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Neuropsychological performance and solvent exposure among car body repair shop workers

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Abstract

A cross sectional study to evaluate symptom reporting and neuropsychological test performance among a cohort of car body repair workers (n = 124) was performed using a computer-administered test system. Subjects with high and medium current exposures to solvent and paint (n = 39 and 32), and low exposure subjects who formerly painted (n = 29) reported significantly more acute and chronic neurological symptoms than did low exposure subjects with no history of painting (n = 24). Subjects with higher current exposure performed significantly less well on selected tests of visual perception and memory, but there were no significant exposure related differences in mood state, motor speed, or visuomotor performance. The exposure related effects were most noticeable among subjects 35 years or older. The findings are consistent with age interactive central neurotoxic effects of current exposure to solvents or of cumulative past exposure, although the study is unable to distinguish between these possibilities. The computer administered test system was effective in this field based investigation involving multiple, geographically dispersed worksites.

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Organic solvents are a broad class of chemical compounds used extensively in industrial processes and in consumer products, commonly in the form of mixtures. Their ability to produce adverse effects on various human organs, particularly the central nervous system, is well recognised. Most individual organic solvents are capable of producing acute narcotising effects,[1] and there is substantial evidence that solvents as a class may be associated with chronic neurological deficits after repeated exposures over long periods. Workers exposed to solvents seem to be at increased risk for the development of clinically significant mood alterations and neuropsychological deficits, and there is evidence that such manifestations may be permanent after about a decade of exposure.[2] Also, numerous studies have documented actively employed, solvent exposed workers to have relative decrements in group average neuropsychological performance as well as greater prevalence of otherwise unexplained non-specific symptoms than are found in comparable non-exposed workers.[1]

Recruitment and evaluation of individual subjects poses a logistical challenge in any occupational epidemiological study. Control of the circumstances of evaluation is essential to ensure optimal quality of collected data and investigators commonly attempt to standardise evaluation by targeting worksites with large numbers of employees or by recruiting workers to come for evaluation at a central location away from their worksites. The second approach can impair rates of participation, and the first fails to consider the problems of small workplaces. Small workplaces are more likely than large ones to have worse hygiene and potentially greater risk for health problems.[3 4]

A number of investigators have developed computer administered neuropsychological test batteries. Although these instruments may sacrifice some attributes of analogous interviewer administered tests, they offer the potential benefits of standardised test presentation, minimisation of interviewer bias, and reduced training of administrators. To the degree that they preserve the sensitivity and reliability of interviewer administered tests, computerised test batteries are ideal instruments for field based investigations in small, geographically dispersed worksites. This study used one such system, the neurobehavioural evaluation system (NES),[5 6] to evaluate workers in car body repair shops, which commonly employ only one to three painters and three to 10 production workers in total. Results were

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available for historical comparison from two previous neurobehavioural studies of workers in this industry in other countries.[7-9]

Methods

This study was one component of a cross sectional study that examined the working conditions and health state of workers in the car body collision repair industry. All businesses performing car body repair work in the extended Seattle area (n = 396) were invited by mail to participate in the study, and responses were received from 38 shops. After exclusions on the basis of inadequate production volume or management disinterest, 25 of the 38 respondent shops were selected for participation. Because of the low shop response rate, a telephone survey was conducted subsequently among a randomly selected subsample of non-respondent shops (n = 40, 10% of original sample) to determine reasons for non-response: 36 (90%) had no previous knowledge of the study and could not recall receiving the invitation, but would have been interested if recruitment were still open: three (7%) expressed disinterest without explanation: and one reported interest in participation but inability to do so because of shop renovations in progress at the time of invitation.

The worker population in production areas at the participating shops consisted of about 45 painters and painter assistants; 25 combination workers, who routinely performed both body work and painting at the study site; and 115 non-painting workers, primarily body workers, but also supervisors, mechanics, parts handlers, and clean up personnel (total 185). Each shop was studied over the course of one or two full work shifts depending on shop size.

All willing painters (and assistants) and combination workers plus half of the non-painters were selected to wear a passive charcoal dosimeter (SKC 530-11) for a full shift to obtain time weighted average (TWA) samples of exposures to solvent vapours (n = 145 worker-days overall, including 118 in this study sample). Solvent exposures were also characterised specifically during spray painting activities in a convenience sample composed of one or two workers at most shops (23 painters and four combination workers), by active personal monitoring with charcoal tubes (SKC 226-09) and by local area sampling with a total hydrocarbon analyser (AID 7100, calibrated to a 50 ppm toluene standard) and strip chart recorder situated 4–10 feet from spraying operations. Charcoal media were analysed using the National Institute for Occupational Safety and Health (NIOSH) 1500 method.[10] Samples exhibited up to 50–100 separate gas chromatographic peaks, and six compounds (toluene, xylene, acetone, methyl ethyl ketone, methyl isobutyl ketone, and n-hexane), which on average accounted for roughly 90% of the identified mass in each air sample, were selected for routine quantification. Other compounds typically were present at concentrations less than one tenth of their threshold limit value as adopted by the American Conference of Governmental Industrial Hygienists (ACGIH TLV).[11] Also, area nuisance dust samples were collected in the centre of each body and paint work area for the entire workshift, and personal nuisance and respirable dust samples were collected among a convenience sample of body workers (n = 12). *x* Ray fluorescence was used to determine metal content of 20% of samples with the most visible collections of dust (n = 14).

All production area workers were considered potential subjects, and 110 participated in the neuropsychological evaluation. A further 11 production workers completed the questionnaire but not the test battery. Ten office area workers (seven men, all except one were former production area workers; three women with no production experience) also participated fully. All study procedures were reviewed and approved in advance by the University of Washington human subjects research committee, and written informed consent was obtained from all participants. Participation was voluntary and no financial inducement was offered. At some shops participants were required by management either to use personal time or suffer loss of commission income while participating. Of the non-participating production workers (n = 64, 35%), 34 were unavailable because of management restriction or schedule conflicts, and 30 elected not to participate (including four painters and two combination workers). As only five women participated (two non-painters and the three office workers), they were excluded from data analysis. Two non-painters with limited English speaking and reading skills were also excluded from analysis. The final study sample consisted of 124 subjects (39 painters, 23 combination workers, and 62 non-painters).

Each subject completed questionnaires that inquired about demographic characreristics, medical history, medication and substance use, general and nervous system symptoms,[12 13] employment history, occupational and non-occupational exposures to potential neurotoxins, and factors that might acutely interfere with test performance. In the morning either before the workshift or within the first three hours of the shift (and before any painting), 113 of the 124 subjects completed a supervised, computer administered battery of neuropsychological tests (the neurobehavioural evaluation system, or NES)[12] during one hour sessions that included up to three subjects simultaneously.

Eleven tests were used in the battery, including tests of verbal ability (modified air force qualifying test of vocabulary), affect (five mood scales), motor speed (finger tapping, in dominant and non-dominant hands, and alternating between two buttons with a single finger), visuomotor performance (hand eye coordination; and continuous performance, which is a test of complex or choice reaction time), visual perception (symbol-digit substitution and pattern recognition), and visual memory (serial digit learning; pattern memory; and paired associate learning and recall).

Responses to individual symptom questions were examined as dichotomous variables (none *v* a little or more). Two symptom summary scores were created by summing the number of positive responses separately for the 11 at work and the 19 in general symptom questions. A summary performance variable was calculated as the outcome of interest for each symbol-digit substitution trial by dividing the number of true positive responses by the time required for the trial and then averaging the two best values. For hand-eye coordination the performance outcome was the average of the root mean square errors in the best two of four trials. Serial digit learning was scored by subtracting from 16 the sum of the scores on individual trials (2 = incorrect, 1 = partially correct, and 0 = correct) repeated for eight trials or until two correct trials were performed. Mood scales represented the averages of subject ratings (with scale of 1 to 5 representing increasing distress) for question responses considered in five clusters established by NES protocol (tension, depression, anger, fatigue, and confusion). The numbers of correct responses, or trial completion times, or both were used as the performance variables for the other tests.

Data analysis was performed on IBM compatible microcomputers using SPSS/PC+.[14] All variables were inspected visually for evidence of skewness before conducting statistical analyses, and no data required transformation for subsequent analyses. Subjects were classified into three current exposure groups on the basis of current job title and second job activities. Intergroup differences in distributions of continuous variables were tested with Student's *t* test or one way analysis of variance (ANOVA); categorical variables with χ^2 tests; and summary scores and skewed numerical data with Mann-Whitney U or Kruskal-Wallis (three sample) tests. Analysis of covariance (ANCOVA) was used to examine relations between test scores, solvent exposure categories, and four non-work independent variables (age, years of education, vocabulary score, and alcohol use), each of which was selected a priori because of previously reported associations with neuropsychological test performance. Vocabulary score was selected as the best available surrogate marker of pre-exposed intellectual function. Error residuals were examined visually to determine the validity of assumptions regarding normality, independence, and homogeneity of variance. All 14 available performance test parameters (and the five mood scale parameters) were considered in the initial analyses, but subsequent analyses were restricted to nine representative performance test parameters. When more than one parameter was available for a performance test, the parameter with the most normal and non-truncated distribution in the study sample was selected to be representative (the response times for pattern recognition and for pattern memory and the dominant hand modality of finger tapping).

An NES outlier summary score was generated to assess overall each subject's relative scores on the NES performance tests. For each of the nine representative performance test parameters, the residual differences between performances found and values predicted by the respective ANCOVA model (including the non-work independent variables but no exposure terms) were dichotomised relative to the entire study sample (within normal or outlier as defined internally relative to the worst fifth percentile). The number of a subject's outlier values constituted his outlier summary score.

Results

CURRENT OCCUPATIONAL EXPOSURES

Passive dosimetry samples and questionnaire information regarding usual job activity were available for 118 participant-days. Overall, the samples consisted primarily of acetone and toluene (with respective arithmetic mean (standard deviation (SD)), molar proportions of 0·46 (0·15) and 0·29 (0·14), and lesser proportions of methyl ethyl ketone, xylenes, methyl isobutyl ketone, and n-hexane, each in mean molar proportions of 0·04 to 0·08. Exposures to the six

Table 1 Full shift TWA air concentrations of the six most prevalent hydrocarbons

	Non-painters (n = 51)*	*Combination workers (n = 21)*	*Painter assistants (n = 17)*	*Painters (n = 29)*
Total hydrocarbons (ppm):				
Mean (SD)	11·0 (9·4)	18·0 (15·7)	35·5 (16·2)	46·2 (25·7)
Range	1·7–55·0	2·7–61·0	11·6–62·0	6·1–114
%TLV†:				
Mean (SD)	6 (8)	11 (11)	23 (15)	24 (16)
Range	0·4–52	1–44	5–53	2–80

*47 metal workers, two mechanics, one production area supervisor, and one worker in office open to production area.
†Percentage of ACGIH TLV for mixture of the six reported solvents based on model of additive effects (no measurement units).

*Table 2 Background characteristics relative to current exposure classification**

	Low (never painted) (n = 24)	Low (formerly painted) (n = 29)	Medium (n = 32)	High (n = 39)
Age (y)	38·0 (14·1)	36·3 (9·2)	29·1 (7·4)	29·0 (9·0)
Years in trade	17·2 (13·4)	17·4 (8·7)	10·2 (7·2)	9·9 (8·0)
Years at study site	6·6 (7·5)	5·7 (5·0)	4·7 (6·2)	3·9 (4·8)
Years as painter*	0	5·6 (3·8)†	8·8 (7·0)	8·6 (7·5)
Years as non-painter*	17·2 (13·4)	11·8 (7·1)	3·5 (2·8) (n = 15)	5·2 (3·0) (n = 9)
Education (y)	12·2 (1·6)	11·8 (1·6)	12·2 (0·6)	12·1 (0·8)
Vocabulary score	16·8 (3·6) (n = 18)	18·3 (3·2) (n = 25)	17·8 (4·0) (n = 31)	17·5 (2·8) (n = 39)
Alcohol use				
Never	1 (4%)	0 (0%)	2 (6%)	0 (0%)
Past	3 (12%)	5 (17%)	5 (16%)	9 (23%)
Current	18 (75%)	23 (79%)	25 (78%)	30 (77%)
Drinks/week	8·9 (7·9)	11·4 (17·8)	6·7 (7·5)	7·1 (7·3)
Coffee use (current)	18 (75%)	17 (59%)	21 (66%)	21 (54%)
Cups/day	3·7 (1·9)	4·2 (1·8)	3·9 (4·2)	3·9 (3·0)
History of head trauma	1 (4%)	1 (3%)	5 (16%)	2 (5%)
History of injury to extremities	5 (21%)	7 (24%)	12 (37%)	10 (26%)

*Table shows number (and %) of subjects, or group mean (SD). References to painter in this table include all painting workers (painters, painter assistants, or combination workers).
†8·6 (SD 6·4) years since last employed as painting worker (range 1·0 to 27 years).

measured solvents did not exceed the combined exposure TLV for any worker, but exposures of six workers exceeded 50% of the combined exposure TLV (highest value 80% TLV). Exposures of painters and painter assistants were on average about twice those of combination workers, and combination workers' exposures were about twice those of non-painters (table 1).

Painting activities commonly generated local area concentrations of total hydrocarbons transiently reaching or exceeding 1000 to 2000 ppm, with the average workers' personal exposures during actual spraying cumulatively lasting only about 30 minutes or less (range 3–83 minutes) and accounting for about one quarter of the total daily exposure (20 painters: 179 (SD 115) ppm TWA over total 36 (SD 23) minutes; three painter assistants: 126 (SD 48) ppm, 16 (SD 13) minutes; and four combination workers: 128 (SD 91) ppm, 15 (SD 13) minutes). Only about 50% of all combination workers painted at all on the study day. Most painting (50–75% of painting events) was conducted outside spray booths. Respirators were worn inconsistently: occasionally while personally spraying (<25%), rarely after spraying activity ended (5–10%), and never when exposed indirectly by an adjacent painter.

Aerosols generated by spray painting produced area total dust concentrations that were roughly twice those seen in body work areas (median 2·7 *v* 1·3 mg/m^3, eight hour TWA), although the one area sample that exceeded the TLV (12·8 mg/m^3, TLV = 10) was from a body work area. Titanium and iron were found in 90% of samples analysed by *x* ray fluorescence, with all concentrations well below the respective TLVs. Chromium, lead, arsenic, nickel, copper, and zinc were detected in some but not all samples, and always at concentrations below instrumental quantification (lower quantification limits each less than 25% of the respective TLVs).

BACKGROUND CHARACTERISTICS

On the basis of current job title and second job activities, the subject sample was categorised into three groups with different degrees of current solvent exposure: high, 39 painters; medium, 23 combination workers plus nine non-painters who painted in part time second jobs; and low, 46 non-painters plus seven office area workers. Half of the low current exposure subjects had worked previously as painters or combination workers, primarily in the early third of their careers, and their background characteristics are therefore presented separately (table 2). Subjects with low current exposure were on average eight years older, had been in the trade seven to eight years longer, and had worked slightly longer at the study sites than had subjects with high and medium current exposure. Most of the subjects with high current exposure had spent all of their years in the trade as painters (n = 30, 77%), but half of the medium current exposure subjects had worked previously in positions with no painting.

Table 3 Number of general/nervous system symptoms relative to current exposure and painting history

Current exposure	Painting history	No of subjects	Symptoms at work (0–11) No (SD)	Symptoms in general (0–21) No (SD)
Low	Never	(24)	2·1 (2·6)	5·2 (4·1)
Low	Past	(29)	3·9 (3·1)	6·8 (4·5)
Medium	Current	(32)	3·8 (2·2)	7·4 (3·3)
High	Current	(39)	4·2 (3·0)	7·1 (4·7)

The three current exposure groups did not differ in years of education or performance on the NES vocabulary test (table 2). Most subjects reported current alcohol use, and current drinkers in the low exposure group described slightly greater current alcohol consumption. The former drinkers generally reported heavier and more often excessive alcohol consumption than the current drinkers, particularly among the high and low exposure groups. Former injuries to the head (with prolonged loss of consciousness) or extremities were more prevalent among medium exposure subjects than among the others. Otherwise, there were no significant differences in reported medical histories or current use of medications that might impair mental activity or performance (data not shown). Only five subjects were non-white.

The background characteristics of the nine non-painter subjects who were included in the medium current exposure group were generally comparable with those of the other medium exposure subjects, apart from being about three years older (31·2 (SD 6·8) *v* 28·3 (SD 7·6) years respectively) and having been in the trade about two years longer (11·8 (SD 6·8) *v* 9·6 (SD 11·8) years). There were no significant differences in background variables between low exposure subjects who formerly painted and those who had never painted, nor between low exposure subjects working in the production areas or those working in offices. All except one of the office area workers had formerly worked in a production area.

SYMPTOMS AND NEUROPSYCHOLOGICAL PERFORMANCE

Subjects in the low exposure group and with no previous painting experience reported, on average, about half as many symptoms acutely associated with work (mean 2·1 (SD 2·6); table 3) as did subjects in the high and medium exposure groups and, unexpectedly, other low exposure group subjects with previous painting experience (combined mean 4·0 (SD 2·8), $p < 0{\cdot}005$ by *t* test; $p < 0{\cdot}05$ by four group ANOVA). The individual acute symptoms showing evidence of this association included lightheadedness ($p < 0{\cdot}01$); tiredness, irritability, and concentration difficulties ($p < 0{\cdot}05$); and headaches, nausea, and memory difficulties ($p < 0{\cdot}10$). The reporting of symptoms in general (not necessarily related to work) also tended to be greater among subjects with high or medium current exposures and among low exposure subjects with previous painting experience (combined mean 7·1 (SD 4·2) than among subjects with low current exposures and no previous painting experience (5·2 (SD 4·1), $p = 0{\cdot}05$ by *t* test). The individual general symptoms showing evidence of

Table 4 Neuropsychological performance among current exposure groups

		Unadjusted mean NES scores			*Difference in ANCOVA adjusted scores (high exposure v low exposure)**		
Test	*(symbol)*	*Low (n = 43)*	*Medium (n = 31)*	*High (n = 39)*	*Difference (% low)*	*Difference (Z score)*	*Significance (p Value)*
Finger tapping:							
Dominant hand	(FT)	65·0 (9·5)	67·3 (8·7)	68·6 (8·1)	1·5	0·14	(0·61)
Non-dominant hand		57·8 (10·3)	62·3 (10·2)	61·4 (8·5)	2·5	0·17	(0·52)
Alternating tap sites		49·0 (9·7)	51·1 (8·2)	51·7 (7·5)	3·3	0·19	(0·43)
Hand-eye coordination:†							
Error score	(HE)	3·48 (0·92)	3·52 (0·96)	3·35 (0·93)	3·1**	0·08	(0·64)
Continuous performance:							
No correct (0–60)		57·1 (3·8)	57·9 (2·1)	58·5 (2·3)	1·5	−0·25	(0·19)
Average time (ms)†	(CP)	454 (47)	457 (41)	458 (39)	2·0**	0·33	(0·36)
Symbol-digit substitution:							
No correct/s	(SD)	0·427 (0·081)	0·441 (0·073)	0·425 (0·080)	−6·8	−0·44	(0·08)
Pattern recognition:							
No correct (0–15)		14·8 (0·5)	14·9 (0·3)	14·8 (0·4)	0·1	−0·04	(0·82)
Averaging time (s)†	(PR)	4·27 (1·48)	3·90 (1·17)	4·32 (1·54)	16·0**	−0·47	(0·05)
Pattern memory:							
No correct (0–15)		12·1 (1·8)	12·5 (1·7)	12·5 (1·7)	1·6	0·12	(0·64)
Average time (s)†	(PM)	6·59 (2·09)	6·53 (1·67)	6·72 (2·10)	7·7**	−0·23	(0·30)
Serial digit learning:							
Score (0–16)	(DL)	10·2 (4·7)	9·6 (4·8)	9·3 (5·2)	−15·5	−0·36	(0·17)
Associate learning (0–10)	(AL)	6·6 (1·8)	6·4 (2·2)	6·5 (1·8)	−4·6	−0·18	(0·50)
Associate recall (0–10)	(AR)	6·1 (2·1)	5·9 (2·6)	5·7 (2·2)	−10·6	−0·29	(0·23)
Mood scales (1–5):†							
Tension		2·5 (0·6)	2·4 (0·7)	2·5 (0·7)	−4·9	0·17	(0·39)
Depression		1·9 (0·5)	1·8 (0·7)	1·9 (0·8)	−9·8	0·27	(0·23)
Anger		1·8 (0·6)	1·8 (0·8)	1·7 (0·6)	−1·9	0·06	(0·82)
Fatigue		2·8 (0·6)	2·5 (0·7)	2·7 (0·8)	−9·6	0·38	(0·12)
Confusion		2·0 (0·6)	2·1 (0·6)	2·1 (0·7)	−3·5	0·12	(0·61)

*Difference between mean scores for high and low groups expressed first as percentage of mean low group value, "(high-low)/low", after adjustment by ANCOVA to sample mean values for age, current alcohol use, and vocabulary score or years of education; and second as absolute difference between similarly adjusted group Z scores (in SD units). Lower or more negative values indicate relatively worse performance by the high group (and conversely for values marked by double asterisk**). Statistical significance represents p value of ANCOVA coefficient for high exposure variable.

†Higher NES scores (and higher, more positive adjusted differences) indicate relatively worse performance for parameters marked by double asterisk. Note that Z score sign has been reversed for these tests, so that for all scores a positive Z score indicates better performance.

this association included lightheadedness ($p < 0.005$); tiredness, irritability, and lack of coordination ($p < 0.05$); and confusion ($p = 0.10$).

Eleven subjects were not able to participate in an NES session because of demands of work but were able to complete a questionnaire. All except one (a combination worker) were in the low exposure group, and their background characteristics were comparable with those of other low exposure group subjects. Inclusion or exclusion of subjects with any history of head or extremity injury did not significantly affect the results of analyses of NES performance, and these subjects were included in all reported analyses.

The four non-work independent variables were tested separately and in combination in ANCOVA models examining the relation of current paint exposure to each of 19 selected NES outcome parameters. Age and moderate alcohol use ($\geqslant$ one drink per day) each satisfied stepwise entry critera (p to enter $\leqslant 0.10$) in 11 and seven respectively of 19 models. Education level contributed only to mood scale models (four of five), and vocabulary score contributed only to performance (non-mood) outcome models (six of 14). Accordingly, subsequent ANCOVA analyses of NES outcomes utilised terms for age and alcohol use, plus vocabulary score for performance outcomes and education level for mood scales.

The crude NES scores showed no significant differences relative to current exposure state (table 4), other than for the number of correct responses on the continuous performance test, where the high and medium exposure groups on average outperformed the low exposure group ($p < 0.05$, Kruskal Wallis test). These differences were no longer significant after adjustment for the effects of age, alcohol use, and vocabulary score. The adjusted differences in performance across the high and low exposure groups, however, were of borderline statistical significance for the symbol digit substitution score ($p = 0.08$) and the pattern recognition response time ($p = 0.05$; table 4), and the patterns of the current exposure groups' performances on these two tests were consistent with adverse exposure related trends (fig 1). Also, although the adjusted group differences did not achieve any degree of statistical significance, adverse exposure related trends were qualitatively evident for serial digit learning score and pattern recognition response time and, to a lesser degree, pattern memory and continuous performance response times. Among the entire study sample, there were three subjects (2%) with outlier summary scores of 3, and 15 (13%) with scores of 2 or more (table 5). More than twice as many subjects with current high or medium exposure had outlier summary scores of 2 or more (prevalence ratio = 2·5, 95% confidence interval (95% CI) = 0·7–8·2). Mood scale responses showed no evidence of association with current exposure.

Because of the differences in average age between current exposure groups, and to assess better any possible age related exposure effects, NES performance was examined by ANCOVA models that tested age and exposure variables separately but simultaneously within three age strata ($\leqslant 25$ years, n = 36; 26 to 35 years, n = 43; $\geqslant 36$ years, n = 34). Current solvent exposure was considered as a single variable, with weighted values approximated from the assessment of current TWA solvent exposures (high:medium:low, 4:2:1). Subjects with high or medium current solvent exposure were more prevalent in the youngest than the oldest strata (n = 29, 81%, versus n = 13, 38%). Also, subjects in the oldest statum with low current exposure were on average five years older than those with medium or high current exposure, and more than half (12/21, 57%) were former painters or combination workers (with median eight years previous painting

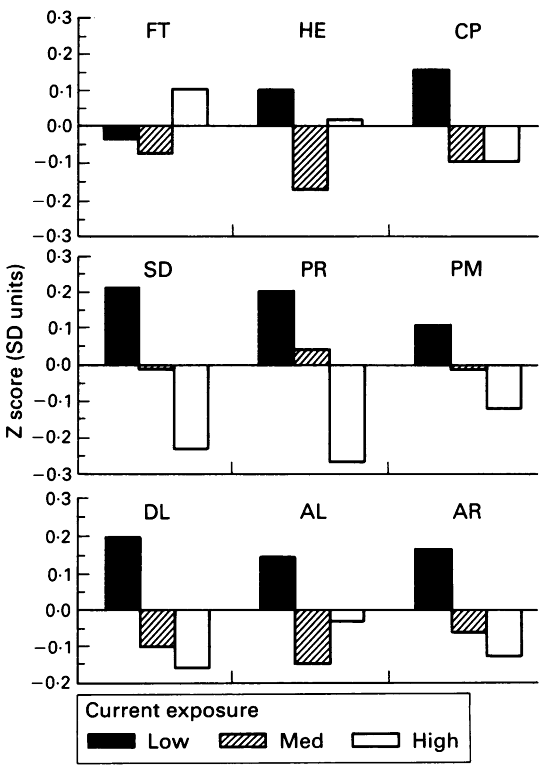

Figure 1 Adjusted scores for representative NES peformance test parameters on Z scale relative to current exposure group. Score adjustment made by ANCOVA, to sample mean values for age, current alcohol use, and vocabulary score. Z scale expressed in SD units, with positive direction indicating better performance. Abbreviations of test names are defined in table 4.

Table 5 *NES outlier summary score relative to current exposure and painting history*

Current exposure	Painting history	No of workers	NES outlier summary score (range 0–9) 0 No (%)	1 No (%)	2 No (%)	3 No (%)
Low	Never	18	11 (61)	5 (28)	1 (6)	1 (6)
Low	Past	25	17 (68)	7 (28)	1 (4)	
Medium	Current	31	19 (61)	6 (19)	6 (19)	
High	Current	39	24 (62)	9 (23)	4 (10)	2 (5)

Summary score represents the number of NES performance test parameters (only the nine representative parameters) on which a worker's performance was worse than the fifth percentile for desirable performance.

experience). In spite of the older age and former painting experience of the current low exposure subjects in the oldest stratum, the subjects with highest current exposure in this stratum performed significantly less well on three tests of visual perception or memory (pattern recognition, $p = 0{\cdot}05$; pattern memory, $p = 0{\cdot}02$; and digit learning, $p = 0{\cdot}04$; fig 2). These tests showed no statistically significant exposure related differences in the middle or youngest age strata, and there were also no statistically significant differences in performance on the other tests or mood scales relative to current exposure within any of the age strata (all, $p > 0{\cdot}10$).

The identification of current non-painters with previous painting experience made no statistically significant contributions to any of the ANCOVA models of NES performance tests when considered dichotomously (any or no or minimal painting experience). Career exposures were also estimated in a retrospective semiquantitative manner and assessed relative to test performance. Career cumulative (and average) exposures were approximated by summing (and averaging) over the total years in the trade a subject's weighted years in each job title defined exposure category, with weighting of past years' exposures extrapolated from the current high:medium:low = 4:2:1 weighting scheme. These career exposure variables showed moderate to strong correlations with current exposure and age (average:current exposures, $r = 0{\cdot}90$; cumulative: current exposures, $r = 0{\cdot}27$; cumulative exposure age, $r = 0{\cdot}65$). The career exposure variables showed associations with test performance that did not vary substantially from the exposure-performance associations found and discussed relative to current exposure, including strong and statistically significant associations between greater cumulative exposure and worse performance within the oldest age stratum on the pattern recognition, pattern memory, and digit learning tests. Greater cumulative exposure within the oldest stratum showed slightly stronger association with worse performance on symbol digit substitution than did current exposure, but the association showed only borderline statistical significance ($p = 0{\cdot}10$). There were no significant cumulative exposure related differences in performance on the other NES tests or mood scales, or within the youngest or middle age strata (all $p > 0{\cdot}10$).

Discussion

This study found evidence of a solvent associated effect on the nervous systems of workers exposed to organic solvents and solvent based paints through employment in the car body repair industry. Subjects with high or medium levels of current exposure reported significantly more neurological symptoms acutely related to work than did subjects with low (or no) current exposure and no previous painting experience.

Interestingly, subjects with low current exposures but with previous painting experience reported acute symptoms as often as did the subjects with high and medium current exposures. Subjects with high or medium current exposures, and low exposure subjects with previous painting experience, also tended to report more neurological symptoms in general, although the difference was less than that seen relative to acute symptoms. Also, high and medium exposed subjects tended to perform less well than did low exposure subjects on tests of visual perception and memory. Subjects in the youngest age stratum (age $\leqslant 25$ years) generally showed no significant exposure related differences on any administered test, and the evidence for probable solvent effect on test performance was increasingly greater across the middle and oldest age strata. The associations found between test performance, age, and cumulative solvent exposure generally were comparable to or less evident than those seen relative to current exposure. However, most subjects with greatest cumulative exposure were also currently exposed at high or medium levels within as recently as 16 hours, and this study had limited power to distinguish between possible effects of current solvent exposures *v* past or cumulative exposures. The findings of this study, therefore, are consistent with there being central neurotoxic effects—with some predisposition to or augmentation of these effects by increasing age—related to either contem-

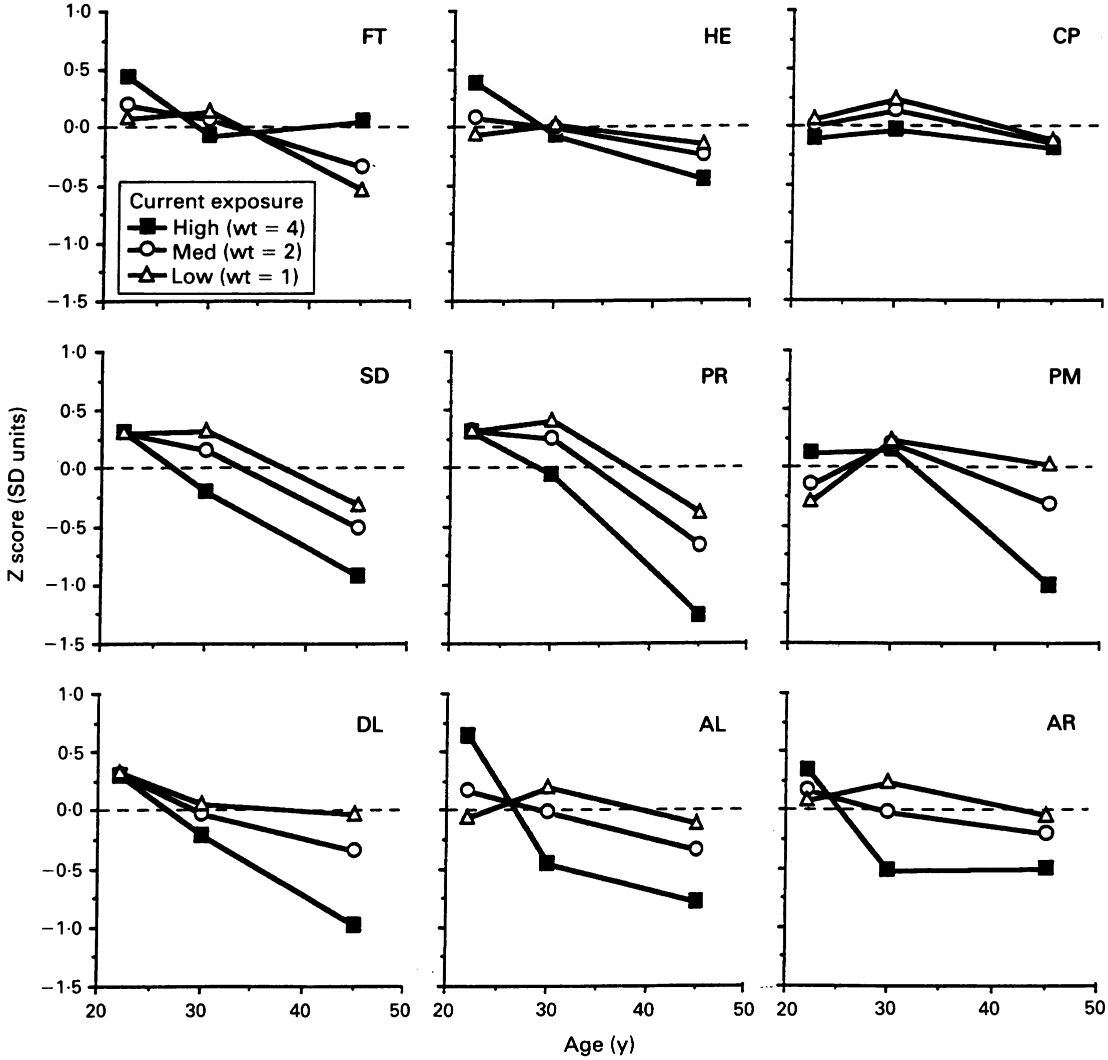

Figure 2 Adjusted scores for "representative" NES performance test parameters within current exposure groups and relative to age. Score adjustment made by ANCOVA, to sample mean values for age, current alcohol use, and vocabulary score. Expressed on Z scale in SD units, with positive direction indicating better performance. Plotted points represent midpoints of three age strata (ages 18–25, median 22; 26–35, median 30; 35–61, median 45). Abbreviations of test names are defined in table 4.

porary or cumulative past occupational solvent exposures, or both.

In this study sample there were dose related trends toward worse performance on at least four of nine neuropsychological tests, primarily affecting tests of visual perception or memory, and there was no evidence of significant exposure association with motor performance or mood state. After adjustments for differences in age, the high and low current exposure subjects differed in group mean performances on individual tests by up to 16%, with the differences achieving statistical significance on one test (pattern recognition) and borderline significance on another (symbol digit substitution). When exposure-performance relations were further considered relative to age strata, subjects in the oldest stratum (>35 years of age) with higher exposure performed significantly less well on three tests (pattern recognition, pattern memory, and digit learning) than did other subjects of comparable age and there was at least qualitative evidence of exposure associated performance decrements on three other tests (symbol digit substitution and associate learning and recall) within the middle and oldest age strata. Three tests of motor and visuomotor performance (finger tapping, complex reaction time, hand-eye coordination) showed no consistent association with exposure, even after consideration within age strata.

The findings of this study are consistent with the general findings from other studies of workers with active solvent exposures, including two Scandinavian studies specifically of vehicle painters.[7-9] Hanninen *et al* evaluated 100 car painters and 101 state railway workers in Finland.[7] The painters reported significantly more symptoms of fatigue and difficulties with memory and attention, and they scored significantly less well on tests of visual intelligence and verbal memory (primarily block design, associate learning, and digit span tests). Elofsson *et al* intensively studied 40 car painters and 40 industrial painters in comparison with two groups of non-exposed industrial workers in Sweden.[8 9] The painters gave positive answers significantly more often than controls on five (out of 11) questions regarding symptoms acutely related to work, 21 (out of 38) neurological symptom questions, and eight (out of 52) psychiatric symptom questions (with no significant differences on the remaining symptom questions). Neuropsychological testing found statistically significant intergroup differences (range 7%–12%) in tests of simple reaction time, manual dexterity, perceptual speed, and short term memory. It may be noteworthy, however, that the relative decrements in manual dexterity and simple reaction time seemed to be more pronounced among the industrial painters than the car painters.

In the present study, we found no apparent associations between current exposure and either mood state or psychomotor performance. Also, symptom reporting by painters and non-painters was significantly different only after non-painters were considered dichotomously depending on whether or not they were formerly painters; symptom reporting was significantly lower among the never painters but not the former painters, for acute as well as chronic symptoms. These differences between the Scandinavian studies and the present study of car painters, however, represent disparity in breadth of findings rather than incongruity, and probably resulted from differences in study design and sample selection. Both Scandinavian studies included external, non-exposed control groups, whereas the present study used an internal low exposure control group. This design should have maximised the comparability of professional and socioeconomic backgrounds among exposure groups. Because the low current exposure subjects had on average, however, spent more years in the trade than the other subjects, and because most of the low current exposure subjects had been employed formerly in high or medium exposure positions within this trade, this study had less potential ability than the Scandinavian studies to detect an exposure effect, particularly one of any cumulative and persistent exposure. The evidence that workers in this industry commonly move from painting to non-painting positions, but rarely the reverse, also suggests that a greater proportion of painters than non-painters might have migrated previously out of the trade, conceivably because of health concerns or problems. Such a phenomenon would also lead a cross sectional study to underestimate the prevalence of disease related to exposure.

The age distribution among subjects in this study is also probably biased against the possibility of the study being able to find any exposure effect. The painters (and combination workers) were younger and had spent fewer years in the trade than the painters in the Scandinavian studies: their average age was 29, in comparison with 35 in the Finnish study and the unstated but probably higher average age produced in the Swedish study by sampling uniformly among 10 year age strata up to age 65. Also the method of age matched subject sample selection, which was employed in the two Scandinavian studies, was not feasible in the present study, and subjects were selected by convenience, giving comparable age ranges among exposure groups but an average age difference of eight years between low exposure control subjects and subjects with high or medium current exposures. Advancing age is often associated with decrements in various areas of neuropsychological performance, and age, independent of solvent exposure, had a significantly negative influence on most of the test outcomes examined in this subject sample.

Despite the potential conservative biases from the disproportionate distribution of age and experience relative to current exposure in this sample, as well as the potential loss of statistical power with age stratification, this study found significant adverse associations between exposure to paint and neuropsychological performance, with indications that age, or age as a surrogate marker for cumulative exposure, may play some part in exposure effect. Indeed, age has been reported elsewhere to be a significant negative modifier of the neurotoxic effects of lead and mercury, independent of the degree of cumulative exposure,[15 16] and close attention should be paid to possible age-exposure synergism in studies of acute or chronic exposures to neurotoxin.

It is noteworthy that the solvent exposures found in the present study and the two Scandinavian studies did not violate the applicable legal regulations or advisory group guidelines for full shift average or short term sampling, and it is likely that these standards are inappropriate measures for assessing workers' risks for solvent neurotoxicity. The Finnish car painters on average sprayed three litres of paint and solvent during one to two hours daily, with combined solvent exposures averaging 32% of the Finnish TLV for solvent mixtures.[7] Similarly, car painters in the Swedish study on average spent only 15% of their work day spray painting, with combined solvent exposures from that activity averaging 30% of the Swedish TLV.[8] Despite these "acceptable" exposures, the painters in the present and the Swedish studies reported significantly more neurological symptoms acutely related to work. Although the long term health significance of different patterns of solvent exposure is not known, workers diagnosed as having solvent induced chronic toxic encephalopathy in two clinical case series[2 17] have uniformly described the preceding regular occurrence of neurological symptoms acutely related to work. It is likely that the transient, very high peak exposures found in our present study have greater relevance than acknowledged by conventional sampling strategies and regulations.

The computer administered neurobehavioural evaluation system (NES) has only recently been deployed widely in field studies of chemical exposures, and published experience with this instrument is still limited. It is conceivable that computer administered tests could be less sensitive or could assess different functional modalities than the analogous interviewer administered versions and that this could then account for the absence of evidence in this study for exposure effects on psychomotor function. Tests in the NES battery have been shown, however, in the limited validity testing reported to date, to be relatively reproducible and to correlate reasonably well with results obtained from analogous interviewer administered tests.[6] Furthermore, the coefficients of variation on individual tests in this sample were comparable with results obtained with clinical, interviewer administered tests.[18] Finally, this test battery has been used effectively in another study to document decrements of neuropsychological performance and alterations of mood relative to history of solvent exposure, also when compared internally among a sample of painters.[19] In the present study, the computer administered NES was simple to use and effective in showing probable solvent related decrements in neurological function among workers tested in geographically dispersed settings.

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