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Exposure to Volatile Organic Compounds and Effect on Neurobehavioral Function.

Abhijeet Jagannath Bhanegaonkar
East Tennessee State University

Exposure to Volatile Organic Compounds and Effect on Neurobehavioral Function

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Abhijeet J. Bhanegaonkar

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Dr. Tiejian Wu, Committee Chair

Dr. Joanne Walker Flowers, Committee Member

Dr. Mary Beth Hogan, Committee Member

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ABSTRACT

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Data of 1338 respondents from the Priority Toxicant Reference Range Study were analyzed to examine exposure to volatile organic compounds (VOCs). Self-reported contact to chemical products and blood concentrations of specific chemicals were analyzed. Neurobehavioral function was assessed by simple reaction time test (SRTT), symbol digit substitution test (SDST), and serial digit learning test (SDLT). Prevalence of exposure to VOC products was, for instance, air freshener/room deodorant – 34.7%, gasoline – 29.2%, finger nail polish – 16.2%, and diesel fuel/ kerosene – 10.6%. The 95th percentiles of blood VOCs (µg/L) were calculated for 41 chemicals including Benzene – 0.476, 1,1,1-Trichloroethane – 0.799, o-Xylene – 0.271, and Styrene – 0.177. Significant correlation coefficients included 0.216* with SRTT and 0.130* with SDST for 1,4-Dichlorobenzene, 0.097* with SDST for 1,1,2-Trichloroethane, 0.098* with SDLT for Chloroform, and 0.115* with SDLT for Dibromochloromethane (* $p<0.05$) suggesting possible neurobehavioral effects. Study results provided pilot data of exposure status and reference ranges of VOCs for the U.S. population.

DEDICATION

I would like to dedicate my thesis work to my wonderful parents, Mrs. Shailaja and Mr. Jagannath Bhanegaonkar, for their love, support, and motivation.

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CHAPTER 1

INTRODUCTION

Volatile Organic Chemicals (VOCs) are carbon-containing compounds that evaporate easily from water into air at normal air temperatures (This is why the distinctive odor of gasoline and many solvents can easily be detected.). VOCs are contained in a wide variety of commercial, industrial, and residential products including fuel oils, gasoline, solvents, cleaners and degreasers, paints, inks, dyes, refrigerants, and pesticides. People are most commonly exposed to VOCs through the air, food, skin contact, and potentially through drinking water. It is estimated that VOCs are present in one fifth of the nation's water supplies, and indoor air concentrations of VOCs are much higher than the outdoor air concentrations (Minnesota Department of Health, 2004).

Problem Statement

There is a great public concern about exposure to these compounds. For example, more than 50% of the human exposure inquiries to the Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry relate to potential exposure to VOCs (Needham, Hill, Ashley, Pirkle, & Sampson, 1995). Many VOCs are suspected or proved to cause various types of cancer and damage to the visual, liver, circulatory system, and nervous system of laboratory animals when these animals were exposed to high levels of VOCs over their lifetime.

However, human data are insufficient in both the exposure and the health effects associated with the exposure. Application of the results from animal studies to humans is very limited due to the differences in VOC exposure, absorption, and metabolisms. Therefore, more human data are needed to assess the health risk of exposure to VOCs.

The purpose of this study is two fold, to describe the status of exposure to VOCs in the U.S. general population and to examine the neurobehavioral effects associated with the exposure. Specifically, exposure status will be analyzed using:

1) Self-reported contact with chemical products containing VOCs and

2) Blood concentrations of VOCs.

The relationship between the exposure status and the assessments of neurobehavioral functioning were explored. Neurobehavioral functioning was assessed by simple reaction time test, symbol-digit substitution test, and serial-digit learning test in Priority Toxicant Reference Range Study (PTRRS). The following hypotheses will be tested:

1. Levels of contact with chemical products containing VOCs (measured by frequency of contact) were associated with poorer neurobehavioral functioning (Measured by simple reaction time test, symbol-digit substitution test, and serial-digit learning test)
2. Blood concentrations of VOCs were associated with poorer neurobehavioral functioning (Measured by simple reaction time test, symbol-digit substitution test, and serial-digit learning test)

Significance of Study

The proposed study provides primary data on environmental exposure to VOCs in the sample population in U.S. These data are very helpful in establishing the reference ranges of exposure to these compounds. Although animal studies have indicated severe health hazards, application of the results from the animal studies to human is very limited due to the differences in the VOC exposure, absorption, and metabolism. If the health effects of environmental exposure in humans are confirmed, the result will help in environmental health decision making and could lead to better protection of the human beings from the health hazards of the compounds.

CHAPTER 2

LITERATURE REVIEW

VOCs are a major public health concern because of their ubiquitous nature and the possible health effects associated with exposure to them (Ashley et al., 1992). As it is known that volatile organic compounds (VOCs) exhibit differential dispositions among anatomically discrete brain regions in rodents as well as in humans, potential toxicological consequences of this pharmacokinetic feature were evaluated using measurements of cyclic GMP (Glucose Monophosphate). With the knowledge of 1,1,1- Trichloroethylene (TRI) uptake and distribution in the various brain regions, cyclic GMP was evaluated due to (1) known susceptibility of the effects of organic solvents, (2) pivotal physiological role in perpetuating changes in neurochemical pathways, and (3) possible involvement with neurobehavioral functions, whose disruption is one of the primary health effects associated with solvent exposure (You & Dallas, 2000).

Sources of VOCs

VOCs are widely used in household and commercial products. Some cleansers, disinfectants, waxes, glues, cosmetics, dry cleaning products, paints, varnishes, and preservatives include VOCs. Gasoline, kerosene, and other fuels also contain VOCs. VOCs are also found in cigarette smoke and pesticides. A number of building and household materials may be sources of VOCs. New carpeting, backing, and adhesives; draperies; wood products that use certain glues, finishes, and waxes in the manufacturing process; and vinyl type flooring and wall coverings may all release VOCs into the air.

The U.S. Environmental Protection Agency (EPA) estimates that VOCs are present in one fifth of the nation's water supplies (Jennings, Sneed, & St. Clair, 1996). They can enter ground water from a variety of sources; Benzene, for example, may enter ground water from gasoline or oil spills on the ground surface or from leaking underground fuel tanks (Jennings et al.). Other examples of commonly detected VOCs are Dichloromethane (Methylene chloride), an industrial solvent; Trichloroethylene, used in septic system cleaners; and Tetrachloroethylene (Perchloroethylene), used in the dry-cleaning industry (Jennings et al.).

VOCs are emitted by a wide array of products numbering in the thousands. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions. VOCs are emitted to air as combustion products as vapor arising from petrol and solvent use and from numerous other sources including forests.

Animal Studies

VOCs exert different effects on human and animals because of their physiological differences. This could be explained on the basis of different partition coefficients of VOCs for the richly perfused brain and blood in humans and animals (Reitz, McDougal, Himmelstein, Nolan, & Schumann, 1988). Another potential physiological difference is that animals have higher respiratory and circulatory rates that contribute to a greater body burden (Schumann, Fox, & Watanabe, 1982a).

1,1,1- Trichloroethane (Methyl chloroform) TRI is a volatile organic solvent used in large quantities as a dissolvent, metal degreaser, chemical intermediate, and a component of consumer products. It is regarded as less toxic than most other VOCs, but in very large doses TRI has been shown to cause adverse effects on liver, kidney, and heart (Lundberg, Ekdahl, Kronevi, Lidums, & Lundberg, 1986; Gerace, 1981; Klaassen & Plaa, 1966, 1967). The primary target of TRI is considered to be the central nervous system (CNS). Profound behavioral changes have been demonstrated upon TRI administration in experimental animals (Moser & Balster, 1985; Mullin & Krivanek, 1982; Warren, Reigle, Muralidhara, & Dallas, 1996) as well as in humans (Stewart, 1968; Gamberale & Hultengren, 1973; Mackey et al., 1987). TRI was used in many studies because it undergoes minimal metabolism and is psychoactive in humans and rodents (Schumann et al., 1982a, 1982b). 2.5 million US workers were potentially exposed to TRI in the last decade and hence it poses a significant public health problem (Evans & Balster, 1991; U.S. Public Health Service, 1995).

Acute and chronic toxicities of TRI are relatively low; however, higher concentrations in the work places have toxic effects (Warren et al., 1998). TRI has produced rate changes in the food-reinforced lever-pressing of mice (Balster, Moser, & Woolverton, 1982; Moser & Balster, 1986), altered performance on a match-to sample discrimination task in baboons (Geller, Mendez, Hartmann, Gause,& Rippstein, 1982), and impaired the ability of rats to avoid shock by lever-pressing. These studies demonstrate that TRI's effects are concentration and time dependent, thereby inferring dependence on blood and target tissue (brain) doses.

Recent reports suggest a relationship between shock avoidance decrements in rats and blood and brain levels of Trichloroethylene and Toluene (Kishi, Harabuchi, Ikeda, Yokota, & Miyake, 1988; Kishi, Harabuchi, Ikeda, Katakura, & Miyake, 1993). Bruckner and Peterson (1981) have shown that the magnitude of Toluene-induced impairment of reflexes and unconditioned performance in mice is paralleled by blood and brain concentrations of Toluene.

In rats, 500 and 1000 ppm exposure groups demonstrated increased response rates whereas higher exposure groups demonstrated drastically decreased response rates. Inhalation of 5000 ppm caused the animals to typically assume an immobile posture. This indicates that the response rate suppression was not solely related to blood and brain concentrations but also depends on the rate of uptake of TRI by the brain (Warren et al., 1998). The pattern of accumulation of TRI for a well perfused and lipid rich organ such as the brain was very similar to that of the blood. Minimum effective concentration of 1000 ppm (Warren et al., 1996) for TRI obtained in study carried out by Warren et al. in 1996 was similar to those reported in rats and mice to elicit changes in flash-evoked potentials, electroencephalograms, and locomotor activity (Bowen & Balster, 1996; U.S. Public Health Service, 1995) and well below levels required for motor impairment, unconditioned reflex failure and ataxia (Moser & Balster, 1985; Mullin & Krivanek, 1982; Clark & Tinston, 1982).

Studies on cGMP levels in mice and rat brains exposed to TRI suggested that chemicals like TRI may exert their effects in part by causing a temporary shift in the mode of cellular signal transduction on a functional level (You & Dallas, 2000). c-GMP is an important intracellular signal transducer believed to be involved in mediating the effects of a number of neuroactive substances (Hoffman, Rabe, Moses, & Tabakoff, 1989; Sethy & Oien, 1991).

A study by Nilsson (1986) showed that intraperitoneal injection of TRI in mice brain tissue caused a dose-dependent and time-dependent depression of cGMP. These effects of TRI were regionally specific. Differences in lipid contents of different brain regions were seen as the primary determinant for the differential distribution of the highly lipophilic VOCs (Gospe & Calaban, 1988). There was a 55% decrease in the cGMP levels in cerebellum of rat brain tissue, whereas decreases in medulla oblongata were minimal 13% after 40 min exposure to TRI (You & Dallas, 2000). These regionally specific effects were similar for both rats and mice in cerebellum and cortex but dissimilar in medulla oblongata.

1,1-Dichloroethane (DCE) is a solvent that is often found as a contaminant of drinking water and a pollutant at hazardous waste sites. Chemically induced histological changes were not seen in the liver, kidney, lung, brain, adrenal, spleen, stomach, epididymis, or testis. Studies in rats have shown that an acute oral dose of 8.2 g/ Kg body weight caused deaths due to CNS depression and respiratory failure (Muralidhara et al., 2001). The extremely high doses of DCE, like many other VOCs, may also induce cardiac arrhythmias and/or autonomic effects, including reductions in heart rate and peripheral vascular resistance.

Human Studies

VOCs pose a major public health concern to humans because of their ubiquitous occurrence in all homes and workplaces and their possible serious health effects. They enter the human system not only by inhalation but also through skin absorption. A wide array of health effects may be linked with exposure to VOCs.

From the standpoint of human health and welfare, VOCs all share one important characteristic i.e. they are all fat or lipid soluble, therefore, they have an affinity for the fatty or lipid tissues of the body. Liver, renal, and hematological effects have been noted in people exposed to chlorinated hydrocarbons (Hayden, Comstock, & Comstock, 1976; Ramsey & Flanagan, 1982), and they cause central nervous system damage in those suffering extreme exposure (Hayden et al.). The brain is a prime target of the VOCs due to its high lipid content and rich blood supply. Because the brain is the primary target of VOCs, symptoms are primarily cerebral in nature. Acute symptoms include dizziness, forgetfulness, headaches, mental fogginess, difficulty in concentrating, and poor coordination.

Studies at University of Pittsburg showed the effects of solvents on occupationally exposed subjects (Morrow, Ryan, Goldstein, & Hodgson, 1989; Morrow et al., 1990a). These findings included social alienation, poor concentration, anxiety, and impairments in learning and memory. Hyperactivity and behavioral problems among school children has coincided with steadily increasing levels of VOCs found in modern buildings. Standard neurotoxicology texts point out that, behavioral problems may be the earliest sign of chemical toxicity (Weiss, 1987; Superintendent of Documents, Government Printing Office, 1990).

Case reports and clinical studies of persons with a history of organic solvent exposure have described the presence of post traumatic stress disorder (Morrow et al., 1989), schizophreniform psychosis (Goldblum & Chouinard, 1985), and panic disorder (Dagar, Holland, Cowley, & Dunner, 1987). Epidemiological studies suggested higher frequencies of neurological and psychiatric symptoms for solvent exposed workers compared to non exposed workers (Baker et al., 1988; Fidler, Baker, & Letz, 1987; Morrow, Ryan, Hodgson, & Robin, 1990b).

It has been suggested that the psychiatric disturbance may result from a direct consequence of central nervous system dysfunction associated with the exposure (Morrow et al., 1990a). Cacosmia has been reported as a consistent predictor of psychiatric symptomatology (Morrow, Kamis, & Hodgson, 1993).

Complex mixtures of volatile organic compounds (VOCs) are often found in new buildings. They are released from various building materials and furnishings and lead to an illness commonly known as Sick Building Syndrome (SBS). SBS is characterized by irritation of eyes, nose, and throat. Memory loss and mental dysfunction have also been associated with this syndrome. TRI at concentrations 175 and 350 ppm for 3.5 hrs reportedly resulted in tracking skills and reaction time (Mackey et al., 1987).

VOCs like Trichloroethylene (TCE) and Perchloroethylene (PCE) and related chemicals are widely spread in the municipal water system (Reif et al., 2003). TCE is neurotoxic to humans at high concentrations and the effects can be persistent. Chronic and low-dose exposure to TCE can reportedly result in neurobehavioral impairment (U.S. Public Health Services, 1997). Some studies indicated that alcohol consumption potentiated the effects of exposure to TCE (Reif et al., 2003). The finding of a strong interaction between exposure to a chlorinated solvent and alcohol consumption in the induction of neurobehavioral deficits is of potential public health significance.

A recent study in a hospital environment in Japan showed a relationship between high total VOC (TVOC) concentration (>1200microgram/ m3) and deterioration in the skin, eye, ear, throat, chest, and CNS (Takigawa et al., 2004).

CHAPTER 3

DESIGN AND METHODS

Data Source

The third National Health and Nutritional Examination Survey (NHANES III) was conducted by the National Center for Health Statistics between 1988-1994. The survey was designed to obtain nationally representative information on the health and nutritional status of the population of US (National Center for Health Statistics, 1996).

This population included people were selected from urban and rural communities across four different regions in US. The NHANES III collected data representing the total civilian, non-institutionalized population, two months of age or over, in the 50 states and District of Columbia. A total of 39,695 people were invited to participate in NHANES III (National Center for Health Statistics, 1994; National Center for Health Statistics, 1996).

About 1338 Adults, who were aged between 20 to 59 years, participated in the NHANES III – PTRRS and were included in this study (Needham et al., 1995). The exposure status was assessed by self-reported contact to chemical products containing VOCs and blood concentration of VOCs. The subset drawn for this study is not a probability based sample (Needham et al.). The 32 VOCs were originally of interest in PTRRS.

Study Sample

Participants examined the priority toxicant reference range study (PTRRS), include 1138 individuals, 20 to 59 years old, who participated voluntarily (Needham et al., 1995). A questionnaire on use of and contact with various chemical compounds was administered and additional 20 ml of blood was obtained. Thirty-two VOCs were selected in PTRRS and their concentrations in whole blood were determined. For the study purposes, the sample of this study was restricted to participants in PTRRS. However, the sample size could be somewhat smaller than 1338 due to missing values in variables of interest. The characteristics of PTRRS participants are shown in Table 2.

The sample of the NHANES III is large in number, diverse, and chosen so as to be probability based for the United States population (Needham et al., 1995). The sample included in the PTRRS is not representative of the population of United States. They might, however, provide information for relatively broad spectrum of the population, as they include individuals from:

- Four regions of the contiguous United States.
- Both urban and rural communities.
- 20 to 59 years old.
- Both men and women.
- Different ethnic group.

Variable of Interest

The variables for this study include:

1. Exposure to VOCs

The assessment of VOCs exposure included a self-administrated questionnaire and measurements of VOCs in whole blood. Questions were asked on the exposure to various chemicals and household products including diesel fuel, gasoline, paint thinner, varnish, bug or insect spray, weed killer, solid toilet bowl deodorant, air freshener, moth balls or crystals, pressure treated wood, finger nail polish, and dry cleaning. The questions on each chemical/product, states “in the last three days: today or yesterday or the day before yesterday, have you either breathed or had on your skin, any of the following?”.

Blood specimen collection and processing procedures were standardized and described in NHANES III (National Center for Health Statistics, 1996). Thirty-two VOCs (Table 1) were originally selected and their concentrations in whole blood were determined (Ashley et al., 1992; Needham et al., 1995). Blood measures of VOCs were not obtained for 320 of the 1338 PTRRS participants due to unavailability of blood samples.

Table 1
Thirty-two VOCs Quantified in Reference Range Study

1,1,1-Trichloroethane	1,1,2,2-Tetrachloroethane	1,1,2-Trichloroethane
1,1-Dichloroethane	1,1-Dichloroethene	1,2-Dichlorobenzene
1,2-Dichloroethane	1,2-Dichloropropane	1,3-Dichlorobenzene
1,4-Dichlorobenzene	2-Butanone	Acetone
Benzene	Bromodichloromethane	Bromoform
Carbon Tetrachloride	Chlorobenzene	Chloroform
Cis-1,2-Dichloroethene	Dibromochloromethane	Dibromomethane
Ethylbenzene	Styrene	Methylene Chloride
Tetrachloroethene	Toluene	Trichloroethene
Hexachloroethene	Trans-1,2-Dichloroethene	1,2-Xylene
1,3-Xylene	1,4-Xylene	

2. Neurobehavioral Assessment of the Central Nervous System

Neurotoxic effects are of such breadth and complexity that functional biomarkers (behavioral tests) that integrate many areas of the nervous system predominate in human neurotoxicology research. The extensive use of behavioral tests as markers of neurotoxicity is due to their integration of multiple subsystems, a feature that distinguishes behavior from other nervous system biomarker effect (Anger et al., 1996).

In NHANES III, three neurobehavioral evaluation tests were administered were components of the Neurobehavioral Evaluation System 2 (NES2 Neurobehavioral Systems, Winchester, MA) to a random sample of examinees aged 20-59 years. The following three computerized tests were performed:

A) Simple reaction time test (SRTT)

This test is a basic measure of motor response speed to a visual stimulus. The participants were instructed to rest the index finger of their preferred hand on a push button and press the button as quickly as possible whenever a solid square (4X4 cm) was displayed in the center of blank computer screen. Fifty reaction responses were measured for each individual tested. The measured response was the time period, measured in milliseconds, between the appearance of the square on the screen and the subject pressing the button (Krieg et al., 2001).

B) Symbol digit substitution test (SDST)

This test measures the coding ability. On the upper half of the computer screen the subject was presented with a grid that paired one of nine different symbols with one of the digits from 1 to 9. A similar grid was displayed on the bottom half of the screen with the same symbols presented in a scrambled order and the spaces for the corresponding digits left blank (Krieg et al., 2001). The subject had to do a digit matching task for each symbol. Total of five readings were recorded. The time was recorded in seconds along with the errors.

C) Serial digit learning test (SDLT)

This test is a used to measure short term memory, where learning and recalling of the subject is tested. The subject was presented with a series of digits displayed one at a time on the computer screen. Each digit was displayed on the screen for 0.6 s with 0.6 s interval between digits (Krieg et al., 2001). Once this is done, the subject is asked to type all the digits in the order they were displayed. The test was carried out until the subject responded correctly on two consecutive trials to until the subject attempted eight trials (Krieg et al.).

These tests are components of the Neurobehavioral Evaluation System 2 developed by Baker and Letz (Baker, Letz, & Fidler, 1985; Letz, 1990). They have been validated and widely used in epidemiological studies to assess the neurobehavioral function in relation to occupational and environmental exposure to chemicals (Anger & Johnson, 1985; Sternberg, 1969). The neurobehavioral assessments were administered following standard protocols/procedures (National Center for Health Statistics, 1996).

3. Covariates

Demographic variables included gender, ethnicity (Non-Hispanic White, Non-Hispanic Black, Mexican American, and other), number of years of education completed, age at examination, and family income level. Smoking status included average number of cigarettes smoked for current users, past use (smoked at least 100 cigarettes in lifetime but had quit at the time of the survey), and never smoked (never smoked or smoked less than 100 cigarettes in lifetime). Average alcohol consumption during past 12 months was assessed including frequency of drinking on occasion and amount of use on occasion. Stroke, diabetes, and hypertension status (yes/no) were obtained in the survey by asking, "Have you ever been told by a doctor that you had a stroke/diabetes/hypertension (high blood pressure)?" Details of the variables can be found elsewhere.

Statistical Analysis

1. Data preparation

NHANES III data sets include several large data files. Before actual analysis, comprehensive data preparation was needed. Study variables of interest were needed to be determined and located. Merging of files and inclusion of variables were performed. Variables of interest were checked for distributions, outliners, and missing values. Characteristics of the final sample for the proposed study were described. The study sample was compared with the NHANES III source data to evaluate possible bias due to selection/ elimination of participants.

2. Analysis of the exposure status

For the questionnaire, data on exposure to each product containing VOC was assessed by asking whether the subject has been exposed to the product containing VOC during the past three days. The percentage of participants with the different exposure situations was calculated. For blood measurement of each VOC, descriptive measures such as mean, median, maximum value, standard deviation, and 95th percentile were calculated. The status and levels of exposure were analyzed and compared by sex, age group, and ethnicity.

3. Analysis of the health effect

Each neurobehavioral assessment served as a dependant variable in this proposed study. The status or levels of exposure to VOCs as defined previously were examined as independent variables. Means in the neurobehavioral assessments across the different VOC categories were compared using t test. Correlation coefficients between the blood VOC concentrations and the neurobehavioral assessment were calculated and a significance test was performed. Multivariate analysis was performed using stepwise multiple linear regressions with simultaneous adjustment for a number of covariates including social and demographic variables (sex, ethnicity, age, and education) health behaviors (smoking, drinking, and physical activity), and disease status (stroke, hypertension, and diabetes). The exposure measures from the questionnaire and the blood determinations of VOCs were analyzed in separate models. The relationship between a measure exposure and the neurobehavioral assessment was evaluated by the test of the regression coefficients in the regression model.

CHAPTER 4

RESULTS

Characteristics of Study Participants

The characteristics of the study participants are shown in Table 2. The study sample comprised of 53.5% males and 46.5% females. Non-Hispanic whites accounted for 40.8%, followed by Non-Hispanic black (33.2%), Mexican Americans (23.2%), and other (2.8%) of the sample. Approximately one third of the study sample had an education of 12 years or more.

For study purposes, the study sample was categorized into 4 age groups. More than half of the study sample consisted of young adults, aged between 20- 39 yrs. Only 16.1% of the study sample was between 50-59 yrs. of age. Analysis of smoking status revealed that 19.1% were past smokers. Little more than one third of the sample consists of current smokers and 45.5% were non-smokers.

Very few participants had experienced episode/s of stroke in the past (1.2%). Study participants with known diabetes comprised 4.6 % of the total study sample. One fifth of the participants were hypertensive. During the last month period more than half of the participants consumed alcohol (56.1%). Only around one fourth of the participants were physically less active. The rest of the participants were moderately or more active.

Table 2
Characteristics of Participants of the Study

Characteristics	Participants	Percentage
Sex (n = 1338)	Male	53.5
	Female	46.5
Ethnicity (n = 1338)	Non Hispanic white	40.8
	Non Hispanic black	33.2
	Mexican American	23.2
	Others	2.8
Education (n = 1331)	12 years or less	67.8
	More than 12 years	32.2
Age (n = 1338)	20-29 years	29.2
	30-39 years	29.5
	40-49 years	25.1
	50-59 years	16.1
Smoking status (n = 1338)	Current	35.4
	Never	45.4
	Past	19.1
Stroke (n = 1338)	Yes	1.2
	No	98.8
Diabetes (n = 1337)	Yes	4.6
	No	95.4
Hypertension (n = 1327)	Yes	20.5
	No	79.5
Drinking during last 12 month (n = 1302)	Yes	56.1
	No	43.9
Physical Activity (n = 1322)	Less active	24.6
	About same	46.4
	More active	29.0

n=Number of participants.

Self-reported Exposure of Contact to Products Containing VOCs

The frequency of exposure to products containing VOCs for male and female participants over the past three days is shown in Table 3. The overall frequency of exposure was found to be higher for air freshener/ room deodorants, gasoline, finger nail polish, and diesel fuel/ kerosene followed by other VOC containing products. The p-values in Table 3 indicate that sex was a significant factor in exposure to diesel fuel, gasoline, paint thinner, varnish lacquer, solid toilet bowl deodorants, air freshener/room deodorants, moth ball crystals, pressure treated wood, fingernail polish, and dry cleaning/spot remover.

The exposure levels were higher in male participants for diesel fuel / kerosene (14.9%), gasoline (35.4%), paint thinner (8.7%), varnish lacquer (8.8%), weed killer (2.7%), and pressure treated wood (8.3%). Female participants showed higher exposure levels than male participants for bug or insect spray (7.8%), solid toilet bowl deodorant (8.0%), air freshener / room deodorants (39.5%), moth ball / crystals (4.8%), finger nail polish (31.6%), and dry cleaning fluid / spot remover (5.9%).

Table 3

Proportion of Participants Exposed to Products Containing VOCs Within Past Three Days by Gender

Product Containing VOC	Total			Female			Male			p value
	n	Exposed	%	n	Exposed	%	N	Exposed	%	
Diesel fuel / Kerosene	1307	139	10.6	610	35	5.7	697	104	14.9	0.000*
Gasoline	1301	380	29.2	603	133	22.1	698	247	35.4	0.000*
Paint thinner	1314	80	6.1	612	19	3.1	702	61	8.7	0.000*
Varnish lacquer	1319	96	7.2	613	34	5.5	706	62	8.8	0.024*
Bug or insect spray	1312	116	8.8	609	61	10.0	703	55	7.8	0.163
Weed killer	1311	27	2.1	608	8	1.3	703	19	2.7	0.078
Solid toilet bowl deodorants	1308	129	9.9	607	73	12.0	701	56	8.0	0.015*
Air freshener / Room deodorants	1307	453	34.7	605	239	39.5	702	214	30.5	0.001*
Moth ball / crystals	1310	46	3.5	610	29	4.8	700	17	2.4	0.023*
Pressure treated wood	1304	77	5.9	604	19	3.1	700	58	8.3	0.000*
Fingernail polish	1315	216	16.4	610	193	31.6	705	23	3.3	0.000*
Dry-cleaning fluid / Spot remover	1307	54	4.1	613	36	5.9	694	18	2.6	0.003*

n – Sample size
% - Percentage
p – Value from Chi-square test
* - $p<0.05$ (Comparing the percentage between males and females)

Frequencies of exposure to products containing VOCs for different ethnicities during the past three days are shown in table 4. Differences in exposure quantified by ethnicity (Non-Hispanic whites, Non-Hispanic blacks, Mexican Americans, and others) are significant for solid toilet bowl deodorants, air freshener/ room deodorants, moth ball crystals, pressure treated wood, fingernail polish, and dry cleaning fluid/ spot remover.

Participants of other ethnicity category show 16.7% of exposure for solid toilet bowl deodorants compared to Non-Hispanic white (7.2%) Non-Hispanic black (10.4%), and Mexican Americans (13.0%). Similarly exposure was observed to be higher in Non-Hispanic black participants for air freshener/room deodorants, and moth ball/crystals compared to exposure for participant of Non-Hispanic white, Mexican American, and others. Participants of Non-Hispanic whites (9.0%) origin show highest exposure for pressure treated wood and participants from other ethnicity origin have highest exposure levels for fingernail polish.

Table 4

Proportion of Participants Exposed to Products Containing VOCs Within Past Three Days by Ethnicities

Product Containing VOC	Non-Hispanic white			Non-Hispanic black			Mexican American			Other			p value
	n	Exposed	%	n	Exposed	%	n	Exposed	%	N	Exposed	%	
Diesel fuel / Kerosene	536	68	12.7	436	45	10.3	298	22	7.4	37	4	10.8	0.125
Gasoline	533	162	30.4	434	126	29.0	299	85	28.4	35	7	18.9	0.595
Paint thinner	538	31	5.8	437	26	5.9	303	20	6.6	36	3	8.3	0.903
Varnish lacquer	541	36	6.7	440	31	7.0	302	25	8.3	36	4	11.11	0.663
Bug or insect spray	540	44	8.1	437	50	11.4	299	19	6.4	36	3	8.3	0.098
Weed killer	540	12	2.2	435	9	2.1	300	5	1.7	36	1	2.8	0.942
Solid toilet bowl deodorants	540	39	7.2	431	45	10.4	301	39	13.0	36	6	16.7	0.023*
Air freshener / Room deodorants	536	166	31.0	436	181	41.5	299	92	30.8	36	14	38.9	0.002*
Moth ball / crystals	540	12	2.2	434	24	5.5	300	9	3.0	36	1	2.8	0.043*
Pressure treated wood	532	48	9.0	435	18	4.1	302	11	3.6	35	0	0.0	0.001*
Fingernail polish	540	84	15.6	438	80	18.3	301	41	13.6	36	11	30.6	0.040*
Dry-cleaning fluid / Spot remover	539	15	2.8	435	18	4.1	297	20	6.7	36	1	2.8	0.052

n – Sample size
% - Percentage
p – Value from Chi-square test
* - $p<0.05$ (Comparing the percentage between different ethnicities)

Table 5 shows the frequencies of exposure for the participants by their age groups. Exposure level for air freshener/ room deodorants (41.0%) was found to be significantly higher among young adult (age groups of 20-29 yrs) compared to the other age groups, 30.4% in 30-39yrs age group, 33.2% in 40-49yrs age group, and 33.3% in 50-59yrs age group . There was relatively less variation among the four groups for exposure to rest of the products containing VOCs based on comparison of age group percentages for each product.

Table 5

Proportion of Participants Exposed to Products Containing VOCs Within Past Three Days by Age

Product Containing VOC	20-29 Years			30-39 Years			40-49 Years			50-59 Years			p value
	N	Exposed	%	n	Exposed	%	N	Exposed	%	N	Exposed	%	
Diesel fuel / Kerosene	384	39	10.2	385	42	10.9	328	37	11.3	210	21	10.0	0.949
Gasoline	382	115	30.1	383	110	28.7	327	98	30.0	209	57	27.3	0.882
Paint thinner	381	21	5.5	390	29	7.4	329	15	4.6	214	15	7.0	0.373
Varnish lacquer	385	28	7.3	388	35	9.0	332	23	6.9	214	10	4.7	0.266
Bug or insect spray	382	29	7.6	387	36	9.3	329	28	8.5	214	23	10.7	0.604
Weed killer	382	6	1.6	387	9	2.3	327	7	2.1	215	5	2.3	0.879
Solid toilet bowl deodorants	380	39	10.3	387	36	9.3	326	32	9.8	215	22	10.2	0.971
Air freshener / room deodorants	378	155	41.0	385	117	30.4	331	110	33.2	213	71	33.3	0.016*
Moth ball / crystals	384	14	3.6	386	18	4.7	327	8	2.4	213	6	2.8	0.403
Pressure treated wood	380	23	6.1	387	26	6.7	324	19	5.9	213	9	4.2	0.669
Fingernail polish	384	70	18.2	389	57	14.7	329	61	18.5	213	28	13.1	0.209
Dry-cleaning fluid / Spot remover	379	19	5.0	388	14	3.6	328	16	4.9	212	5	2.4	0.368

n – Sample size
% - Percentage
p – Value from Chi-square test
* - $p<0.05$ (Comparing the percentage between different age groups)

Blood Concentration of Selected VOCs

Table 6, 7, and 8 displays blood concentrations of selected VOCs, the summary measures (mean, SD, 95th percentile) categorized by exposure to different VOCs for the overall study sample and by gender. These values can be used as a reference range for comparative purposes. The standard deviation values provide the measure of variation in blood concentration.

For example, 546 participants have blood measurement of 1,1,1-Trichloroethane with mean of 0.348 µg/L; standard deviation of 1.131, and the 95th percentile equals to 0.799 µg/L (Table 6).

As shown in Table 7, for 530 male participants blood concentration for 1,1-Dichloroethane revealed mean of 0.006 µg/L; standard deviation of 0.001; and 95th percentile of 0.006 µg/L. As many as Four Hundred and Twenty-five female participants were tested for the same chemical and the mean of 0.006 µg/L, standard deviation of 0.002, and 0.081 µg/L as 95th percentile are observed (Table 8).

Table 6

Descriptive Statistics of Blood Concentrations of Selected VOCs for All Study Participants

Chemical (µg/L)	n	Mean	SD	95th Percentile
1,1,1-Trichloroethane	546	0.348	1.131	0.799
1,1,2,2-Tetrachloroethane	971	0.006	0.000	0.006
1,1,2-Trichloroethane	970	0.011	0.000	0.011
1,1-Dichloroethane	955	0.006	0.002	0.006
1,1-Dichloroethene	951	0.013	0.002	0.013
1,2-Dichlorobenzene	727	0.031	0.000	0.031
1,2-Dichloroethane	960	0.008	0.000	0.008
1,2-Dichloropropane	882	0.006	0.001	0.006
1,3-Dichlorobenzene	920	0.013	0.002	0.013
1,4-Dichlorobenzene	915	1.975	5.367	11.081
2-Butanone	970	7.029	6.316	16.829
Acetone	911	3078.355	4266.985	8608.400
Benzene	796	0.132	0.172	0.476
Bromodichloromethane	937	0.008	0.010	0.019
Bromoform	579	0.021	0.018	0.034
Carbon tetrachloride	935	0.013	0.002	0.013
Chlorobenzene	901	0.006	0.004	0.013
Chloroform	876	0.045	0.167	0.118
Cis-1,2-Dichloroethene	931	0.009	0.000	0.009
Dibromochloromethane	919	0.010	0.007	0.022
Dibromomethane	608	0.031	0.000	0.031
Ethylbenzene	606	0.109	0.224	0.245
m-/p-Xylene	1018	0.238	1.131	0.607
Methylene chloride	604	0.074	0.102	0.063
o-Xylene	628	0.138	0.201	0.271
Styrene	624	0.074	0.203	0.177
Tetrachloroethene	566	0.192	0.703	0.618
Toluene	575	0.512	0.654	1.483
trans-1,2-Dichloroethene	936	0.010	0.001	0.010
Trichloroethene	645	0.019	0.147	0.021
Carbofuranphenol	973	0.770	0.667	0.707
2-Isopropoxyphenol	975	0.878	0.781	1.840
Pentachlorophenol	931	2.575	3.523	7.970
1-Naphthol	963	17.462	95.979	43.592
2-Naphthol	957	7.778	11.119	29.011
2,4-Dichlorophenoxyacetic-acid	963	1.008	1.733	2.190
2,4-Dichlorophenol	968	14.523	39.507	65.603
2,4,5-Trichlorophenol	915	1.191	1.685	3.411
2,4,6-Trichlorophenol	923	2.541	6.560	4.832
3,5,6-trichloro-2-pyridinol	973	4.518	5.215	13.186
4-Nitrophenol	954	1.754	3.399	5.165

n – Sample size
SD – Standard deviation

Table 7

Descriptive Statistics of Blood Concentrations of Selected VOCs for Male Participants

Chemical (µg/L)	n	Mean	SD	95th Percentile
1,1,1-Trichloroethane	305	0.435	1.425	1.156
1,1,2,2-Tetrachloroethane	538	0.006	0.000	0.006
1,1,2-Trichloroethane	536	0.011	0.000	0.011
1,1-Dichloroethane	530	0.006	0.001	0.006
1,1-Dichloroethene	527	0.013	0.002	0.013
1,2-Dichlorobenzene	422	0.031	0.000	0.031
1,2-Dichloroethane	534	0.008	0.000	0.080
1,2-Dichloropropane	490	0.006	0.000	0.006
1,3-Dichlorobenzene	516	0.013	0.002	0.013
1,4-Dichlorobenzene	515	1.908	5.607	9.892
2-Butanone	537	7.588	7.346	18.967
Acetone	500	3368.33	5189.214	9705.550
Benzene	442	0.155	0.197	0.551
Bromodichloromethane	518	0.008	0.012	0.017
Bromoform	319	0.022	0.023	0.034
Carbon tetrachloride	521	0.013	0.002	0.013
Chlorobenzene	501	0.006	0.005	0.013
Chloroform	487	0.049	0.214	0.116
Cis-1,2-Dichloroethene	516	0.009	0.000	0.009
Dibromochloromethane	507	0.011	0.007	0.024
Dibromomethane	331	0.031	0.001	0.031
Ethylbenzene	338	0.134	0.276	0.316
m-/p-Xylene	566	0.306	1.497	0.688
Methylene chloride	340	0.076	0.101	0.063
o-Xylene	356	0.159	0.256	0.328
Styrene	349	0.093	0.267	0.022
Tetrachloroethene	315	0.164	0.313	0.642
Toluene	321	0.582	0.753	1.769
trans-1,2-Dichloroethene	512	0.010	0.000	0.010
Trichloroethene	358	0.027	0.197	0.022
Carbofuranphenol	522	0.751	0.619	0.707
2-Isopropoxyphenol	524	0.881	0.736	1.971
Pentachlorophenol	501	2.654	3.213	8.651
1-Naphthol	517	17.428	112.765	44.141
2-Naphthol	515	8.864	12.536	35.379
2,4-Dichlorophenoxyacetic-acid	518	1.115	2.261	2.474
2,4-Dichlorophenol	522	16.632	41.101	73.866
2,4,5-Trichlorophenol	492	1.238	1.981	3.537
2,4,6-Trichlorophenol	495	2.833	7.418	6.860
3,5,6-trichloro-2-pyridinol	523	4.805	5.429	13.239
4-Nitrophenol	512	1.685	2.002	5.103

n – Sample size
SD – Standard deviation

Table 8

Descriptive Statistics of Blood Concentrations of Selected VOCs for Female Participants

Chemical (µg/L)	n	Mean	SD	95th Percentile
1,1,1-Trichloroethane	241	0.239	0.558	0.630
1,1,2,2-Tetrachloroethane	433	0.006	0.000	0.006
1,1,2-Trichloroethane	434	0.011	0.000	0.011
1,1-Dichloroethane	425	0.006	0.002	0.081
1,1-Dichloroethene	424	0.013	0.003	0.013
1,2-Dichlorobenzene	305	0.031	0.000	0.031
1,2-Dichloroethane	426	0.008	0.001	0.008
1,2-Dichloropropane	392	0.006	0.001	0.006
1,3-Dichlorobenzene	404	0.013	0.002	0.013
1,4-Dichlorobenzene	400	2.062	5.045	11.337
2-Butanone	433	6.336	4.652	14.277
Acetone	411	2725.581	2722.211	7933.600
Benzene	354	0.103	0.128	0.332
Bromodichloromethane	419	0.007	0.006	0.020
Bromoform	260	0.021	0.010	0.037
Carbon tetrachloride	414	0.013	0.002	0.013
Chlorobenzene	400	0.006	0.004	0.012
Chloroform	389	0.040	0.075	0.119
Cis-1,2-Dichloroethene	415	0.009	0.000	0.009
Dibromochloromethane	412	0.010	0.006	0.020
Dibromomethane	277	0.031	0.000	0.031
Ethylbenzene	268	0.079	0.123	0.177
m-/p-Xylene	452	0.153	0.256	0.445
Methylene chloride	264	0.072	0.104	0.063
o-Xylene	272	0.110	0.080	0.214
Styrene	275	0.049	0.044	0.140
Tetrachloroethene	251	0.229	0.995	0.608
Toluene	254	0.424	0.488	1.138
trans-1,2-Dichloroethene	424	0.010	0.001	0.010
Trichloroethene	287	0.009	0.009	0.019
Carbofuranphenol	451	0.791	0.718	0.707
2-Isopropoxyphenol	451	0.874	0.832	1.789
Pentachlorophenol	430	2.484	3.855	7.446
1-Naphthol	446	17.510	71.899	42.865
2-Naphthol	442	6.513	9.049	23.807
2,4-Dichlorophenoxyacetic-acid	445	0.883	0.727	1.813
2,4-Dichlorophenol	446	12.055	37.450	63.967
2,4,5-Trichlorophenol	423	1.136	1.254	2.948
2,4,6-Trichlorophenol	428	2.202	5.390	3.308
3,5,6-trichloro-2-pyridinol	450	4.185	4.940	13.188
4-Nitrophenol	442	1.835	4.507	5.554

n – Sample size
SD – Standard deviation

Neurobehavioral Assessment

The descriptive statistics of the three neurobehavioral assessments, SRTT, SDST, and SDLT are shown by gender (Table 9), ethnicity (Table 10), and age group (Table 11). For example Mean (SD) of SRTT is 227.33 (41.421) for males and 249.592 (63.655) for females. Mean values of the assessments appeared to be different among the ethnic groups in the study. No observable general trends in the dataset were present for the different age groups. For example, 346 males were tested to assess changes in the neurobehavioral function using SRTT, the minimum and maximum values were found to be 158.49 and 616.78 respectively, mean value was found to 227.313, and standard deviation of 41.421 was observed. (Table 9)

As shown in Table 10, for 274 Non-Hispanic white participants, neurobehavioral assessment was performed using SDST, which revealed minimum of 1.61, maximum of 6.91, mean of 2.631, and standard deviation of 0.618.

The 194 participants between 20-29 years of age who were tested for the neurobehavioral performance using SDLT were found to have minimum of 0.00, maximum of 16.00, mean of 4.530, and standard deviation of 4.112. (Table 11)

Table 9

Descriptive Statistics of the Three Neurobehavioral Assessments by Gender

Sex	Test	n	Minimum	Maximum	Mean	Std. Deviation
Male (N=716)	SRTT	346	158.49	616.78	227.313	41.421
	SDST	342	1.85	8.14	2.915	0.894
	SDLT	339	0.00	16.00	5.427	4.810
Female (N=622)	SRTT	310	163.40	619.64	249.592	63.655
	SDST	312	1.61	11.79	2.881	1.329
	SDLT	307	0.00	16.00	5.879	4.985
Total (N=1338)	SRTT	656	158.49	619.64	237.841	54.214
	SDST	654	1.61	11.79	2.899	1.122
	SDLT	646	.00	16.00	5.642	4.895

N = Number of participants by sex
n = Number of test participants
SRTT – Simple Reaction Time Test
SDST – Symbol Digit Substitution Test
SDLT – Serial Digit Learning Test

Table 10

Descriptive Statistics of the Three Neurobehavioral Assessments by Ethnicity

Ethnicity	Test	n	Minimum	Maximum	Mean	Std. Deviation
Non-Hispanic white (N=546)	SRTT	275	158.49	619.64	229.992	42.516
	SDST	274	1.61	6.92	2.631	0.618
	SDLT	275	0.00	16.00	4.280	4.268
Non-Hispanic black (N=444)	SRTT	213	167.98	616.78	246.674	69.741
	SDST	213	1.76	11.79	3.123	1.533
	SDLT	208	0.00	16.00	5.927	4.830
Mexican American (N=311)	SRTT	152	163.40	501.98	241.462	48.107
	SDST	151	1.86	8.56	3.103	1.088
	SDLT	148	0.00	16.00	7.587	5.313
Other (N=37)	SRTT	16	186.30	271.48	220.745	24.530
	SDST	16	1.93	3.67	2.576	0.460
	SDLT	15	0.00	16.00	7.466	5.012

N = Number of participants by ethnicity
n = Number of test participants
SRTT – Simple Reaction Time Test
SDST – Symbol Digit Substitution Test
SDLT – Serial Digit Learning Test

Table 11

Descriptive Statistics of the Three Neurobehavioral Assessments by Age Group

Age Group	Test	n	Minimum	Maximum	Mean	Std. Deviation
20-29 yrs. (N=391)	SRTT	196	159.30	616.78	233.361	50.860
	SDST	196	1.61	9.82	2.523	0.742
	SDLT	194	0.00	16.00	4.530	4.112
30-39 yrs. (N=395)	SRTT	184	170.20	619.64	239.819	59.927
	SDST	183	1.73	6.41	2.717	0.772
	SDLT	180	0.00	16.00	5.511	5.087
40-49 yrs. (N=336)	SRTT	177	158.49	607.87	239.374	55.492
	SDST	175	1.87	11.24	3.121	1.248
	SDLT	172	0.00	16.00	6.482	5.011
50-59 yrs. (N=216)	SRTT	99	180.33	549.04	240.292	46.933
	SDST	100	2.05	11.79	3.579	1.577
	SDLT	100	0.00	16.00	6.590	5.331

N = Number of participants by age
n = Number of test participants
SRTT – Simple Reaction Time Test
SDST – Symbol Digit Substitution Test
SDLT – Serial Digit Learning Test

Relationship of Self-reported Exposure to VOCs with Neurobehavioral Assessment

Relationship Based on Gender

Mean levels of neurobehavioral assessments for all the participants by status of exposure to VOC containing products are shown in table 12. Except for gasoline and pressure treated wood, no significant difference were found between those who were exposed compared to those who were not exposed. Mean (SD) SRTT is 227.0402 (29.8852) for participants who were exposed (n=198) to gasoline in the past 3 days and 242.1736 (61.5978) for participants who were not exposed (n=442). For participants who were exposed (n=197) to pressure treated wood, the mean (SD) SDLT was 3.5532 (3.9387) and 5.8589 (4.9306) for who were not exposed (n=433) during previous 3 days period.

Table 13 shows significant association between neurological function tested using SDLT in males with exposure to pressure treated wood. None of the other products containing VOCs shows significant effects on neurological function of the tested individuals. For male participants who were exposed (n=33) to pressure treated wood, the mean (SD) SDLT was 3.4242 (4.2502) and the mean was 5.6823 (4.8330) for those who were not exposed (n=299) during previous 3 days period.

Neurological function as assessed by SRTT and SDLT was found after exposure to gasoline in female participants compared to those who were not exposed during past 3 days and is shown in Table 14. The mean (SD) SRTT is 233.4547 (30.0075) for female participants who were exposed (n=73) during past 3 days to gasoline and the mean was 254.1955 (70.4095) for those who were not exposed (n=228) during the same time period. For female participants who were exposed (n=73) to gasoline, the mean (SD) SDLT was 4.4110, (4.3647) and the mean was 6.3244 (5.0503) for who were not exposed (n=225) during previous 3 days period.

No significant impairment of neurological function was observed in the exposed female population compared to controls using SRTT, SDST, and SDLT for the rest of the VOC containing products. Notably, the significant differences in the mean levels of the neurobehavioral assessments between the exposed and the non-exposed, if they exist, indicate possibility of healthy worker effect, rather than toxic effect of the exposure.

Table 12

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in All Participants

Product containing VOC		SRTT			SDST			SDLT		
		N	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	79	232.2825	31.0449	79	2.8911	0.8372	79	5.7722	4.9014
	No	564	238.3430	56.8959	562	2.9046	1.1677	554	5.6300	4.8991
	p	0.530			0.817			0.963		
Gasoline	Yes	198	227.0402	29.8852	197	2.8527	1.1265	197	4.8223	4.4497
	No	442	242.1736	61.5978	441	2.9243	1.1339	433	5.9492	5.0048
	p	0.004*			0.513			0.024*		
Paint thinner	Yes	44	231.2420	40.1526	44	2.8936	0.7530	43	5.4884	4.9250
	No	599	238.7200	55.4691	597	2.9048	1.1554	590	5.6712	4.9100
	p	0.707			0.896			0.892		
Varnish lacquer	Yes	49	224.7168	29.1170	49	2.7014	0.6633	48	5.5417	4.8988
	No	598	238.7200	55.9009	596	2.9193	1.1577	589	5.6774	4.8973
	p	0.283			0.517			0.661		
Bug or Insect spray	Yes	55	239.7999	48.1008	56	3.0609	1.5066	52	5.4615	4.6923
	No	589	237.5778	55.1487	586	2.8909	1.0884	582	5.7079	4.9169
	p	0.723			0.453			0.283		
Weed killer	Yes	12	220.3458	22.3572	12	2.7683	0.8846	11	5.2727	4.6279
	No	630	238.0551	55.0219	628	2.9072	1.1374	621	5.6876	4.9005
	p	0.478			0.811			0.478		
Solid toilet bowl deodorants	Yes	59	235.2399	47.0561	59	3.0683	1.4454	57	5.9474	5.1284
	No	579	237.6588	55.1678	577	2.8846	1.0946	571	5.6252	4.8705
	p	0.282			0.495			0.562		
Air freshener / room deodorants	Yes	236	240.1288	59.8512	238	2.8961	1.3088	231	5.3074	4.5622
	No	406	236.2100	51.2524	402	2.9099	1.0154	401	5.8828	5.0861
	p	0.361			0.857			0.368		
Moth balls / crystals	Yes	25	235.8041	35.4897	25	2.9940	1.8153	24	4.1667	4.6313
	No	614	237.6429	55.2835	612	2.8911	1.0766	605	5.7124	4.8976
	p	0.803			0.598			0.489		
Pressure Treated Wood	Yes	48	223.4117	29.4297	48	2.6240	0.4568	47	3.5532	3.9387
	No	590	238.7879	56.1417	588	2.9261	1.1635	581	5.8589	4.9306
	p	0.162			0.245			0.008*		
Fingernail Polish Remover	Yes	105	245.5102	58.3378	106	2.9088	1.4866	105	6.1238	4.9704
	No	540	236.0952	53.6574	537	2.8994	1.0444	530	5.5679	4.8656
	p	0.250			0.868			0.457		
Dry-cleaning fluid / Spot remover	Yes	31	238.4099	30.7370	30	2.6870	0.4607	30	5.8333	4.8571
	No	609	237.3475	53.4038	608	2.9173	1.1561	600	5.6800	4.9191
	p	0.332			0.516			0.528		

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Table 13

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in Male Participants

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	59	227.6475	24.4787	59	3.0108	0.9142	59	5.8814	4.8816
	No	279	226.7869	44.0135	275	2.9009	0.8989	272	5.3125	4.7832
	p	0.884			0.396			0.410		
Gasoline	Yes	125	223.2942	29.2866	123	2.9393	0.9588	124	5.0645	4.4988
	No	214	229.3652	47.4648	212	2.9074	0.8629	208	5.5433	4.9351
	p	0.197			0.754			0.378		
Paint thinner	Yes	34	229.6175	42.5152	34	2.9194	0.6896	33	5.5152	5.0715
	No	304	227.0461	41.7813	300	2.9215	0.9240	298	5.4329	4.8015
	p	0.734			0.990			0.926		
Varnish lacquer	Yes	28	218.6309	24.6265	28	2.8829	0.7365	27	4.8889	4.6939
	No	313	227.9411	42.7770	309	2.9234	0.9131	307	5.5081	4.8178
	p	0.258			0.820			0.522		
Bug or Insect spray	Yes	22	223.1219	41.3622	22	3.1273	1.2296	22	6.1818	5.0297
	No	318	227.5153	41.7643	314	2.9081	0.8723	311	5.4212	4.7924
	p	0.633			0.270			0.474		
Weed killer	Yes	7	217.5334	21.9257	7	3.0157	1.0162	7	5.2857	5.2825
	No	332	227.3750	42.0510	328	2.9209	0.8995	325	5.4923	4.8000
	p	0.538			0.783			0.911		
Solid toilet bowl deodorants	Yes	21	223.3644	22.1326	21	2.9938	1.0191	21	6.3810	6.0454
	No	317	227.0354	42.2994	313	2.9166	0.8953	310	5.3677	4.7268
	p	0.694			0.705			0.352		
Air freshener / room deodorants	Yes	102	232.7156	55.7891	102	2.9216	1.0218	99	5.0202	4.5557
	No	238	224.8691	33.7724	234	2.9162	0.8443	234	5.6197	4.9187
	p	0.112			0.960			0.300		
Moth balls / crystals	Yes	7	229.1289	21.0903	7	2.8500	0.5944	7	3.4286	5.8554
	No	330	227.1239	42.1505	326	2.9011	0.8552	323	5.4582	4.7666
	p	0.900			0.875			0.268		
Pressure Treated Wood	Yes	34	221.9620	32.668	34	2.6841	0.4756	33	3.4242	4.2502
	No	305	227.6808	42.5467	301	2.9472	0.9335	299	5.6823	4.8330
	p	0.448			0.107			0.010*		
Fingernail Polish Remover	Yes	12	233.0879	23.1364	12	2.7192	0.6168	12	4.5000	4.3379
	No	329	227.0037	42.1582	325	2.9287	0.9067	322	5.4907	4.8254
	p	0.620			0.428			0.484		
Dry-cleaning fluid / Spot remover	Yes	9	228.8889	34.2185	8	2.8725	0.5329	9	5.4444	5.5251
	No	325	226.3903	36.1295	322	2.9289	0.9131	318	5.4937	4.8294
	p	0.838			0.862			0.976		

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Table 14

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in Female Participants

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	20	245.9558	43.1734	20	2.5380	.3877	20	5.4500	5.0728
	No	285	249.6558	65.2795	287	2.9080	1.3786	282	5.9362	4.9978
	p	0.803			0.233			0.675		
Gasoline	Yes	73	233.4547	30.0075	74	2.7088	1.3555	73	4.4110	4.3647
	No	228	254.1955	70.4095	229	2.9400	1.3386	225	6.3244	5.0503
	p	0.015*			0.199			0.004*		
Paint thinner	Yes	10	236.7650	32.1150	10	2.8060	.9770	10	5.4000	4.6475
	No	295	249.9528	64.7454	297	2.8879	1.3509	292	5.9144	5.0150
	p	0.522			0.849			0.749		
Varnish lacquer	Yes	21	232.8314	33.0907	21	2.4595	.4647	21	6.3810	5.1427
	No	285	250.5579	65.4978	287	2.9150	1.3749	282	5.8617	4.9845
	p	0.221			0.132			0.646		
Bug or Insect spray	Yes	33	250.9185	49.6275	34	3.0179	1.6782	30	4.9333	4.4406
	No	271	249.3854	65.6990	272	2.8710	1.2953	271	6.0369	5.0448
	p	0.897			0.548			0.251		
Weed killer	Yes	5	224.2831	24.9048	5	2.4220	.5881	4	5.2500	3.9475
	No	298	249.9538	64.5856	300	2.8923	1.3519	296	5.9020	5.0078
	p	0.376			0.439			0.796		
Solid toilet bowl deodorants	Yes	38	241.8026	55.5274	38	3.1095	1.6458	36	5.6944	4.5845
	No	262	250.5122	65.3511	264	2.8467	1.2926	261	5.9310	5.0279
	p	0.435			0.260			0.789		
Air freshener / room deodorants	Yes	134	245.7717	62.3827	136	2.8769	1.4917	132	5.5227	4.5725
	No	168	252.2763	65.6413	168	2.9011	1.2170	167	6.2515	5.3048
	p	0.383			0.876			0.211		
Moth balls / crystals	Yes	18	238.4000	39.9459	18	3.0500	2.1250	17	4.4706	4.1999
	No	284	249.8656	65.3890	286	2.8798	1.2847	282	6.0035	5.0361
	p	0.463			0.603			0.220		
Pressure Treated Wood	Yes	14	226.9324	20.0905	14	2.4779	0.3844	14	3.8571	3.2071
	No	285	250.6744	65.7636	287	2.9039	1.3651	282	6.0461	5.0338
	p	0.179			0.245			0.109		
Fingernail Polish Remover	Yes	93	247.1131	61.3227	94	2.9330	1.5636	93	6.3333	5.0289
	No	211	250.2709	65.4397	212	2.8544	1.2269	208	5.6875	4.9366
	p	0.693			0.636			0.298		
Dry-cleaning fluid / Spot remover	Yes	22	242.3049	29.1352	22	2.6195	.4249	21	6.0000	4.6797
	No	284	249.8864	65.8565	286	2.9043	1.3810	282	5.8901	5.0186
	p	0.593			0.337			0.923		

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Relationship Based on Ethnicity

Table 15 classifies mean levels of neurobehavioral assessment by ethnicity. Significant difference in neurobehavioral assessment is found in Non-Hispanic white participants tested using SDST, following exposure to bug or insect spray, with the mean (SD) SDST of 2.9050 (1.1225) for those who were exposed (n=20) and 2.6115 (0.5611) for those who were not exposed (n=250) during previous 3 days period. No other significant differences were observed.

In the Non-Hispanic black population no significant effect on neurological function was noticed using SDLT, SRTT, and SDST following exposure to products containing VOCs. (Table 16)

In the Mexican American participants, significant differences in neurobehavioral assessment were observed following exposure to gasoline as tested by SRTT and SDLT. Exposure to varnish lacquer as tested by SDST; and exposure to finger nail polish remover as tested by SDLT. (Table 17)

Participants from other ethnicities were found to have significant differences in neurological assessment following exposure to gasoline as shown by the results of SDST and after exposure to air freshener / room deodorants as tested by SRTT. (Table 18)

Table 15

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in Non-Hispanic White Participants

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	42	232.5186	31.8327	42	2.7331	0.5301	42	5.2143	4.8011
	No	228	228.9561	43.9356	227	2.6123	0.6345	228	4.0965	4.1331
	p	0.616			0.247			0.118		
Gasoline	Yes	88	224.4668	28.4294	86	2.7086	0.7519	88	3.6364	3.8422
	No	180	231.6228	46.5071	181	2.6007	0.5414	180	4.4944	4.3422
	p	0.186			0.183			0.166		
Paint thinner	Yes	18	238.6626	43.8186	18	2.8017	0.4714	18	5.2222	4.7842
	No	252	229.3917	42.8231	251	2.6216	0.6312	252	4.2341	4.2478
	p	0.376			0.237			0.345		
Varnish lacquer	Yes	18	222.2333	25.4020	18	2.6528	0.5961	18	4.0000	3.5146
	No	254	230.4510	43.6790	253	2.6321	0.6242	254	4.3425	4.3280
	p	0.431			0.892			0.743		
Bug or Insect spray	Yes	20	236.5560	46.2982	20	2.9050	1.1225	20	4.2000	3.8058
	No	252	229.4282	42.4763	251	2.6115	0.5611	252	4.3254	4.3186
	p	0.474			0.042*			0.900		
Weed killer	Yes	7	212.4821	16.3597	7	2.4214	0.5037	7	2.5714	1.8126
	No	265	230.4137	43.1142	264	2.6388	0.6240	265	4.3623	4.3148
	p	0.274			0.362			0.275		
Solid toilet bowl deodorants	Yes	16	222.3756	17.0961	16	2.4831	0.3766	15	3.6000	3.5010
	No	255	230.3234	43.8907	254	2.6409	0.6329	256	4.3750	4.3195
	p	0.472			0.325			0.496		
Air freshener / Room deodorants	Yes	83	235.1511	56.5822	83	2.6035	0.7032	82	4.0854	3.8974
	No	187	227.5925	35.0344	186	2.6457	0.5844	188	4.3989	4.4439
	p	0.182			0.608			0.581		
Moth balls / Crystals	Yes	6	223.4213	17.7879	6	2.4783	0.1000	6	2.1667	4.8339
	No	265	230.0444	43.2119	264	2.6369	0.6285	265	4.3736	4.2666
	p	0.709			0.538			0.213		
Pressure Treated Wood	Yes	27	219.4865	30.8783	27	2.5830	0.3522	27	2.4444	3.0297
	No	239	231.0774	44.1685	238	2.6435	0.6462	239	4.5732	4.3745
	p	0.186			0.633			0.015*		
Fingernail Polish / Remover	Yes	40	238.6747	39.1010	40	2.4932	0.3905	40	4.5000	4.0762
	No	232	228.3320	43.2164	231	2.6574	0.6507	232	4.2931	4.3115
	p	0.158			0.123			0.778		
Dry-cleaning fluid / Spot remover	Yes	8	225.1406	23.2583	7	2.6314	0.3566	8	2.2500	3.5757
	No	263	230.1670	43.2270	263	2.6319	0.6277	263	4.3802	4.2944
	p	0.744			0.998			0.166		

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Table 16

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in Non-Hispanic Black Participants

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	23	237.4722	32.8954	23	3.2196	1.2075	23	6.2174	4.6216
	No	187	247.7957	73.4137	187	3.1205	1.5815	182	5.9451	4.8828
	p	0.507			0.772			0.800		
Gasoline	Yes	63	233.4920	34.0755	64	3.0936	1.5963	63	5.5556	4.52512
	No	148	252.0860	80.0442	147	3.1337	1.5187	143	6.0420	4.9388
	p	0.077			0.862			0.505		
Paint thinner	Yes	15	229.2769	22.8032	15	3.2087	1.0975	15	6.200	5.4798
	No	195	248.2671	72.2478	195	3.1233	1.5745	190	5.9053	4.8251
	p	0.313			0.827			0.822		
Varnish lacquer	Yes	17	233.9849	27.3289	17	2.8859	0.8761	17	6.5882	5.6353
	No	195	247.5606	72.3123	195	3.1472	1.5811	190	5.8789	4.7755
	p	0.443			0.503			0.564		
Bug or Insect spray	Yes	24	241.7784	52.9137	25	3.2472	1.9604	22	5.5455	4.7881
	No	186	247.3937	72.1262	185	3.1184	1.4825	183	6.0383	4.8543
	p	0.713			0.696			0.653		
Weed killer	Yes	2	230.4125	44.9543	2	2.3750	0.7424	2	8.5000	2.1213
	No	206	247.0017	70.6945	206	3.1440	1.5540	201	6.0000	4.8569
	p	0.741			0.486			0.469		
Solid toilet bowl deodorants	Yes	20	223.6776	21.9391	20	3.4300	2.1343	20	5.2500	4.5983
	No	185	248.4444	73.1373	185	3.0948	1.4805	180	5.9278	4.8658
	p	0.134			0.360			0.553		
Air freshener / Room deodorants	Yes	92	244.9054	68.3798	93	3.2318	1.8055	90	5.9111	4.7110
	No	119	248.0224	71.4049	118	3.0431	1.29617	116	5.9397	4.9752
	p	0.749			0.378			0.967		
Moth balls / Crystals	Yes	13	238.7077	36.1515	13	3.4677	2.4456	13	5.1538	4.7931
	No	193	247.4139	72.4718	193	3.0786	1.4344	188	5.9149	4.8411
	p	0.668			0.370			0.584		
Pressure Treated Wood	Yes	15	236.3383	26.1097	15	2.6160	0.4255	15	4.5333	3.9255
	No	194	247.0670	72.4943	194	3.1572	1.5825	189	6.0212	4.8826
	p	0.570			0.189			0.251		
Fingernail Polish / Remover	Yes	42	253.0224	70.3038	42	3.2169	2.0713	42	5.6667	4.8573
	No	168	244.9056	70.1861	168	3.0995	1.3806	163	5.9755	4.8163
	p	0.504			0.659			0.712		
Dry-cleaning fluid / Spot remover	Yes	9	238.0194	27.5722	9	2.6667	0.5759	9	8.5556	4.7199
	No	199	245.6323	66.6575	199	3.1599	1.5752	194	5.8402	4.8607
	p	0.734			0.351			0.103		

n – Number of the participants; SD – Standard deviation; p – Significance; * =$p<0.05$.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Table 17

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days in Mexican American Participants

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	12	223.8729	26.8684	12	2.9333	0.7694	12	7.0833	6.1268
	No	135	242.8885	49.5598	134	3.1266	1.1311	131	7.6336	5.2655
	p		0.193			0.564			0.733	
Gasoline	Yes	42	224.4909	26.25343	42	2.8581	0.8867	41	6.0488	4.9241
	No	105	247.5138	53.6017	104	3.2105	1.1710	102	8.1961	5.3677
	p		0.009*			0.081			0.028*	
Paint thinner	Yes	11	221.7786	52.3173	11	2.6145	0.3523	10	4.9000	4.6773
	No	136	242.7013	48.0014	135	3.1547	1.1340	133	7.8571	5.2974
	p		0.169			0.199			0.089	
Varnish lacquer	Yes	13	216.0947	35.6332	13	2.5300	0.3863	12	5.5000	4.6612
	No	134	243.5650	48.9517	133	3.1711	1.1345	131	7.8473	5.3226
	p		0.051			0.045*			0.142	
Bug or Insect spray	Yes	10	244.5766	45.1665	10	2.8960	0.8845	10	7.8000	5.5737
	No	136	241.0270	48.9911	135	3.1378	1.1193	132	7.6894	5.2844
	p		0.824			0.506			0.949	
Weed killer	Yes	2	243.2625	8.1494	2	4.1750	1.1243	2	11.5000	6.3639
	No	144	241.0434	48.9559	143	3.1006	1.1036	140	7.5571	5.2850
	p		0.949			0.174			0.297	
Solid toilet bowl deodorants	Yes	19	261.4601	72.0831	19	3.2868	1.09785	19	9.0000	5.7638
	No	127	238.2496	43.6494	126	3.0961	1.10700	123	7.4959	5.2030
	p		0.052			0.485			0.250	
Air freshener / Room deodorants	Yes	5	248.3900	51.1022	5	2.3460	0.3950	5	4.0000	4.0000
	No	141	240.2664	48.1532	140	3.1500	1.1102	137	7.8321	5.2881
	p		0.712			0.109			0.112	
Moth balls / Crystals	Yes	5	248.3900	51.1022	5	2.3460	0.3950	5	4.0000	4.0000
	No	141	240.2664	48.1532	140	3.1500	1.1102	137	7.8321	5.2881
	p		0.712			0.109			0.112	
Pressure Treated Wood	Yes	6	208.7583	20.7949	6	2.8283	0.8663	5	6.6000	6.4265
	No	141	242.5134	48.8558	140	3.1262	1.1133	138	7.6884	5.2746
	p		0.095			0.519			0.653	
Fingernail Polish / Remover	Yes	16	254.9359	71.4156	17	3.2218	1.4852	17	10.1765	5.0029
	No	131	239.4501	44.9753	129	3.0998	1.0496	126	7.3095	5.2603
	p		0.229			0.670			0.036*	
Dry-cleaning fluid / Spot remover	Yes	13	249.0756	35.0542	13	2.6938	0.4545	13	6.1538	4.5248
	No	132	240.9649	49.6607	131	3.1652	1.1456	128	7.8984	5.3416
	p		0.567			0.144			0.258	

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Table 18

Mean Levels of Neurological Assessments by Status of Exposure to Products Containing VOCs During Past 3 Days Among Participants From Other Ethnicity Group

Product containing VOC		SRTT			SDST			SDLT		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Diesel fuel / Kerosene	Yes	2	218.1000	3.0052	2	2.1800	0.0141	2	4.5000	2.1213
	No	14	221.1232	26.3129	14	2.6336	0.4659	13	7.9231	5.2195
	p	0.877			0.203			0.388		
Gasoline	Yes	5	212.4550	14.4724	5	2.2040	0.2803	5	6.4000	5.5946
	No	9	227.8833	27.5307	9	2.7067	0.2890	8	8.3750	4.2740
	p	0.271			0.008*			0.485		
Paint thinner	Yes	-	-	-	-	-	-	-	-	-
	No	16	220.7453	24.5300	16	2.5769	0.4605	15	7.4667	5.0123
	p	-			-			-		
Varnish lacquer	Yes	1	223.9500	-	1	2.6700	-	1	16.0000	-
	No	15	220.5317	25.3756	15	2.5707	0.4760	14	6.8571	4.5885
	p	0.898			0.843			0.076		
Bug or Insect spray	Yes	1	209.4250	-	1	3.1700	-	-	-	-
	No	15	221.5000	25.1980	15	2.5373	0.4477	15	7.4667	5.0123
	p	0.650			0.193			1.000		
Weed killer	Yes	1	209.4250	-	1	3.1700	-	-	-	-
	No	15	221.5000	25.1980	15	2.5373	0.4477	15	7.4667	5.0123
	p	0.650			0.193			1.000		
Solid toilet bowl deodorants	Yes	4	219.9625	26.4741	4	2.5625	0.5065	3	3.0000	1.7320
	No	12	221.0063	25.0816	12	2.5817	0.4681	12	8.5833	4.9627
	p	0.944			0.945			0.084		
Air freshener / Room deodorants	Yes	8	237.4406	21.7598	8	2.5600	0.3298	7	6.4286	5.6230
	No	8	204.0500	13.3720	8	2.5938	0.5874	8	8.3750	4.5961
	p	0.002			0.889			0.474		
Moth balls / Crystals	Yes	1	209.4250	-	1	3.1700	-	-	-	-
	No	15	221.5000	25.1980	15	2.5373	0.4477	15	7.4667	5.0123
	p	0.650			0.193			1.000		
Pressure Treated Wood	Yes	-	-	-	-	-	-	-	-	-
	No	16	220.7453	24.5300	16	2.5769	0.4605	15	7.4667	5.0123
	p	-			-			-		
Fingernail Polish / Remover	Yes	7	217.9536	26.4323	7	2.6743	0.5723	6	8.6667	4.9261
	No	9	222.9167	24.3406	9	2.5011	0.3705	9	6.6667	5.1961
	p	0.702			0.475			0.470		
Dry-cleaning fluid / Spot remover	Yes	1	209.4250	-	1	3.1700	-	-	-	-
	No	15	221.5000	25.1980	15	2.5373	0.4477	15	7.4667	5.0123
	p	0.650			0.193			1.000		

n – Number of the participants; SD – Standard deviation; p – Significance; * =p<0.05.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Relationship of Blood Concentration of VOCs to Neurobehavioral Assessment

Correlation Based on Gender

As shown in Table 19 VOCs like, 1,1,2,2 – Tetrachloroethane (r = 0.124 for SDLT); 1,1,2 – Trichloroethane (r = 0.097 for SDST); 1,2 – Dichloroethane (r = 0.132 for SDLT); 1,4 – dichlorobenzene (r = 0.216 for SRTT and r = 0.130 for SDST); chloroform (r = 0.098 for SDLT); Dibromochloromethane (r = 0.115 for SRTT); and Tetrachloroethene (r = 0.153 for SRTT) showed significant effects on the neurobehavioral function in the overall study population.

Correlation coefficients for male participants were significant for 1,1,2,2 – Tetrachloroethane with SDLT (r = 0.170); 1,4 – Dichlorobenzene with SRTT (r = 0.309); Benzene with SDST (r = 0.147); Chloroform with SDLT (r = 0.150); Dibromochloromethane with SRTT (r = 0.147); and Carbofuranphenol with SDST and SDLT (r = 0.260 and r = 0.222) as shown in the Table 19. In male participants, negative correlation with poor neurobehavioral function was seen for Tetrachloroethene (r = -0.203 with SDLT) and pentachlorophenol (r = -0.144 with SDLT).

Significant correlation coefficients for female participants were observed for 1,1,2 – Tricholoethane (r = 0.169 with SDST and r = 0.274 with SDLT); 1,2 Dichloroethane (r = 0.195 with SDLT); 1,4 – Dichlorobenzene (r = 0.164 with SRTT and r = 0.196 with SDST); Benzene (r = 0.175 with SRTT); Chlorobenzene; Toluene; Trichloroethane; 2,4,5 – Trichlorophenol; and 3,5,6 – Trichloro 2 – pyridinol, as shown in the Table 19. Negative correlation were detected for 1,1,2,2 – Tetrachloroethane (r = -0.259 with SDST, r = -0.307 with SDLT); Bromoform (r = -0.188 with SDLT); 2,4,5–Trichlorophenol (r = -0.145 with SRTT) for neurobehavioral function assessment in female participants. (Table 19)

Table 19

Pearson's Correlation Coefficients Between VOCs and Neurobehavioral Assessments for All the Participants (Males, Females, and Together)

Chemical		All			Male			Female		
		SRTT	SDST	SDLT	SRTT	SDST	SDLT	SRTT	SDST	SDLT
1,1,1-Trichloroethane	n	259	258	253	149	147	146	110	111	107
	r	-0.072	-0.050	-0.042	-0.077	-0.073	-0.041	-0.101	-0.125	-0.121
	p	0.247	0.427	0.510	0.353	0.380	0.620	0.292	0.192	0.214
1,1,2,2-Tetrachloroethane	n	472	470	464	264	261	259	208	209	205
	r	-0.009	0.054	0.124	0.004	0.091	0.170	-0.081	-0.259	-0.307
	p	0.841	0.242	0.007*	0.948	0.143	0.006*	0.243	0.000*	0.000*
1,1,2-Trichloroethane	n	473	470	465	-	-	-	208	209	205
	r	0.058	0.097	0.083	-	-	-	-0.020	0.169	0.274
	p	0.205	0.035	0.075	-	-	-	0.770	0.014*	0.000*
1,1-Dichloroethane	n	458	456	450	258	255	253	200	201	197
	r	-0.031	-0.013	-0.086	-0.038	0.004	-.054	-0.044	-0.024	-0.120
	p	0.502	0.775	0.067	0.543	0.948	0.388	0.540	0.739	0.092
1,1-Dichloroethene	n	455	453	448	254	251	249	201	202	199
	r	-0.015	-0.031	-0.084	-0.025	-0.038	-0.075	-0.020	-0.026	-0.097
	p	0.749	0.517	0.076	0.691	0.554	0.241	0.777	0.717	0.174
1,2-Dichloroethane	n	470	467	462	-	-	-	204	205	201
	r	-0.006	0.064	0.132	-	-	-	-0.027	0.081	0.195
	p	0.901	0.166	0.005*	-	-	-	0.704	0.251	0.006*
1,2-Dichloropropane	n	432	429	424	243	239	238	189	190	186
	r	0.003	0.009	-0.020	-0.001	-0.010	-0.076	-0.014	0.021	-0.025
	p	0.955	0.856	0.426	0.990	0.882	0.245	0.852	0.777	0.737
1,3-Dichlorobenzene	n	448	445	442	251	247	248	197	198	194
	r	-0.043	0.009	-0.020	-0.059	-0.018	-0.027	-0.034	0.032	-0.011
	p	0.361	0.852	0.674	0.355	0.780	0.675	0.639	0.651	0.874
1,4-Dichlorobenzene	n	441	437	434	253	249	249	188	188	185
	r	0.216	0.130	0.089	0.309	0.108	0.098	0.164	0.196	0.080
	p	0.000*	0.006*	0.065	0.000*	0.089	0.123	0.024*	0.007*	0.280
2-Butanone	n	469	465	461	260	256	255	209	209	206
	r	0.014	0.035	0.028	0.030	0.064	0.067	0.061	-0.024	-0.051
	p	0.758	0.445	0.546	0.636	0.310	0.283	0.383	0.734	0.463
Acetone	n	447	445	440	250	247	245	197	198	195
	r	0.062	0.043	0.014	0.065	0.081	0.029	0.111	0.004	-0.010
	p	0.188	0.367	0.768	0.309	0.202	0.650	0.122	0.952	0.892
Benzene	n	389	387	383	220	217	215	169	170	168
	r	0.077	0.090	0.091	0.059	0.147	0.102	0.175	0.041	0.083
	p	0.127	0.076	0.077	0.386	0.030*	0.138	0.023*	0.594	0.285
Bromodichloromethane	n	457	454	449	257	253	252	200	201	197
	r	0.026	0.037	-0.017	0.090	0.085	-0.030	-0.061	-0.054	0.044
	p	0.570	0.432	0.724	0.149	0.178	0.636	0.387	0.449	0.540
Bromoform	n	281	279	273	155	153	151	126	126	122
	r	-0.015	-0.051	-0.033	0.125	0.001	0.082	-0.128	-0.107	-0.188
	p	0.809	0.369	0.591	0.123	0.987	0.314	0.154	0.231	0.038*
Carbontetrachloride	n	455	452	448	256	252	252	199	200	196
	r	-0.039	0.014	0.017	-0.037	0.041	-0.001	-0.046	-0.009	0.043
	p	0.407	0.771	0.716	0.557	0.518	0.984	0.516	0.900	0.553

Table 19 continued

Chlorobenzene	n	438	436	431	247	244	242	191	192	189
	r	0.042	0.037	0.002	0.075	-0.024	-0.032	0.023	0.156	0.090
	p	0.381	0.437	0.974	0.239	0.707	0.622	0.750	0.030*	0.219
Chloroform	n	421	418	414	239	235	234	182	183	180
	r	-0.026	0.010	0.098	-0.025	0.013	0.150	-0.022	0.006	0.044
	p	0.592	0.838	0.046*	0.704	0.837	0.022*	0.764	0.938	0.557
Cis 1,2-Dichloroethene	n	451	448	443	256	252	251	195	196	192
	r	-0.069	-0.045	-0.072	-0.100	-0.034	-0.072	-0.051	-0.054	-0.073
	p	0.144	0.339	0.129	0.110	0.587	0.253	0.478	0.449	0.313
Dibromochloromethane	n	443	440	435	248	244	243	195	196	192
	r	0.115	0.064	0.014	0.147	0.087	0.027	0.138	0.031	0.002
	p	0.015	0.258	0.768	0.020*	0.178	0.681	0.054	0.666	0.983
Dibromomethane	n	299	297	295	166	163	163	-	-	-
	r	-0.035	-0.013	-0.025	-0.048	-0.118	-0.153	-	-	-
	p	0.550	0.822	0.667	0.541	0.134	0.051	-	-	-
Ethylbenzene	n	296	295	290	168	166	164	128	129	126
	r	-0.009	-0.007	-0.038	0.025	-0.012	-0.068	0.017	-0.079	0.080
	p	0.883	0.898	0.518	0.746	0.881	0.386	0.852	0.376	0.374
m-/p-Xylene	n	495	492	487	278	274	273	217	218	214
	r	-0.026	-0.026	-0.050	0.000	-0.023	-0.059	-0.019	-0.070	-0.024
	p	0.565	0.565	0.272	0.995	0.701	0.331	0.777	0.302	0.728
Methylenechloride	n	290	288	284	167	164	163	123	124	121
	r	0.015	0.025	-0.099	0.000	0.040	-0.095	0.078	-0.005	-0.120
	p	0.795	0.678	0.097	0.996	0.615	0.226	0.390	0.955	0.190
o-Xylene	n	309	303	302	179	176	175	130	131	127
	r	-0.037	-0.017	-0.067	0.023	-0.019	-0.078	-0.104	-0.063	-0.043
	p	0.519	0.770	0.243	0.757	0.807	0.303	0.238	0.471	0.632
Styrene	n	305	304	298	173	172	169	132	132	129
	r	-0.045	-0.015	0.054	-0.036	-0.034	0.066	-0.033	-0.033	0.009
	p	0.437	0.800	0.349	0.634	0.660	0.393	0.711	0.703	0.921
Tetrachloroethene	n	276	275	270	159	157	155	117	118	115
	r	0.153	0.004	-0.123	0.130	0.047	-0.203	0.155	-0.004	-0.118
	p	0.011*	0.954	0.440	0.102	0.559	0.011*	0.096	0.968	0.208
Toluene	n	270	268	265	156	153	153	114	115	112
	r	0.029	0.026	0.037	0.040	-0.012	-0.035	0.105	0.066	0.299
	p	0.637	0.669	0.554	0.617	0.885	0.672	0.268	0.481	0.001*
Trans 1,2-Dichloroethene	n	455	452	449	255	251	250	200	201	199
	r	0.000	-0.045	0.076	-0.008	-0.038	0.125	0.003	-0.048	0.029
	p	0.997	0.345	0.106	0.893	0.550	0.049	0.965	0.500	0.680
Trichloroethene	n	313	311	307	176	173	173	137	138	134
	r	0.004	0.002	-0.040	0.014	-0.003	-0.050	0.263	0.036	-0.048
	p	0.946	0.975	0.487	0.854	0.971	0.512	0.002*	0.672	0.582
Carbofuranphenol	n	485	485	477	252	250	247	233	235	230
	r	-0.015	-0.036	-0.036	0.102	0.260	0.222	-0.043	-0.043	-0.058
	p	0.734	0.431	0.438	0.106	0.000*	0.000*	0.518	0.516	0.379
2-Isopropoxyphenol	n	485	485	477	252	250	247	233	235	230
	r	-0.045	0.047	-0.001	-0.056	0.122	0.007	-0.041	0.006	-0.007
	p	0.321	0.298	0.990	0.377	0.055	0.914	0.529	0.932	0.915

Table 19 continued

Pentachlorophenol	n	464	464	456	244	242	239	220	222	217
	r	0.010	0.003	-0.051	-0.006	-0.020	-0.144	0.022	0.018	0.043
	p	0.831	0.948	0.281	0.928	0.760	0.026*	0.740	0.788	0.528
1-naphthol	n	480	480	472	250	248	245	230	232	227
	r	-0.043	-0.012	0.012	-0.087	-0.040	0.040	-0.001	0.023	-0.043
	p	0.349	0.788	0.791	0.172	0.528	0.534	0.988	0.725	0.521
2-naphthol	n	475	475	467	246	244	241	229	231	226
	r	0.032	0.048	0.028	0.015	0.099	0.092	0.068	0.012	-0.039
	p	0.490	0.301	-0.546	0.816	0.124	0.153	0.309	0.859	0.562
2,4-Dichlorophenoxyacetic acid	n	481	481	473	250	248	245	231	233	228
	r	-0.021	-0.040	-0.037	0.008	-0.065	-0.035	-0.046	-0.029	-0.045
	p	0.646	0.376	0.420	0.899	0.307	0.565	0.478	0.661	0.498
2,4-Dichlorophenol	n	485	485	477	253	251	248	232	234	229
	r	-0.023	0.002	-0.026	0.010	0.068	0.033	-0.041	-0.035	-0.074
	p	0.614	0.970	0.570	0.878	0.278	0.609	0.534	0.597	0.266
2,4,5-Trichlorophenol	n	462	462	455	242	240	238	220	222	217
	r	-0.079	-0.021	0.016	-0.055	-0.046	0.025	-0.145	0.010	0.016
	p	0.090	0.648	0.732	0.391	0.480	0.698	0.031*	0.883	0.820
2,4,6-Tricholrophenol	n	456	456	448	237	235	232	219	221	216
	r	0.024	-0.056	-0.034	0.090	-0.063	0.023	0.005	-0.088	-0.052
	p	0.606	0.234	0.475	0.167	0.333	0.723	0.937	0.191	0.447
2,5-Dichlorophenol	n	488	488	480	254	252	249	234	236	231
	r	0.032	0.032	-0.012	0.035	0.024	0.030	0.024	0.038	-0.052
	p	0.483	0.480	0.786	0.575	0.706	0.635	0.714	0.566	0.431
3,5,6-Trichloro-2-Pyridinol	n	486	486	478	253	251	248	233	235	230
	r	-0.035	0.054	0.066	-0.032	-0.065	0.018	-0.028	0.172	0.141
	p	0.442	0.235	0.148	0.616	0.308	0.781	0.665	0.008*	0.032*
4-Nitrophenol	n	471	471	463	243	241	238	228	230	225
	r	-0.023	-0.005	0.017	-0.020	0.006	0.046	-0.035	-0.008	0.000
	p	0.614	0.921	0.714	0.752	0.928	0.483	0.603	0.903	1.000

n – Sample size; r – Correlation coefficient; p – Significance; * – p <0.005.
SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Correlation Based on Ethnicity

For Non-Hispanic white samples, positive correlation for neurobehavioral function was observed with 1,1,2,2 – Tetrachloroethane (r = 0.178 with SDLT); 1,1,2-Trichloroethane (r = 0.312 with SRTT); 2-Butanone (r = 0.154 with SDST); Acetone (r = 0.157 with SDST); Benzene (r = 0.242 with SDST); Bromoform (r = 0.247 with SDLT); Dibromochloromethane (r = 0.156 with SRTT); Tetrachloroethene (r = 0.457 with SRTT); Carbofuranphenol (r = 0.140 with SDLT); 2-Naphthol (r = 0.167 with SDST) along with a negative correlation with 1,2-Dichloroethane (r = -0.284 with SRTT); 2,4,5-Trichloro Phenol (r = -0.164 with SRTT) as shown in Table 20.

The correlation coefficients for Non-Hispanic black participants were found to be significant for 1,2-Dichloroethane (r = 0.234 with SDLT); 1,4-Dichlorobenzene (r = 0.299 with SRTT); Acetone (r = 0.165 with SRTT); benzene (r = 0.239 with SDLT); Dibromochloromethane (r = 0.171 with SRTT and r= 0.178 with SDLT); Toluene (r = 0.242 with SRTT and r = 0.384 with SDLT); and 1-Naphthol (r = 0.288 with SDST). Other VOCs like, 1,1,1-Trichloroethane (r = -0.235 with SRTT); Trans-1,2-Dichloroethene (r = -0.196 with SDST); 2,4,5-Trichlorophenol (r = -0.169 with SDLT) showed a negative correlation with the neurobehavioral assessments.

Correlation coefficients for Mexican American participants were found to be significantly negative for 1,2-Dichloroethane (r =-0.191 with SRTT); 1,2-Dichloropropane (r = - 0.209 with SRTT); and Cis-1,2-Dichloroethene (r = -0.234 with SRTT).

Table 20

Pearson's Correlation Coefficients Between VOCs and Neurobehavioral Assessments by Ethnicity

Chemical		Non-Hispanic white			Non-Hispanic black			Mexican American		
		SRTT	SDST	SDLT	SRTT	SDST	SDLT	SRTT	SDST	SDLT
1,1,1-Trichloroethane	n	97	96	96	79	80	77	74	73	72
	r	-0.097	-0.003	-0.025	-0.235	-0.105	-0.168	-0.027	-0.107	-0.032
	p	0.344	0.974	0.811	0.037*	0.352	0.144	0.819	0.368	0.788
1,1,2,2-Tetrachloroethane	n	182	181	181	-	-	-	119	118	116
	r	0.023	0.134	0.178	-	-	-	-0.033	0.072	0.140
	p	0.756	0.071	0.017*	-	-	-	0.723	0.411	0.135
1,1,2-Trichloroethane	n	185	183	184	-	-	-	-	-	-
	r	0.312	0.022	0.089	-	-	-	-	-	-
	p	0.000*	0.765	0.229	-	-	-	-	-	-
1,1-Dichloroethane	n	175	174	174	152	152	149	118	117	115
	r	-0.022	0.020	-0.091	-0.056	-0.026	-0.048	-0.002	0.071	-0.034
	p	0.775	0.793	0.232	0.497	0.754	0.559	0.980	0.447	0.716
1,1-Dichloroethene	n	178	176	177	145	145	142	117	117	114
	r	-0.015	-0.004	-0.084	0.005	-0.030	-0.074	0.127	0.003	-0.097
	p	0.842	0.957	0.266	0.949	0.723	0.379	0.171	0.744	0.306
1,2-Dichloroethane	n	187	185	186	156	156	153	111	110	108
	r	-0.284	-0.144	-0.090	-0.027	0.067	0.234	-0.191	-0.161	-0.233
	p	0.000*	0.051	0.221	0.739	0.405	0.004*	0.045*	0.093	0.021*
1,2-Dichloropropane	n	168	166	167	137	137	134	113	112	110
	r	0.038	0.041	0.027	-0.014	0.016	-0.069	-0.209	-0.091	-0.155
	p	0.623	0.597	0.725	0.871	0.853	0.425	0.026*	0.340	0.105
1,3-Dichlorobenzene	n	180	178	179	148	148	145	105	104	104
	r	-0.114	-0.034	-0.033	-0.017	0.073	0.106	-0.027	-0.078	-0.162
	p	0.127	0.648	0.657	0.841	0.376	0.203	0.783	0.431	0.100
1,4-Dichlorobenzene	n	171	169	170	149	148	146	109	108	107
	r	0.006	-0.006	-0.061	0.299	0.081	0.021	0.0230	0.133	0.166
	p	0.938	0.937	0.431	0.000*	0.326	0.800	0.812	0.169	0.087
2-Butanone	n	188	186	187	152	151	149	114	113	111
	r	-0.059	0.154	0.019	0.029	0.004	0.061	0.013	0.004	0.036
	p	0.419	0.036*	0.796	0.720	0.959	0.460	0.895	0.963	0.706
Acetone	n	171	169	170	151	151	148	112	112	109
	r	0.033	0.157	-0.040	0.165	0.045	0.155	-0.053	0.008	0.117
	p	0.670	0.041*	0.603	0.043*	0.580	0.059	0.579	0.932	0.224
Benzene	n	145	144	144	120	120	118	111	110	108
	r	0.035	0.242	0.155	0.165	0.099	0.239	-0.064	0.063	0.006
	p	0.674	0.004*	0.063	0.071	0.282	0.009*	0.506	0.515	0.949
Bromodichloromethane	n	183	181	182	147	147	144	114	113	111
	r	0.115	0.131	-0.005	-0.005	0.025	0.021	-0.056	-0.055	-0.013
	p	0.121	0.080	0.948	0.949	0.760	0.803	0.555	0.559	0.172
Bromoform	n	107	105	106	79	80	77	84	83	80
	r	-0.041	0.045	0.247	0.008	-0.061	-0.171	-0.021	-0.133	-0.211
	p	0.676	0.647	0.011*	0.944	0.594	0.137	0.849	0.232	0.061

Table 20 continued

Carbon Tetrachloride	n	181	179	180	146	146	143	113	112	111
	r	0.016	0.060	-0.032	-0.049	-0.069	0.063	-0.066	0.062	0.091
	p	0.826	0.421	0.666	0.560	0.410	0.455	0.484	0.514	0.340
Chlorobenzene	n	173	172	172	137	137	135	114	113	111
	r	-0.068	-0.078	0.037	0.117	0.122	0.090	0.012	-0.012	-0.076
	p	0.375	0.309	0.632	0.174	0.156	0.301	0.898	0.903	0.430
Chloroform	n	163	161	162	130	130	127	114	113	111
	r	0.075	-0.092	0.015	-0.051	0.001	0.159	0.002	0.042	0.136
	p	0.342	0.246	0.846	0.566	0.992	0.073	0.982	0.656	0.154
Cis 1,2-dichloroethene	n	180	178	179	-	-	-	117	116	114
	r	-0.134	-0.083	-0.087	-	-	-	-0.234	-0.144	-0.181
	p	0.074	0.269	0.245	-	-	-	0.011*	0.124	0.053
Dibromochloromethane	n	177	175	176	142	142	139	109	108	106
	r	0.156	0.135	-0.013	0.171	0.000	0.178	0.051	0.021	-0.170
	p	0.038*	0.074	0.868	0.042*	0.998	0.036*	0.598	0.829	0.082
Dibromomethane	n	-	-	-	-	-	-	87	86	85
	r	-	-	-	-	-	-	0.145	-0.151	0.002
	p	-	-	-	-	-	-	0.182	0.166	0.853
Ethylbenzene	n	113	112	112	84	85	83	89	88	86
	r	0.045	0.110	0.063	-0.040	-0.026	0.052	-0.024	-0.048	-0.129
	p	0.635	0.250	0.512	0.718	0.817	0.640	0.824	0.656	0.237
m-/p-Xylene	n	195	193	194	160	160	157	124	123	121
	r	0.035	-0.012	-0.021	-0.073	-0.023	-0.104	-0.028	-0.061	-0.101
	p	0.624	0.867	0.767	0.361	0.769	0.197	0.758	0.506	0.270
Methylenechloride	n	108	106	108	81	82	79	90	89	87
	r	0.022	0.073	-0.036	0.012	0.032	-0.188	0.130	-0.025	0.036
	p	0.822	0.454	0.715	0.918	0.777	0.098	0.222	0.815	0.740
o-Xylene	n	115	113	114	89	90	87	96	95	93
	r	0.019	0.009	0.002	-0.111	0.016	-0.123	-0.021	-0.087	-0.150
	p	0.842	0.925	0.980	0.302	0.884	0.257	0.842	0.403	0.151
Styrene	n	115	114	114	92	92	90	87	87	84
	r	-0.006	0.011	-0.019	0.111	0.158	0.185	-0.106	-0.050	0.115
	p	0.950	0.908	0.844	0.291	0.133	0.081	0.330	0.646	0.296
Tetrachloroethene	n	103	102	102	71	72	70	94	93	91
	r	0.457	0.050	-0.076	-0.037	-0.007	0.189	0.020	0.065	-0.015
	p	0.000*	0.617	0.450	0.762	0.953	0.118	0.849	0.538	0.155
Toluene	n	109	107	108	78	79	77	74	73	72
	r	-0.007	0.068	0.053	0.242	0.093	0.384	0.046	0.103	0.111
	p	0.940	0.488	0.585	0.033*	0.417	0.001*	0.698	0.386	0.352
Trans 1,2-dichloroethene	n	180	178	179	143	143	141	117	116	114
	r	-0.028	-0.055	0.136	-0.072	-0.196	-0.095	-0.018	-0.114	0.129
	p	0.709	0.463	0.069	0.390	0.019*	0.262	0.851	0.224	0.172

Table 20 continued

Trichloroethene	n	116	114	115	90	91	89	96	95	93
	r	0.152	-0.024	-0.087	-0.002	-0.076	0.174	-0.006	-0.011	-0.113
	p	0.103	0.800	0.354	0.983	0.473	0.103	0.955	0.912	0.281
Carbofuranphenol	n	196	196	196	156	157	153	122	121	118
	r	0.062	-0.053	0.140	-0.039	-0.053	-0.104	-0.048	-0.012	0.127
	p	0.391	0.465	0.050*	0.633	0.507	0.199	0.602	0.900	0.172
2-Isopropoxyphenol	n	197	197	197	155	156	152	122	121	118
	r	-0.024	-0.050	0.001	-0.065	0.029	-0.076	-0.113	0.193	0.042
	p	0.737	0.484	0.994	0.424	0.722	0.355	0.214	0.034	0.653
Pentachlorophenol	n	186	186	186	155	156	152	112	111	108
	r	-0.018	0.042	-0.098	0.038	0.021	0.017	0.027	-0.019	0.072
	p	0.807	0.571	0.183	0.642	0.795	0.836	0.776	0.839	0.461
1-Naphthol	n	195	195	195	155	156	152	119	118	115
	r	-0.063	-0.023	0.057	0.091	0.288	-0.033	-0.076	-0.092	0.012
	p	0.382	0.753	0.428	0.261	0.000*	0.686	0.411	0.322	0.901
2-Naphthol	n	192	192	192	154	155	151	118	117	114
	r	-0.075	0.167	0.083	0.150	0.086	0.144	0.013	-0.115	-0.099
	p	0.304	0.021*	0.253	0.063	0.288	0.165	0.887	0.217	0.297
2,4-Dichlorophenoxyacetic acid	n	194	194	194	155	156	152	121	120	117
	r	0.003	-0.037	-0.042	-0.062	-0.009	-0.066	-0.112	-0.068	-0.030
	p	0.968	0.612	0.561	0.441	0.911	0.419	0.223	0.462	0.744
2,4-Dichloro Phenol	n	196	196	196	156	157	153	122	121	118
	r	-0.056	0.081	-0.089	-0.032	-0.046	-0.093	-0.068	-0.069	0.008
	p	0.435	0.258	0.214	0.692	0.568	0.252	0.459	0.453	0.929
2,4,5-Trichloro Phenol	n	192	192	192	144	145	141	116	115	113
	r	-0.164	-0.060	0.058	-0.162	-0.048	-0.169	0.021	-0.006	0.064
	p	0.023*	0.411	0.421	0.053	0.563	0.045*	0.823	0.950	0.503
2,4,6-Tricholrophenol	n	178	178	178	152	153	149	115	114	111
	r	-0.045	0.016	-0.155	0.042	-0.068	0.024	0.096	-0.129	-0.035
	p	0.555	0.831	0.127	0.604	0.406	0.773	0.305	0.172	0.718
2,5-Dichlorophenol	n	198	198	198	157	158	154	122	121	118
	r	-0.053	0.058	0.047	0.076	0.028	-0.078	0.042	0.001	-0.013
	p	0.454	0.418	0.507	0.342	0.730	0.339	0.648	0.991	0.890
3,5,6-Trichloro-2-pyridinol	n	196	196	196	157	158	154	122	121	118
	r	-0.065	-0.058	0.007	-0.022	0.134	0.097	-0.022	0.042	0.135
	p	0.365	0.416	0.923	0.784	0.094	0.233	0.809	0.645	0.145
4-Nitrophenol	n	193	193	193	147	148	144	120	119	116
	r	-0.085	-0.033	-0.009	0.019	-0.005	0.059	-0.086	0.055	0.124
	p	0.239	0.646	0.903	0.819	0.954	0.480	0.350	0.552	0.185

n – Sample size; r – Correlation coefficient; p – Significance; * – $p < 0.005$.
SRTT – Simple Reaction Time Test ; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Multiple Linear Regression

Stepwise multiple regression analysis was carried out to assess the relationship of the exposure variables on the neurobehavioral function of the participants. The Tables 21 to 25 show regression coefficient (β value) of variables selected into the regression model along with the t-test values and the corresponding p values for the variables. The regression coefficient for the exposure variables indicated the degree of change in the dependent variable for a one unit change in the exposure variable, provided all the other variables in the model are kept constant. Beta coefficients are standardized coefficient and their magnitudes reflect the relative importance of the predictor variables (age, gender, ethnicity etc.) on the dependent variable (Neurobehavioral function).

In the regression of simple reaction time test (SRTT) on self-reported exposure to various products containing VOCs (TABLE 10a), sex, education, and Non-Hispanic black participants were found to be significant ($p < 0.05$). The coefficient (β) for Non-Hispanic black participants was observed to be positive which indicates that participants from this ethnic group had a relationship with the neurobehavioral function tested by SRTT for the products containing VOCs. The coefficient for education was negative and has an inverse relationship with the neurobehavioral function. None of the products containing VOC were selected in the model.

Table 21
Stepwise Multiple Linear Regression of Simple Reaction Time Test (SRTT) on Self-reported Exposure to VOC Products

Variable	Unstandardized Coefficients		Standardized Coefficient	t	p
	B	Std. Error	Beta		
Constant	235.525	10.720		21.970	0.000
Sex	22.243	4.183	0.215	5.318	0.000
Education	-3.042	0.685	-0.180	-4.441	0.000
Ethnicity – Non-Hispanic Black	11.434	4.469	0.104	2.558	0.011

p – Significance (<0.05); $R^2 = 0.094$

For the regression of symbol digit substitution test (SDST) on self-reported exposure to product containing VOCs, age of the participants and Non-Hispanic black population in the study were found to be significant with positive coefficients, as shown in Table 22. This indicated that as the age of the participants increased the neurological function also decreased. Also Non-Hispanic black participants had poorer effect neurobehavioral assessment score. The coefficient of education (β =-0.426 p=0.000) was significant and its coefficient was negative indicating that the greater the education the better the neurobehavioral function.

Table 22
Stepwise Multiple Linear Regression of Symbol Digit Substitution Test (SDST) on Self-reported Exposure to VOC Products

Variable	Unstandardized Coefficients		Standardized Coefficient	t	p
	B	Std. Error	Beta		
Constant	3.774	0.182		20.784	0.000
Education	-0.151	0.012	-0.426	-12.120	0.000
Age	0.332	0.037	0.322	9.076	0.000
Ethnicity – Non-Hispanic Black	0.436	0.081	0.189	5.364	0.000

p – Significance (<0.05); R^2 = 0.323

Education was found to be a significant factor and people with a higher education had better neurobehavioral function tested by Serial Digit Learning Test (SDLT), as shown in Table 23. Age was a significant variable in predicting effect on the neurological assessment. Increase in the age had a negative effect on neurobehavioral function. Interestingly, exposure to pressure treated wood was significantly associated with better neurobehavioral activity.

Table 23
Stepwise Multiple Regression of Serial Digit Learning Test (SDLT) on Self-reported Exposure to VOC Products

Variable	Unstandardized Coefficients		Standardized Coefficient	t	p
	B	Std. Error	Beta		
Constant	11.228	1.578		7.115	0.000
Education	-0.797	0.060	-0.490	-13.386	0.000
Age	0.469	0.171	0.101	2.746	0.006
Ethnicity – Other	2.733	1.215	0.082	2.249	0.025
Pressure Treated Wood	-1.406	0.678	0.076	2.074	0.039

p – Significance (<0.05), R^2 = 0.278

No significant association was observed between neurobehavioral assessment outcomes of Simple Reaction Time Test (SRTT) and variables including blood concentrations of VOCs.

Multiple linear regression analysis was also performed for variables including the blood concentration of VOCs to examine the association with the neurobehavioral assessment using SDST (Table 24). None of the VOCS were found to be significantly associated with the neurobehavioral assessment of the exposed individuals in the study. Participants with diabetes and their education levels were also found to be significant factors in the neurobehavioral assessment.

Table 24
Stepwise Multiple Regression of SDST on Blood Concentrations of VOCs

Variable	Unstandardized Coefficients		Standardized Coefficient	t	p
	B	Std. Error	Beta		
Constant	12.521	2.478		5.053	0.000
Diabetes	-3.678	1.211	-0.446	-3.038	0.005
Education	-0.182	0.061	-0.439	-2.992	0.006

p – Significance (<0.05); $R^2 = 0.398$

As shown in Table 25, Education was significant variable in determining the effect on the neurobehavioral assessment using SDLT; however, the effect of education was inversely proportional as it had negative coefficient value (β = -0.580 p = 0.000). Participants who are exposed to toluene were more likely to have an effect on their neurological assessment. Blood level of toluene had positive coefficient value (β = 0.421 p = 0.002), indicating the high blood levels of toluene may be associated with poor neurobehavioral function.

Table 25
Stepwise Multiple Regression of SDLT on Blood Concentrations of VOCs

Variable	Unstandardized Coefficients		Standardized Coefficient	t	p
	B	Std. Error	Beta		
Constant	13.785	2.310		5.053	0.000
Education	-0.851	0.182	-0.580	-4.681	0.000
Toluene	3.943	1.161	0.421	3.397	0.002

p – Significance (<0.05); $R^2 = 0.547$

CHAPTER 5

DISCUSSION

This study was conducted with primary objectives to describe the status of exposure to VOCs in the US general population and to examine the neurobehavioral effects associated with the exposure using data collected from NHANES III study. The results reported in this study can be used as a reference in screening trends of exposure to VOCs in the future.

The study used a national sample. The study sample comprised of varying mix of male and female individuals between 20-59 years of age. Ethnic groups included in the study sample were Non-Hispanic white, Non-Hispanic black, Mexican-American, and others. The importance of having a large study sample is that different variables of exposure and characteristics of the study sample can be analyzed to provide exposure information for different groups. Also, this study will provide important pilot data for the US general population regarding exposure to VOCs and product containing VOCs.

However, this study has certain limitations. Firstly, it is not a completely random sample because the dataset used were derived from the NHANES III study. Study participants in PTRRS were a selective sample from NHANES III and the results can not be generalized to entire US population even though they provide importance pilot data. Most of the study participants were free from disorders like stroke and diabetes, and only 20% of the participants were hypertensive. Little more than half of the study participants consumed alcohol during the last month before the study. The study sample was physically active which might be attributed to the age factor.

The majority of the participants in the study were 20-49 years of age. This age range is usually characterized by people who are healthy and active. One practical challenge faced is the "healthy worker effect" characterized by the trend for healthier individuals gaining and retaining employment at higher rates compared to their less healthy counterparts (Breslow & Day, 1987).

Exposure to product containing VOCs within the past 3 days showed different trends for male and female participants. In males, increased exposure was observed to diesel fuel / kerosene, gasoline, paint thinner, varnish lacquer, and pressure treated wood, which are mostly industrial products containing VOCs. These observations were consistent with the fact that most of these products are used in construction, transportation, and building/grounds cleaning and maintenance operations in which males comprise the dominant work force as reported by Bureau of Labor Statistics (U.S. Department of Labor, 2004a, 2004b). On the other hand, female participants showed increased exposure to household products and products used in personal care and services that contain VOCs, which include solid toilet bowl deodorants, air freshener/room deodorants, moth ball/crystals, finger nail polish, and dry cleaning fluid, spot remover.

This observation from our study has been supported by the report released by Bureau of Labor Statistics (U.S. Department of Labor, 2004a) which shows that females make up the major portion of the work force employed in these sectors (U.S. Department of Labor, 2004a). Therefore, gender differences exist in the profile of exposure to VOCs, which needs to be considered in exposure and risk assessment.

When exposure to VOCs was analyzed based on ethnicity, significantly high risk of exposure was observed in the Non-Hispanic black population with air freshener/room deodorant, moth ball/crystals, which are primarily used in household and hospitality services. This is in contrast to the fact that larger population of workers involved in household and hospitality services are Non-Hispanic whites (US department of Labor, 2004a).

Significantly higher exposure levels were observed in Non-Hispanic white participants for pressure treated wood, which is a material frequently used in the construction industry. This association also correlates with the gender distribution reported in the Current Population Survey (CPS) which states that Non-Hispanic whites comprise the majority of construction workers (US Department of Labor, 2004b). These data emphasize the importance of carrying out a national survey of exposure to VOC s on a larger sample to investigate any association between exposure and ethnicity based on occupation.

Although there is established evidence that there is significant neurological impairment on the exposure to VOCs in animals, there is little evidence in human beings due to exposure variation, physiological differences, and other variables. Descriptive statistics of blood concentration levels of 41 selected VOCs for male and female determined in this study will provide a reference range for future exposure studies. Analyses of the blood concentrations of the VOCs in the study sample reveal that the distribution of the mean levels is lower in females than males. The only exceptions are 1,4-Dichlorobenzene (bug or insect spray, solid toilet bowl deodorants, air freshener and room deodorants, moth balls/crystals), Tetrachloroethene(used in dry-cleaning fluid as a solvent), Carbofuranphenol (pesticides), and 1-Naphthol (pesticides). This gender difference in the exposure levels could be a result of differences in the occupation of male and female participants.

It will be appropriate to investigate associations between neurobehavioral assessment output based on gender, ethnicity, occupation, age, and other variables influencing outcomes of exposure to VOCs.

Surprisingly, for self-reported exposure to products containing VOCs, exposed individuals showed lower mean levels for neurobehavioral assessments with pressure treated wood indicating that lower mean level is associated with the better neurobehavioral performance on the test. The neurobehavioral performance is found to be better in those who were exposed than in unexposed participants on simple reaction time test. Even among female participants, the poor neurobehavioral performance on the simple reaction time test and serial digit learning test is seen unexposed individuals compared to those who were exposed. When mean levels of performance on neurobehavioral tests were compared against the pressure treated wood among Non-Hispanic white participants, we observed that a better performance was associated with exposure. Only bug or insect spray proved to have significant higher exposure-poor performance relationship with lower mean values for exposed individual on symbol digit learning test.

In Mexican American participants, the same type of association was observed with gasoline (with SRTT and with SDLT), varnish lacquer (SDST), and finger nail polish (with SDLT). Improved neurobehavioral function observed in exposed individuals could be attributed to the "healthy worker effect", characterized by a tendency of relatively healthy individuals to be more likely to gain employment and expose to products containing VOCs. During the analysis of exposure - response patterns in studies like ours where subtle associations are being analyzed, the healthy worker effect generally attenuates an adverse effect of exposure.

Positive Pearson correlation values imply that higher VOC concentrations in blood are associated with poorer neurobehavioral function assessment score. Correlation coefficients for blood levels of VOCs and neurobehavioral function as assessed by SRTT, SDST, and SDLT was shown to affect by different degrees in males and females. The VOCs showed significant and positive associations with the neurobehavioral assessments are summarized by gender in Table 26. The neurobehavioral effects of these chemicals are suggestive and deserve further investigation.

Table 26
VOCs Showing Significant and Positive Correlation with Neurobehavioral Assessment

	SRTT	SDST	SDLT
Male	1, 4- Dichlorobenzene Dibromochloromethane	Benzene Carbofuranphenol	1,1,2,2- Tetrachloroethane Chloroform Carbofuranphenol
Female	1, 4- Dichlorobenzene Benzene Trichloroethene	1, 1, 2- Trichloroethane 1, 4- Dichlorobenzene Chlorobenzene 3, 5, 6- Trichloro-2-Pyridinol	1, 1, 2- Trichloroethane 1, 2-Dichloroethane Toluene 3, 5, 6- Trichloro-2-Pyridinol

SRTT – Simple Reaction Time Test; SDST – Symbol Digit Substitution Test; SDLT – Serial Digit Learning Test.

Stepwise multiple regression analysis performed on the neurobehavioral assessments carried out using SRTT, SDST, and SDLT for exposure variables revealed significant effect of sex, education, age, exposure to pressure treated wood, Non-Hispanic black origin, disease status (diabetes), and blood concentration of toluene on neurobehavioral assessment. The analyses help to examine the effect of VOCs with adjustment for covariates; the statistical power is largely reduced due to decreased sample size. Therefore, results from multiple regressions need to be carefully analyzed.

In summary, this analyses of data obtained from NHANES III provides important information on probable association between neurobehavioral effects and exposure VOCs. Descriptives of the exposure to VOCs provide pilot data for reference ranges of different VOCs for the sample of US population. Select VOC exposures in humans were shown to be associated with poor neurobehavioral assessments. This study has set up an important foundation for further investigation.

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VITA

Abhijeet J. Bhanegaonkar, B.Pharm., MPH. contact.abhijeet@gmail.com

Personal Data:	Date of Birth: November 23rd, 1978
	Nationality: Indian
	Marital Status: Single
Education:	BVP's Institute of Pharmacy, Affiliated to Maharashtra State Board of Technical Examination, Pune, INDIA.
	Diploma in Pharmacy, *May 1998*
	MAEER's Maharashtra Institute of Pharmacy, Affiliated to University of Pune, Pune, INDIA
	Bachelor of Pharmacy, *May 2001*
	East Tennessee State University, College of Public & Allied Health, Johnson City, TN, USA.
	Health Care Management Certificate, *May 2005*
	Master of Public Health, Public Health Administration, *August2005*
Work Experience:	Department of Geology and Geography, East Tennessee State University
	Teaching Assistant (Part time) *August 2003-December 2003*
	Department of Public Health, East Tennessee State University
	Tuition Scholar, *August 2003-December 2003*
	Office of International Programs, East Tennessee State University
	Graduate assistant, *January 2004-May 2004*
	Department of Family Medicine, East Tennessee State University
	Research Technician, *June 2004-August 2004*
	Office of International Programs, East Tennessee State University
	Graduate assistant, *August 2004-May 2005*