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Evaluation of Tremor in Aluminum Production Workers

ROBERT B. DICK,* EDWARD F. KRIEG, JR.,* MALCOLM A. SIM,‡ BRUCE P. BERNARD† AND BOBBY T. TAYLOR*

*U.S. Department of Health and Human Services, Public Health Service/Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, *Division of Biomedical and Behavioral Sciences, and † Division of Surveillance, Hazard Evaluations and Field Studies, Cincinnati, OH 45226*
‡ The Department of Epidemiology and Preventive Medicine, Monash University Clayton, Victoria, Australia

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DICK, R. B., E. F. KRIEG, JR., M. A. SIM, B. P. BERNARD AND B. T. TAYLOR. *Evaluation of tremor in aluminum production workers.* NEUROTOXICOL TERATOL **19**(6) 447–453, 1997.—A cross-sectional study of 63 current and former aluminum potroom workers and 37 comparison workers was conducted to evaluate for evidence of neurological dysfunction, including tremor from long-term exposures to aluminum using sensitive quantitative measures of arm/hand and leg tremor. Signs of upper extremity tremor were also evaluated by neurological examination and compared with the quantitative measures of arm/hand tremor. Both arm/hand and leg tremor were measured using fatiguing test conditions, but no statistically significant differences due to exposure to aluminum were present between the potroom workers and the comparison workers. The neurological examination also showed no statistically significant differences between the groups on the evaluation of signs of tremor. These results do not support the findings of Best-Pettersen et al., who reported evidence of increased tremor in aluminum workers using the static steadiness test in the Halstead-Reitan battery. Differences between the studies that may have contributed to the contrasting results are discussed. In addition, techniques are presented for using microcomputer-controlled devices to evaluate tremor in both the visible (1–6 Hz) and nonvisible (7–18 Hz) frequencies of the tremor spectrum. Published by Elsevier Science Inc.

Aluminum exposure Tremor Neurotoxicity Aluminum production

ALUMINUM was first identified by Doellken as a neurotoxin in 1897 and Spofforth in 1921 reported specific effects (e.g., memory loss, impaired coordination) on the human central nervous system (CNS) (13). In addition to neurotoxic effects, a large body of literature exists documenting the biological effects of aluminum at the cellular level. Experimentally, aluminum encephalophathy can be induced in animals by injecting aluminum salts intracranially, intravenously, or subcutaneously. Typically, after administration there is a progressive decline of higher cortical functions, which are manifested by short-term memory impairments and motor disturbances (13).

Direct experimental evidence of aluminum neurotoxicity in humans has not been conclusive, but aluminum has been suspected as a causative agent of neurological disorders in hemodialysis patients (1,2), human neurodegenerative diseases such as Alzheimer's (12,13), amyotrophic lateral sclerosis (17), and Parkinson's disease (8).

Studies of workers exposed to aluminum dust in industrial exposures have also reported some evidence of impaired cognitive functions, encephalopathy, and neurological dysfunction (11,14,19,23). Recently, Bast-Pettersen et al. (3) reported on a study of neuropsychological deficits in older workers employed for 10 years or more in aluminum production. One statistically significant effect reported was an elevation of tremor in the potroom group in comparison with a group of foundry workers and a control group. Tremor was measured by the static steadiness test in the Halstead-Reitan battery.

In 1993, the National Institute for Occupational Safety and Health performed a study to investigate neurological disorders in a study of aluminum potroom workers at a plant where an increased prevalence of neurological symptoms was reported by workers. The overall study results, which showed no differences in neurologic function between the potroom and comparison workers, have been reported elsewhere (22)

Requests for reprints should be addressed to Robert B. Dick, National Institute for Occupational Safety and Health, MS C-24, 4676 Columbia Parkway, Cincinnati, OH 45226.

and in a NIOSH Health Hazard Evaluation report (15). The purpose of this article is to report a study of tremor in a group of workers exposed to alumina dust using quantitative measurement techniques conducted with physically fatiguing test conditions. Tremor was also assessed by a neurologist using a standard examination protocol and compared with the measurements of both the visible and nonvisible tremor in the arm/hand segments. Whereas brief summaries of the tremor data have been reported in two other reports, the significance of dissimilar tremor results between two populations in different countries with similar exposures requires an assessment of the methods and techniques of measurement to explain the contrasting findings.

In addition to the results of the exposure effects, this article is intended to be useful to other investigators who wish to use quantitative measurement techniques for the evaluation of tremor in field studies.

METHOD

Study Design

The tremor data were collected in 1993 during a NIOSH cross-sectional study of 100 current and former workers employed at an aluminum reduction plant. The plant had been in operation since 1966 and used the Hall-Heroult process to reduce alumina into aluminum. The highest exposures to aluminum take place in a potroom, which is a series of electrically connected pots (e.g., electrolytic cells) called a potline. During alumina reduction, a crust forms on top of the molten bath and the continuous feed of alumina requires the crust to be broken. The plant used a side-break method to remove the crust. Workers are exposed to dust containing aluminum and fumes when the crust is broken. The Hall-Heroult process uses anodes and cathodes made of carbon and coal tar pitch and, at this plant, these anodes are prebaked in a separate building. The final product, molten aluminum, is siphoned from the pots and transformed by ladles to a separate location on the plant site called the casting area or cast house.

At this large plant site, the workers were employed in three physically separate plant areas, with different exposure concentrations to aluminum: 1) potroom—maximal exposure; 2) carbon plant—minimal exposure; and 3) cast house—minimal exposure. Production methods have been consistent since the opening of the plant with only one major production change that would affect aluminum exposure. In 1972, hoods were installed on the potlines that reduced exposures to aluminum considerably (21).

Subjects

Historically, worker turnover at the plant has been low, the workforce has been predominantly male, and workers have generally worked at the same plant location, which minimized demographic and employment variables. Procedures describing subject selection, testing procedures, and test methods for all the tests are described in other publications (15,22). With the exception of the tremor test procedures, only brief summaries of the overall methods are reported below.

In total, 98 potroom workers (65 still employed and 35 former workers) and 76 comparison group workers (49 still employed and 27 former workers) met the eligibility criteria (15) and were contacted to participate in the study. Former workers also included a small number who were compensation claimants for neurologic disorders. Members of each group were sent a letter outlining the study, the details of testing, the time required for participation, and procedures for volunteering to participate. Using procedures that caused minimal disruption to workers and plant production, testing took place on the plant site between 0800 h and 2300 h for 6 consecutive days.

The exposed group consisted of 63 out of the 98 eligible current and former potroom workers. This group consisted of 52 of 65 (80%) current workers, but only 11 of 35 (31%) former workers. The comparison group consisted of 37 out of 76 eligible current and former cast house and carbon plant workers. This group included 35 of 49 (71%) current workers and 2 out of 27 (7%) former workers. Because of the low participation rates, separate analyses were performed with the former and compensatory workers removed. Several current and former workers at this plant who were eligible for the study had been involved in previous published studies (11,23) and no attempts were made to exclude those workers from this study.

Tests

All participants completed a self-administered questionnaire, underwent a neurological examination, and performed neurobehavioral testing (e.g., tremor, postural sway, reaction time, and vocabulary). Anthropometric measurements of the arm, hand, leg, and foot were taken along with height and weight on each worker. All evaluations and tests were conducted single blind; the experimenters had no knowledge whether the workers were from the exposed group or the comparison group, were former workers, or were compensation claimants. Only the results of the tremor testing will be reported in this article.

Test Procedures

Arm/hand tremor was measured by a user-developed device (6). Leg tremor was also measured by a device that is not commercially available (9). The technical details for each device are available from the first author. Tremor signs were evaluated by a Board-Certified Neurologist. This evaluation included resting tremor of the head, upper extremity (e.g., hands, arms), lower extremity (e.g., legs, feet), and upper extremity postural tremor. Upper extremity postural tremor, evaluated with arms outstretched on a five-point rating scale (e.g., 0 = none to +4) provided a comparison for the arm/hand tremor device.

The quantitative arm/hand and leg tremor measurements were taken under test conditions that would produce enhanced physiological tremor, characterized by large oscillations of an enhanced peak frequency between 7–12 Hz. Enhanced physiological tremor was produced by physically fatiguing limb segments (6) for two reasons: 1) to confirm the sensitivity of the test devices, and 2) to create a test condition more likely to detect subclinical tremor. Based on previous research (6) and exploratory testing, 3 min of continuous extension of the preferred arm or leg was selected for the fatigue test condition for both arm/hand and leg tremor.

Participant workers were instructed to sit up straight in a chair 1.2–1.5 m from the wall where a vertical column of circles was mounted. The tremor device was gripped (e.g., not squeezed) in the preferred hand and the workers sighted through the device at one of the circles on the wall so that the outstretched arm was in a horizontal position at a right angle to the body. The chair and the circles on the wall were adjusted until the desired horizontal position of the arm was reached, and the chair was positioned forward or backward so that the tremor device was 1.2 m from the wall with the arm held straight out. A patch was placed over the nonsighting eye to prevent squinting during the test. All workers completed the 3 min of testing.

After completion of the arm/hand tremor testing, the workers removed the eye patch and rotated their chair for leg tremor testing. With their shoes removed the workers were instructed to sit in an upright posture and extend their preferred leg straight at a 45° angle, relative to the floor, with the foot extended 30° inside the frame-shaped test device. The chair was adjusted so that the heel of the foot broke the vertical plane of the test device at least 10 cm above the bottom of the frame. All workers completed the 3 min of testing.

Tremor Device Measurements

Data samples from each minute were fast Fourier transformed into 1-Hz bands producing a power spectrum of 256 discrete points covering a frequency range of 0–30 Hz. The bottom band and top 13 bands represented frequencies of limited interest and were not retained, leaving a spectrum range of 1–18 Hz (0.94–17.70 Hz). The raw power values from each frequency were log transformed, producing for each frequency, power values for minutes 1, 2, and 3 for both horizontal and vertical measurements. Power represents a measure of amplitude expressed as power units of log transformed measurements; the base measurement is m/s^2.

The data were further characterized by calculating amplitude and frequency measures. Amplitude (e.g., total power) was calculated for each third (1–6, 7–12, 13–18 Hz) of the frequency range and total power summed over the entire frequency range. Initially, several measures were calculated to characterize the tremor, but this number was reduced by measures that showed low power (e.g., all measures in the 13–18 Hz range), little or no change with fatigue, or poor agreement with the neurological evaluation of tremor. The final measurements chosen were: 1) total power, 1–18 Hz; 2) total power, 1–6 Hz; 3) total power, 7–12 Hz; and 4) power at peak frequency, 7–12 Hz.

Statistical Analyses

To determine the final model for statistical analysis, preliminary analyses to test for the effects of several demographic/anthropomorphic variables were carried out to determine if these variables had a significant influence on the tremor measurements. Measures of tremor for group differences were analyzed using a 2 (exposure) × 2 (the direction) × 3 (fatigue) repeated measures ANOVA using the SAS® General Linear Model (GLM) program (20). The exposure factor was the group type (potroom vs. comparison), the direction factor was the horizontal measurements vs. the vertical measurements, and the fatigue factor was the three 1-min test periods. The Greenhouse–Geisser estimate of epsilon was used to adjust the degrees of freedom for the ANOVA within-subject main effects and interactions. *F*-tests were judged to be significant at $p \leq 0.05$. Separate analyses were performed with all workers tested, and with the former and compensated workers removed to account for possible selection bias.

Chi-square analysis of the workers tremor measurements was performed to determine whether there were significant differences between the groups on the neurological evaluation of the signs of tremor and if there were more outliers in the exposed workers group vs. the comparison workers. For the latter analysis, the tremor measurement scores were arranged into percentile scores. Minute two measurement scores were chosen because the scores from this period were the least variable; workers were not adjusting their target aim (occurred in minute 1) and the effects of fatigue were minimal (fatigue effects maximized in minute 3).

RESULTS

Industrial Hygiene

Industrial hygiene monitoring was not carried out because the investigation was retrospective in nature and the prime interest was in the cumulative effect of exposures over the past 25 years. Therefore, available plant records and the 1988 plant sampling data were used to document exposure histories for the worker groups. Plant site air sampling data had been collected since 1968 for total particulates, fluorides, coal tar pitch volatiles, carbon monoxide, and sulfur dioxide. In 1988 respirable aluminum was measured to provide estimates of past and present exposures to aluminum. The 1988 samples documented ratios of respirable particulate to total particulate within departments and throughout the plant. Aluminum exposure was measured to calculate the relative ratios of exposure to respirable aluminum dust, and daily work exposure was estimated by the annual mean in each department (Table 1). Other

TABLE 1
ESTIMATES OF WORK HISTORY EXPOSURES TO ALUMINUM

Measurement	Potroom	Casthouse	Carbon Plant
Mean total particulates: 1968–88*	12.5 mg/m^3	4.5 mg/m^3	10.5 mg/m^3
Ratio of respirable aluminum	6.3	1	1.9
Percent of respirable = aluminum†	60–94%	21–30%	14.7–38.9%‡
Conc. range of aluminum exposures†	0.24–0.61 mg/m^3	0.03–0.09 mg/m^3	0.03–0.07† mg/m^3
Est. mean respirable aluminum conc.† (SD)	0.50 mg/m^3 (0.17)	0.08 mg/m^3 (0.06)	0.15 mg/m^3 (0.24)

*Represents average daily estimated exposure to total particulates for years 1968–1988 based on a single summary number (12.48 mg/m^3) obtained from company records representing the mean total particulate of 1186 samples for the period 1968–1988. In some years this annualized mean was above the OSHA proposed PEL of 15 mg/m^3 and for some years the value was lower.

†The percent of the respirable particulates that is aluminum. Values calculated from measurements taken in 1988 when the mean total particulates measured were lower (6.54 mg/m^3). Total particulate measurements in the cast house and carbon plant were not markedly different from prior years. Separate measurements were not available for aluminum prior to 1988.

‡Bake oven and paste plant areas of carbon plant only.

chemicals detected in the potrooms, carbon plant, and cast house have been carbon monoxide, sulfur dioxide, hydrogen fluoride, coal tar pitch derivatives, and benzene solubles.

Aluminum exposures in the other plant areas are derived from the 1988 measurements of total particulates and the percent aluminum measurements. Examination of company records over the 25-year history of plant production revealed significant changes in the annual mean concentrations of total particulates during the years when production was high. The Occupational Safety and Health Administration (OSHA) proposed permissible exposure limits (PEL) (16) for aluminum are 15 mg/m^3 for total particulates and 5 mg/m^3 for respirable dust (e.g., aluminum). Since the installation of hoods in 1972, available records indicate that there may have been 4 years between 1973 and 1987 that mean exposures exceeded the proposed OSHA PELs due to high production.

In summary, potroom workers were exposed to higher levels of total particulates and to respirable aluminum than workers in the carbon plant or the cast house. Coal tar pitch derivative exposures were the highest in the carbon plant, with some exposures in the pot room. The highest exposures to hydrogen fluoride, CO, and SO_2 occurred in the potrooms. Some fluoride levels were detected in the casthouse and carbon plant, but were low to negligible.

Tremor Measurements

The results of the demographic and anthropometric characteristics of the worker groups revealed no significant differences in age, height, weight, leg length, arm length, hand length, and foot length between the potroom and comparison group workers. Combining the measurements for both groups, age showed a significant ($r = 0.24, p = 0.0158$) but small correlation with one power measure (1–6 Hz, horizontal) for arm/hand tremor, but no significant correlations were noted for age with leg tremor. Height, weight, and the length of the leg showed significant Pearson correlation coefficients with three power measures (1–18, 1–6, 7–12 Hz) for leg tremor on both the horizontal and vertical measures. The significant coefficients ranged between 0.25 and 0.43. Due to the lack of significant differences between the groups on the demographic and anthropometric variables and the low correlation coefficients ($r <$ 0.50), the analysis for group differences did not include any of the demographic or measurement variables in the final analysis model.

The *F*-test results for the measurements of arm/hand tremor and leg tremor showed no statistically significant differences between the groups on any of the measures of arm/hand and leg tremor, indicating the lack of any significant exposure effects. Large statistically significant effects caused by fatigue were present on all the measurements of arm/hand and leg tremor, but there were no statistically significant *F*-tests with the fatigue × exposure interaction. Figure 1 shows the 1–18 Hz total power arm/hand and leg tremor horizontal spectrum for all workers on the fatigue variable and the 1–18 Hz total power spectrum for the group comparisons using the data from minute 2. Figure 1 illustrates the expected bimodal pattern of the tremor spectrum for arm/hand tremor (6). The bimodal pattern is not present with leg tremor because the leg tremor measurement device used was not designed to measure the entire tremor spectrum.

The chi-square analysis of data showed only one statistically significant tremor score; an increase in power at the peak frequency between 7 and 12 Hz. This significant result occurred only with the vertical measurement of arm/hand tremor ($\chi^2 =$ $19.53, p = 0.02$). The result ($\chi^2 = 17.90, p = 0.04$) was still significant in the analysis with the former and compensatory workers removed. This significant result, however, was not an increase of potroom workers scores in the 80th and 90th percentiles (expected = 12.4 vs. observed = 12), but more than expected potroom workers scores in the 70th percentile and less than expected in the 50th percentile. Chi-square analysis of the leg tremor results revealed no statistically significant differences.

Neurological Examination

One or more neurologic symptoms were found in 33 (52%) of the potroom workers group and 15 (41%) of the comparison workers group. Nine of the 33 potroom workers showed evidence of tremor, eight workers had upper limb tremor, and there was one case of head tremor. Five of 15 comparison workers were judged to have upper limb tremor. The groups did not differ significantly on the evaluation of tremor signs ($\chi^2 = 0.012$, $p = 0.914$). Ratings of tremor signs by the neurologist did not exceed +2 except for the one case of a head tremor rating of +3. The location of the tremor changed from trial to trial in the case of one worker who was suspected of deception.

To evaluate the ratings of tremor signs by the neurologist and the quantitative measurement of arm/hand tremor (e.g., leg tremor was not evaluated by neurological examination) comparisons were constructed to provide evidence of agreement between the observation of the signs of tremor and the tremor test device. Because the techniques used by the neurologist rate visible tremor, the measurement of tremor on the same subjects identified by the neurologist with signs of tremor should produce measurements with the greatest amplitudes. Table 2 presents the percentile data by the number of workers with scores in the 80th and 90th percentile, the standard deviations of the scores in the 80th and 90th percentiles, and the correlation coefficients for the ratings of all workers with the measurement device. The agreement between the ratings of tremor and the measurement of tremor is $>$ 75% for workers in the 80th and 90th percentiles, where tremor is most observable. Correlation coefficients comparing the ratings of tremor with the measurement of tremor are all significant at $p \leqslant 0.0001$, confirming a statistically significant relationship between the quantitative measurement of tremor and the physical examination of tremor. A study comparing vibrotactile thresholds using an electromechanical device with the physical examination (tuning fork) of vibration sensitivity showed similar correlation results (7).

DISCUSSION

The results of this study do not confirm that long-term low-dose exposures to aluminum produce either increased signs or objective accelerametric measurements of tremor. These results conflict with a report of increased tremor in aluminum production workers in Norway (3). Restricting this discussion to the differences regarding tremor measurement and analysis and thus excluding factors such as survivor bias and participation rates, which are discussed in Sim et al. (22), there are important differences between the studies. The present study provides more complete assessment of tremor, using both observable ratings and quantitative measurements of tremor. The Bast-Pettersen (3) study assessed tremor using a test from the Halstead-Reitan neuropsychological test battery, the Klove-Matthews static steadiness test (18). The static steadiness test requires individuals to insert a stylus into a series of progressively smaller holes. The stylus is kept in the hole for 15-s periods during which total time of contact and number of

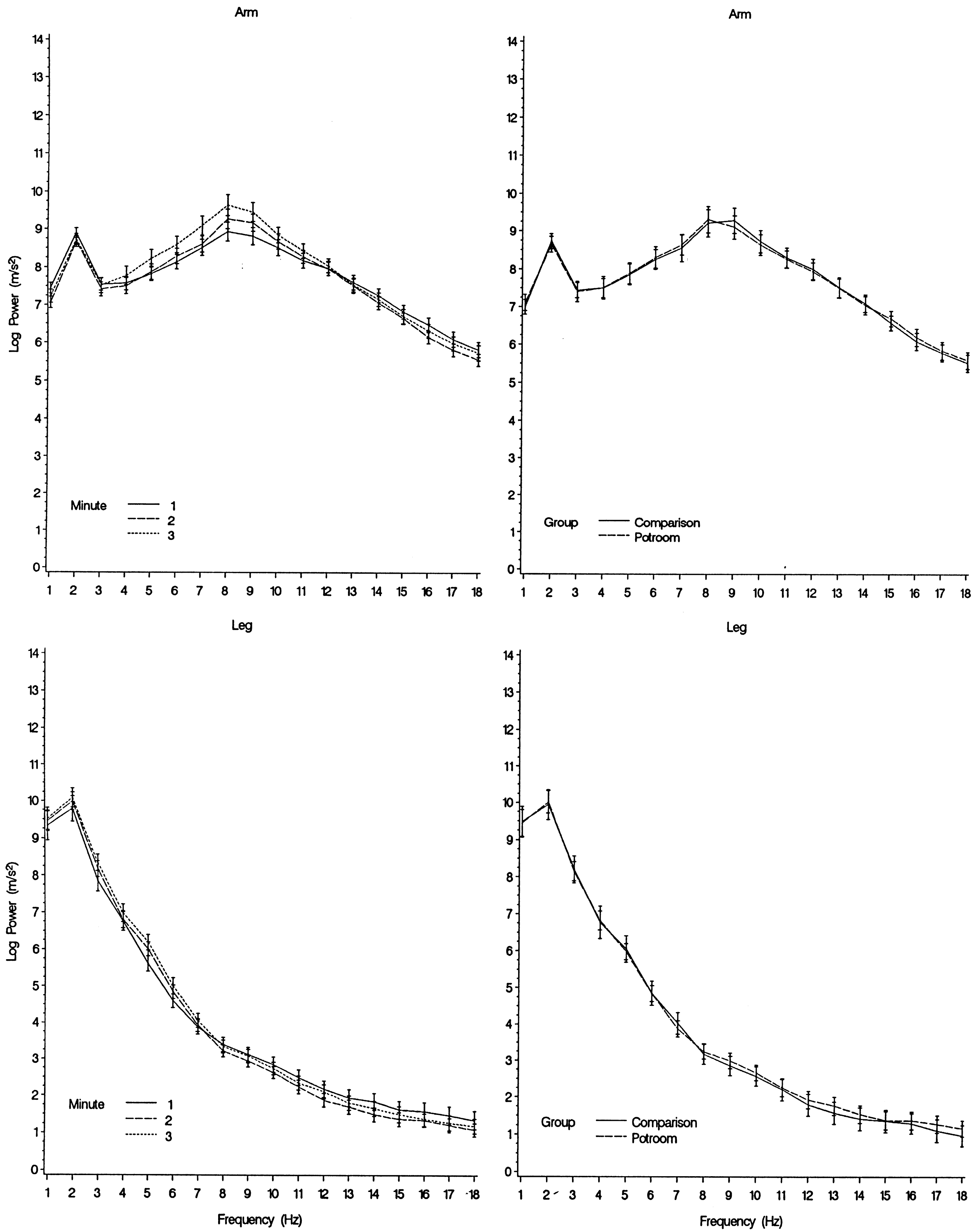

FIG. 1. Effects of fatigue on arm/hand and leg tremor using mean total power scores for each minute and the comparison of mean total power scores combined between the comparison group and the potroom group. Only horizontal measurements are displayed.

contacts are recorded for each hand. This test of tremor would grossly detect tremors of both high and low frequencies, but could not produce a power spectrum where the amplitude of tremor could be broken down by frequency bands. In addition, the Bast-Pettersen (3) study did not use test conditions that would produce enhanced physiological tremor.

Employment durations are very similar for both study groups (mean ⩾ 19), but the mean age of the worker groups in the Norwegian study is about 10 years older (63.1 vs. 54). Tremor increases with age so there is a possibility of age-related effects in the Norwegian study. In the present study age was correlated with some tremor measurements, but the test for the interaction between age and exposure was not significant for any of the arm/hand or leg tremor measurements. This type of statistical test was not reported in the Norwegian study (3).

The exposure histories of the worker groups are comparable. Echeverria et al. (5) estimated the aluminum exposure concentration for the years 1968–1987 at this study plant ranged between 1.66 and 3.99 mg/m^3. For the years after 1988, because of lower total particulates in the air (see Table 1), the range was 0.49–0.64 mg/m^3. The historical record at the Norwegian plant reported in Bast-Petterson et al. (3) dates to 1977. In 1990, the concentration of aluminum exposure was estimated at 0.48 mg/m^3 for the potroom workers at the Norwegian plant. Similar to this study plant, the average total dust concentrations at the Norwegian plant dropped from 9.5 mg/m^3 in 1977 to 3.0–3.5 mg/m^3 from 1984–1990. In summary, the exposure histories of both aluminum-exposed study groups are very comparable and for most years below the proposed OSHA PEL (16). The Norwegian study, however, does have the advantage of urinary measurements of aluminum that confirm the presence of higher concentrations of aluminum in tissues at the time of testing for the potroom group compared to the control groups.

The tremor device used in this study demonstrated good agreement with the evaluation of signs of tremor by a trained neurologist when the tremor scores were arranged into deciles. Excluding the worker with head tremor and one bad record due to equipment malfunction, only one worker rated with tremor was not detected at the 70th percentile or higher on the total power measure 1–18 Hz. This worker, however, measured in the 80–90th percentile on the total power 1–6 Hz measure and was diagnosed by the neurologist as having distal tremor, irregular, low frequency, which indicates the value of examining the power spectrum separately. The tremor device, however, recorded an almost equal number of worker scores in the 80th and 90th percentiles (see Table 2) than the observable evaluation of tremor. Tremors in workers detected by the device and not on the exam, however, tended to be less than 2 SD from the mean and may not have been detectable by observation. There were four workers with tremors detected by the device but not by the neurological exam who had measurements that fell more than 2 SD above the mean. These were probably four workers with signs of tremor not detected by the neurological examination.

Quantitative measurement devices for the detection of tremor are relatively easy to construct and with the availability of data acquisition software programs for microcomputers these devices can be set up for large field studies. Major manufacturers of data acquisition boards provide software that operate with several environments such as Microsoft C/C++, Visual Basic™, and Borland Turbo Pascal™ or in Windows based data acquisition and control programs (e.g., LabVIEW®, LABTECH®). Microcomputer-controlled devices

TABLE 2

EVALUATION OF SIGNS OF TREMOR* WITH THE MEASUREMENTS OF TREMOR USING PERCENTILES, STANDARD DEVIATIONS, AND CORRELATIONS

	Horizontal							Vertical						
	Percentile		Standard Deivation†					Pecentile		Standard Deviation				
	90th	80th	0 < 1	1 < 2	>2	Match	r‡	90th	80th	0 < 1	1 < 2	>2	Match	r
Total power 1–18 Hz														
Neurologist and device§	6	4	1	7	2	83%¶	0.57	6	3	0	6	3	75%	0.56
Device only#	4	7	5	3	3			9	3	6	4	2		
Total power 1–6 Hz														
Neurologist and device	5	6	5	5	1	92%	0.53	5	4	4	4	1	75%	0.50
Device only	5	4	4	3	2			8	3	6	3	2		
Total power 7–12 Hz														
Neurologist and device	9	2	2	5	4	92%	0.54	8	1	0	6	3	75%	0.59
Device only	2	9	5	6	1			2	9	6	5	0		
Power at peak frequency 7–12 Hz														
Neurologist and device	5	4	1	4	4	92%	0.55	7	2	0	6	3	75%	0.59
Device only	5	6	5	5	1			3	9	5	7	0		

*Fourteen workers examined by the neurologist that were reported to have signs of tremor. One of the 14 workers evidenced head tremor, (e.g., probably not detectable with the tremor device) and with another worker the device did not record a valid tremor record that was usable. Therefore, data were available from 12 workers for comparison purposes.

†The number of workers broken down by the standard deviations of their tremor measurement scores in the 80th and 90th percentiles.

‡Pearson Correlation Coefficients between the rating of tremor and the measurement of tremor for *all* workers at all percentiles.

§Number of workers with signs of tremor reported by the neurologist and scores in the 80th and 90th percentiles.

¶Percent agreement between workers with signs of tremor and tremor scores in the 80th and 90th percentile.

#Number of workers with scores in the 80th and 90th percentiles that did not have signs of tremor reported by the neurologist.

also allow for the manipulation of task parameters that may be useful in detecting subclinical effects. In this study the workers were asked to aim at a target with their arm extended for 3 min. This test condition produced enhanced physiological tremor, which may be further amplified by exposure to a neurotoxic chemical. The changes in amplitude, however, are difficult to observe or may occur at frequencies not detected easily by observation and thus require electronic measurement devices. It would be premature at this time, however, to expect this type of device to provide anything more than a test to compare exposure conditions. More research is needed on the parametric characteristics of each tremor measurement as well as a comparison with clinical populations to determine whether this type of test device is a valid screening instrument or is useful for individual diagnosis. There is evidence, however, that arranging scores into percentiles is one technique that can be used to identify outliers that may need further physical examination.

In summary, the findings of this study do not support the suggestion that workplace exposures to aluminum in potroom workers in the range of the proposed OSHA PEL (16) result in increased incidences of tremor. Neither the signs of tremor nor the quantitative measurements of tremor showed any significant differences between the potroom workers exposed to aluminum when compared to a comparison group with minimal exposures to aluminum. Similarly, the workers in Norwegian study group were also exposed to concentrations of aluminum below the proposed OSHA PEL. Frequently, when exposure concentrations are low, conflicting results can occur between studies as has been the case with several studies of nervous system functions involving exposures to organic solvents (4). Future research should concentrate on the assessment of populations that have higher exposures to aluminum so dose–response comparisons can be performed. Aluminum exposures may be associated with a threshold effect.

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REFERENCES

1. Alfrey, A. C.; LeGendre, G. R.; Kheany, W. D.: The dialysis encephalopathy syndrome: Possible aluminum intoxication. N. Engl. J. Med. 294:184–188; 1976.
2. Alfrey, A. C.: Studies related to gastrointestinal absorption of aluminum. In: Proceedings, 2nd International Conference on Aluminum and Health, Tampa, Florida, Feb. 2–6, 1992:5–6.
3. Bast-Pettersen, R.; Drablrs, P. R.; Goffeng, L. O.; Thomassen, Y.; Torres, C. G.: Neuropsychological deficit among elderly workers in aluminum production. Am. J. Ind. Med. 25:649–662; 1994.
4. Dick, R. B.: Neurobehavioral Assessment of Occupationally Relevant Solvents, Metals and Chemicals/Drugs in Humans. In: Chang, L.; Dyer, R., ed. Handbook of neurotoxicology. New York: Marcel Dekker; 1995:217–322.
5. Echeverria, D.; Graves, A.; Holland, J.; Milberg, J.; White, R.; Woods, J. S.: An investigation of factors influencing the neurologic health of Intalco aluminum workers. Batelle Human Affairs Research Centers. Report No. 100/89/9044. Seattle, Washington: October, 1989.
6. Galinsky, T. L.; Rosa, R. R.; Wheeler, D. D.: Assessing muscular fatigue with a portable tremor measurement system suitable for field use. Behav. Res. Methods Instrum. Comput. 22(6):507–516; 1990.
7. Gerr, F.; Letz, R.; Hershman, D.; Farraye, J.; Simpson, D.: Comparison of vibrotactile thresholds with physical examination and electrophysiological assessment. Muscle Nerve 14:1059–1086; 1991.
8. Hirsch, E. C.; Brandel, J. P.; Galle, P.; Javoy-Agid, F.; Agid, Y.: Iron and aluminum increase in the substantia nigra of patients with Parkinson's disease; an x-ray microanalysis. J. Neurochem. 56:446–451; 1991.
9. Kondraske, G. V.: A PC-based performance measurement laboratory system. J. Clin. Eng. 15(6):467–478; 1990.
10. Larsen, L. B.: Report of industrial hygiene surveys conducted during fiscal year 1973 in six aluminum plants located in the northwestern United States, Western Area Occupational Health Laboratory, Division of Technical Services, NIOSH, Cincinnati, OH; 1974.
11. Longstreth, W. T.; Rosenstock, L.; Heyer, N. J.: Potroom palsy? Neurologic disorder in three aluminum smelter workers. Arch. Intern. Med. 145:1972–1975; 1985.
12. Lukiw, W. J.; Bergeron, C.; Wong, L.; Kruck, T. P. A.; Kirshnan, B.; Crapper McLachlan, D. R.: Nuclear compartmentalization of aluminum in Alzheimer's disease (AD). Neurobiol. Aging 13:115–121; 1992.
13. Lukiw, W. J.; McLachlan, D. R.: Aluminum Neurotoxicity. In: Chang, L. W.; Dyer, R. S., eds. Handbook of neurotoxicology. New York: Marcel Dekker; 1995:104–142.
14. McLaughlin, A. I. G.; Kazantis, G.; King, E.; Teare, D.; Porter, R. J.; Owen, R.: Pulmonary fibrosis and encephalopathy associated with the inhalation of aluminum dust. Br. J. Ind. Med. 19:253–263; 1962.
15. National Institute for Occupational Safety and Health (NIOSH). HETA 90-0149–2522 Inlalco Aluminum Corporation, NIOSH Publication Office, Cincinnati, OH; 1995.
16. Occupational Safety and Health Administration, Department of Labor, 29 CFR Part 1910, Air Contaminants; Final Rule. Federal Register, 54(12), January 19, 1989.
17. Perl, D.; Gajdusek, C.; Garruto, R.; Yanagihara, R.; Gibbs, C.: Intraneuronal aluminum accumulation in amyotrophic lateral sclerosis and parkinsonism dementia of Guam. Science 217:1053–1055; 1982.
18. Reitan, R. M.; Davison, L. A.: Clinical Neuropsychology: Current status and applications. Washington, DC: V. H. Winston & Sons; 1974.
19. Rifat, S. L.; Eastwood, M. R.; Crapper McLachlan, D. R.; Corey, P. N.: Effect of exposure of miners to aluminum powder. Lancet 336:1162–1165; 1990.
20. SAS Institute Inc. SAS/STAT user's guide, version 10, 6th ed., vol. 2. Cary, NC: SAS Institute Inc.; 1994.
21. Shuler, P. J.; Bierbaum, P. J.: Environmental surveys of aluminum reduction plants. DHEW/PHS/CDC/NIOSH, HEW Publication No. (NIOSH) 74-101; 1974.
22. Sim, M.; Dick, R.; Russo, J.; Bernard, B.; Grubb, P.; Krieg, E., Jr.; Mueller, C.; McCammon, C.: Are aluminum potroom workers at increased risk of neurological disorders? Occup. Environ. Med. 54:229–235; 1997.
23. White, D. M.; Longstreth, W. T.; Rosenstock, L.; Keith, H. J.; Claypoole, H. J.; Brodkin, C. A.; Townes, B. D.: Neurologic syndrome in 25 workers from an aluminum smelting plant. Arch. Intern. Med. 152:1443–1448; 1992.