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Workers exposed to metallic mercury vapor were subjects for EMG, hand tremor and psychomotor tests conducted over an eighteen month period. Performance decrements in neuromuscular functions and psychmotor skills were found to be reversible and correlated with blood and urine mercury levels.

Subclinical psychomotor and neuromuscular changes in workers exposed to inorganic mercury

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Introduction

It is a well recognized fact that chronic exposure to mercury can result in complex alterations to a person's physiological state with the primary effects being to the central nervous system. These manifest themselves in varied symptoms and signs, as well as in altering the person's performance capabilities. If the chronic exposure is incurred as part of the person's job, occupational health and safety problems can exist, depending upon both the amount of exposure (dose), the length of time exposed and the individual's decrement in capabilities.

A current management problem is to prevent mercurialism by means of adequate monitoring of levels in both the air and in the exposed workers. This will assure that even the earliest signs of deterioration in the person's health or performance are detected and prevented from progression. An objective of this study, therefore, was to explore the means of recognizing overexposure subclinically in order that appropriate corrective action can be taken before permanent damage is incurred.

It was desirable to be able to compare the results of this study with past research which has relied on correlations between clinical findings and exposure levels. Thus, traditional clinical neurological and blood-urine analyses data were collected in order to determine the extent to which they might correlate with the unique subclinical psychomotor and neuromuscular measures being explored.[1,2]

Methodology

INDEPENDENT FACTORS

The independent factors in this study included: subjects; blood and urine mercury levels; and subject biological and historical factors. This study involved 142 male volunteer *subjects*

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TABLE I
Summary of Independent Variables from First Visit Studies

PLANT	I			II			III		
GROUP	CONTROL	EXPOSED	COMBINED	CONTROL	EXPOSED	COMBINED	CONTROL	EXPOSED	COMBINED
Sample Size	15	20	35	14	23	37*	26	24	50
Height	70.2	69.5	69.8	69.3	70.6	70.1	69.7	69.5	69.6
(inches)	(3.08)	(2.42)	(2.70)	(3.15)	(2.98)	(3.7)	(2.68)	(2.66)	(2.64)
Weight	172	174	173	166	172	169	177	184	181
(pounds)	(18.7)	(38.0)	(30.8)	(32.4)	(31.2)	(31.3)	(23.6)	(26.0)	(24.9)
Age	31.2	27.2	28.9	49.9	41.5	44.7	33.6	36.4	35.1
(years)	(7.0)	(7.3)	(7.4)	(6.4)	(7.4)	(8.0)	(9.6)	(8.9)	(9.4)
Dur. of Exp.	—	30.8	—	—	93.2	—	—	25.2	—
(months)		(26.7)			(85.4)			(16.1)	
Cigarette	0.29	0.0	0.21	0.79	0.83	0.81	0.42	0.42	0.42
(packs/day)	(0.49)	(data on 6 subjects only)	(0.48)	(0.55)	(0.68)	(0.63)	(0.56)	(0.56)	(0.56)
Blood Mercury	2.17	6.25	4.45	5.89	17.11	12.74*	0.90	3.97	2.56
(μg/100 ml)	(1.10)	(3.66)	(3.47)	(2.71)	(5.77)	(7.32)	(0.45)	(3.04)	(2.72)
Urine	68	288	197	152	787	547*	18.3	143	84
(μ/liter)	(53)	(240)	(216)	(100)	(471)	(486)	(22.1)	(104)	(99)

Note: Numbers in parentheses indicate Standard Deviation.
*Only parts of this sample were used for the various comparisons made in the text; thus, the blood-urine means discussed are for those subjects in the respective sub-samples used from these 37.

from four different plants. Seventy-seven of these people were working in jobs where daily exposure to inorganic mercury was incurred, thus resulting in them being identified for this study as the *exposed group*. The remaining sixty-five people were classified as *controls,* based on the participating plant's industrial hygiene and safety personnel designating that they were not currently, nor had they (within the past six months) been working in areas where mercury exposure could take place. Many from this control group were, however, exposed to some degree, as measured by their increased blood-urine mercury levels. Thus, the "exposed" vs. "control" group designations were to some extent a misnomer and must be cautiously interpreted. Age matching was also requested of the cooperating plant people but reasonably achieved only in the last two plant groups visited.

The first three plant groups (Groups I, II and III) were engaged in chloralkali manufacturing, while the fourth group (Group IV) worked in a patented process for the manufacturing of magnetic materials. Groups I and II were revisited during the study period. This provided the opportunity to collect some retest data on people who had demonstrated marked reductions in their urine mercury levels as a result of changes in climatic conditions, industrial hygiene controls, and/or jobs which reduced their exposure to mercury.

The major objective of this study was to gather the necessary data to indicate how specific neurological and psychomotor functions correlate with a person's blood or urine mercury levels at the time of testing. Thus, the current blood and urine mercury levels were chosen as two of the major independent variables. The laboratory method for determining the value of each was that of flameless atomic absorption.

There were several subject related biological and historical independent factors which were chosen as possibly relating to the dependent measures. These included:

(1) Height (stature) and Weight,
(2) Age,
(3) Smoking Habits, and
(4) Duration of Exposure to Mercury.

A summary of the data which resulted for these independent factors is listed in Table I.

Response variables

It is noted that the response variables were not collected on all 142 subjects in the four plant groups. Since this was an exploratory study taking place in the dynamic and uncontrolled real work situation, numerous reasons contributed to the varying patterns of data collection which are summarized in Table II as a relation between numbers of subjects tested vs. type test used.

IV			ALL (I, II, III & IV)		
CONTROL	EXPOSED	COMBINED	CONTROL	EXPOSED	COMBINED
10	10	20	65	77	142
69.3	69.7	69.5	69.7	69.8	69.8
(2.16)	(2.67)	(2.37)	(2.74)	(2.71)	(2.72)
179	183	181	173	178	176
(20.2)	(19.9)	(19.6)	(24.6)	(30.2)	(27.8)
37.9	36.9	37.4	37.1	35.7	36.4
(6.45)	(6.67)	(6.41)	(10.39)	(9.47)	(9.89)
—	90.6	—	—	55.9	—
	(49.1)			(60.5)	
0.45	0.20	0.33	0.52	0.48	0.50
(0.60)	(0.34)	(0.49)	(0.58)	(0.60)	(0.59)
0.93	4.51	3.49	2.49	8.56	5.97
(0.38)	(2.54)	(2.70)	(2.51)	(6.90)	(6.23)
7.11	129	71.5	62.6	374	240
(3.26)	(69.7)	(79.8)	(78.1)	(399)	(342)

A standard clinical neurological status evaluation was administered to 32 Group II people by a neurologist. The measures included:

- History of neurological symptoms
- Mental status
- Neuromuscular symptoms
- Sensory modality status
- Cerebellar functions
- Involuntary movements
- Visual acuity
- Deep tendon reflexes
- Dermatographia
- Autonomic functions

Retesting of twelve of the people was accomplished after a four to six month period using all of the above tests.

A psychomotor test battery was developed and administered and included the following tests:

- Discrete positioning eye-hand coordinations (maze test)
- Simple reaction time
- Two-choice decision time
- Four-choice decision time
- Finger tapping speed
- Toe tapping speed
- Pencil flipping speed

This study also involved the establishment of a set of quantitive non-invasive tests of a person's neuromuscular functions which, from past data, could be expected to be sensitive to the adverse effects of inorganic mercury.

These consisted of:

- Surface Electromyography, and
- Forearm Tremor.

Data collection

TEST APPARATUS

Both the forearm tremor and biceps surface EMG were obtained simultaneously. To accomplish this a four-channel FM tape recorder (Hewlett Packard Model 3970) having a bandwidth from DC to 312 Hz. (at 15/17 IPS) was utilized. A specially constructed preamplifier (10^{11} ohms input impedance, 5K Hz. response) was used to amplify the signals with known gains. The EMG electrodes were Hewlett Packard Model 14057. The tremor transducer was specifically constructed to detect changes in a force load of less than two ounces. An oscilloscope was used to monitor both the EMG and tremor signals during the tests to assure that peak clipping did not occur[4] (Figure 1).

The discrete positioning eye-hand coordination test chosen for the study was developed by Poock.[4] It was chosen due to its test-retest repeatability, its correlation with other motor

TABLE II
Number of Subjects Tested vs. Type Test

TYPE DATA COLLECTED	GROUP I	GROUP II	GROUP III	GROUP IV	ALL I-IV
Initial Visit					
Blood-Urine	35	37	50	20	142
Eye-Hand Psychomotor	35	37	50	20	142
Other Psychomotor	—	32	50	—	82
Neuromuscular	35	37	50	20	142
Clinical Neurological	—	32	—	—	32
Revisit (Re-test)					
Blood Urine	—	12	—	20	32
Eye-Hand Psychomotor	—	12	—	20	32
Other Psychomotor	—	12	—	—	12
Neuromuscular	—	12	—	20	32
Clinical Neurological	—	12	—	—	12

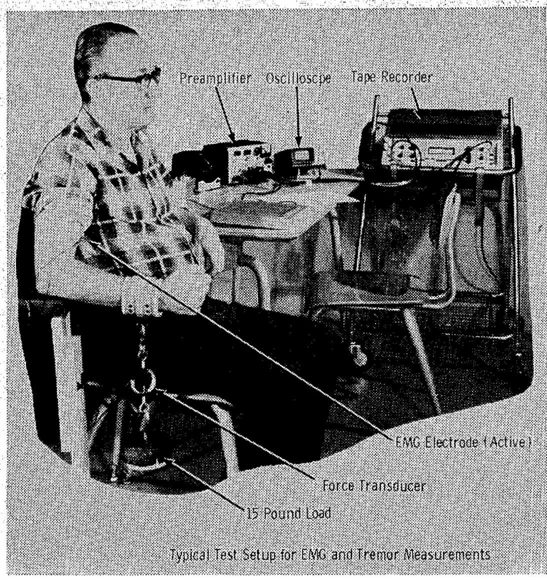

Figure 1 – Typical test setup for EMG and tremor measurements.

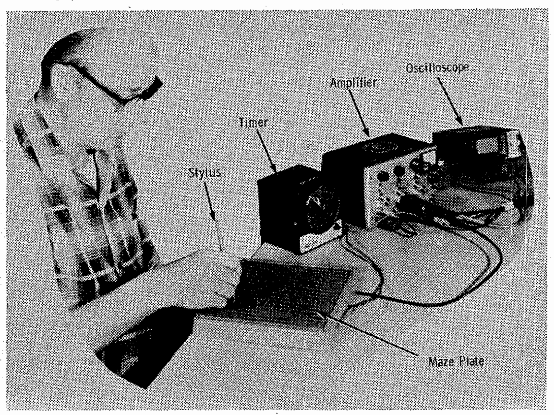

Figure 2 – Eye-hand coordination test setup.

Figure 3 – Decision test and experimental layout.

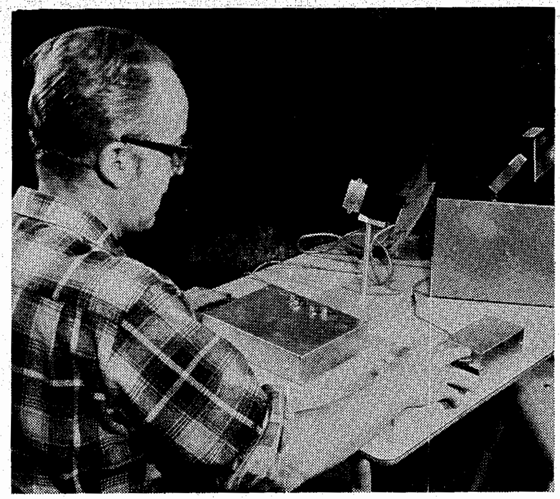

Figure 4 – Finger tapping.

functions, and its correlation with the performance demonstrated by industrial people on various hand motions (i.e., reaches, grasps, and moves) composing common industrial manual tasks.

The test is composed of a directionally varying maze of 119 holes (1/8 inch diameter) in an eight inch square steel plate. The subject is asked to repeatedly insert a stylus in each hole following a sequence dictated by a painted line connecting each hole as shown in Figure 2. Measurements were taken on both the gross time to complete the 119 hole tasks and on the individual hole-to-hole times.

With respect to other psychomotor tests in the battery, there was a sequence of ten used to investigate primarily response time and tapping capabilities. This series included the following. Note the accompanying figures referenced which depict the key tests.

Test No. 1: Two-choice decision time, Trial #1, (Figure 3)
Test No. 2: Two-choice decision time, Trial #2.
Test No. 3: Four-choice decision time, Trial #1.
Test No. 4: Four-choice decision time, Trial #2.
Test No. 5: Simple reaction time.
Test No. 6: Finger tapping (Figure 4).
Test No. 7: Toe tapping (right foot).
Test No. 8: Toe tapping (left foot) (Figure 5).
Test No. 9: Toe tapping (alternating) (Figure 6).

Test No. 10: Pencil flipping.

As noted in Table II, the psychomotor test battery described above was used in the first visit of plant Group II, the first visit to plant Group III, and finally, in the retesting of 11 subjects from plant Group II after they had been away from the mercury exposure for from four to six months.[5]

PROCEDURE

The following is a general description of the data collection sequence at each site visit:[6]

1. Set up test apparatus in quiet area of plant (usually Medical Department).
2. Coordinate scheduling of volunteers with plant nurse or medical technician to achieve an approximate interval of between 30 to 45 minutes for each volunteer.
3. Ask each volunteer to read and sign a statement regarding the purposes, risks and data confidentiality of the study.
4. Have each volunteer fill in a standardized medical questionnaire, and have him designate a physician to whom his personal test results should be sent.
5. Obtain a urine sample in an acid washed bottle.
6. Attach EMG surface electrodes in a monopolar configuration to the skin over the belly of the biceps brachii of the dominant arm.
7. Instruct the volunteer as to the eye-hand-psychomotor coordination test procedure and have him perform the test four times while recording his performance.
8. Strap a 15-pound weight and tremor measuring device to his wrist and ask the person to hold the weight for a period of five minutes, while recording both the tremor and EMG signals.
9. Perform the eye-hand psychomotor coordination maze test a fifth time immediately after the subject has set the weight down.
10. Perform clinical neurological examination. (Group II only.)
11. Conduct other psychomotor testing. (Group II and III only.)
12. Obtain a blood sample using 10 ml. vacutainers with potassium oxalate preservative.

Figure 5 – Single foot tapping.

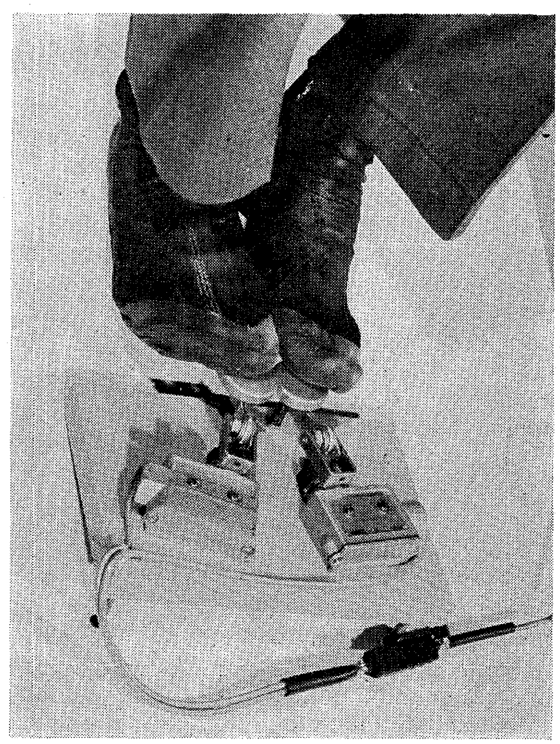

Figure 6 – Alternating foot tapping.

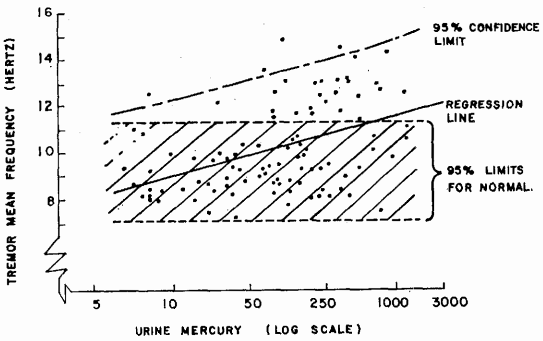

Figure 7 – Tremor frequency mean vs. urine mercury levels for all subjects.

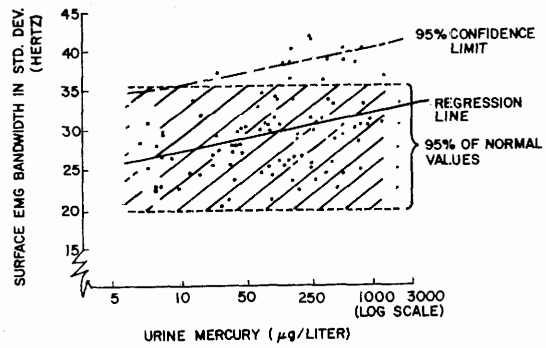

Figure 8 – Surface EMG bandwidth vs. urine mercury levels for all subjects.

Results

CLINICAL NEUROLOGICAL EXAMS

The initial group examined was 32 chloralkali workers from Group II, 18 of whom were directly exposed to mercury vapor and whose mean blood mercury level was 10 μg/100 ml. The duration of exposure ranged from 6 months to 20 years with the mean being approximately 9 years. The 12 subjects chosen for re-examination, 4 to 6 months after removal from exposure, were selected on the basis of the highest blood and/or urine mercury levels found at the initial assessment. A variety of clinical neurological abnormalities were found. These included: impaired judgment, eyelid fasiculations, hyperactive deep-tendon reflexes, and dermatographia. The extent to which these abnormalities were the result of exposure to mercury is questionable since these exam results did not correlate with mercury levels (blood and urine) or length of exposure. Furthermore, even those subjects with the high blood-urine mercury levels could not be identified by the neurologist as being sick by clinical criteria. Therefore, it is concluded that the clinical neurological exams were not sensitive enough to be used as a means of establishing the pathology of chronic exposures to inorganic mercury.

NEUROMUSCULAR TESTS

By performing a power spectral analysis on the forearm tremor for the first 15 seconds of the weight holding test, it was possible to quantify each worker's tremor frequency distribution and amplitude. The resulting values were then correlated (by step-wise regression) with the worker's biological data presented in Table I. This procedure indicated that the average tremor frequency increased significantly for persons having elevated urine mercury burdens, as depicted graphically in Figure 7. A similar graph results when blood mercury levels are plotted; although it is not quite as well correlated.[1]

Thirty-two of the same people were retested after being at reduced exposure for from four to six months. During this time, their urine mercury levels reduced from the initial mean levels of 562 ugm/L. to a mean of 347 ugm/L. It was found that their mean tremor frequencies also decreased significantly from a mean of 11.4 Hz. to a more normal mean of 9.3 Hz. This, then, indicated a reversal in the effects of mercury on tremor frequency.

A power spectra analysis was also performed on the EMG's obtained from the biceps brachii of each worker during this same 15 seconds of weight holding. Once again the resulting power spectra statistical moments were regressed onto each person's biological data presented in Table II. From this, it was determined that as body mercury levels increased the bandwidth of the electromyogram was larger with both the low and high frequency power increased. Figure 8 depicts this data as plotted against the log of the urine mercury levels.

When retesting 24 of the same Group II workers after from four to six months in a greatly reduced exposure, their EMG frequency bandwidths (standard deviations) were significantly reduced from 31.7 Hz to 28.6 Hz. This corresponded to a lowering in urine mercury levels from a mean of 599 ugm/L. to a mean of 292 ugm/L.

Frequency shifts in the surface EMG were monitored during the five minute weight holding test. The rate of these shifts with time was taken as the indicator of localized muscle fatigue. These rates for each worker were then

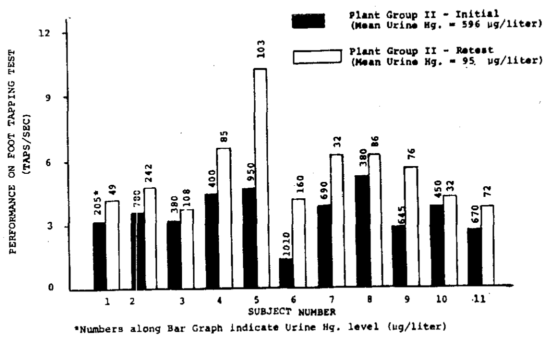

Figure 9 – Test/retest comparison of right foot tapping rates.

correlated with his biological data in Table I. The results of this analysis disclosed that a greater height or weight tended to correlate with a higher rate of fatigue, but current urine or blood mercury levels did not correlate with these same fatigue rates.

PSYCHOMOTOR TESTS

With respect to gross time to perform the eye-hand coordination maze task the age factor was the most important in explaining an overall slowed performance. The mercury effect was the next factor to come out of the multistep linear regression used to analyze performance time. However, this effect seemed to act to speed up performance time, contrary to what might have been expected. But at the same time, variability as measured by hole-to-hole time increased as discussed below.

The statistical moments describing each worker's hole-to-hole motion time distribution were regressed onto their biological data in Table II. This resulted in the finding that the workers who had elevated blood and urine mercury levels also tended to be slightly more erratic in their movements between the 119 holes. This effect was slightly more pronounced when these same workers had preceded the test with the physical activity of holding a 15 pound weight in the dominant hand.

For the retest situation, the reduced exposure period decreased their mean urine mercury levels from 599 ugm/L. to 292 ugm/L. and also resulted in improving their eye-hand coordination. This improvement consisted of about a 5% faster mean time with 5% lower standard deviations. These effects, though significant, are admittedly small and should not be overemphasized without further experimental evidence.

Tapping performance was the secondary psychomotor test that became most significantly correlated with increased mercury body burdens. Rates for finger tapping, right foot tapping, left foot tapping, and alternating foot toe tapping were all significantly decreased in those people having elevated mercury burdens. This result was based on the testing of the 82 workers comprising plant groups II and III, as depicted in the earlier Table II. When 11 of the workers having initially high urine mercury levels of 596 ugm/Liter were removed from exposure for from four to six months, their mean urine mercury levels decreased to 95 ugm/Liter. Their tapping rates increased an average of about 40 percent showing a considerable reversal effect. The dramatic reversal in right toe tapping was particularly striking for all 11 workers on the retest (Figure 9).

It was also found that those people having elevated mercury burdens tended to be slower in responding to simple forced-choice tasks and simple reaction time tests. Unfortunately, a lack of consistency among the various response time statistical significance tests makes us reluctant to draw any conclusions. However, it would appear that further research is warranted.

SUMMARY OF RESULTS

With respect to the clinical neurological findings, the presence of the abnormalities of dermatographia (skin writing) and eye-lid fasciculations in those people having currently elevated urine and blood mercury levels was significant. These signs did not remit in those people after removed from exposure. Cerebellar functioning and involuntary movements were evaluated by observing intention tremors, dysmetria and dysdiadikokinesia. Of the 32 people initially tested, 12 had at least one type of the more classical symptoms of mercury poisoning. Especially noted were tremors about the mouth, tongue, and other facial and head tremors. In the retest group, four who had the tremors initially showed complete clearing of the cerebellar deficits.

The following neuromuscular and psychomotor characteristics were found with elevated levels of blood and urine mercury burdens.

1. The frequency of forearm tremor increased.
2. The bandwidth of the surface EMG increased.

3. The speed of hand and foot tapping decreased while response times tended to increase.
4. The ability to consistently move the hand quickly to discrete position (eye-hand coordination) becomes more varied.

On retesting of the above measures after a four to six month period of reduced exposure, it was concluded from the data that these decrements in functional capabilities were reversible below a mercury body burden of about 600 ugm liter of blood. These findings seem to be more consistent than the reversals found in the clinical neurological exam and seem to further substantiate the feasibility of subclinical functional measures as having a potential utility for assessing the health of a person who is occupationally exposed to inorganic mercury. It was, therefore, proposed that a longitudinal demonstration project be established to assess the utility of these tests in controlling industrial mercury intoxication. This is currently being performed by these authors.

Discussion

With further development and evaluation of additional quantitative neurological tests, it should be possible to better establish the pathology of long term chronic exposures to inorganic mercury. The present study clearly indicates that psychomotor control is greatly affected.

It was surprising that the simple variable, "length of time exposed to occupational mercury," was not a good predictor of either the effects on a person's health, or a person's current urine and blood mercury burdens. Future studies of this type should include a long history of either routine atmospheric or biological sampling records to provide more detailed information regarding the worker's history of exposure as compared to his performance decrement and health status.

It would appear that health status testing using behavioral and neurological measures should be considered for any person routinely exposed to mercury when their blood concentrations exceed approximately 100 ugm/liter. In other words, this might be considered as a recommended "Health evaluation action level" for mercury. It was at this level that a significant number of people had changes in their neuromuscular indices of tremor and EMG. Psychomotor performance seemed to be adversely affected at slightly higher urine levels. On exceeding this 100 ugm/liter level, a person would be routinely examined to determine if any deterioration in his health status has taken place. The outcome of these functionally based health evaluations would assist in determining if the individual should be removed from exposure, or be retested at frequent intervals. The basis for choosing between these alternatives should be the subject of further investigations.

Localized muscle fatigue per se, as determined by EMG frequency changes in the standardized five minute weight holding test, is probably not associated with increased mercury body burdens. It must be noted, however, that the performance on the eye-hand coordination test was more adversely affected by mercury when the test was performed after the standard exertion period. Thus, a standardized exertion may be helpful in differentiating the effects of mercury on certain psychomotor test parameters; and therefore, its use in the development of better performance testing should be pursued. Furthermore, additional evaluations of muscle fatigue as affected by elevated mercury body burdens should be undertaken using measures other than the EMG frequency shift (since only bandwidth was found to change).

In general, is it believed by these investigators that this study has greatly contributed to the knowledge required to define the mercury control procedures which are both necessary and reasonable. The challenge now is to further develop and implement health evaluation tests which can be routinely administered when mercury intoxication is suspected. With these tests, it is proposed that the effects due to other toxic materials as well as mercury could be controlled in a manner that would provide the maximum protection of the individual's health and safety.

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