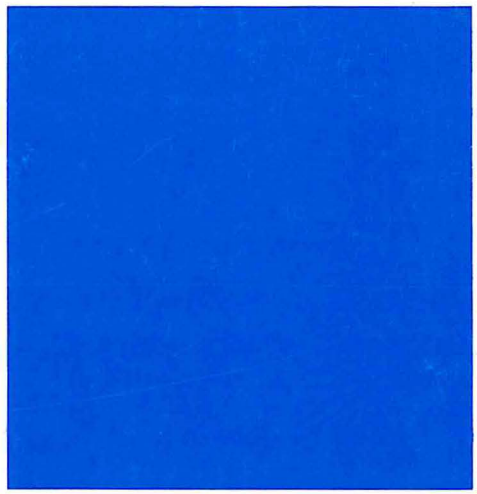
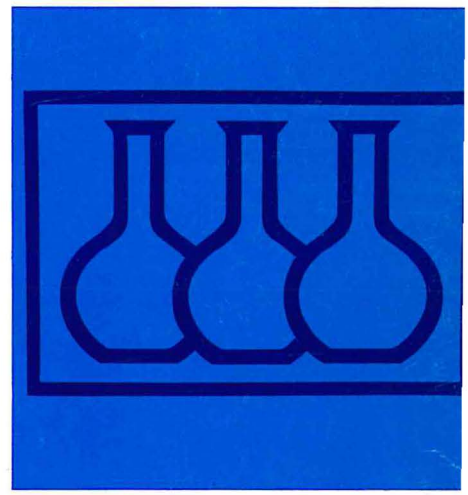
SELF-PROPELLED COMPACTOR	_____Yrs._____Months
DOZER	_____Yrs._____Months
RUBBER-TIRED DOZERS	_____Yrs._____Months
LOADERS, RUBBER-TIRED OR TRACK TYPE	_____Yrs._____Months
RUBBER-TIRED SCRAPER, SELF LOADING	_____Yrs._____Months
TRENCHING MACHINE	_____Yrs._____Months
PORTABLE CRUSHING & SCREENING PLANTS	_____Yrs._____Months
COMBINATION BACKHOE AND LOADER	_____Yrs._____Months
BLADE OPERATOR	_____Yrs._____Months
OTHER MACHINES (Please list)	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months
	_____Yrs._____Months

7. In the course of a year's work do you change from one job classification to another: Frequently _____,

Occasionally _____, Not at all _____.

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Public Health Service
Center for Disease Control
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