

Response of solvent-exposed printers and unexposed controls to six-hour toluene exposure

by Jesper Bælum, MD,¹ Ib Andersen, MD,² Gunnar R Lundqvist, MSc,¹ Lars Mølhave, MSc,¹ Ole Find Pedersen, MD,¹ Michael Væth, MSc,³ David P Wyon, PhD⁴

BÆLUM, J ANDERSON I, LUNDQVIST GR, MØLHAVE L, FIND PEDERSEN O, VÆTH M, WYON DP. Response of solvent-exposed printers and unexposed controls to six-hour toluene exposure. *Scand J Work Environ Health* 11 (1985) 271–280. The acute effects of toluene were studied in 43 male printers and 43 control subjects matched according to sex, age, educational level, and smoking habits. The mean age of the subjects was 36 (range 29–50) years. The printers had been exposed to solvents for 9 to 25 years during employment at flexo and rotogravure printing plants, while the controls had no history of solvent exposure. Each subject was exposed once in a climate chamber to either 100 ppm of toluene or clean air for 6.5 h preceded by a 1-h acclimatization period. The effects of toluene were measured from subjective votes with linear analogue rating scales on 16 items, and on the performance of 10 different tests measuring psychomotor skills, perceptual skills, and vigilance. Exposure to 100 ppm of toluene compared with exposure to clean air caused discomfort with complaints of low air quality, strong odor, fatigue, sleepiness, a feeling of intoxication, and irritation of the eyes, nose and throat. Furthermore, the subjects exposed to toluene showed decreased manual dexterity, decreased color discrimination, and decreased accuracy in visual perception. There was no significant difference in the effects of toluene on printers compared to those of toluene on controls, but tendencies toward a greater sensitivity were seen for the printers in two tests.

Key terms: air quality, color discrimination, discomfort, environmental chamber, manual dexterity, organic solvents, psychometric performance, subjective response, visual perception.

Toluene is a solvent that is widely used for both domestic and industrial purposes. The acute effects of high levels of this substance are well documented and are dominated by symptoms from the central nervous system (7). However, there are only a few controlled human studies of the effects of toluene in concentrations near the present hygienic standard, which in most Western countries is 100 ppm (1, 4).

A recent study concerning 6-h experimental exposure to 0, 10, 40, and 100 ppm of toluene has shown that exposure to 100 ppm causes moderate annoyance but no impairment of visual perception, vigilance, psychomotor functions, or higher cortical functions (2). No acute effect of toluene on the upper and lower airways was found. In this study and in the earlier experimental studies of toluene (10, 12, 17, 18, 25), the subjects were young and healthy without previous exposure to solvents.

The aim of the present study was to investigate the effects of a 6-h exposure to 100 ppm of toluene (hygienic standard) on a group of middle-aged workers and to investigate whether a long-time occupational exposure

to solvents has a significant influence on the reaction to an acute exposure. Therefore the study includes two groups, one with several years of occupational exposure to a mixture of solvents and another without a history of exposure to solvents or other chemicals (a control group).

Subjects and methods

Eighty-six men, 43 printers and 43 control subjects, were studied in the climate chamber at the Institute of Hygiene, University of Aarhus, Denmark. Each person was exposed once only in groups of three or four to either 100 or 0 ppm of toluene during 6.5 h, preceded by a 1-h acclimatization period. The subjects carried out a program of psychological tests and physiological measurements. In the study lung, liver, and kidney function was investigated together with the urinary excretion of the toluene metabolites hippuric acid and orthocresol. The results of these investigations have been reported elsewhere (8, 9) or will be published.

Subjects

The occupationally exposed subjects were skilled and unskilled workers working at the presses in six printing plants. These subjects are called printers. The six plants employed more than 90 % of the persons working with flexo and rotogravure printing within 100 km from the Institute. It was impossible to obtain a group of sufficient size with long-term ex-

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posure to toluene alone, and therefore the exposed group comprised printers regularly exposed to a mixture of solvents including toluene. In the plants 140 printers were exposed to solvents, and these 140 persons filled out a questionnaire about job history, general health history, smoking, and drinking habits.

Only persons under 50 years of age with more than ten years of employment in the printing industry and with at least five years of the present printing process were included. From this group were excluded persons with heart, lung, and other chronic diseases and those with more than 15 d of absence from work during the past 12 months. Regular use of hypnotics, psychotropic drugs, or a daily consumption of more than three alcoholic drinks was also reason for exclusion. Fifty-three printers fulfilled the criteria for entering the study, and 43 of these participated.

The printers had, on the average, been employed with flexo or rotogravure printing for 15 (range 9–25) years. The most frequently used solvents were mixtures of ethanol, ethyl acetate, and ethoxyethanol with toluene as a frequent but minor component. Individual exposure levels could be estimated from air analyses performed during the two preceding years. Calculated as the sum of concentrations divided by their threshold limit values (1), the exposures ranged from 0.1 to 1.1 with a mean of 0.48. Toluene was found in concentrations ranging from 0 to 20 ppm, which was 0 to 20 % of the total exposure due to solvents. There was no difference in exposure level between the skilled and unskilled workers.

The present exposure levels were lower than the exposure during the previous 10 years. In this period concentrations had decreased by two to five times, and toluene had partly been replaced by other solvents.

For each printer a control subject was selected, matched according to sex, age ($\pm$ two years), smoking habits [nonsmoker, moderate smoker (≤ 10 cigarettes/d), and heavy smoker (> 11 cigarettes/d)], educational level (skilled or unskilled worker), and residential area. The control subjects were drawn from the Municipal Register of Aarhus.

Two hundred and seventy-nine persons matching the printers with regard to age and educational level were selected from the register, and a questionnaire similar to that filled out by the printers was mailed to these persons. Only control subjects with no present or former occupational exposure to solvents were included, while the other inclusion criteria were the same as those of the printers. Among the 186 (67 %) subjects who answered the questionnaire, 78 (42 %) fulfilled the inclusion criteria, and the control subjects were chosen from these persons. Fourteen control persons were office workers, while the rest were employed in different industrial or service jobs.

The 86 printers and control subjects made up 41 matched pairs, while two printers and two controls were without a specific matched subject due to a last minute cancellation by their matching person.

The pairs of printers and controls were randomized into two groups, of which one was exposed to 100 ppm of toluene and one to clean air. The four groups are called printers exposed to 100 ppm of toluene (P100), control persons exposed to 100 ppm of toluene (C100), printers exposed to clean air (P0), and control persons exposed to clean air (C0). The four groups are described in table 1. It appears that no difference in age, height, body weight, and smoking existed between the groups of printers and controls. The alcohol consumption was slightly higher among the printers than among the controls [$p \sim 0.10$, Mann Whitney U-test (23)]. More smokers happened to be allocated to the P-100 group and the C-100 group than to the P0 and C0 groups, but no other group difference existed.

Exposure conditions

The exposure facility has been described elsewhere (2). During the present study spectroscopy grade toluene [Merck Uvasol art 8331 (99.7 %)] was used, and the average concentration was 102 (SD 2) ppm during the exposure. During clean air exposure the total concentration of hydrocarbons was below the detection limit of 0.1 ppm. The average air tem-

Table 1. Mean age, height and body weight, number of skilled workers and smokers, and the average alcohol consumption of the subjects. The range is shown in parentheses.

Group ^a	Number of persons	Age (years)	Height (cm)	Weight (kg)	Number of skilled workers	Number of smokers	Alcohol consumption in drinks per day	
							Average	Day before exposure
<i>Printers</i>								
P100	20	36.1	176.6	74.1	15	17	1.5	2.2
P0	23	36.6	179.3	83.2	17	10	1.2	1.1
All printers	43	36.4	178.0	79.0	32	27	1.3	1.6
		(29—50)	(162—192)	(53—108)			(0—4)	(0—10)
<i>Controls</i>								
C100	21	36.0	178.4	75.9	15	17	0.9	0.6
C0	22	36.9	177.3	78.5	17	10	1.0	1.4
All controls	43	36.4	177.8	77.2	32	27	0.9	1.0
		(30—49)	(161—196)	(62—101)			(0—5)	(0—5)

^a P100 and C100 are groups exposed to 100 ppm of toluene; P0 and C0 are groups exposed to clean air only.

perature was 22.8 (SD 0.5) °C, and the relative humidity 40.2 (SD 1.2) %. The fresh air supply was 60 m³ · h⁻¹ per person, corresponding to an air change of 4.6 h⁻¹.

Experimental design

The exposures took place Tuesday through Friday from 0800 to 1600, and the persons performed normal daytime work the previous day. For printers the exposure-free interval preceding the study was 15 to 18 h. The persons were told to avoid hypnotics, psychotropics, and analgetics during the exposure day and the day before, and to avoid alcohol intake the last 12 h before exposure.

Before entering the exposure chamber the subjects went through a general medical examination. Health history, job history, and smoking and drinking habits were explored followed by a physical examination including measurement of oral temperature and blood pressure.

The rest of the day the persons stayed in the chamber. The day was divided into the following three periods: the acclimatization period from 0830 to 0930, the instruction period which ended at the lunch break at 1120, and the test period from 1200 to 1600. On days with exposure to toluene, the concentration gradually increased from 0930 until 100 ppm was reached at 1000 and maintained during the rest of the exposure. During the day smoking was prohibited, and no coffee, tea, or alcohol was served.

Measurements

Subjective ratings and performance on 10 different tests were used as measures of the effects of exposure.

Subjective ratings. A questionnaire including 16 items was used to grade the quality of the environment and the annoyance due to exposure. The scale type was linear analogue rating (6). Four questions referred to the environmental parameters temperature, sound level, air quality, and odor level. Furthermore, the subjects were asked about their feeling of fatigue, sleepiness, and strain. Finally, they were asked about irritation of the eyes, nose, throat and lower airways, cough, headache, feeling of intoxication, dizziness, and nausea.

Three of these questionnaires were answered by each person during the day. The first was filled out at 0900 before the onset of exposure. The next was filled out at 1000 in order to detect the immediate response to the exposure, and the last one came at the end of the day at 1600.

Performance tests. Ten tests were used in the study. Six concerned different aspects of visuomotor coordination, while four concerned perceptual speed and quality, as well as higher cortical functions. The fol-

lowing list provides a brief description of each. Tests 1 through 6 have been used in a recent study on the effect of cold and heat stress on performance (26). Tests 7 through 10 measured visual performance and higher cortical functions.

1. The *peg board test* has been used in different versions for measuring finger dexterity (19). The subject takes pegs (length 10 mm and diameter 7 mm) with his dominant hand from a tray and puts them into precisely drilled holes in a plate. Three pegs must be inserted into each of the 100 holes. The time spent filling the whole plate is measured.

2. The *screw plate test* demands coordination between vision and finger movements, both hands cooperating. The time consumed to transfer 64 nuts and bolts between holes in a steel plate is recorded. The test has been more specifically described in another report (2).

3. The *rotary pursuit test* demands coordination between vision and arm movement and has shown sensitivity to heat and cold (19). The test has been more specifically described earlier (2, 19).

4. The *track tracing test* is a measure of arm-hand steadiness in slow precision movements (19). In a vertical plate facing the subject there is an irregular track with one circular entry point with a diameter wider than the track. A stylus with a disc on the end wider than the track is inserted at the entry point. The subject must move the stylus through the track without touching the sides. Errors are recorded on a counter measuring the total contact time during four passages which take about 3 min.

5. The *simulated assembly-line peg test* is an automated task, simulating the work of a typical assembly line. A continuous band moves intermittently, 15 cm at a time, 30 times/min. At 15-cm intervals bars are transversely attached to the band. Each bar has three small holes, 1 cm deep, 6 mm in diameter, and 8 cm apart in a line across the band. The subject must pick up 3-cm pegs from a tray in front of the band and place these in the holes leaving as few bars as possible unfilled. The scoring is done electronically by counting the number of bars with 0, 1, 2, and 3 pegs in place. The pegs are returned to the tray, a process that thus makes the test continuous. The duration of the test is 30 min, and performance is scored according to the average number of pegs placed in each bar and the number of bars without pegs.

6. The *five-choice serial reaction test* has been extensively used to measure the effects of various environmental factors on perseverance and concentration (2, 22). The test is more specifically described in another report (2); it is a self-paced choice reaction test including a vigilance component. The nine different parameters which are computed are listed in table 2 in the Results section.

7. The *Landolt's ring test* examines visual perception and has been more specifically described earlier (2). In the present study, however, four sheets were used instead of one.

8. The *vigilance clock test with peripheral lights* is a combination of two standard tasks (15). The primary task is to observe a 7-cm black pointer on a white background rotating with one revolution per minute with occasional 200-ms stops. A secondary task is to notice brief flashes in any of six lamps placed symmetrically in a horizontal plane at visual angles of 30, 60, and 90°. The pointer stops, and flashes occur randomly in time and sequence at a mean rate of 3/min. One-fourth of the events to be observed are pointer stops, while the rest is equally distributed among the six lamps. Seeing the stimulus, the subject must react by pressing one of seven buttons placed in front of him. The duration of the test is 30 min, and the following three values are recorded: score (percentage of right responses), errors (percentage of reactions pressing the wrong button), and false reactions (reactions without preceding stimulus). Each of these values is recorded for the clock, for the lamps at each angle, and for all lamps.

9. The *color discrimination test* was included because it represents a task essential for printers. Problems with color discrimination were reported from the plants. In the test 20 color specimens are identified on a reference chart with 210 samples. There are 30 colors covering the whole color spectrum and with each color represented by seven intensities ranging from 5 to 100 % saturation. In order to achieve a suitable degree of difficulty, all samples were shaded by grey to a lightness of 50 %. The test is scored as the number of correct answers out of 20 and as the estimation of the cumulated deviation between the subjects' judgement and the right color specimen, both according to color and intensity.

10. In the *multiplication test* two three-digit numbers without zeroes are to be multiplied. The time used to complete 25 units and the number of errors are recorded. A time limit of 25 min is set for this test.

Nine of the tests were administered to each subject only once (in the afternoon). The color test was performed twice (before the exposure and in the afternoon). During the instruction period the subjects tried out all the tests of short duration and 5-min sessions of the tests of long duration.

Statistical procedure

The results were processed by an analysis of variance using the GENSTAT program package (16). The distribution of each variable was initially examined graphically, and the values were transformed when necessary to stabilize the variances. Typically logarithmic or square-root transformations were used.

The following four types of statistical analyses were performed:

1. For each of the variables the results were analyzed by ordinary analysis of variance in order to test for the effect of acute toluene exposure (dose), difference between printers and controls (group), and interaction between group and dose. Then the effects of the covariables age, smoking habits, consumption of alcohol and drugs, educational level, and shift work were tested.

2. For the printers alone the effects of the covariables duration and level of exposure, as well as age, were tested as in procedure 1.

3. Votes on environment, fatigue, sleepiness, and strain were obtained three times a day, and they were tested by a variance component technique to separate the inter- and intraindividual differences before testing as in procedure 1.

4. A large proportion (50–96 %) of the answers about irritation of the eyes and airways and about neurological symptoms indicated that no annoyance was experienced; therefore the results were described as either no complaint (N) or complaint (A). The analysis was compressed to a Kruskal-Wallis one-way analysis of variance (23) on an ordinal scale where the eight combinations — of no complaints and complaints — during the three votes were ranked. The sequence of combinations (A-N-N, A-A-N, A-N-A, N-N-N, A-A-A, N-A-N, N-N-A, N-A-A) indicated increasing effect of exposure on annoyance.

The results were analyzed for the groups as both pair-matched and unmatched subjects. Five percent was used as the level of significance, and in the following discussion significant difference refers to probability values below the 5 % level, and tendency refers to values between 5 and 10 %.

Results

Valid results were obtained from 96.4 % of the intended measurements. The following presentation is restricted to the analyses of unmatched groups as the matched-pair analyses did not reveal any more interesting details.

Subjective votes

The time course of the subjective votings during the exposure is shown in figures 1 and 2. Initially the subjects exposed to toluene responded strongly to *air quality* and *odor level*, whereas the level of the response declined at the end of the day. The experiences of air quality and odor level were highly correlated.

The exposure to toluene did not influence the experience of *room temperature* and *sound level*, and all subjects felt these to be acceptable.

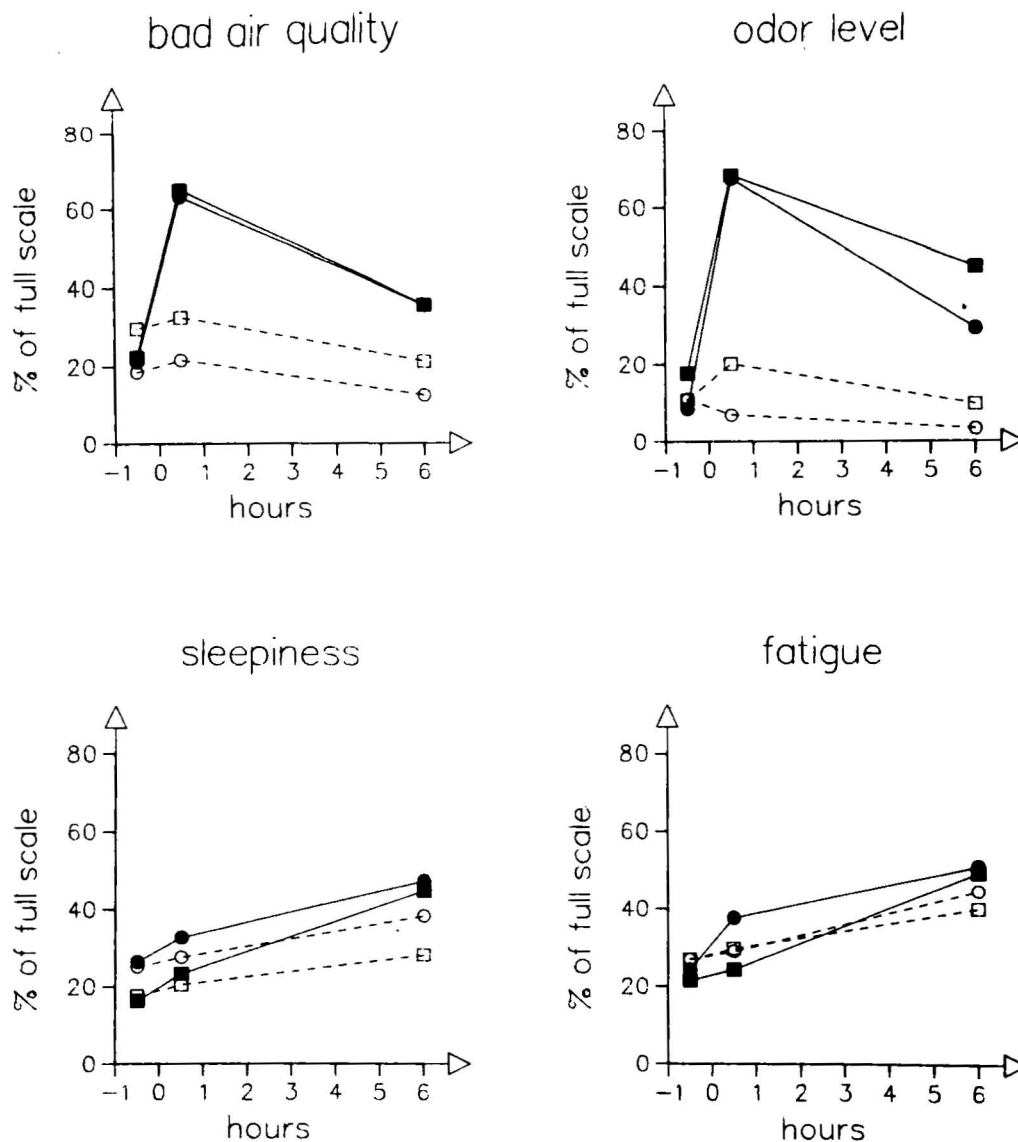


Figure 1. Time course of the average of the subjective ratings in the four groups. Only ratings significantly correlated to toluene exposure are included. The abscissa shows time in relation to start of exposure. (■—■ = printers exposed to 100 ppm, □····□ = printers exposed to clean air, ●····● = controls exposed to 100 ppm, and ○····○ = controls exposed to clean air)

The ratings on *fatigue* and *sleepiness* increased during the day for all the subjects. At the beginning of the exposure the P100 group felt tireder than the three other groups. At the end of the exposure the fatigue was significantly more pronounced in the P100 and C100 groups than in those exposed to clean air. The printers were significantly sleepier in the morning than the controls. The feeling of *strain* was higher among the printers than among the controls, but it showed no relation to acute toluene exposure.

Irritation of the eyes, nose, and throat was significantly increased by exposure to 100 ppm of toluene in comparison with exposure to clean air. The irritation occurred as an immediate response to exposure.

During the rest of the day the frequency of symptoms was almost constant. The C100 group had a lower frequency of eye irritation than the C0 group; however this difference was not statistically significant and declined during the day.

Irritation of the lower airways and cough was seldom reported and was not related to toluene exposure. The frequency of *headaches* increased during the day, but no relation to toluene exposure was seen.

The feeling of *intoxication* and *dizziness* was related to toluene exposure although the frequency of the latter symptoms was low. *Nausea* was not reported by any of the subjects.

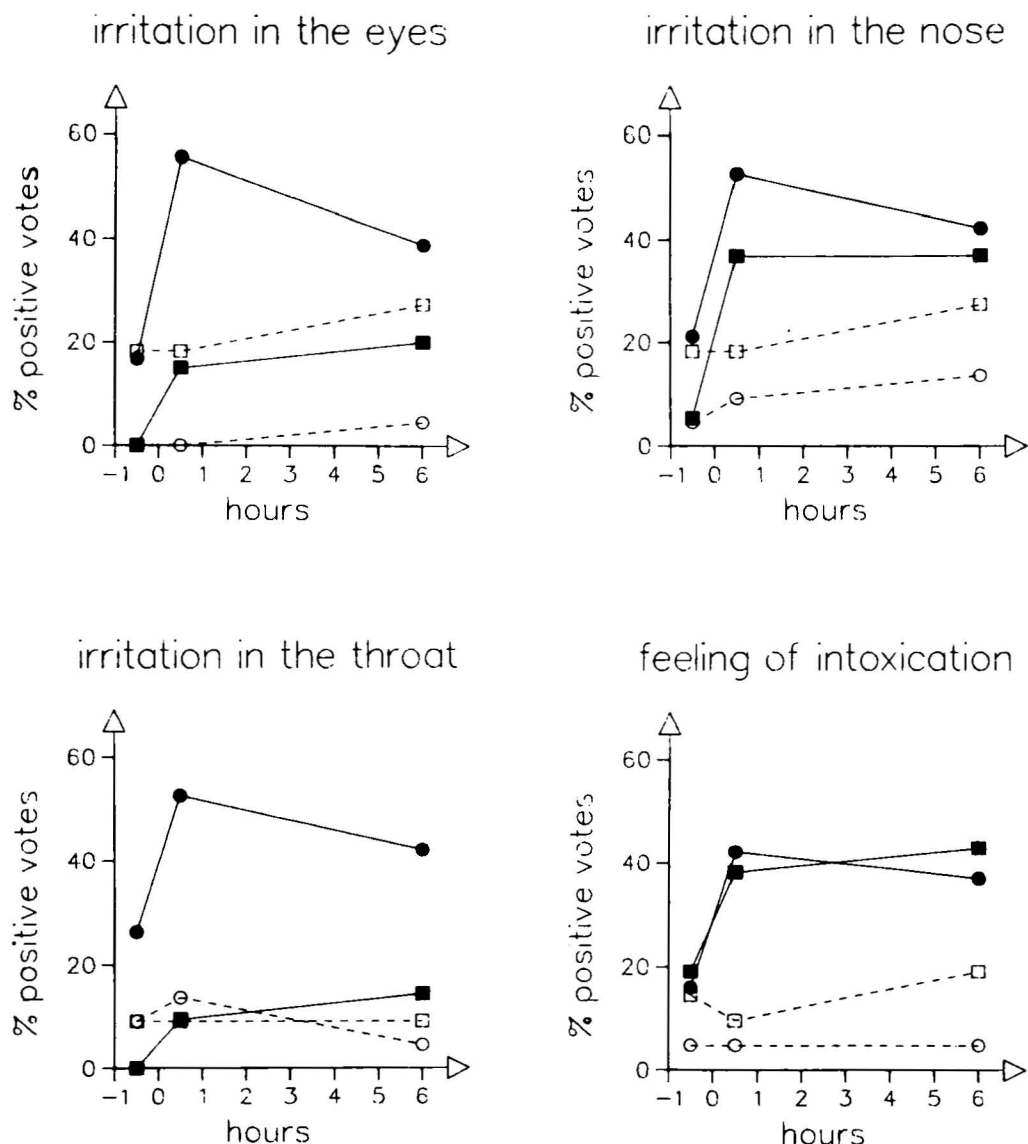


Figure 2. Time course of the percentage of persons with annoyance in the four groups. Only ratings significantly correlated to toluene exposure are included. (■—■ = printers exposed to 100 ppm, □...□ = printers exposed to clean air, ●...● = controls exposed to 100 ppm, ○...○ = controls exposed to clean air)

Performance tests

The main results of the performance tests are shown in table 2. The effect of toluene exposure was seen in one of the six tests of visuomotor coordination. On the *peg board test* the toluene-exposed printers were significantly slower — they spent 15 % more time on the task — than the printers exposed to clean air, whereas no difference existed between the toluene-exposed controls and the controls exposed to clean air. Accordingly a tendency towards a group-dose interaction was found.

In the other five tests no effect of toluene was seen. On the *screw plate test* the printers were significantly (9 %) slower than the controls, while the score in the *rotary pursuit test* was 30 % higher among the

printers. In the *five-choice serial reaction test* no difference in response rate was seen, but printers showed tendencies toward a larger irregularity in response rate, counted as the individual standard deviation, and toward a larger number of wrong targets than the controls.

The effect of toluene exposure was seen in three of the four tests of perception and higher cortical functions.

In the *vigilance test* the percentage of responses and the number of errors showed no difference between the groups, but there was a tendency toward a higher number of responses without preceding stimulus (false responses) in the groups exposed to 100 ppm of toluene. In the detailed analysis this dif-

ference was significant for the lamps at a visual angle of 30°. The difference for the peripheral lamps and the pointer did not reach significance. Skilled workers and the subjects with the highest alcohol consumption showed more false responses to the pointer than the other subjects, and, when these correlations were included in the statistical model, the printers had significantly fewer false responses than their controls.

Time used and number of errors on the *Landolt's ring test* were significantly correlated with age, and the statistical model included this variable. There was a tendency for the subjects acutely exposed to toluene in the chamber to work more slowly than those exposed to clean air, and they made significantly more errors. The latter difference was restricted to the group of printers, as no difference was seen between

the C100 and the C0 group. The printers spent more time performing the test than the controls, while no difference in errors was seen.

On the *color discrimination test* the printers made 31 % fewer errors than the controls. From the first to the second test during the day the number of errors in the P0 and the C0 groups decreased by 13 and 12 %, respectively, while the number of errors in the P100 group was unchanged and that of the C100 group was increased by 3 %. This significant decrease in performance was even more pronounced in the cumulated color deviation, while no change was seen in the intensity deviation. The effect of the acute toluene exposure was evenly distributed over the 20 test samples and thus was not related to any special color or intensity.

Table 2. The four groups' performance on the tests.

Test	Group ^a								Effect of toluene	Statistical significance	
	P100 (N = 20)		P0 (N = 23)		C100 (N = 22)		C0 (N = 21)			Difference between printers and controls	Difference in sensitivity to toluene between printers and controls
	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
Peg board (time)	739	128	641	81	664	90	656	99	*	—	(*)
Screw plate (time)	1 024	176	977	122	926	173	902	137	—	*	—
Rotary pursuit (% contact time)	36.9	15.7	40.6	14.9	30.5	13.7	29.1	14.4	—	*	—
Track tracing errors (s)	18.4	8.2	17.1	7.4	14.1	6.6	17.4	9.4	—	—	—
Simulated assembly line											
Number of empty bars	33	33	30	29	26	30	32	30	—	—	—
Mean number of pegs inserted per bar	1.44	0.28	1.53	0.28	1.54	0.24	1.47	0.19	—	—	—
Landolt's rings											
Time (s)	257	62	238	85	217	39	252	96	(*)	*	* ^b
Errors/100 rings	1.5	2.5	0.6	0.8	1.4	1.5	1.8	4.3	*	—	— ^b
Color discrimination											
Errors — before exposure	7.58	4.07	8.00	3.31	10.19	3.47	12.27	3.64	—	**	—
Change during exposure	0.00	1.89	−1.00	2.47	0.29	3.82	−1.50	2.91	*	—	—
Color deviation — before exposure	6.79	6.42	8.45	6.05	10.43	8.18	15.00	12.07	—	**	—
Change during exposure	0.31	3.74	−1.50	5.75	0.95	4.01	−2.41	7.09	**	—	—
Intensity deviation — before exposure	5.11	3.24	5.55	3.10	7.29	3.23	8.55	3.83	—	**	—
Change during exposure	−0.05	2.17	−0.73	2.83	0.00	3.32	−0.27	4.08	—	—	—
Multiplication											
Time/25 units (min)	25.2	8.2	25.9	7.8	29.4	11.3	30.8	13.1	—	*	—
Errors/25 units	6.2	4.4	6.5	3.9	8.8	3.7	8.6	4.9	—	*	—
5-choice											
Ordinary taps/1 000 s	860	125	880	111	848	147	849	148	—	—	—
Wrong targets/1 000 taps	18	13	16	19	15	13	11	10	—	(*)	—
Plate taps/1 000 taps	48	35	55	31	59	31	50	49	—	—	—
False button presses/1 000 taps	5.5	10.5	3.1	3.9	2.5	2.4	2.9	2.8	—	—	—
True button presses/1 000 delays	354	289	485	281	402	263	380	266	—	—	—
Reaction gaps > 1.5 s/1 000 taps	122	105	117	56	147	127	142	114	—	—	—
Mean reaction time (s) without button presses	1.16	0.20	1.14	0.14	1.18	0.22	1.18	0.22	—	—	—
Standard deviation of reaction time without button presses	0.69	0.67	0.41	0.10	0.51	0.21	0.45	0.18	—	(*)	—
Reaction time (s) with button presses	2.76	0.76	2.17	0.54	2.59	0.73	2.60	1.18	—	—	—
Vigilance (%)											
Score											
Lamps	87.2	12.3	86.2	13.0	87.6	14.2	87.4	12.4	—	—	—
Clock	59.7	26.2	64.0	25.6	55.9	25.2	53.5	24.5	—	—	—
Errors											
Lamps	2.6	2.9	2.1	2.9	1.5	1.7	0.6	2.1	—	—	—
Clock	0.0		0.7	1.6	0.3	1.2	1.2	2.3	—	—	—
False response											
Lamps	3.3	6.0	1.0	1.4	5.0	21.6	1.3	15.8	(*)	—	—
Clock	4.5	8.6	1.7	2.7	11.7	10.2	5.3	3.3	—	(*)	—

^a P100 = printers exposed to 100 ppm of toluene, P0 = printers exposed to clean air, C100 = controls exposed to 100 ppm of toluene, C0 = controls exposed to clean air.

^b Based on age-corrected values.

(*) $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

The printers worked faster and made fewer errors in the *multiplication test* than did the controls, but no effect of the acute toluene exposure was seen. Within the groups the skilled subjects worked faster and made fewer errors than the unskilled.

Discussion

The present study was an attempt to estimate the effect of a controlled acute exposure to toluene on two groups of healthy workers, one with occupational exposure to solvents (printers) and one without solvent exposure (controls). No attempts were made to include printers who had left their trade due to disease, etc.

We have chosen a single exposure design for this study in order to avoid the interaction between dose and learning effect especially seen in the performance tests in the design of a Latin-square type (2, 20). Another reason was that it was difficult for most persons to leave work for more than 1 d.

In the present design conclusions are based on comparisons between persons, and the validity of these conclusions relies on the comparability of the groups. The printers and the controls were pair-matched according to five criteria, of which age, educational level, and smoking habits showed correlation to annoyance and performance. The frequency of alcohol consumption and shift work differed between the printers and controls, but, although the latter factor influenced the frequency of symptoms reported by printers in a workplace study (5), the imbalance of these confounders did not affect the results of the present study.

The printers had a better performance than the controls on three tests (rotary pursuit, color test, and multiplication), while the controls had a better score on two (screw plate and Landolt's rings). Thus, no systematic difference in the relatively simple skills was seen between the printers and controls participating in the study.

The exposure of car painters in a Finnish study (11) was comparable with the exposure of the printers in this study. In the Finnish study the exposed group had an impaired performance on mainly complex psychological function tests, while only minor differences in psychomotor performance were seen when the car painters and referents were compared. In a study of jet fuel workers (14) the exposed persons showed greater irregularity on a simple reaction test, together with a poorer performance on a test of visual perceptual speed (Bourdon-Wiersma test), in comparison with the referents.

Both the printers and the controls complained of an unacceptable air quality and odor level during the toluene exposure, although some adaptation did take place during the day. Irritation of the nose followed the same pattern, but there was less adaptation during the day. For air quality, odor level, and nasal irrita-

tion there seems to be no long-term adaptation, as the results of the printers and controls were almost identical. Nasal irritation seems to be the most reliable subjective information on airway irritation due to acute solvent exposure.

Signs of neurotoxic effects during the acute toluene exposure were seen in the form of fatigue, sleepiness, and the feeling of intoxication. These symptoms were reported similarly by the occupationally exposed printers and their controls. Headache seemed to be a much more nonspecific indicator than the three other mentioned symptoms, as the frequency of headaches rose during the day, both in the exposed and in the unexposed groups. This occurrence is in agreement with experience from epidemiologic studies (6, 13).

The subjects acutely exposed to toluene had a lower performance than those exposed to clean air on four of the ten tests; three of these tests concerned visual perseverance.

In the vigilance test we found an increased number of false responses to signals from the centrally placed lamps, but not a lower percentage of correct reactions in the groups exposed to toluene. This result might be explained by a light intoxication causing the subjects to overreact in their effort to respond to the pointer stops and flashes. A more severe intoxication would probably have caused a general impairment of performance, including the ability to hit the right targets.

The number of faults on the Landolt's ring test was positively correlated with age, probably due to the beginning of presbyopia. The difference between the toluene-exposed and those exposed to clean air in the study might be due to an effect on the visual cortex, an impaired accommodation, or an irritation of conjunctiva or corneae. The latter is in agreement with the irritation of the eyes reported by the subjects exposed to 100 ppm of toluene.

The most pronounced difference between the subjects acutely exposed to toluene and subjects exposed to clean air was seen in the color discrimination test. As expected, the printers performed better on the color discrimination test than the controls due to their professional education and training, but the effect of toluene was seen both on the printers and on the controls.

A chronic impairment of color vision due to several years' exposure to n-hexane or carbon disulfide has been reported (21, 22), but effects of controlled acute solvent exposure have not previously been published. The acute effect seemed to be independent of color, and intensity, but a systematic analysis with a standardized test covering the whole color spectrum would be preferable to reveal the details of the acute effects of solvents on color vision; such a test would, however, have been too time-consuming in the present study.

Only in the most simple test of visuomotor function, the peg board test, could a significant decrease

in performance be shown. The effect was furthermore restricted to the printers, as the exposed control subjects had roughly the same score as the unexposed controls. In the five more complicated visuomotor tests, where more composite movements were required, a much larger interindividual variation was seen, and, although the scores on the individual motor test were correlated to some extent, no effect of toluene was seen in these tests.

No significant difference in sensitivity to acute exposure to toluene was seen when the printers and controls were compared. In the peg board test and the Landolt's ring test tendencies toward a group-dose interaction were seen as signs of a larger difference between the exposed and unexposed printers in comparison with the controls. No sign of different sensitivity was seen in the subjective votes. However, the strength of the statistical testing of interactions was rather small, so, to detect a small difference in sensitivity, a much larger material or a higher dose would be required.

Compared with our previous study of toluene (2), in which 16 young students participated, the results of the subjects in the present study were lower, but, except for the workrate in the multiplication test, differences only amounted to 25 %, or about one standard deviation. This systematic but small difference in the simple tests used is in accordance with a study of white spirit (24). In that study nine house painters had a considerably lower performance on verbal memory and serial addition tests than students, while the painters' simple reaction time and results of a Purdue peg board test did not differ from those of the students.

In a study of 12 young healthy persons without occupational exposure to solvents Gamberale & Hultengren (10) found impaired simple reaction time during 20-min exposure to 300 ppm of toluene, while no effects were seen in four different tests at 100 ppm. Ogata et al (18) found a tendency toward a prolonged simple reaction time during 7-h exposure to 200 ppm of toluene but no effect at 100 ppm, while Winneke et al (25) did not see any effect of a 4-h 100-ppm exposure on performance in simple reaction time, rotary pursuit or tapping. In a study of concomitant exposure to toluene and xylene no effect of 80 ppm of toluene during 4 h was seen in simple or choice reaction time or in short-term memory (3). No effect of 53 ppm of toluene, together with 23 ppm of xylene, was seen either.

Although the differences in experimental design make the comparison difficult, the sensitivity of the subjects in the present study seemed to be higher than in previous studies, all involving young healthy subjects without occupational exposure to solvents, as more tests were impaired and more subjective complaints were registered at the same exposure level.

This difference may partly be caused by the higher age and lower educational level of the subjects, while

the occupational exposure of the printers also may be a contributing factor in some tests.

The present study shows that pure toluene at a concentration equal to the present hygienic standard of 100 ppm adversely affects persons irrespective of former occupational solvent exposure. The acute 6-h exposure to toluene caused moderate fatigue, sleepiness and subjective intoxication, deterioration of the perceived air quality, irritation of the eyes and airways, and decreased psychometric performance, mainly in visual perceptual speed and accuracy, in persons comparable with the occupationally exposed population. This finding is not in accordance with the general criteria for a threshold limit value (1), and the study supports the conclusion of our previous study suggesting a reduction of the present standard of 100 ppm for toluene (2). The Danish standard has been adjusted accordingly, as it was lowered to 75 ppm, and to 50 ppm for new production facilities, in 1984 (4).

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