ORIGINAL RESEARCH ARTICLE

Effect of Volatile Organic Compounds on the Neurobehavioral Functions of Painters in Chennai, Tamilnadu: A Cross Sectional Study

Lavanya Sekhar[1], Ashwin Kumar N[2], Vidhya Venugopal[3], Santhanam R[4], Priscilla Johnson[5*]

[1,2,5]Sri Ramachandra Medical College & Research Institute, SRIHER (DU), Porur, Chennai, Tamilnadu, India
[3]WHO Collaborating Center for Occupational & Environmental Health, ICMR Center for Advanced Research on Air Quality, SRIHER (DU), Porur, Chennai, Tamilnadu, India
[4]Sree Balaji Medical College & Hospital, BIHER, Chennai, Tamilnadu, India

DOI: 10.55489/njcm.141020233308

ABSTRACT

Background: Paints are a major source of volatile organic compounds (VOCs) among painters. Limited information is available on neurobehavioral effect of long-term exposure to VOCs among painters working in unorganised industrial sectors such as construction site. Hence, this study was conducted to evaluate the neurobehavioral impact of long-term exposure to VOCs among construction painters.

Methods: This cross-sectional study was conducted among male painters in Chennai. VOC exposure index was calculated using questionnaire as well as personal exposure monitors. Neurobehavioral tests including hand dexterity, auditory (ART) and visual reaction time (VRT) were used to assess motor coordination, fine motor activity, focused attention, and psychomotor speed.

Results: Prevalence of prolonged ART and VRT in painters was 69% and 73%, respectively and 65% exhibited reduced hand dexterity. Hand dexterity had mild negative correlation ($r = -0.3$, $p = 0.01$) with VOC exposure index and work experience ($r = -0.3$, $p = 0.02$), whereas VRT had mild positive correlation ($r = 0.3$, $p = 0.01$) with VOC exposure index. Independent t-test showed a significant decrease in motor coordination with higher VOC exposure index (≤ 18.5×10^3 ppm-hrs = 60.1 ±10.1, >18.5×10^3 ppm-hrs = 53.3 ±12.3, p=0.03) and increase in work experience (≤ 10 years = 58.8 ±11.6, >10years = 52.5 ±11.5, p=0.05).

Conclusion: Neurobehavioral functions gradually decline with VOC exposure in painters working in unorganized sectors indicating a need to create awareness among the public and workers in unorganized sectors about the organic solvent-induced neurobehavioral changes.

Key words: Volatile organic compounds, solvents, occupational exposure, painters, motor coordination, reaction time, psychomotor speed

ARTICLE INFO

Financial Support: Partially funded by the Chancellor's Summer Research Fellowship-2020, SRIHER (DU), Chennai
Conflict of Interest: None declared
Received: 06-08-2023, **Accepted**: 09-09-2023, **Published**: 01-10-2023
***Correspondence:** Dr. Priscilla Johnson (Email: priscillajohnson@sriramachandra.edu.in)

How to cite this article: Lavanya S, Ashwin KN, Venugopal V, Santhanam R, Johnson P. Effect of Volatile Organic Compounds on the Neurobehavioral Functions of Painters in Chennai, Tamilnadu: A Cross Sectional Study. Natl J Community Med 2023;14(10):658-665. DOI: 10.55489/njcm.141020233308

www.njcmindia.com | pISSN09763325 | eISSN22296816 | Published by Medsci Publications

Introduction

Volatile organic compounds (VOCs) are one of the most prevalent air pollutants, representing a broad range of organic chemicals derived from a variety of sources in everyday life.[1] Paint is a well-known indoor and outdoor source of volatile organic compounds (VOCs). Due to the high vapor pressure and low boiling point, these organic compounds present in paint rapidly evaporate and sublimate into the air. VOCs are emitted during all painting processes, including blending, spraying, scrapping, rolling, brushing, and cleaning, and painters are frequently exposed to them.[2] Inhalation, ingestion, and dermal absorption of VOCs present in paints such as benzene, xylene, toluene, ethylbenzene (BETX compounds), styrene being most abundant (>60%) cause a wide range of detrimental health impacts that can range from mild irritation of the eyes, nasal or throat irritation, headache, dizziness, nausea, fatigue, & asthma-like symptoms among non-asthmatics to very severe effects like neurotoxicity and cancer.[3] In addition, some VOCs might not cause immediate hazards but they can have long-term effects on cardiorespiratory and neurocognitive function.[4,5] Since VOCs are inert and lipophilic, they can traverse the blood-brain barrier and cause various neurological, psychological, and behavioral symptoms in workers such as dementia, forgetfulness, poor coordination, concentration difficulties, and hallucinations. The extent and nature of the effect are determined by the exposure's duration, intensity, and rate of volatilization.[6] Few animal[7] and invitro[8] studies have also demonstrated that chronic exposure to low-levels of VOC can impede motor coordination and simple reaction time.

Environmental exposure to volatile organic compounds (VOCs) and their neurobehavioral effects have been studied globally[9], including in India[10], with evidence suggesting that elevated exposure to these VOCs has a significant impact on neurobehavioral functions. In addition, the majority of these epidemiological studies have evaluated the effects of VOCs on painters working in organized industrial sectors; however, there is a scarcity of research on painters employed in unorganized industrial sectors, such as construction sites especially in Indian settings. In addition, only a limited number of studies have measured the inhaled concentration of VOC and calculated the cumulative index of VOC exposure. Hence, this cross-sectional study was conducted to determine the effect of cumulative long-term VOC exposure on neurobehavioral functions among unorganized sector construction site painters.

Methodology

This cross-sectional study was conducted at a private medical institution in Chennai in accordance with the Declaration of Helsinki and the Code of Ethics of the World Medical Association, with the approval of the Institutional Ethics Committee (Registration No. IEC-NI/21/FEB/77-33). Male construction painters (full time) between the ages of 25 and 55 with at least five years of experience working in seven different construction sites in and around Chennai were screened. Painters with history of epilepsy, mental illness, cerebrovascular accident, hormonal imbalances including hypothyroidism, or who were taking psychoactive medications were excluded from the study. Using the formula $n = Z^2_{1-\alpha/2} S^2/L^2$ where Z = 1.96 and a mean hand dexterity level of 76 with a standard deviation (S) of 13.5 among dockyard workers exposed to toluene and paint solvents in the south of England[11], with a confidence interval of 95% and a tolerable level of error (L) of 4%, the sample size (n) was calculated as 75. After obtaining written informed consent from the 75 study participants who met the inclusion criteria, general information such as age, literacy status, socioeconomic status, smoking status, alcoholic status, and medical history were obtained using a standardized questionnaire. In addition, comprehensive history of VOC exposure pertaining to the number of years, months, weeks, days, and hours spent painting, as well as predominant type of paint used & the method of application was obtained using a standardized exposure questionnaire. Further details regarding Personal Protective Equipment (PPE) awareness & usage were also gathered.

VOC exposure assessment was carried out in the construction sites using an active sampling technique and a portable personal air sampler. The evaluation of direct personal VOC exposure included 15 randomly selected study participants who were executing various painting tasks such as enamel brushing (n=5), emulsion brushing (n=5), and paint scraping (n=5). Active sampling was done with a calibrated, battery-powered sampling pump that was connected via flexible tubing to a solid sorbent tube. During active sampling, a known volume of air was drawn through an absorbent medium (Carboxean & tenax), and contaminants were subsequently collected by adsorption. The samples were then analyzed for VOCs using GCMS Agilent 7890B/5977B GCMSD-54 VOC analyzer and gas chromatography. Concentrations of 15 individual constituents present in VOCs were measured in parts per million (ppm). In order to assess the cumulative VOC concentration, the geometric mean of the average concentrations of the various VOCs was calculated.

Using the solvent exposure index developed by Wang et al[12] (2011), the participant's long-term VOC exposure index (ppm-hrs), which is the product of exposure duration (T), use of personal protective equipment (P), and VOC concentration (C), was calculated.

Long term VOC Exposure Index[12]

$$=\sum_{i=1}^{n1} \sum_{j=1}^{n2} \sum_{k=1}^{n4} \sum_{m=1}^{n3} Cijkm \times Tijkm \times (1 - Pijkm)$$

where i, j, k, m are indices for years, months, week and application methods respectively, Cijkm is the concentration of VOCs (ppm), Tijkm is the painting time (hours per week), Pijkm is the proportion of usage of personal protective equipment.

Health assessment was performed on an exposure-free day of at least 24 hours, and the study participants were instructed not to consume any alcoholic beverages and it was ensured that they had adhered to a normal sleep pattern the night before the assessment. Hand dexterity and reaction time were measured to evaluate neurobehavioral skills such as motor coordination and fine motor activity, psychomotor speed, focused attention, and alertness. Hand dexterity was measured using a pegboard developed by Mavom Labs Private Limited in Bengaluru (Fig 1), which reflects fine motor activity and motor coordination. Study participants were instructed to insert peg pins in a writing pattern from left to right (sinistrodextral pattern) in 90 seconds, and the number of pegs inserted was recorded. A healthy individual between the ages of 25 and 55 will be able to insert at least 60 pins into the peg holes in 90 seconds[13]. Using a PC 1000 Hertz reaction timer (Fig 2), auditory (ART) and visual reaction time (VRT) were used to evaluate attention span, alertness, and psychomotor speed. ART and VRT are the length of time required to respond to auditory and visual stimuli, respectively. The average visual reaction time is between 180 and 200 milliseconds[14], while the average auditory reaction time is between 140 and 160 milliseconds.

Figure 1: Pegboard for assessing hand dexterity

Figure 2: Auditory & Visual reaction timer for assessing ART & VRT

The R (version 4.0.1) software was utilized for data analysis. For categorical variables, descriptive parameters are presented as frequency and percentage, whereas continuous variables are reported as mean and standard deviation, median, and range. Chi-square and independent t-tests were used to assess statistical significance and a p-value of <0.05 was considered statistically significant. Correlation was estimated using Pearson's correlation. Using multivariate linear regression analysis, the influence of confounding variables on neurobehavioral functions was adjusted.

RESULTS

This cross-sectional study included 75 male painters with a mean age of 37.5±9.3 years and a mean BMI of 22.15±4.9. Their average number of years of work experience was 13±7.7. Almost, 72% of the painters were alcoholics, and 37% were smokers with an average pack- year of 2.7. Despite the fact that 71% of the study participants were aware of the significance of wearing personal protective equipment, only 8% were found to be effective users. The demographic details of the participants are summarized in Table 1.

Table 1: Descriptive characteristics of the construction painters (n=75)

Variables	Participants (%)
Age (years)	
≤35	37 (49)
>35	38 (51)
BMI (kg/m²)	
<18	14 (19)
18 - 25	48 (64)
>25	13 (17)
Work Experience (years)	
≤10	41 (55)
>10	34 (45)
VOC exposure Index (*10³ppm-hrs)	
≤18.5	36 (48)
>18.5	39(52)
Education status	
Illiterate/Primary School	21 (28)
Middle School	34 (45)
High school /Graduate	20 (27)
Smoking status	
Smoker	35 (37)
Nonsmoker	40 (53)
Alcohol consumption	
Yes	54 (72)
No	21 (28)
Socio economic status*	
Upper Lower	29 (39)
Lower middle	46 (61)
PPE awareness	
Yes	53 (71)
No	22 (29)
PPE usage	
Yes	6 (8)
No	69 (92)

*Socioeconomic status measured using Kuppuswamy scale[16]

Table 2: Concentration of Volatile Organic Compounds (VOCs) volatilized from paints

VOC	Median (ppm)	Range	TLV (ACGIH)*
Benzene	0.01	0.01–0.2	0.5
O-Xylene	1.06	0.1-10	100
M-xylene	0.7	0.03-2.6	
P-xylene	0.56	0.04-0.9	
Toluene	3.5	0.01-35.5	20
Ethyl benzene	1.14	0.1-10.5	20
Styrene	0.05	0.01-0.3	10
Cumene	0.15	0.01-0.3	5
Mesitylene	0.55	0.02-1.8	25
1,2,4-Trimethlybenzene	0.97	0.1-7.1	25
Dichloromethane	0.7	0.31-1.30	50
1,3-Dichlorobenzene	0.05	0.02-0.6	25
Cymene	0.14	0.03-1.03	20
Naphthalene	0.11	0.02-1.4	2
Carbon tetra chloride	0.03	0.01–0.05	5

*Threshold Limit Value (American Conference of Government Industrial Hygienists)

While assessing the primary paint types employed by the majority of painters, with a usage rate exceeding 90%, it was observed that approximately 47% of construction site painters utilized emulsion paints (water-based), 23% of painters employed enamel paints (solvent-based), and the remaining 30% utilized powder/putty (a type of substance used to cover cracks and cavities making the surface even for smooth paint application). Figure 3 depicts the major paint application methods used while painting and it was found that rolling/brushing with enamel/emulsion paints and paint scraping and cleaning with powder/putty were employed by more than 70% of painters.

The median long-term exposure index was 18.5 x 10^3 ppm-hr, with values ranging from 5.1 x10^3 ppm-hrs to 57.4 x10^3 ppm-hrs. Table 2 shows that the airborne concentrations of the major VOCs (15 organic compounds) emitted from paints were found to be less than the American Conference of Government Industrial Hygienists (ACGIH) Threshold Limit Value (TLV), and Figure 4 shows that the VOC concentrations emitted from paints during various painting activities were less than the TLV (ACGIH). However, the toluene level in the paint scraping method exceeded the TLV (30ppm).

This study showed that 65% (Fig 5A) of construction site painters had diminished motor coordination (<60 pegs/90 secs) and that nearly 69% (Fig. 5B) and 73% (Fig. 5C) had prolonged ART (>160 ms) and VRT (>200 ms) respectively. In addition, painters with >10 years of experience and VOC exposure index >18.5 x10^3 ppm-hrs had significantly reduced hand dexterity compared to painters with <10 years of experience (Table 3). Further, the VRT was significantly prolonged among painters with VOC exposure indices >18.6 x10^3ppm-hr (Table 3).

Table 3: Association between covariates and neurocognitive functions among painters

Variables	Motor coordination		Auditory reaction time		Visual reaction time	
	Mean ± SD	p value	mean ± SD	p value	mean ± SD	p value
Age (years)						
≤35	58.3 ±11.5	0.1	173.2 ± 39	0.3	241.4 ± 65.9	0.5
>35	53.3 ±11.9		185.1 ± 51.4		252.4 ± 79.9	
BMI						
<18	54.4 ±16.5	0.7	166.1 ± 30.9	0.2	224.2 ± 54.1	0.4
18 - 25	55.7 ±11.4		178.4 ± 50.5		250.4 ± 80.1	
>25	58.7 ±7.7		196.6 ± 38		259.5 ± 63.1	
Work Experience (Years)						
≤10	58.8 ±11.6	0.05	172.4 ± 48.3	0.1	239.5 ± 77.4	0.3
>10	52.5 ±11.5		187.8 ± 41.8		256.4 ± 67.6	
VOC exposure Index (*10^3ppm-hrs)						
≤18.5	60.1 ±10.1	0.03	177.4 ± 56.9	0.7	230.8 ± 88.2	0.05
>18.5	53.3 ±12.3		181.1 ± 32.9		262.4 ± 52.1	
Education status						
Illiterate/Primary School	56.3 ± 8.1	0.4	190.9 ± 60.5	0.4	190.9 ± 60.5	0.5
Middle School	53.6 ±11.3		176.3 ± 45.5		176.3 ± 45.5	
High school /Graduate	58.8 ±14.7		172.6 ± 24.8		172.6 ± 24.8	
Smoking status						
Smoker	55.1 ±12.1	0.6	176.1 ± 42.1	0.5	271.5 ± 76.4	<0.01
Nonsmoker	56.5 ±11.9		183 ± 50.3		226.3 ± 64.2	
Alcohol consumption						
Yes	52.6 ±12.3	<0.01	178.5 ± 50.4	0.8	250.7 ± 82.6	0.4
No	61.5 ± 8.9		181.1 ± 32.9		237.9 ± 41.3	
Socio economic status*						
Upper Lower	55.7 ±14.4	0.9	176.9 ± 31.8	0.7	246 ± 64.7	0.9
Lower middle	56.1 ±10.3		180.8 ± 53.3		247.69±78.9	
PPE usage						
Yes	58.7 ± 18.9	0.8	180.8 ± 46.3	0.3	224.8 ± 77.3	0.5
No	55.7 ±11.6		161 ± 39.8		248.9 ± 73.1	

*Socioeconomic status measured using Kuppuswamy scale[22]

Table 4: Model 1: Regression analysis of the effect of VOC exposure index & neurobehavioral function

Variable	Motor coordination			VRT		
	β	p value	R^2	β	p value	R2
VOC exposure index	-0.4	0.02	0.18	1.65	0.04	0.11
Smoking	1.2	0.6		37.6	0.02	
Alcohol	-8.5	< 0.01		7.3	0.7	
Constant	68.3	0.000		192.25	0.000	

Table 5: Model 2: Regression analysis of the effect of VOC exposure duration (years) & neurobehavioral function

Variable	Motor coordination			VRT		
	β	p value	R^2	β	p value	R2
Years	-0.5	0.01	0.2	1.57	0.2	0.08
Smoking	0.1	0.9		42.5	0.01	
Alcohol	-9.2	<0.01		5.3	0.7	
Constant	68.2	0.000		203.6	0.000	

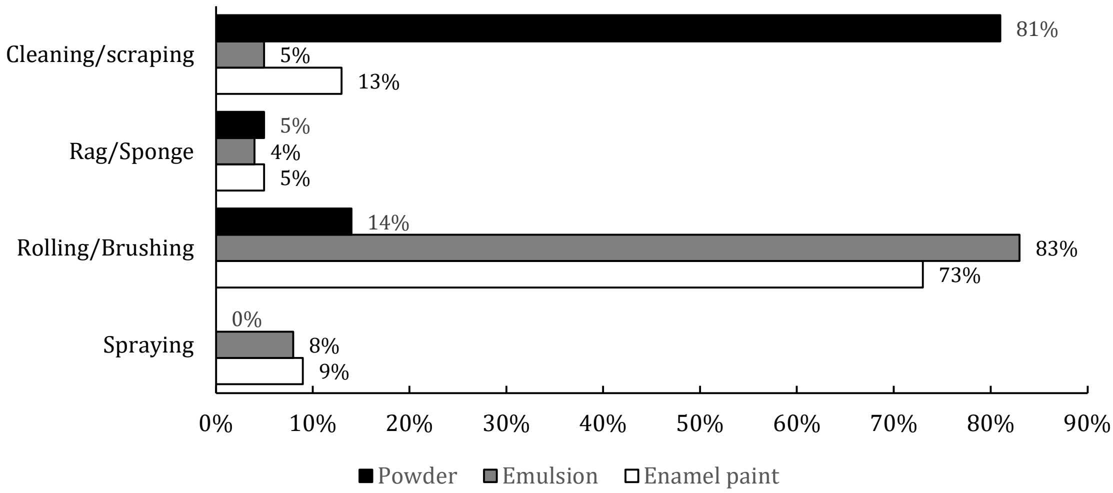


Figure 3: Painting methods frequently utilized by construction painters

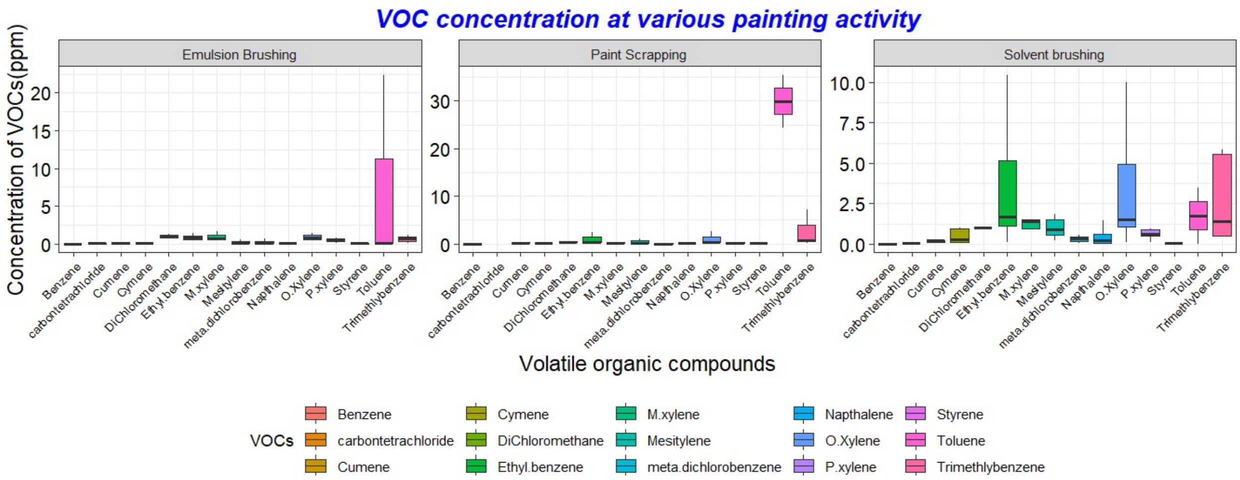
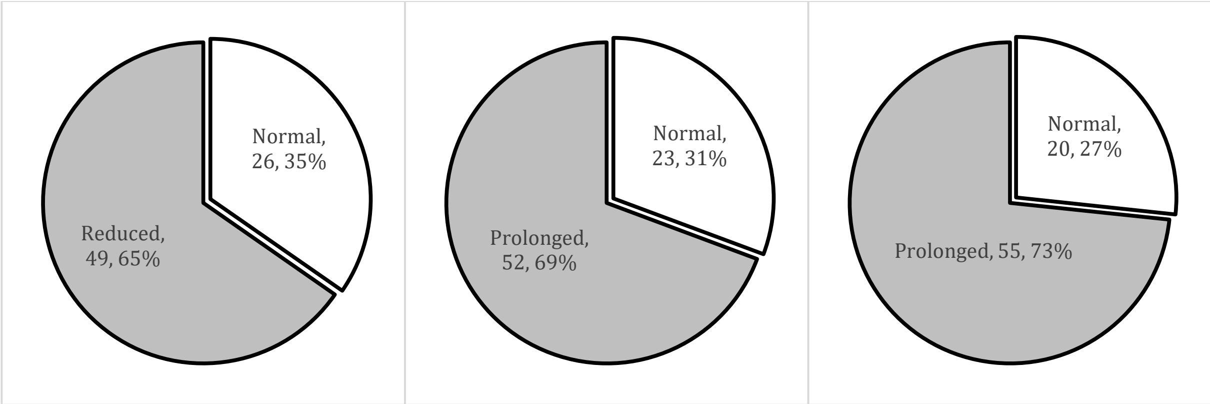


Figure 4: Concentrations of VOC (ppm) emitted during various painting activities

However, there was no significant association between the VOC exposure and ART. Variables such as age, BMI, literacy status, socioeconomic status, and usage of PPE had no effect on the neurocognitive functions. Nevertheless, there was a significant reduction in motor coordination among alcoholics and a significant increase in the VRT in smokers (Table 3).



A- Motor coordination **B- Auditory reaction time** **C- Visual reaction time**

Figure 5: Prevalence of altered neurobehavioral functions among painters

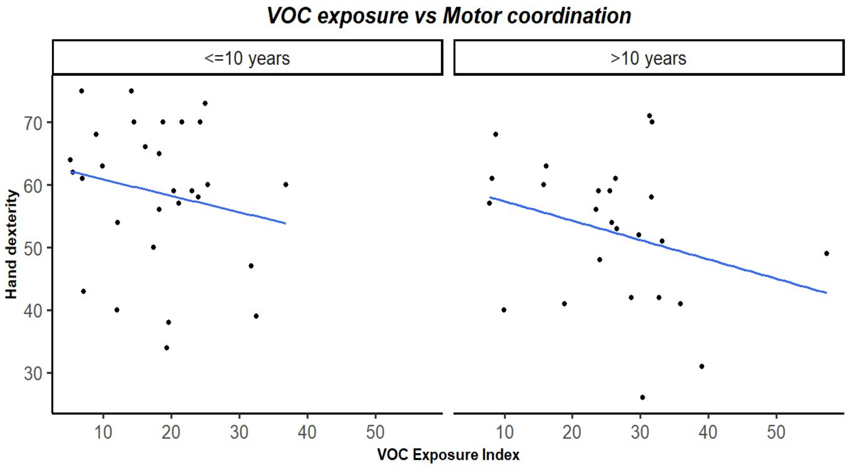


Figure 6: Correlation of VOC exposure and years of work experience on motor coordination

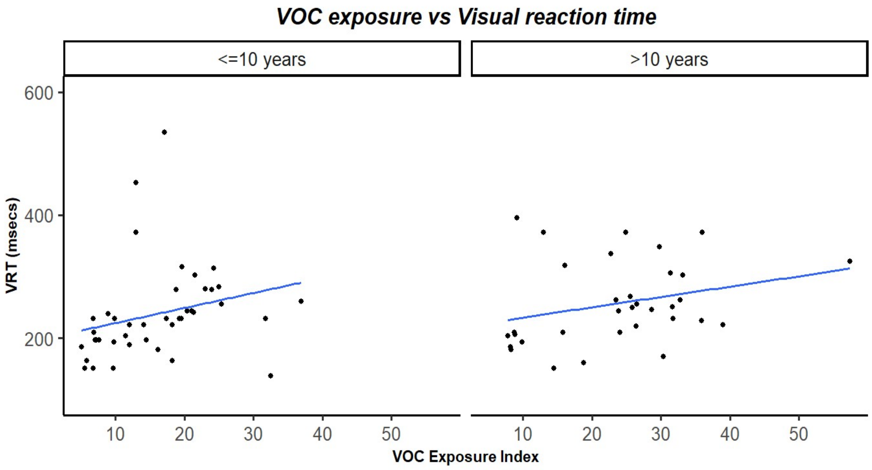


Figure 7: Correlation of VOC exposure and years of work experience on Visual Reaction Time

Fig. 6 displays a mild negative correlation (r = -0.3, p = 0.01) between the long-term VOC exposure index and motor coordination, as well as between exposure duration (years) and motor coordination (r = -0.3, p = 0.02). In addition, there was a mild positive correlation between VOC exposure index and VRT (r = 0.3, p = 0.01) and a mild positive correlation between exposure duration (years) and VRT (r = 0.2, p = 0.1) (Fig. 7).

Multiple linear regressions were used to adjust for smoking and alcohol's effects on neurocognition. Model 1 (table 4) examined the effect of VOC exposure index on neurocognitive functions while adjusting for smoking and alcohol intake, whereas Model 2 (table 5) examined the influence of years of work experience. For every 1ppm-hrs increase in VOC exposure index, motor coordination significantly reduced by 0.4 and visual reaction time significantly prolonged by 1.65 ms (Table 4, Model 1), while for every year increase in work experience, motor coordination was significantly reduced by 0.5 (Table 5, Model 2).

Discussion

This cross-sectional study assessed the impact of VOC exposure on the neurobehavioral functions of construction site painters employed in unorganized sectors in and around Chennai. Paints, thinners, and lacquers expose the painters to an array of volatile organic compounds, such as benzene, ethylbenzene, toluene, xylene (BETX), styrene, and others. The concentrations of the 15 major VOCs present in paints were found to be below the ACGIH TLVs, but the concentration of toluene in paint scraping activity exceeded the TLVs.

While assessing the neurobehavioral outcome, painters showed a higher prevalence of reduced hand dexterity, showing decreased motor coordination. In addition, years of exposure and the VOC exposure index were significantly associated with diminished motor coordination and fine motor activity. The plausible mechanism is that, VOCs and organic solvents are highly lipophilic in nature and cross the blood-brain barrier, causing Schwann cell and oligodendritic mutations as well as demyelination of nerve fibers, resulting in impaired motor coordination.[15] In addition, exposure to these substances may increase the level of reactive oxygen species in the brain, leading to oxidative injury and neurodegeneration. Previous studies on automobile painters exposed to organic solvents showed a decrease in motor coordination[16,17,18], which is consistent with our findings.

Although VOC exposures were below ACGIH TLVs, painters demonstrated a mild positive correlation between duration of exposure and VOC exposure index, indicating that long-term exposure to lower TLVs of VOCs has an effect on neurobehavioral functioning. This was congruent with the findings, demonstrated in an animal model[7] that prolonged exposure to low levels of mixed VOCs (10 g/hr) affected motor coordination in the Morris water Maze.

In this study, painters had a higher prevalence of prolonged visual and auditory reaction times, indicating decreased psychomotor speed and attention span. This could be probably due to the fact that VOCs may cause abnormal neurotransmitter metabolism, resulting in decreased cholinergic system activity, increased glutamic acid concentrations, and altered NMDA receptor expression, resulting in decreased neuronal activation in the dorsolateral prefrontal cortex and cingulate gyrus[7], and demyelination in the premotor cortex and cerebellum, resulting in reduced attention span, motor coordination, and psychomotor speed. This association was substantial for VRT in terms of both the VOC exposure index and the number of years spent painting. In this study, however, there was no correlation between exposure status and prolonged auditory reaction time. This was congruent with the findings of a study conducted on industrial workers[19] exposed to organic solvents, who had delayed auditory reaction times than matched controls regardless of exposure level.

In this study, alcohol consumption and smoking were associated with diminished neurobehavioral performance, and this association persisted even after multiple regression analysis. After controlling for these variables, it was found that motor coordination and visual reaction time remained significantly associated with years of experience and the VOC exposure index. Other determinants, however, exhibited no significant association.

Similar to other related studies, this study has also demonstrated a significant increase in neurobehavioral symptoms among painters, and is closely related to both painting experience and age.[12,20,21] The key reason for such detrimental effects on the health conditions of workers could be probably due to the poor working conditions in the unorganized sector and the owners/employers do not provide them with any personal protective equipment such as an apron, mask etc. In addition, low nutrition intake, because of low wages and continual physical labour lead to certain health issues causing risks to the lives of workers in such unorganized sectors. Lack of healthcare resources often forces poor workers to forget it. Moreover, the employees are not formally educated and are not aware of the legislative safety laws proposed by the government.

Few challenges are faced in implementing several major social welfare schemes of the government in such unorganized sectors: Lack of awareness; Lack of state-governed distribution infrastructure; Deficient organizational capacity on the part of the distribution agencies; Failure to identify program beneficiaries; Incidence of corrupt practices, rent-seeking from agencies of administration and delivery and elite capture of schemes; Lack of people's knowledge about program information as well as their entitlements; and failure to follow up properly. Unless, these challenges are addressed, the damage produced cannot be prevented or repaired.

Limitation of the study is that the effects of other neurotoxic compounds to which painters may be exposed, including lead, semi-VOCs such as isocyanate, diisocyanate, organic acid anhydrides, and others, were not evaluated; and the strength of association and temporality could not be determined due to the nature of the study design.

This study will pave the way for pursuing further research using longitudinal study design wherein assessment of motor and sensory nerve conduction study can be undertaken to evaluate the accurate impact of VOC on neurobehavioral functions.

Conclusion

Occupational exposure to VOCs and organic solvents causes neurobehavioral changes that can worsen with time. It not only affects the motor coordination but also affects the attention span, and psychomotor speed in painters working in construction sites. Motor coordination and visual reaction time are significantly associated with years of experience and the VOC exposure index. To mitigate further repercussions, awareness must be created among unorganized workers who have little to no awareness of workplace hazards, work for an extended period of time, and have no idea of occupational safety and services, health and safety legislation, and no concept of trade unions. For both economic and social growth, security and support for unorganized sector workers are very important. Only then, the regulations for the engineering and administrative control measures can be enforced and implemented in these unorganized sectors in order to reduce morbidity.

Acknowledgement

We are thankful to the study participants for their cooperation and the management of SRIHER (DU) Chennai for their encouragement, support and partial funding.

Funding

The current study was partially funded by the Chancellor's Summer Research Fellowship for Undergraduate Students/2020, Sri Ramachandra Institute of Higher Education and Research-SRIHER (DU), Chennai, Tamil Nadu, India, for the acquisition of the equipment.

References

1. US EPA O. US EPA. 2014 [cited 2021 Feb 19]. Volatile Organic Compounds' Impact on Indoor Air Quality. Available from: https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality
2. Kim YM, Harrad S, Harrison RM. Concentrations and sources of VOCs in urban domestic and public microenvironments. Environ Sci Technol. 2001 Mar 15;35(6):997–1004.doi: 10.1021/es000192y. Cited: in: PMID: 11347947.
3. Kyle L.Alford, Naresh Kumar. Pulmonary Health Effects of Indoor Volatile Organic Compounds—A Meta-Analysis. Int J Environ Res Public Health. 2021 Jul 2;18:1578.
4. Bleecker ML, Bolla KI, Agnew J, Schwartz BS, Ford DP. Dose-related subclinical neurobehavioral effects of chronic exposure to low levels of organic solvents. Am J Ind Med. 1991; 19(6):715–28.
5. Ogbodo JO, Arazu AV, Iguh TC, Onwodi NJ, Ezike TC. Volatile organic compounds: A proinflammatory activator in autoimmune diseases. Front Immunol. 2022 Jul 29;13:928379.
6. Lolin Y. Chronic neurological toxicity associated with exposure to volatile substances. Hum Toxicol. 1989 Jul;8(4):293–300. doi: 10.1177/096032718900800407.
7. Wang F, Li C, Liu W, Jin Y. Potential mechanisms of neurobehavioral disturbances in mice caused by sub-chronic exposure to low-dose VOCs. Inhal Toxicol. 2014 Mar 1;26(4):250–8. doi: 10.3109/08958378.2014.882447. Cited: in: PMID: 24568580.
8. Gostner JM, Zeisler J, Alam MT, Gruber P, Fuchs D, Becker K, et al. Cellular reactions to long-term volatile organic compound (VOC) exposures. Sci Rep. 2016 Dec 1;6:37842.
9. Ruijten MW, Hooisma J, Brons JT, Habets CE, Emmen HH, Muijser H. Neurobehavioral effects of long-term exposure to xylene and mixed organic solvents in shipyard spray painters. Neurotoxicology. 1994;15(3):613–20.
10. Saha A, Tripathi SR. A Study on Neurobehavioral Performance of Workers Occupationally Exposed to Solvent in Synthetic Resin Manufacturing. Toxicol Int. 2018 Jun 4;21(3):264–8.
11. Cherry N, Hutchins H, Pace T, Waldron HA. Neurobehavioural effects of repeated occupational exposure to toluene and paint solvents. Br J Ind Med. 1985 May;42(5):291–300. doi: 10.1136/oem.42.5.291.
12. Wang SW, Qian H, Weisel C, Nwankwo C, Fiedler N. Development of Solvent Exposure Index for Construction Painters. J Occup Environ Hyg. 2011 Jun;8(6):375–86. doi: 10.1080/15459624.2011.583488.
13. Grice KO, Vogel KA, Le V, Mitchell A, Muniz S, Vollmer MA. Adult norms for a commercially available Nine Hole Peg Test for finger dexterity. Am J Occup Ther. 2003;57(5):570–3.
14. Kosinski B, Cummings J. The Scientific Method: An Introduction Using Reaction Time. 1999;20:63–84.
15. Bowen SE, Batis JC, Paez-Martinez N, Cruz SL. The last decade of solvent research in animal models of abuse: mechanistic and behavioral studies. Neurotoxicol Teratol. 2006;28(6):636–47.
16. Elofsson SA, Gamberale F, Hindmarsh T, Iregren A, Isaksson A, Johnsson I, et al. Exposure to organic solvents. A cross-sectional epidemiologic investigation on occupationally exposed care and industrial spray painters with special reference to the nervous system. Scand J Work Environ Health. 1980 Dec; 6(4):239–73.
17. Jovanović J, Jovanović M. [Neurotoxic effects of organic solvents among workers in paint and lacquer manufacturing industry]. Med Pregl. 2004 Feb;57(1–2):22–5. doi: 10.2298/mpns0402022j.
18. Seppäläinen AM, Husman KAJ, M\aartenson C. Neurophysiological effects of long-term exposure to a mixture of organic solvents. Scand J Work Environ Health. 1978;304–14.
19. Per Gregersen MD, Bent Stigsby MD. Reaction time of industrial workers exposed to organic solvents: Relationship to degree of exposure and psychological performance. Am J Ind Med. 1981; 2(4): 313–21. doi: https://doi.org/10.1002/ajim.4700020403.
20. Hassan AAEH, Elnagar SAEM, El Tayeb IM, Bolbol SAEH. Health hazards of solvents exposure among workers in paint industry. 2013;
21. Valciukas JA, Lilis R, Singer RM, Glickman L, Nicholson WJ. Neurobehavioral changes among shipyard painters exposed to solvents. Arch Environ Health Int J. 1985;40(1):47–52.
22. Wani RT. Socioeconomic status scales-modified Kuppuswamy and Udai Pareekh's scale updated for 2019. J Fam Med Prim Care. 2019 Jun;8(6):1846–9.doi: 10.4103/jfmpc.jfmpc_288_19.