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Chronic neurobehavioural effects of elemental mercury in dentists

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Abstract

Neurobehavioural tests were performed by 98 dentists (mean age 32, range 24–49) exposed to elemental mercury vapour and 54 controls (mean age 34, range 23–50) with no history of occupational exposure to mercury. The dentists were exposed to an average personal air concentration time weighted average (TWA) of 0·014 (range 0·0007–0·042) mg/m^3 for a mean period of 5·5 (range 0·7–24) years and had a mean blood mercury concentration of 9·8 (range 0·6–57) μg/l. In neurobehavioural tests measuring motor speed (finger tapping), visual scanning (trail making), visuomotor coordination and concentration (digit symbol), verbal memory (digit span, logical memory delayed recall), visual memory (visual reproduction, immediate and delayed recall), and visuomotor coordination speed (bender-gestalt time), the performance of the dentists was significantly worse than that of the controls. The dentists scored 3·9 to 38·9% (mean 13·9%) worse in these tests. In trail making, digit span, logical memory delayed recall, visual reproduction delayed recall, and bender-gestalt time test scores were more than 10% poorer. In each of the tests in which significant differences were found and in the block design time, the performance decreased as the exposed dose (product of the TWA of air mercury concentrations and the years of exposure) increased. These results raise the question as to whether the current threshold limit value of 0·050 mg/m^3 (TWA) provides adequate protection against adverse effects of mercury.

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The organs most frequently affected by metallic mercury in chronically exposed subjects are the nervous system, kidney, and mucosal surfaces of the mouth.[1,2] The central nervous system is probably the most sensitive organ.[3-5] Many studies on the neurotoxic effects of mercury have been reported.[4-13] The earlier ones were usually on subjects exposed to high concentrations (more than 0·05 mg/m^3) of mercury.[5,7] Some of the more recent studies generally lack adequate measurements on exposure to mercury.[4,12]

Neurobehavioural performance tests are sensitive methods used to detect subclinical effects.[9,10] The purpose of this study was to measure early changes in performance of motor speed, manual dexterity, visual scanning, and visual and verbal memory among dentists exposed to mercury vapour at concentrations of less than 0·05 mg/m^3 in their work environment.

Materials and methods

STUDY POPULATION

A cross sectional study of 98 dentists (representing 32% of active dentists in Singapore), 38 women and 60 men exposed to a time weighted average (TWA) concentration of air mercury vapour below 0·05 mg/m^3 was undertaken. The dentists typically worked 10 hours a day for a six day work week in air conditioned rooms. A control group of 54 persons (27 women and 27 men) with no history of occupational exposure to mercury were selected from staff at the National University of Singapore. Questionnaires were used to select subjects (dentists and controls) that did not have a history of neuropathy from diabetes, renal diseases and excessive alcohol use, disease of the central or peripheral nervous system or psychiatric disorders, surgery or injuries to arms or legs, or head or spinal cord surgery or injuries.

EXPOSURE TO MERCURY

Exposure to mercury among the dentists was monitored with diffusive personal sampling badges (catalog No 520–02 and 520–03, SKC Inc 334 Valley View Road, 84, PA 15330, USA) over the entire working hours for the individual dentists (8–10 hours) and expressed as eight hour TWA. Venous blood samples were taken towards the end of the work day to allow a check on the exposure concentrations. Four of the dentists were randomly selected for monitoring through a work week to assess the daily variation in exposure to mercury.

MERCURY ANALYSIS

The mercury concentrations of the biological and air samples were analysed by cold vapour atomic absorption spectrophotometry. The details of the instruments and the analytical technique have been described elsewhere.[14] Our laboratory has participated in an interlaboratory quality control programme offered by the Centre of Toxicology of Quebec (2705, Boul Laurire, Sainte-Foy, Quebec GIV 4G2). The exposed SKC badges were first treated with 5 ml of concentrated nitric acid and 5 ml of concentrated hydrochloric acid for 30 minutes to extract the mercury. The extract was made up to 25 ml with deionised water and 1–5 ml of the solution were analysed. For an eight hour sample, the detection limit was 0·001 mg/m^3. Ten parallel samples using SKC and 3M badges were taken at a mercury battery plant. The exposed 3M badges were analysed by the manufacturer. The air mercury concentrations ranged from 0·008 to 0·049 mg/m^3. The differences in air mercury concentrations obtained by the two brands of sampling badges averaged 12%.

NEUROBEHAVIOURAL TEST BATTERY

The neurobehavioural performance of the dentists and controls was evaluated with a battery of 10 tests comprised of finger tapping, trail making, symbol digit modalities, digit span, Wechsler memory scale, grooved peg board, visual reproduction, bender-gestalt, block design, logical memory, and seashore rhythm. The first five of these tests have been previously described.[15 16] The other tests are described here.

Visual reproduction test—Three cards with printed design from the Wechsler memory scale were shown, one at a time, to the subject for 10 seconds each. Then the card was removed and the subject was instructed to draw the design immediately and again 60 minutes later. Scoring was according to Wechsler's method.[16 17] The higher the score the better the performance.

Bender gestalt test—The subject was asked to copy nine designs, one at a time, on to a piece of paper. The time for the completion of the test was recorded. The test was administered and scored according to the procedure of Lacks.[18] The higher the score the poorer the performance.

Logical memory test—This test consisted of two separate passages.[17] The subject was instructed to recall as many of the 24 "elements" or "ideas" in each short passage presented from a tape recorder immediately and 30 minutes later. The higher the score the better the performance.

Block design test—The subject was presented with nine red and white blocks and was instructed to build, one at a time, replicas of nine printed designs using the blocks. The times (seconds) for completing each design were recorded and the performance was scored on a standard score sheet, from the revised Wechsler adult intelligence scale (WAIS-R).[16 19] The longer the time the poorer the performance. Block design is associated with perceptual motor coordination and motor speed.

Seashore rhythm test—The subject was required to discriminate between like and unlike pairs of musical beats.[20] A total of 30 musical pairs was administered with a portable tape recorder. The number of correct discriminations was scored.

PSYCHIATRIC SYMPTOMS

Profile of mood states—A 65 item questionnaire[21] was used. The subjects were asked to indicate their moods during the week before and including the date of testing, on a five point scale. The test was scored with templates from the Educational and Industrial Testing Service (San Diego, California 92107, USA). The mood states evaluated were tension, depression, aggression, fatigue, confusion, and vigour.

INTELLIGENCE TESTS

Four subtests from the WAIS-R (Wechsler adult intelligence scale revised)[19] were selected to assess the subjects' verbal, perceptual and, integration abilities. The tests were:

Block design test—This has been described under the section, neurobehavioural test battery.

Block design scores measure the perceptual intelligence of the subjects.

Similarity—This is a 14 items subtest. The subject was asked to comment verbally on how two objects were similar. The higher the score the better the performance. It assesses the verbal abstract ability of the subjects.

Comprehension—This is a 16 item questionnaire. The subject was asked to answer the questions and score according to WAIS-R recommendations. The higher the score the better the performance. Comprehension assesses the verbal reasoning ability of the subjects.

Picture completion—The subject was asked to identify the missing part in each of 20 pictures shown one at a time. Each picture was shown for no more than 20 seconds. The correct answers were scored. The higher the score the better the performance. Picture completion measures the visual perception and visual search ability of the subjects.

Survey

Interviews and tests were carried out at the start of the work day, between 09.00 and 11.00 hours. Personal information was recorded with a structured questionnaire. Fish consumption was recorded as number of meals containing fish per week, and alcohol intake, smoking, and drug intake with a yes or no answer. Amalgam fillings were evaluated through dental charting. The subjects were examined orally using a standard dental mouth mirror and a disposable tongue blade. Standard dental charting was done for each subject by a trained dentist (Dr Ngim). All the existing teeth were examined. The extent and dimension of the fillings were sketched on to dental charts. Dental surface area was scored using a weighted scale where each surface charted was scored as one. For example, a distal class II dental amalgam restoration on a premolar was scored as two. On a molar, a class II with entire occlusal and distal surfaces inlaid was scored as three. A lingual pit filling on incisors was scored as one.

Subjects were randomly tested. As the identity of the subjects was known to the interviewer (surveys were carried out at subjects' offices), the interviewer was required to follow the testing procedure strictly. Air and blood samples were collected on the day that neurobehavioural tests were conducted and the identity of the air and blood samples was protected through coding. Blood samples were not collected from the controls.

STATISTICAL ANALYSIS

Statistical analysis was run with a commercial software package from the SAS Inc (SAS Circle, Cary, NC 27512). Differences between the subjects exposed to mercury and their controls were tested by analyses of covariance. The dose-effect relation between neurobehavioural performance score and amount of exposure was examined by regression analysis with the general linear models procedure. The PROC GLM procedure was used for both the analysis of covariance and the regression analysis.

The normality of the neurobehavioural performance data sets was tested separately for the dentists and controls with PROC UNIVARIATE. Cumulative logit models (using PROC LOGISTIC) were also applied to some of the data sets with non-normal distributions.

Significant differences between exposed and controls could arise through bias in the selection controls. Conducting statistical analysis on the dentists alone should avoid the pitfalls. The dentists were categorised into four exposure subgroups by dividing at the median value of the blood mercury concentration (or air mercury concentration) and duration of exposure for the comparison between these exposed subgroups and between the subgroups and the controls. Differences in performance were evaluated by analysis of covariance using the PROC GLM procedure.

Profiles of mood states were analysed by the cumulative logit model using the PROC LOGISTIC procedure. In this analysis, each of the six mood states studied was divided into four categories (roughly corresponding to quantiles) according to the scores of the controls ($n = 54$), giving a frequency of 11 to 16 for each category of the controls. Comparison was also made between controls and two subgroups of dentists, the low exposure group ($n = 47$) exposed at maximum to 0·93 mg months/m^3 mercury, and the high exposure group ($n = 51$) exposed to more than 0·93 mg-months/m^3.

Results

Table 1 shows the characteristics of the study population. The exposed group and controls were adequately matched in age, amount of fish consumption, and number of amalgam dental fillings. The men were less well matched for alcohol consumption and smoking habits, the differences were not significant.

Statistically significant differences were found between the years of education and the use of traditional Chinese medicinal products that might contain mercury. The sex distribution between the dentists and controls was not identical. All of the above mentioned factors were adjusted for in statistical analysis.

Table 1 Characteristics of study population

	Controls			*Exposed*		
	Women	*Men*	*All*	*Women*	*Men*	*All*
Sample size	27	27	54	38	60	98
Age (y)	31·2	36·0	33·6 (23–50)	28·2	33·9	31·7 (24–49)
Education (y)	16·7	17·5	17·1 (14–22)	16·2*	16·3*	16·2* (16–19)
Fish (meals per week)	5·4	4·5	4·9 (0–11)	5·4	5·1	5·2 (0–14)
Dental surfaces†	13·6	9·52	11·6 (0–48)	12·9	8·66	10·3 (0–45)
Alcohol (%)	3·7	37	20	5·3	18	13
Smokers (%)	3·7	30	17	2·6	17	11
Traditional medicine (%)	96	63	80	34*	25*	29*

*$p < 0·05$.
†Number of standardised amalgam surfaces.
With the exception of sample size, figures are arithmetic means (range in parentheses).

Table 2 Indicators of exposure to mercury for the dentists

	Women	*Men*	*All*
Air conc (8h TWA) μg/m³			
AM (SD)	16·4 (9·4)	16·9 (9·5)	16·7 (9·4)
GM (SD)	13·8 (1·9)	13·5 (2·2)	13·6 (2·1) (0·7–42)*
Duration (months):			
AM (SD)	61·3 (42·5)	106·4 (69·8)	88·9 (64·3)
GM (SD)	47·7 (2·1)	81·1 (2·3)	66·0 (2·3) (8–288)*
Dose (mg months/m³):			
AM (SD)	1·07 (1·08)	1·94 (1·63)	1·60 (1·49)
GM (SD)	0·66 (2·9)	1·13 (3·7)	0·93 (3·4) (0·013–17·2)*
Blood (μg/l):			
AM (SD)	13·1 (7·3)	11·9 (8·6)	12·3 (8·1)
GM (SD)	10·4 (2·2)	9·5 (2·2)	9·8 (2·2) (0·63–57·3)*

*Ranges.
AM = arithmetic mean; GM = geometric mean.

Table 2 shows the exposure indicators for the dentists. The product of the exposure intensity and the total duration of exposure was used as a surrogate for dose. The dentists were exposed to a geometric mean (GM) of 0·014 mg/m³ of mercury vapour for a period of 66 months. Their GM mean dose was 0·93 mg months/m³. Their blood mercury concentrations averaged (GM) 9·8 μg/l. The male and female dentists seemed equally exposed but the men had been practising much longer than their female counterparts at the time of study (81 *v* 48 months).

The dentists were exposed to a low dose of mercury vapour. About half were exposed to less than 1·0 mg months/m³ and about 30% were exposed to less than 0·5 mg months/m³. Figure 1 shows the frequency distribution of the dose.

Table 3 shows the results of the intelligence tests between the dentists and the controls. The dentists were better in the comprehension test and the difference was significant. No statistically significant differences were detected in similarity, picture completion, and block design scores; IQ scores were not assessed for the subjects but standard scores (averaged Z scores for the four intelligence tests) were calculated. No statistically significant differences was found.

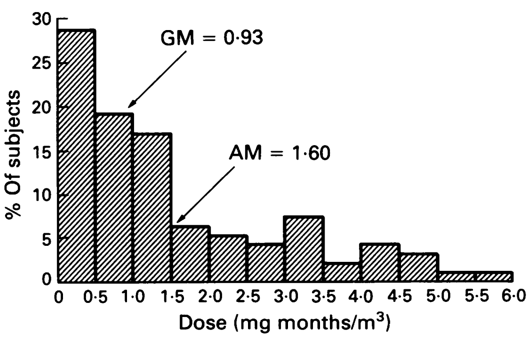

Figure 1 Frequency distribution of mercury exposure dose (mg/m³ months) in the dentists. GM geometric mean, AM arithmetic mean.

Table 4 shows the results of the battery of neurobehavioural tests. The dentists generally performed worse than the controls. The differences in finger tapping, trail making, symbol digit, digit span, logical memory recall, visual reproduction, visual reproduction recall, and Bender gestalt time scores between the dentists and the controls were significant. The size of the differences ranged from 3·9 to 38·9% (average 13·9%). Trail making, digit span, logical memory delayed recall, visual reproduction delayed recall, and Bender gestalt time recorded a test score difference of more than 10%. The differences in neurobehavioural performance scores for the rest of the tests were not statistically significant.

Table 5 shows the relation of the neurobehavioural test scores with the dose in mg months/m³. The factors entered in the generalised linear models (PROC GLM of SAS Inc) were dose, age, sex, education, traditional Chinese medicinal products, dental fillings, smoking, alcohol, and fish consumption. The confounding factors most often found to be significant were age, sex, education, and traditional Chinese medicinal products. The controls and dentists were included in the analysis. The controls were given a mercury dose of zero. The dentists exposed to a higher dose generally performed worse in the neurobehavioural tests carried out in this study. The dose-effect between performance scores and dose was statistically significant for finger tapping, trail making, symbol digit, digit span, logical memory (delayed recall), visual reproduction (immediate and delayed recall), and block design time.

Due to daily variation in exposure, the surrogate dose (TWA × months exposed) could wrongly classify the levels of dosage the dentists received. To assess the magnitude of daily fluctuation of exposure, four randomly selected dentists were monitored over

Table 3 Effects of mercury vapour on WAIS-R subscales

	*Analysis of covariance**		
	Least square means (SE)		
WAIS-R subscales	*Controls*	*Exposed*	*p Value (two tailed)*
Block design	39·2 (1·00)	*38·0*† (1·05)	0·38
Similarity	*21·5* (0·53)	22·5 (0·47)	0·10
Comprehension	*25·5* (0·49)	26·8 (0·44)	0·02
Picture completion	14·7 (0·38)	*14·4* (0·34)	0·46
Average standard score‡	*0·047* (0·12)	0·16 (0·11)	0·29

*Adjusted for age, sex, education, dental fillings, smoking, and consumption of alcohol, fish, and chinese traditional medicine.
†Values in italics are worse in performance.
‡Average Z score value for the four WAIS-R subscales.

Table 4 Neurobehavioural effects of exposure to mercury vapour tests

Tests	Analysis of covariance* — Least square means (SE) — Controls	Exposed	p Value (two tailed)
Finger tapping			
Dominant hand	51·3 (0·84)	*49·5*† (0·62)	0·11
Non-dominant hand	46·6 (0·72)	*44·5* (0·53)	0·03
Average	48·9 (0·73)	*47·0* (0·53)	0·04
Seashore rhythm	*25·3* (0·46)	25·6 (0·34)	0·57
Trail making test			
Part A (numerical sequence)	25·9 (0·92)	*28·8* (0·67)	0·02
Part B (α-numerical sequence)	49·2 (2·0)	*59·2* (1·5)	0·00
Average	37·6 (1·27)	*44·0* (0·93)	0·00
Symbol digit			
Written	63·1 (1·1)	*58·2* (0·81)	0·00
Oral	70·2 (1·4)	*67·3* (1·0)	0·11
Average	66·6 (1·17)	*62·7* (0·81)	0·01
Digit span			
Forward	7·6 (0·14)	*7·1* (0·11)	0·00
Backward	6·8 (0·15)	*5·7* (0·11)	0·00
Total	14·4 (0·26)	*12·7* (0·20)	0·00
Grooved peg board:			
Dominant hand	57·7 (0·92)	*59·3* (0·68)	0·18
Non-dominant hand	63·8 (1·3)	*65·2* (0·98)	0·41
Average	60·7 (1·00)	*62·2* (0·73)	0·25
Logical memory (immediate recall)	17·2 (0·42)	*16·2* (0·31)	0·09
Logical memory (delayed recall)	16·9 (0·44)	*14·6* (0·32)	0·00
Visual reproduction (immediate recall)	12·1 (0·31)	*11·1* (0·22)	0·01
Visual reproduction (delayed recall)	10·3 (0·47)	9·1 (0·34)	0·05
Block design:			
Score	39·2 (0·99)	*38·0* (0·73)	0·38
Time	311·3 (14·6)	*342·1* (10·6)	0·11
Bender Gestalt:			
Lacks score	0·33 (0·09)	*0·44* (0·04)	0·39
Lacks time	5·4 (0·40)	*7·5* (0·30)	0·00

*Adjusted for age, sex, education, dental fillings, smoking, and consumption of alcohol, fish and Chinese traditional medicine.
†Values in italics represent worse performance.

Table 5 Relation between cumulative exposure to mercury vapour and behavioural tests in dentists

Performance tests	General linear model analysis* — Dose — Effect	Coeff (SE)	p Value (two tailed)
Finger tapping:			
Dominant hand	+	−0·471 (0·270)	0·08
Non-dominant hand	+	−0·501 (0·229)	0·03
Average	+	−0·486 (0·625)	0·04
Seashore rhythm	+	−0·092 (0·147)	0·53
Trail making test:			
Part A (numerical sequence)	+	0·216 (0·293)	0·46
Part B (α-numerical sequence)	+	1·787 (0·635)	0·01
Average	+	1·001 (0·405)	0·01
Symbol digit:			
Written	+	−1·030 (0·361)	0·01
Oral	+	−0·961 (0·434)	0·03
Average	+	−0·995 (0·374)	0·01
Digit span:			
Forward	+	−0·197 (0·043)	0·00
Backward	+	−0·203 (0·049)	0·00
Total	+	−0·400 (0·085)	0·00
Grooved peg board:			
Dominant hand	+	0·275 (0·300)	0·36
Non-dominant hand	−	−0·013 (0·432)	0·98
Average	+	0·131 (0·324)	0·69
Logical memory (immediate recall)	+	−0·199 (0·134)	0·14
Logical memory (delayed recall)	+	−0·341 (0·143)	0·02
Visual reproduction (immediate recall)	+	−0·279 (0·097)	0·00
Visual reproduction (delayed recall)	+	−0·378 (0·146)	0·01
Block design:			
Score	+	−0·532 (0·314)	0·09
Time	+	10·17 (4·59)	0·03
Bender Gestalt:			
Lacks score	+	0·053 (0·029)	0·07
Lacks time	+	0·321 (0·133)	0·02

*Adjusted for age, sex, education, dental fillings, smoking, and consumption of alcohol, fish, and traditional Chinese medicine.
+Positive effect: regression analysis showing poorer performance with increasing dose; −negative effect: regression analysis showing better performance with increasing dose.

a period of one work week. Figure 2 shows the results.

The dentists had a high aggression score more often than the controls (fig 3). The odds for the dentists to score higher than 1 on the aggression scale was 6·8 (95% CI 2·2–21·4) times, and the odds for scoring higher than 4 on the aggression scale was 2·8 (95% CI 1·3–6·3) times higher than the controls. The aggressive mood was related to dose. The odds for the dentists exposed to a dose less than 0·93 mg months/m^3 (GM 0·32, 95% CI 0·05–2·0) was 1·4 (95% CI 0·9–2·1) times higher than the controls, and the odds for the dentists exposed to a dose of more than 0·93 mg months/m^3 (GM 2·24, 95% CI 0·80–6·33) was 2·2 (95% CI 1·0–4·8).

Statistical analyses were also carried out after subdividing the dentists into low and high intensity of exposure (I_1 and I_2) and duration (D_1 and D_2) at the median value, giving I_1D_1 (blood mercury (BHg) 7·2 μg/l; exposure duration (D) 41·5 months), I_1D_2 (BHg 8·1 μg/l, D 125·8 months), I_2D_1 (BHg 19·5 μg/l, D 32·4 months), and I_2D_2 (BHg 18·6 μg/l, D 160·4 months) four subgroups. The higher exposure subgroups performed generally worse than the lower exposed subgroups (lower blood mercury concentrations, or shorter years of exposure, or both). The poorer performance by the higher exposed subgroups compared with lower exposed subgroups was statistically significant ($p < 0·05$) in the digit symbol, digit span, trail making, logical memory delayed recalls and visual reproduction delayed recall tests. Figure 4 is a bar chart for the trail making and visual reproduction test for the four subgroups and controls. Similar results were obtained when air mercury, instead of blood mercury concentrations were used to characterise the intensity of exposure.

The data were also viewed by plotting scattergrams. No extreme values were seen. For regression

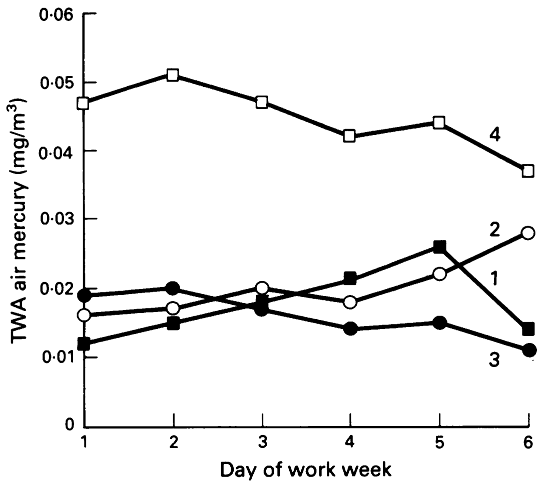

Figure 2 Daily variation of 8 h TWA mercury exposure concentrations (mg/m³) in four dentists.

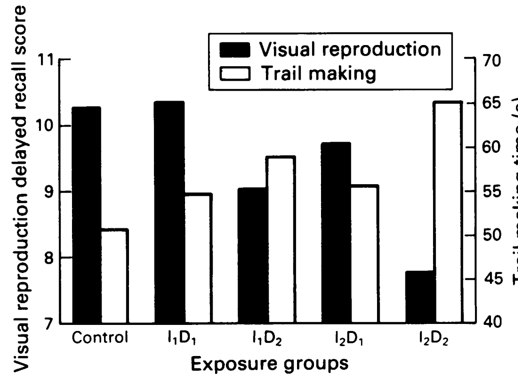

Figure 4 Trail making time and visual reproduction delayed recall scores for four subgroups of dentists. For description of subgroups see text. The performance of the I_2D_2 subgroup was significantly worse ($p < 0.05$) than the I_1D_1 subgroup and the controls in both tests.

analysis of dose-effect, removing dentists with extreme exposures often strengthened the effect, indicating that such subjects were not contributing greatly to the trends in the regression analysis.

For the normality test, neurobehavioural performance data sets found to depart significantly from normality include digit span, visual reproduction immediate and delayed recall, Bender gestalt test, and seashore rhythm test. Even though these performance tests failed the normality test, the frequency plots were overtly skew, with isolated extreme subjects. Figures 5, 6 and 7 give frequency plots for digit span (backward), visual reproduction

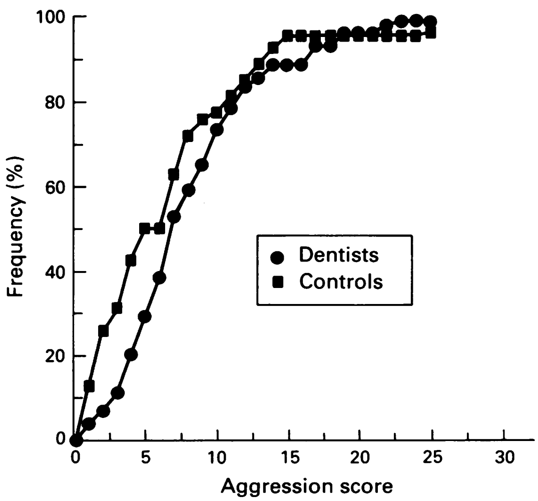

Figure 3 Cumulative frequency for percentage of study populations up to the plotted aggression score.

immediate recall and Bender gestalt (time). Digit span and visual reproduction data were also analysed by the cumulative logit models (PROC LOGISTIC procedure), the dentists differed significantly ($p < 0.05$) from the controls and the effects were related to dose.

Discussion

Even though the results of the intelligence tests showed that difference in intelligence between the controls and dentists was not statistically significant, the dentists had a higher least square mean standard score and performed significantly better in the WAIS-R subtest of comprehension. The controls smoked more cigarettes and drank more alcohol; only a few of the dentists smoked cigarettes or drank alcohol. The controls were also more likely to take traditional Chinese medicinal products containing mercury and to have a higher number of dental amalgam fillings.

Dentists are exposed to vibration and physical load at the hands, wrists and arms when using drilling and grinding tools. This may affect motor speed (finger tapping speed) and manual dexterity (grooved peg board time). Furthermore, dentists are probably self selected persons with greater fine movement of the fingers and hands and would be expected to have a better basic performance, before exposure, in finger tapping and grooved peg board tests compared with the controls.

Despite these confounding factors (mostly in favour of the dentists), the performance of the dentists in most of the neurobehavioural tests was significantly worse than their controls and a dose effect was seen between cumulative dose and performance.

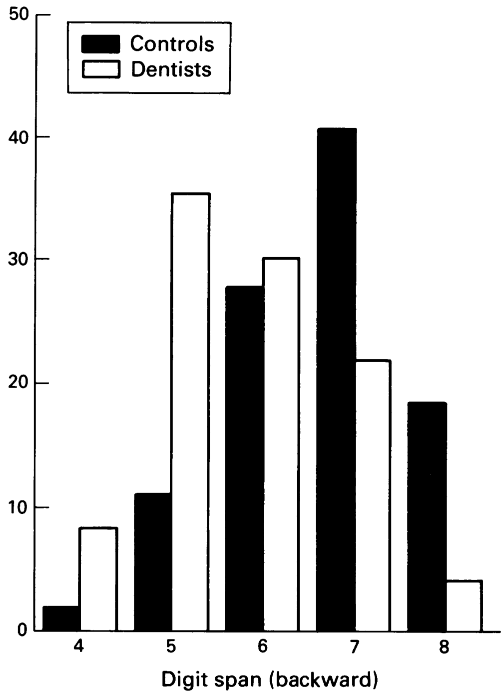

Figure 5 Frequency response of digit span (backward) score for the dentists and controls.

The exposure doses for the dentists were estimated by the product of exposure intensity (TWA personal air exposure concentrations) at the time of survey and the years of exposure, assuming that the exposure was constant throughout. In the present study, all the dental offices surveyed were air conditioned. Some older dentists may have worked in naturally ventilated offices and have had different levels of exposure before air conditioning systems were installed. Historical exposure data were not available for dentists in Singapore. The average duration of practice, however, was only 5·5 years with a maximum duration of 24 years. Most dentists surveyed would have begun their practice in air conditioned offices with similar exposure concentations as measured in this study.

The exposure concentrations were low. The air TWA mercury concentrations averaged 0·014 mg/m^3 and the end of exposure blood mercury concentrations averaged 9·8 μg/l. Generally there is a lack of published data relating environmental mercury and blood mercury concentrations around this concentration. Roels *et al*[22] published data showing that blood mercury concentrations from 7·5 to 15 μg/l correspond to air mercury concentrations from 0·010 to 0·020 mg/m^3. Our data compare favourably.

The neurobehavioural effects of mercury from earlier studies on workers exposed to air mercury concentrations around or below 0·05 mg/m^3 are inconsistent. Studies by Roels *et al*,[5] and Langolf *et al*[8] did not detect any symptoms of chronic mercury poisoning or impaired psychometric tests. Changes in verbal intelligence and short term memory were reported by Piikivi *et al*[9] in a group of chlorine manufacturing plant workers with blood mercury concentrations of 15 μg/l and an estimated air mercury concentration of 0·025 mg/m^3. Soleo *et al*[10] administered the World Health Organisation neurobehavioural test battery to a group of workers at a fluorescent lamp factory and detected changes in short term auditory memory (digit span) in eight workers whose urinary mercury concentrations ranged from 30 to 40 μg/l (blood mercury concentration roughly 18–24 μg/l). Finger tremor was detected by Verberk *et al*[11] in 21 workers with a mean urinary mercury concentration of 35·5 μg/g of creatinine (blood mercury concentration roughly 20 μg/l). In our study, significant differences in performance were found for most neurobehavioural tests carried out between dentists and controls.

A significant increase in aggressive mood measured by the profile of mood states was found between exposed and control groups. This increase in aggressive mood seemed to be related to dose, suggesting

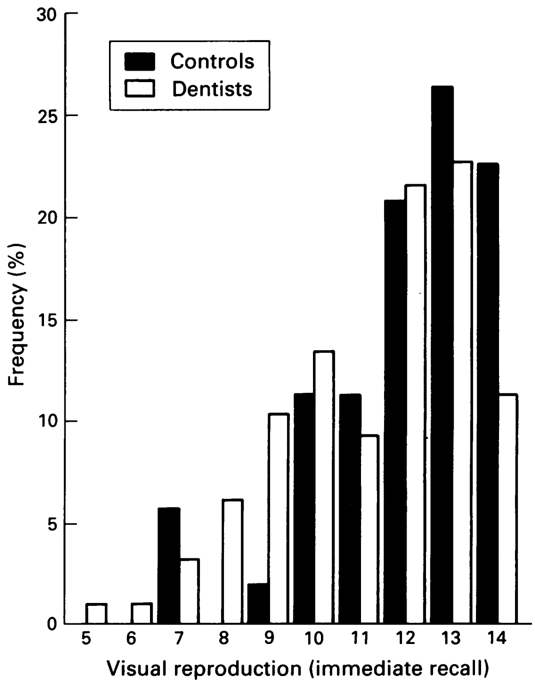

Figure 6 Frequency response of visual reproduction (immediate recall) score for the dentists and controls.

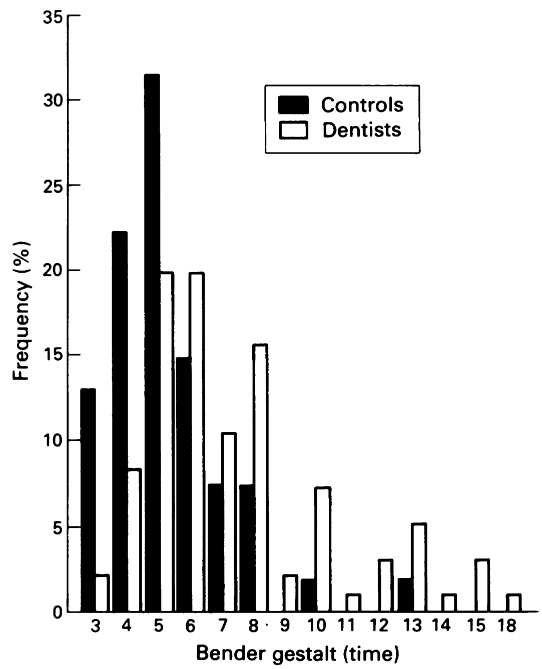

Figure 7 Frequency response of Bender gestalt time score for the dentists and controls.

possible effects of exposure to mercury vapour on personality.

In the present study, no dentists, based on their current neurobehavioural test performances alone, and the fact that, at the time of study, they did not show any overt neurological and behavioural signs and symptoms on clinical examination or complain of difficulty in performing their jobs, would be classified as suffering from neurological damage or deficits as a result of exposure to mercury vapour in their work. The fall in performance in tests measuring memory and visuomotor performance could, however, be a sign of early damage to the central and peripheral nerves that may lead to presenile dementia and finger tremor if exposure is continued. Detailed neurophysiological study including nerve conduction velocity and evolved potential evaluation would provide further information on the neurological state of the dentists and is recommended.

The effects could not be due to bias in the selection of controls or to chance as they were not only found between the controls and dentists, but also between the high exposed and the low exposed dentists. The differences in digit span, visual reproduction, and Bender-gastalt tests between the dentists and controls could not be fully explained by non-normal data distributions alone as a general trend of gradual performance shift was seen in the test score distributions and there was no evidence that the differences were due to isolated extreme exposed dentists. The results of statistical analysis on the digit span and visual reproduction using cumulative logit models supported these findings. The effects were also not likely due to confounding factors as most of the important potential confounders were either adequately matched in survey design or statistically adjusted for during analysis. The effects of using vibrating hand tools by the dentists were not taken into account.

In conclusion, significant differences in neurobehavioural performance tests were found in subjects exposed for a comparatively short period (5·5 years) and at concentrations (GM 0·014 mg/m^3) well below the current threshold limit value TWA recommended by the American Conference of Governmental Industrial Hygienists.[23] Some of the results may well be significant by chance alone. The dentists scored consistently worse, however, in the neurobehavioural tests. Also, a dose effect was also noted in these tests. In view of the consistency of this finding, a current TLV-TWA value of 0·05 mg/m^3 as providing protection against adverse effects of mercury requires to be reviewed.

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1 Public Health Service, National Institute for Occupational Safety and Health. *Occupational exposure to inorganic mercury. Criteria for a recommended standard.* Washington, DC: United States Department of Health, Education and Welfare, 1973. (HSM 73–11024.)
2 Gerstner BG, Huff JE. Clinical toxicology of mercury. *J Toxicol Environ Health* 1977;2:471–526.
3 Berlin M. On estimating threshold limits for mercury in biological material. *Acta Medica Scandinavica* 1963;173(suppl 396):7–29.
4 Uzzell BP, Oler J. Chronic low-level mercury exposure and neuropsychological functioning. *J Clin Exp Neuropsychol* 1986;8:581–93.
5 Roels H, Gennart J-P, Lauwerys R, Buchet J-P, Malchaire J, Bernard A. Surveillance of workers exposed to threshold limit value for mercury concentration in urine. *Am J Ind Med* 1985;7:45–71.
6 Rosenman KD, Valciukas JA, Glickman L, Meyers BR, Cinotti A. Sensitive indicators of inorganic mercury toxicity. *Arch Environ Health* 1986;41:208–15.
7 Smith RG, Vorwald AJ, Patil LS, Mooney TF. Effects of

exposure to mercury in the manufacture of chlorine. *Am Ind Hyg Assoc J* 1970;**31**:687–700.
8 Langolf GD, Chaffin DB, Henderson E, Whittle HP. Evaluation of workers exposed to elemental mercury using quantitative tests of tremor and neuromuscular functions. *Am Ind Hyg Assoc J* 1978;**39**:976–84.
9 Piikivi L, Hanninen H, Martelin T, Mantere P. Psychological Performance and long-term exposure to mercury vapours. *Scand J Work Environ Health* 1984;**10**:35–41.
10 Soleo L, Urbano ML, Petrera V, Ambrosi L. Effects of low exposure to inorganic mercury on psychological performance. *Br J Ind Med* 1990;**47**:105–9.
11 Verberk MM, Salle HJA, Kemper CH. Tremor in workers with low exposure to metallic mercury. *Am Ind Hyg Assoc J* 1986;**47**:559–62.
12 Lamm O, Pratt H. Subclinical effects of exposure to inorganic mercury revealed by somatosensory-evoked potentials. *Eur Neurol* 1985;**24**:237–43.
13 Shapiro IM, Sumner AJ, Spitz LR, Corwblath DR. Neurophysiological and neuropsychological function in mercury exposed dentists. *Lancet* 1982;i:1147–50.
14 Ngim CH, Foo SC, Phoon WO. Atomic absorption spectrophotometric microdetermination of total mercury in undigested biological samples. *J Anal Toxicol* 1988;**12**:132–5.
15 Foo SC, Jeyaratnam J, Koh D. Chronic neurobehavioural effects of toluene. *Br J Ind Med* 1990;**47**:480–4.
16 Lezak MD. *Neuropsychological assessment*. 2nd Ed. New York: Oxford University Press, 1983:342–559.
17 Wechsler D. A standardized memory scale for clinical use. *J Psychol* 1945;**19**:87–95.
18 Lacks P. Bender-Gestalt screening for brain dysfunction. New York: John Wiley, 1984, pp 223.
19 Wechsler D. *WAIS-R manual*. New York: Psychological Corporation, 1981.
20 Seashore CE, Lewis D, Saetveit DL. *Seashore measurement of musical talents* (Revised ed). New York: Psychological Corporation, 1960.
21 McNeil DM, Lorr M, Droppleman LF. *Profile of mood states manual*. San Diego, CA: Educational and Industrial Testing Service, 1981.
22 Roels H, Abdeladim S, Ceulemans E, Lauwerys R. Relationships between the concentrations of mercury in air and in blood or urine in workers exposed to mercury vapour. *Ann Occup Hyg* 1987;**31**:135–45.
23 American Conference of Governmental Industrial Hygienists. *Threshold limit values for chemical substances in work environment adopted by the American Conference of Governmental Industrial Hygienists for 1987–88*. Cincinnati: ACGIH, 1987.

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