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Neurobehavioral Effects of Occupational Exposure to Low-Level Organic Solvents among Taiwanese Workers in Paint Factories[1,2]

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At six paint factories in northern Taiwan, 325 workers participated in a detailed evaluation that included medical and occupational questionnaires, blood sampling, neurobehavioral tests, vibratory perception threshold tests, and thermal perception threshold tests. Because of cultural differences, a Chinese test battery was modified from the Neurobehavioral Evaluation System 2. Eleven tests were performed: finger tapping, continuous performance, associated learning, symbol–digit, pattern comparison, pattern memory, visual digit span, switch attention, associated delayed recognition, mood scales, and vocabulary. Air concentrations of organic solvents were measured by passive personal samplers and analyzed by gas chromatography. Results showed that major solvents to which the workers were exposed were toluene, xylene, *n*-hexane, methyl iso-butyl ketone, and *n*-butyl acetate. The exposure index (EI) was classified by different exposure patterns and different air concentrations in the breathing zone as follows: EI 0, nonexposure; EI 1, low exposure; and EI 2, high exposure (the medians of 8-hr hygienic effects were 0, 0.03, and 0.25, respectively). Because of their diverse socioeconomic status and demographic characteristics, the workers were divided into two groups for additional analysis: one group comprised white-collar workers, including technicians and administrative staff, and the other comprised blue-collar workers. By using multiple linear regression analysis controls for age, sex, education, and alcohol intake, significant associations were found between increased exposure to solvent mixtures and performance on some neuropsychologic tests. In the blue-collar group, significantly prolonged response latencies were observed in the tests of continuous performance, pattern comparison, and pattern memory. Among white-collar workers, significant impairment was observed in the continuous performance test. All three tests involved visual attention and perceptual (speed and memory) functions. It was concluded that these may be the earliest neurotoxic signs of occupational exposure to low-level organic solvents in paint manufacturing workers. © 1997 Academic Press

INTRODUCTION

Neurotoxic syndromes resulting from occupational solvent exposure are a worldwide health problem, the magnitude of which varies from country to country (Juntunen, 1993). The neurotoxic effects of mixed organic solvents in various working environments have been reported over the past two decades in Europe and the United States (Anger, 1990). Similar but relatively fewer studies have been conducted in Asian countries (Ng *et al.,* 1990; Kishi *et al.,* 1993; Lee, 1993), especially in Taiwan (Wang and Chen, 1993).

Neurobehavioral dysfunction caused by occupational exposure to mixed organic solvents has been documented in many studies (Hänninen *et al.,* 1976; Valciukas *et al.,* 1985, Baker *et al.,* 1988; Bleecker *et al.,* 1991; Colvin *et al.,* 1993). However, some studies have reported insignificant results (Cherry *et al.,* 1985; Hooisma *et al.,* 1993). Controversial opinions and debates on this matter are frequently encountered in the literature. The debate has continued in part because of differences in the neurobehavioral methods used and in part because of difficulties in

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obtaining accurate information about exposure (Juntunen, 1993).

Review of previous studies on this topic indicates that tests were usually performed on blue-collar workers (Anshelm, 1982; Ng *et al.,* 1990, Bleecker *et al.,* 1991; Colvin *et al.,* 1993). In this study, the neurobehavioral effects on both white-collar and blue-collar workers occupationally exposed to low levels of mixed organic solvents were investigated.

MATERIALS AND METHODS

Materials

From October 1992 to February 1993, workers in six paint manufacturing plants in northern Taiwan were enrolled in this study. The number of workers in each factory ranged from 28 to 180; 479 (93%) of 514 persons received health examinations. The mean age was 38 ± 13 years (range, 16–74 years); the mean duration of education was 11 ± 3 years. Workers voluntarily participated in the study; workers who did not attend were not interviewed.

The factory was closed on the examination day to prevent acute effects of exposure to organic solvents. All examinations were performed in the morning to prevent effects from different physiologic conditions, and in a location far from organic solvent exposure. The interviewer was not aware of the workers' exposure. Data collected included health characteristics; occupational characteristics; blood sampling results; physical examination results; and results of neurobehavioral, vibration threshold, and thermal threshold tests.

Exposure assessments were performed on other work days between Tuesday and Friday. At each company, the health examinations and exposure assessments were finished within 2 weeks.

Data Collection: Questionnaire

The health questionnaire requested information about (1) the worker's personal habits: native language, handedness, smoking history, and alcohol and caffeine consumption; and (2) the worker's state of health: medical history, current use of medication, and drug abuse.

The occupational questionnaire requested information about (1) demographic data: age, sex, educational level, and parent's occupation; and (2) occupational history: date of employment, position, previous jobs, shift, lead exposure, and personal protection methods. The classification of parental socioeconomic status was assigned according to Sheu's scale (Sheu, 1987, 1990).

Laboratory Study

Blood sampling. Biochemistry studies of liver and renal functions, blood sugar, and Electrolytes were performed as a general screening of workers' physical conditions. The analysis of the relationship between the liver function test and exposure to mixed organic solvents has been discussed in another paper (unpublished). Blood lead levels were measured to exclude the possibility of lead intoxication.

Vibration threshold test. The vibration threshold test was performed by vibrameter (Yufu Seiki Co., Japan). The stimulator was put on the distal phalanx of the left index finger or big toe. If there was a wound on the left hand or foot, the right hand or foot was the alternative choice. Incremental stimulation was given until the worker could sense the stimulation, and then decremental stimulation was given until the worker could not sense the stimulation. Similar stimulation was given three times; six results were recorded. The mean of the six values represented the vibration threshold value of the index finger or big toe.

Thermal threshold test. The thermal threshold test was evaluated by thermometer (Medelec Co., England). The stimulator was put on the left forearm, 5 cm distal to the wrist. If there was a wound on the left upper limb, the right one was the alternative choice. Thermal sense to hot or cold temperatures was measured by the forced-choice method.

Neurobehavioral test. To fit the workers' cultural background, a Chinese version of the Neurobehavioral Evaluation System 2 (NES2) (Letz, 1990, 1991) was developed.

Pretest questionnaire. Participants were initially asked six questions about visual acuity, sleeping conditions, physical condition, consumption of stimulating beverages, alcohol consumption, and smoking within the preceding 24 hr.

Finger tapping. Tapping of the right and left index fingers was recorded during 30-sec trials.

Continuous performance test. Five geometric graphs were randomly displayed on a screen. The worker was instructed to tap the keyboard as soon as the triangle-shaped graph was displayed. Twelve positive stimuli occurred randomly within 60 stimuli. The mean response time was calculated.

Associate learning. Seven pairs of names and occupations were displayed on the screen, one pair at a time. Workers had to memorize and then match the pairs in three cycles; each cycle consisted of seven questions. Correct answers were recorded.

Symbol–digit test. Nine pairs of symbols and digits were displayed at the top of a screen. The subject was required to press the keyboard digits that corresponded to a test set of nine scrambled symbols. Three sets of nine symbol–digit pairs were presented in succession (the first was a practice set). Errors could not be entered on the practice trial. Errors above a certain number on other trials prompted the appearance of a message that stressed that there should be no errors. The pairs of symbols and digits varied between sets to prevent the effects of incidental learning. The mean response latencies for each of the nine items in each trial were recorded.

Pattern comparison. Three geometric graphs appeared on a screen simultaneously. Two were identical; workers had to choose the graph that was similar, but not identical, as quickly as possible. A total of 15 items were included in the test. The mean response latencies and number of correct responses were recorded.

Pattern memory. A geometric graph appeared on a screen for 4 sec. Workers had to memorize its shape. Then, three similar geometric graphs appeared simultaneously on the screen. Only one was identical to the originally displayed graph, and workers had to select it as quickly as possible. A total of 15 items were included in the test. The mean response latencies and number of correct responses were recorded.

Visual digit span. Workers had to memorize displayed digits in this two-part test. In the first part, the worker was to memorize the digits forward and, in the second part, backward. A series of numbers appeared on a screen, one at a time. Workers had to correctly type the numbers on the keyboard. The length of each number increased until a worker typed it incorrectly, ending the test.

Attention switching. Three testing conditions were presented in a series. In the first ("side"), the worker had to respond to each of a series of large rectangles presented successively on the screen. In each trial, the rectangle appeared on either the left or the right side of the screen, and the worker had to press the button on the corresponding side of the keyboard. In the second ("direction"), the worker had to respond to large arrows presented in the middle of the screen pointing to either the left or the right by pressing the left or right button on the keyboard. In the third ("switching"), the word "side" or "direction" appeared immediately before each stimulus. The stimuli were arrows pointing to either the left or the right, presented on either the left or the right side of the screen. The worker had to respond to each stimulus on the basis of the response criterion signified by a word presented immediately before it in each trial. The stimulus remained on the screen until a correct response was made. The mean latencies of correct responses for each condition were recorded.

Associate delayed recognition. A single recall trial of names and occupations used in the associate learning test was given. The number of correct responses was recorded.

Mood scales. This presentation was similar to that of Mood Scales in the NES2. For this test, however, the test items were translated into Chinese. A five-dimensional mood profile (tension, anger, depression, fatigue, and confusion) was obtained by combining ratings on the individual test items. The mean scores of the five test items in each dimension were recorded.

Posttest questionnaire. Two questions were asked about (1) the frequency of computer use and (2) the difficulty in completing the aforementioned tests.

Vocabulary test. This test was similar to the vocabulary test in the NES2. The worker was asked to select the synonym for a test word from a set of 4 words. A total of 40 words were given. Because of intercultural differences, the words were selected from the standard vocabulary test published by the Chinese Behavioral Science Company (Lu *et al.*, 1990). The number of correct answers was recorded.

Exposure assessment. Personal sampling was performed using a passive sampler (ORSA 5, Drager Co., Germany); 245 samples were collected. All were analyzed by gas chromatography (Model 5890, Series 2, Hewlett–Packard, U.S.A.). The results showed that the workers were exposed to the solvents benzene, toluene, xylene, *n*-hexane, methyl iso-butyl ketone, *n*-butyl acetate, and acetone. The results are shown in Table 1 [benzene and acetone were excluded because (1) benzene was found in only four samples at concentrations below 2 parts per million (ppm) and (2) the air concentration of ac-

TABLE 1
Air Concentration of Mixed Organic Solvents Classified by Jobs (Expressed by Median and Range, ppm)

Job	Toluene	Xylene	*n*-Hexane	Methyl iso-butyl ketone	*n*-Butyl acetone	Total exposure	8-hr TWA hygienic effect
Mixing	3.14	4.27	0	0	1.91	12.41	0.11
(29)	(0–15.06)	(0–18.6)	(0–5.96)	(0–5.3)	(0–15.92)	(0–41.33)	(0–0.45)
Grinding/thinning	13.7	15.9	0	0	5.0	32.55	0.31
(18)	(0–106.53)	(1.2–108.14)	(0–18.81)	(0–36.6)	(0–39.5)	(2.4–154.97)	(0.02–1.51)
Tinting	2.32	4.62	0	0	1.85	12.6	0.11
(25)	(0–232.39)	(0–391.62)	(0–62.35)	(0–11.6)	(0–18.62)	(1.2–778.54)	(0.01–7.61)
Packaging	11.9	13.65	0	0	4.4	31.4	0.3
(39)	(0–57.27)	(1.3–89.4)	(0–19.91)	(0–6)	(0–14.64)	(1.3–118.8)	(0.01–1.21)
Machine maintenance	0.9	0	0	0	0	1.5	0.02
(5)	(0–16.1)			(0–11.9)		(0–16.1)	(0–0.25)
Field supervisor	0.75	2.85	0	0	0	4.4	0.04
(8)	(0–2.56)	(0–4.79)	(0–0.77)	(0–0.26)	(0–7.46)	(0.18–11.87)	(0–0.1)
Water-based paint	0	0	0	0	0	0	0
(9)		(0–2.8)				(0–2.8)	(0–0.028)
Powder department	0	0	0	0	0	0	0
(10)							
Warehouse	0	0	0	0	0	0	0
(25)	(0–1.3)	(0–3)			(0–3.27)	(0–5.5)	(0–0.04)
Technique	0	0.8	0	0	0.45	2.9	0.03
(49)	(0–4.8)	(0–5.54)	(0–13.37)	(0–0.85)	(0–3.25)	(0–15.67)	(0–0.29)
Administration	0	0	0	0	0	0	0
(28)	(0–1.71)	(0–2.72)	(0–0.35)		(0–0.38)	(0–3.68)	(0–0.04)

etone was low (median, 0 ppm) and the neurotoxic effect was generally considered to be low (Spencer and Schaumburg, 1977)].

The hygienic effect was used as a measure of total solvent exposure and was defined as the sum of the fractions of the respective threshold limit values that each solvent represented (ACGIH, 1990). In keeping with the results of measurement of air concentrations of exposed chemicals, differences in working zones, and workers' personal conditions, exposure indexes (EIs) were divided into three grades:

- EI 0 (no exposure) included workers from administration, the warehouse, and the water-based paint and powder departments. The median hygienic effect was 0 (range, 0–0.04).
- EI 1 (low exposure) included workers from the technique department, field supervision, and machine maintenance. The median hygienic effect was 0.03 (range, 0–0.29).
- EI 2 (high exposure) included workers from the mixing, grinding, thinning, tinting, and packaging departments. The median hygienic effect was 0.25 (range, 0–7.61).

The EI was totaled for each participant's working lifetime to calculate a cumulative exposure (CE) variable.

Statistical analysis. The Statistical Analysis System (ver. 6.04) was utilized. Log transformation was performed for data that did not fit a normal distribution. Multiple regression analysis was applied to control for possible confounding factors.

RESULTS

Of 479 persons who participated in the survey, 325 completed the neurobehavioral tests. The major reasons for nonparticipation were refusal of the workers and low educational levels (29 workers had fewer than 6 years of school). Reasons given for refusing to participate were mainly the long testing time and the workers' beliefs that they were already healthy and it was unnecessary to perform the tests. Workers with any of the following conditions were excluded: blood lead level greater than 40 μg/dl ($n = 5$); drug abuse (analgesic, stimulant, or tranquilizer) ($n = 4$); or a medical history of diabetes mellitus, severe head injury (loss of consciousness longer than 10 min), emotional disorders, alcoholism, epilepsy, or other peripheral or central nervous system disorder ($n = 23$). Data for 298 workers were included in the analysis.

Workers were divided into two groups: blue collar and white collar (administrative and technical).

TABLE 2
Demographic Data of Blue-Collar Workers Stratified by Exposure Index

	Exposure indexes		
	0 (N = 47)	1 (N = 34)	2 (N = 88)
Total concentration of mixed organic solvents			
Range (ppm)	0–1.5	1.2–12.8	2–445.6
Median (ppm)	0	4.1	24.7
8-hr TWA hygiene effect of mixed organic solvents			
Range	0–0.02	0.01–0.25	0.02–4.90
Median	0	0.04	0.25
Cumulative exposure of mixed organic solvents (EI × work years)			
Range	0	0.2–27.4	0.2–66
Median	0	4	8
Age	37.9 ± 14.8	38.5 ± 13.5	38.9 ± 11.9
Education (years):	10.46 ± 2.54	9.94 ± 2.61	9.73 ± 2.84
Sex (M:F):	38:9	27:7	72:16
Parental socioeconomic status:	1.20 ± 0.41	1.3 ± 0.47	1.15 ± 0.36
Work years:	5.22 ± 8.63	6.99 ± 7.74	7.66 ± 8.18
Smokers:	46%	47%	57%
Alcohol >20 g/day:	3	0	5

White-collar workers were generally younger, had higher educational levels and parental socioeconomic status, and smoked less than blue-collar workers. To prevent any interference from these potentially confounding factors, results from the two groups were analyzed separately. Table 2 shows the demographic data of the blue-collar group stratified by EI. There were no statistical differences in age, educational level, parental socioeconomic status, working years, or current smoking history or alcohol consumption. Table 3 shows the demographic data of white-collar workers stratified by EI. None of the workers in this group belonged to EI 2. There were differences between EI 0 and EI 1 in age, but none in educational levels, parental socioeconomic status, working years, or current smoking history or alcohol consumption.

Tables 4 and 5 list the results of neurobehavioral

TABLE 3
Demographic Data of Administrative and Technical Staff Stratified by Exposure Index

	Exposure indexes	
	0 (N = 72)	1 (N = 57)
Total concentration of mixed organic solvents		
Range (ppm)	0–3.68	0–15.67
Median (ppm)	0	3.48
8-hr TWA hygienic effect of mixed organic solvents		
Range	0–0.04	0–0.29
Median	0	0.03
Cumulative exposure of mixed organic solvents (EI × work years)		
Range	0	0.1–30
Median	0	1.8
Age:	33.2 ± 9.96	30.6 ± 8.19
Education (years):	13.6 ± 2.09	13.7 ± 1.66
Sex (M:F):	38:34	38:19
Parental socioeconomic status:	1.33 ± 0.48	1.37 ± 0.53
Work years:	5.60 ± 7.55	5.28 ± 7.46
Smokers:	37%	41%
Alcohol >20 g/day:	4	0

TABLE 4

Neurobehavioral Test Results of Blue-Collar Workers Stratified by Exposure Index

	Exposure indexes		
	0 (N = 47)	1 (N = 34)	2 (N = 88)
Finger tapping (count)			
Preferred hand	69.4 ± 29.1	71.5 ± 30.3	71.4 ± 26.1
Nonpreferred hand	73.2 ± 20.5	73.7 ± 22.1	71.6 ± 19.1
Continuous performance test (msec)	479.1 ± 78.5	454.5 ± 65.5	498.6 ± 102.9
Associate learning (count)			
1st time	2.65 ± 1.83	2.32 ± 1.51	2.08 ± 1.71
2nd time	3.25 ± 2.08	2.74 ± 1.96	2.42 ± 1.72
3rd time	3.34 ± 2.20	3.80 ± 2.29	2.98 ± 1.81
Symbol digit substitution test (msec)	2.99 ± 1.10	2.76 ± 1.16	3.19 ± 1.17
Pattern comparison test			
Corrected counts	14.1 ± 1.59	14.4 ± 1.23	13.8 ± 2.08
Latencies	7.80 ± 3.76	8.28 ± 4.65	9.33 ± 4.30
Pattern memory test			
Corrected counts	9.15 ± 3.34	9.10 ± 2.60	9.83 ± 2.61
Latencies	5.64 ± 2.20	6.22 ± 2.43	6.72 ± 2.72
Visual digit span test (count)			
Forward	6.91 ± 1.65	7.40 ± 1.71	7.23 ± 2.11
Backward	6.03 ± 2.07	6.63 ± 2.56	6.57 ± 2.43
Switching attention test (msec)			
Side	396.7 ± 83.2	409.2 ± 66.1	448.3 ± 140.5
Direction	509.8 ± 91.4	508.7 ± 73.5	540.6 ± 134.1
Switching	725.7 ± 183.4	813.4 ± 155.8	802.4 ± 172.9
Associate delayed recognition test (count)	3.60 ± 2.26	3.00 ± 2.02	2.71 ± 1.91
Mood scales			
Tension	−0.15 ± 0.83	−0.91 ± 0.53	−0.71 ± 0.67
Anger	1.65 ± 0.68	1.78 ± 0.82	1.57 ± 0.74
Depression	0.72 ± 0.75	0.29 ± 0.62	0.37 ± 0.67
Fatigue	−1.18 ± 0.88	−0.57 ± 0.77	−1.48 ± 0.87
Confusion	0.11 ± 0.49	−0.06 ± 0.61	−0.03 ± 0.54
Posttest questionnaire			
Hardness of completing test	1.82 ± 0.78	2.00 ± 0.63	2.03 ± 0.76
Familiarity to computer operation	1.31 ± 0.80	1.38 ± 0.80	1.30 ± 0.66
Vocabulary test (no.)	18.9 ± 4.67	18.5 ± 6.14	18.2 ± 5.57
Vibration threshold test (dB)			
Hand	9.13 ± 35.5	6.54 ± 18.3	4.61 ± 14.2
Leg	22.9 ± 44.8	23.4 ± 48.8	15.2 ± 27.8
Thermal threshold test (°C)			
Hot	0.39 ± 0.58	0.27 ± 0.35	0.37 ± 0.75
Cold	0.37 ± 0.51	0.40 ± 0.46	0.36 ± 0.52

tests, stratified by EI, of blue-collar and white-collar groups, respectively. The results of multiple regression analysis for both groups are shown separately in Tables 6 and 7. Except for two of the tests given to white-collar workers, only test items with P less than 0.05 were listed. The purpose was to let readers compare the data between blue-collar and white-collar workers. As previously reported, confounding factors of neurobehavioral functions include age, sex, educational level, parental socioeconomic status, smoking history, and alcohol consumption (Fidler *et al.,* 1987). In this study, parents' socioeconomic status correlated greatly with the subjects' educational levels and EIs and caused collinearity in multiple regression analyses. Smoking correlated greatly with alcohol consumption and EIs and

TABLE 5

Results of Neurobehavioral Tests of Administrative and Technical Staff Stratified by Exposure Index

	Exposure indexes	
	0 (N = 72)	1 (N = 57)
Finger tapping (count)		
Preferred hand	81.1 ± 21.6	81.5 ± 26.2
Nonpreferred hand	83.7 ± 11.3	84.3 ± 13.7
Continuous performance test (msec)	449.3 ± 59.4	460.6 ± 51.4
Associate learning (count)		
1st time	3.14 ± 1.83	2.67 ± 1.77
2nd time	3.94 ± 1.92	3.71 ± 1.93
3rd time	4.63 ± 2.02	4.63 ± 1.94
Symbol digit substitution test (msec)	2.24 ± 0.45	2.41 ± 0.96
Pattern comparison test		
Corrected counts	14.5 ± 0.85	14.6 ± 0.72
Latencies	6.12 ± 1.75	6.13 ± 1.62
Pattern memory test		
Corrected counts	11.1 ± 2.06	10.4 ± 2.41
Latencies	5.58 ± 1.54	5.82 ± 1.54
Visual digit span test (count)		
Forward	8.76 ± 1.92	8.15 ± 1.63
Backward	7.54 ± 2.14	7.20 ± 2.36
Switching attention test (msec)		
Side	390.5 ± 88.9	412.1 ± 92.7
Direction	528.2 ± 120.8	513.3 ± 97.3
Switching	789.3 ± 182.1	802.8 ± 177.5
Associate delayed recognition test (count)	4.39 ± 2.19	4.3 ± 2.03
Mood scales		
Tension	−0.58 ± 0.68	−0.25 ± 0.74
Anger	1.63 ± 0.64	1.67 ± 0.66
Depression	0.35 ± 0.43	0.67 ± 0.64
Fatigue	−1.42 ± 0.82	−1.13 ± 0.82
Confusion	−0.21 ± 0.43	−0.11 ± 0.44
Posttest questionnaire		
Hardness of completing test	1.70 ± 0.58	1.88 ± 0.05
Familiarity with computer operation	2.38 ± 1.31	1.90 ± 1.01
Vocabulary test (no.)	23.9 ± 3.52	22.8 ± 3.57
Vibration threshold test (dB)		
Hand	1.70 ± 1.34	2.34 ± 4.40
Leg	8.23 ± 17.7	4.33 ± 5.93
Thermal threshold test (°C)		
Hot	0.17 ± 0.23	0.10 ± 0.06
Cold	0.19 ± 0.15	0.18 ± 0.08

caused collinearity in regression analyses. Four variables—age, sex, educational level, and alcohol consumption—were included in the multiple regression model to control for confounding factors. In the blue-collar group, statistically significant results were seen in the tests of continuous performance, pattern comparison (response latency), and pattern memory (response latency) (Table 6). In the white-collar group (Table 7), only the continuous performance test was significantly affected by organic solvent exposure.

We also used CE instead of EI for multivariate modeling. However, no significant result was found.

DISCUSSION AND CONCLUSIONS

Among blue-collar workers, the continuous performance test and response latencies of pattern comparison and pattern memory tests were related to exposure to solvent mixtures after controlling for potential confounding by other, nonoccupational factors. Similar results were reported by Baker *et al.* (1988); that study also found additional positive effects on the symbol–digit test and mood scales. Because the subjective mood scales and peripheral nervous function, including vibration and thermal sensations, were not affected in the exposed workers, and because the median exposure level was usually below 0.25 hygienic effects, we inferred that visual attention and perceptual function (speed and memory) might be the neurobehavioral functions affected first by low exposure to solvents. However, because there were no comprehensive air sampling data in Baker's study, no conclusions could be drawn except that these three tests were probably the most sensitive. They are highly recommended as part of any screening of paint industry workers exposed to low levels of solvents.

Also of interest in this study were the neurobehavioral effects of low levels of solvent exposure on white-collar workers. The multivariate regression analysis showed that only the continuous performance test was affected by organic solvent exposure after confounding factors were controlled for. Although they are different in many respects from blue-collar workers, white-collar workers did not appear to be spared neurobehavioral dysfunction. Given their median exposure level of only 0.03 hygienic effect, this might imply that even a young, well-educated population is sensitive to the effects of organic solvents.

Because the peripheral nervous system was not affected in either the blue-collar or the white-collar workers, the central nervous system was considered more susceptible to the effects of organic solvents. Visual attention and perceptual function (speed and memory) may be the earliest neurotoxic signs of occupational exposure to low-level organic solvents in paint manufacturing workers.

TABLE 6
Multiple Linear Regression Analysis of Outcome Variables Demonstrating a Significant Association with Solvent Exposure in Blue-Collar Workers

Dependent variable	Independent variable	β coefficient (SE)	*P*	Model fitting
Continuous performance test	Constant	2.572 (0.038)	0.000	$P = 0.0001$
	Age (years)	0.003 (0.000)	0.000	$R^2 = 0.32$
	Education	−0.002 (0.002)	0.280	
	EI	0.016 (0.006)	0.012	
	Sex	−0.019 (0.014)	0.182	
	Alcohol	0.002 (0.024)	0.946	
Pattern comparison (latencies)	Constant	0.718 (0.090)	0.000	$P = 0.0001$
	Age (years)	0.007 (0.001)	0.000	$R^2 = 0.35$
	Education (years)	−0.012 (0.005)	0.019	
	EI	0.030 (0.014)	0.043	
	Sex	0.031 (0.033)	0.350	
	Alcohol	−0.091 (0.055)	0.100	
Pattern memory (latencies)	Constant	0.594 (0.082)	0.000	$P = 0.0001$
	Age (years)	0.004 (0.001)	0.000	$R^2 = 0.21$
	Education (years)	−0.006 (0.005)	0.224	
	EI	0.034 (0.013)	0.012	
	Sex	0.020 (0.029)	0.504	
	Alcohol	−0.085 (0.056)	0.132	

Note. EI: exposure index, 0,1,2. Sex: male, 1; female, 0. Alcohol: >20 g/day, 1; others, 0.

How organic solvents damage the central nervous system remains an unresolved question. Although some authors have suggested that brain dopamine may be a target for solvent toxicity (Mutti *et al.,* 1988), other investigators have been unable to demonstrate the associated neurobehavioral dysfunction under a dopamine-changed condition induced by white spirit inhalation in rats (Ostergaard *et al.,* 1993). Alteration of synaptosomal membrane function induced by solvent exposure has been reported

TABLE 7
Multiple Linear Regression Analysis of Outcome Variables Demonstrating a Significant Association with Solvent Exposure in Administrative and Technical Staff

Dependent variable	Independent variable	β coefficient (SE)	*P*	Model fitting
Continuous performance test	Constant	2.535 (0.047)	0.000	$P = 0.0003$
	Age (years)	0.002 (0.000)	0.000	$R^2 = 0.17$
	Education	−0.000 (0.002)	0.919	
	EI	0.018 (0.008)	0.026	
	Sex	−0.014 (0.008)	0.115	
	Alcohol	0.010 (0.021)	0.631	
Pattern comparison (latencies)	Constant	0.765 (0.114)	0.000	$P = 0.0008$
	Age (years)	0.004 (0.001)	0.000	$R^2 = 0.16$
	Education (years)	−0.011 (0.006)	0.050	
	EI	0.017 (0.019)	0.390	
	Sex	0.003 (0.021)	0.982	
	Alcohol	0.005 (0.050)	0.927	
Pattern memory (latencies)	Constant	0.454 (0.130)	0.000	$P = 0.0561$
	Age (years)	0.003 (0.001)	0.048	$R^2 = 0.08$
	Education (years)	0.009 (0.006)	0.149	
	EI	0.027 (0.022)	0.219	
	Sex	0.020 (0.024)	0.410	
	Alcohol	−0.119 (0.057)	0.037	

Note. EI: exposure index, 0,1,2. Sex: male, 1; female, 0. Alcohol: >20 g/day, 1; others, 0.

(Korpela, 1989; LeBel and Schatz, 1989, 1990). Gliosis without neuronal death has been found in rats after chronic exposure to toluene (Huang *et al.,* 1992). It may be concluded that organic solvents usually elicit neurotransmitters or membrane integrity of neurons and may cause impairment of axonal transmission, but usually do not result in permanent neuronal damage. Therefore, the neurobehavioral dysfunction observed in this study may be explained by the delayed transmission of the neuron's impulse to external stimuli as a result of solvent exposure.

This study indicated that some neurobehavioral functions were associated with EI, but not with CE. Because this was a cross-sectional study, past exposure data were not available, which might have resulted in an inaccurate estimate of a worker's previous exposure. Another possible explanation is that the duration of exposure may not directly influence nervous system function if the exposure concentration is relatively low (Albers *et al.,* 1988).

Some investigators proposed that the results of neurobehavioral testing be adjusted for vocabulary score, which is a sounder measure of intellectual capacity than level of education (Cherry *et al.,* 1985; Bleecker *et al.,* 1991). To test that theory, the multiple regression analysis for this study was conducted again, and the effect attributed to solvent exposure became insignificant. However, an understanding of Chinese vocabulary requires strong visual perception (Keung and Hoosain, 1989); this differs from most Western countries, where vocabulary is usually constructed according to speech. Accordingly, the adjustment for vocabulary score may be inappropriate when the Chinese versions of the neurobehavioral function tests are administered.

Although some inferences were drawn from this study, its cross-sectional nature limits reaching strong conclusions about causality (Williamson and Winder, 1993). The investigators hope to perform a follow-up study to confirm or refute those inferences.

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