Neuropsychological studies on lead workers in Singapore

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ABSTRACT The neuropsychological performance of a group of 49 workers occupationally exposed to lead was compared with a matched control group of 36 non-exposed workers. The psychometric measurements were composed of tests covering a broad range of different neuropsychological functions, particular emphasis being given to perceptual motor ability and attention concentration functioning. A questionnaire to assess subjective symptoms in mood, sleep disturbance, poor concentration and forgetfulness, somatic complaints, and social passivity was also included in the battery of tests. Compared with the controls, the performance of the lead workers was found to be significantly poorer for digit symbol, Bourdon-Wiersma, trail making test (part A), Santa Ana test, flicker fusion, and simple reaction time. In terms of subjective symptoms the exposed group also reported significantly more complaints of anxiety and depressed mood, poor concentration and forgetfulness, and other somatic complaints. These differences were observed among lead workers with a mean blood lead value of $2.35 \mu\text{mol/l}$ (SD 0.7).

In the past lead poisoning was usually associated with clinical evidence of anaemia, toxic encephalopathy, and peripheral neuropathy. Increasingly it is being recognised that abnormal responses may exist among people exposed to lead in the absence of overt evidence of clinical lead poisoning. Such subclinical evidence of lead poisoning has particularly been reported in neurophysiological and neuropsychological studies.¹⁻³ The relatively few neuropsychological studies undertaken have come from the industrialised countries, none having been reported from countries in the developing world. The present study reports the findings of a neuropsychological study undertaken among workers in Singapore exposed to a mixture of lead stearate and tribasic lead sulphate.

Methods

SUBJECTS

The 49 workers exposed to lead were drawn from a company in Singapore manufacturing lead based stabilisers used in the manufacture of polyvinyl chloride (PVC) material. The control group of 36 workers were matched for educational level (all below 12 years of education) and ethnicity. The mean age of the exposed group was 26.1 years (SD 7.6) and the mean age of the

control group 29.8 years (SD 6.4). This difference, though statistically significant should have no effect on neuropsychological test performance as it is recognised that performance generally reaches a peak at 20-24 and remains relatively constant up to 40. The control group was drawn from among industrial workers with no occupational exposure to lead.

BLOOD LEAD ESTIMATION

For blood lead analysis, 2 ml of heparinised blood was collected from the workers exposed to lead. Precautions were taken during the collection of samples to prevent contamination so far as possible by using plastic disposable syringes and the blood was collected in lead free polystyrene tubes for analysis.

Lead analysis was carried out using a modified Delves method utilising a Perkin-Elmer model 10 spectrophotometer with Delves accessories. Laboratory analysis was carried out at the Department of Social Medicine and Public Health in Singapore which is a collaborating laboratory with the National External Quality Assessment Scheme (NEQAS) in Birmingham, United Kingdom. The precision of blood lead analysis in our laboratory over the range of 0.24 to $3.86 \mu\text{mol/l}$ ($5 \mu\text{g}$ to $8 \mu\text{g}/100 \text{ ml}$) is $0.072 \mu\text{mol/l}$ ($1.50 \mu\text{g}/100 \text{ ml}$). As an additional check duplicate blood samples were occasionally sent to Glasgow Western Infirmary for comparison.

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NEUROPSYCHOLOGICAL MEASUREMENTS

The psychometric measurements comprised tests covering a broad range of different neuropsychological functioning. In deciding on the tests to be used special emphasis was given to perceptual motor ability and attention concentration functioning, which are generally regarded as sensitive indicators of impairment of brain function. Thus the digit symbol (DSy) of WAIS and Bourdon-Wiersma vigilance tests (B-W) were selected to provide measures of visual motor speed, whereas the digit span (DSp) was used to give a measure of immediate auditory memory, attention, and freedom from distractibility. Attention in the visual modality was assessed by the visual tracing test (VTT), a test which is in principle similar to Talland's (1965) line tracing test. The trail making test (TMT) parts A and B were selected for assessing concentration, visual conceptual scanning, and visuomotor tracking, and the Santa Ana dexterity test (SA) to provide a measure of manual dexterity and eye hand coordination. The measurement of eye hand coordination was supplemented by another paper and pencil test, the line pursuing test (LPT), in which subjects were required to draw a continuous line by going through narrow openings between vertical lines. Finally, the flicker fusion test (FFT), simple reaction time test (SRT), and a questionnaire adapted for Hannian and Lindstrom⁴ for subjective symptoms in mood, sleep disturbance, poor concentration and forgetfulness, somatic complaints, and social passivity were also included in the test battery. Detailed descriptions of these psychometric tests may be found elsewhere⁴⁻⁶ and are described only briefly below.

Digit symbol (DSy)—In the test the subject is required to fill in the blank spaces with symbols associated with the numbers 1 to 9. The symbols to be substituted are always visible in a key printed above the blank. The score of this test is the number of blank spaces filled within the time limit of 90 seconds.

Bourdon-Wiersma vigilance test (B-W VT)—The test sheet of B-W has 50 rows, each containing 25 groups of three, four, or five dots in varying configurations. The task is to strike through all groups of four dots as accurately and as quickly as possible. The score of this test is the time the subject takes to complete the 50 rows (B-W speed) and the number of omissions and errors (B-W error).

Digit span (DSp)—This test has two sections (the digit forward and digit backward). In digit forward the examiner reads aloud number sequences that are from three to nine digits and the subject's task is to repeat each sequence exactly as he hears them. The digit backward number sequence runs from two to eight digits, and on hearing them read, the subject's task is to say them in an exactly reversed order. The total score for these tests is the total number of digits

in the longest correctly repeated sequence for the two sections.

Visual tracing test (VTT)—The VTT consists of 40 tangled lines numbered only on the left. The subject is required to follow visually the numbered lines from the left to the right of the page and then write the number of each line where it comes out. The score of this test is the total number of lines that are traced correctly in five minutes.

Trail making test (TMT)—This test has two parts, each consisting of 25 circles distributed over a sheet of paper. In part A the circles contain numbers 1 to 25. The subject is required to draw a line connecting the circles in numerical sequence as quickly as possible. Part B differs from part A in that the circles contain numbers 1 to 13 and letters A to L. In connecting the circles the subject is required to alternate between numbers and letters as he proceeds in ascending sequence. The test is scored as the number of seconds needed to finish each part.

Santa Ana dexterity test (SA)—The task in this test is to turn pegs in succession through 180 degrees. The result of the test is scored as the number of pegs turned in 30 seconds, repeated twice with the preferred hand (SA right), twice with the non-preferred hand (SA left), and once with both hands at the same time (SA both).

Line pursuing test (LPT)—In this test the subject's task is to use a pencil to draw a continuous line by going through narrow openings between vertical lines. The score is the number of openings that the subject has gone through without touching the vertical lines in two minutes.

Flicker fusion test (FFT)—The FFT is used to measure fatigue. An electronic instrument (Strobotac) with a short flash duration is used to provide intermittent light at variable frequencies and the subject is required to adjust a knob until the flashing rate of the light is increased to the point where fusion is reached and the light appears to be steady. The flicker value is the frequency of intermittent light that is expressed in terms of cycle per second.

Questionnaire for subjective symptoms—This questionnaire was adapted from Hannian and Lindstrom⁴ for assessing subjective symptoms. It consists of 45 items grouped into the following subscales: mood, sleep disturbance, poor concentration and forgetfulness, somatic complaints, and social passivity. Each item is a statement and the subject can indicate on a three point scale the extent to which it is applicable to him.

Results

The means and standard deviations of the scores of the neuropsychological tests for the exposed and con-

Table 1 Comparison of means and standard deviations on neuropsychological measures between exposed and control groups

Measures	Exposed group (n = 49)		Control group (n = 36)		t Value
	$\bar{x}$	SD	$\bar{x}$	SD	
Digit symbol	48.9	13.3	59.9	9.9	4.19***
Bourdon-Wiersma:					
B-W (speed)	13.5	3.5	10.6	2.4	4.33***
B-W (error)	47.1	24.3	51.3	39.9	0.54
Digit span	10.2	2.4	11.0	2.1	1.59
Visual tracing	9.9	4.5	10.0	4.9	0.13
Trail making test:					
Part A	44.8	24.6	31.6	10.7	3.19**
Part B	94.0	60.3	75.0	42.7	1.58
Santa Ana:					
SA-right	16.3	2.2	17.4	2.6	2.05*
SA-left	16.1	2.3	17.1	2.4	1.96*
SA-both	18.1	5.1	19.8	4.5	1.55
Line pursuing test	93.4	28.1	102.2	25.3	1.41
Flicker fusion	28.4	2.5	29.4	2.2	1.96*
Simple reaction time	50.7	10.2	37.9	6.8	4.39***

*p < 0.05; **p < 0.01; ***p < 0.001.

Table 2 Comparison of self reported symptoms between exposed and control groups

Measures	Exposed group (n = 49)		Control group (n = 36)		t Value
	$\bar{x}$	SD	$\bar{x}$	SD	
Mood	5.5	2.4	4.1	1.8	2.78**
Sleep disturbance	5.1	2.2	4.4	1.7	1.31
Poor concentration and forgetfulness	4.1	1.7	3.2	1.6	2.27*
Somatic complaints	10.8	4.9	7.5	4.2	3.08**
Social passivity	12.6	2.8	12.8	2.2	0.42

*p < 0.05 (one tailed test); **p < 0.01 (one tailed test).

trol groups are presented in table 1. As can be seen, except for B-W error the differences on all other measures between the two groups are in the expected direction. To examine if the differences are significant, a one tailed *t* test for independent samples was used. The *t* values thus computed are also shown in table 1.

Compared with the control group, the exposed group was significantly poorer in perceptual motor speed, sustained attention, and concentration as measured by digit symbol and Bourdon-Wiersma (speed). On the trial making test the exposed group took significantly longer time to complete part A; on part B, although a difference was observed it was not statistically significant. The average score of the exposed workers on this test (94 seconds) falls beyond the cut off score (79 seconds or less for normal 20–39 age group) whereas the time taken by the control group (75 seconds) is within the normal range.

Significant findings on the Santa Ana test suggest that the lead workers were also affected in their manual dexterity and eye hand coordination. The results of the flicker fusion test found the exposed workers to

be significantly less alert than the control group and this was confirmed by their longer latency in the simple reaction time test.

In terms of subjective symptoms the exposed group also reported significantly more complaints of anxiety and depressed mood, poor concentration and forgetfulness, and other somatic complaints such as headache, dizziness, and numbness in arms and legs (table 2).

Discussion

In general this study supports the view that lead exposure among adults at levels previously considered safe may result in impairment of certain neuropsychological functions. The workers in this study were exposed to lead stearate and tribasic lead sulphate and had a mean blood lead value of 2.35 $\mu\text{mol/l}$ (SD 0.7). The control group of workers were presumed to have a blood lead value of about 0.70 $\mu\text{mol/l}$.

(SD 0.13), the typical value for workers not exposed to lead in Singapore.⁷

The aspects of performance most affected by exposure to lead were, by comparison with the referent group, perceptual motor speed, attention concentration, manual dexterity, and eye hand coordination, the lead workers also reported more subjective symptoms. The observation that the simple response speed was significantly slower in exposed groups is in harmony with the observations of a decrement in the above tests. It needs to be recorded that it was not possible to demonstrate a statistically significant dose-response relation between blood lead values and test performance, probably due to inadequate numbers in the study. Further, it must be recognised that the present study shows that the mean performance of the group of workers exposed to lead is poorer than the mean performance of the group of workers not exposed to lead. As such, the data cannot be used to decide on diagnostic cutoff values for use on an individual basis.

Our data confirm and extend previous reports¹⁻³ of impaired neuropsychological performance in workers with blood lead values below the traditionally accepted "safe" values of 3.86 $\mu\text{mol/l}$ and it is being increasingly recognised that a review of this level is necessary. A directive adopted by the Council of Ministers of the European Communities suggests that studies be undertaken to determine if the blood lead value of 1.93 $\mu\text{mol/l}$ should not be the objective for all workers.⁸ A similar value of 1.93 $\mu\text{mol/l}$ is suggested by the World Health Organisation.⁹

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