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Toluene-Impaired Drivers: Behavioral Observations, Impairment Assessment, and Toxicological Findings

ABSTRACT: Toluene is an aromatic hydrocarbon solvent frequently abused for its euphoric and intoxicating properties. This report describes a series of six cases involving drivers arrested for driving under the influence who subsequently tested positive for toluene. Case data including driving behavior, physiological signs and symptoms, evidence of impairment, and toxicology findings were reviewed. Blood toluene concentrations in the drivers ranged from 12 to 45 mg/L (median 23 mg/L, mean 25 mg/L, SD 12.1 mg/L). All drivers were determined to be intoxicated, and displayed symptoms including balance problems, confusion and disorientation, loss of coordination, and inability to follow instructions. They also displayed horizontal but not vertical nystagmus, elevated pulse and blood pressure, and lower body temperature. These findings are consistent with prior reports that subjects with blood toluene concentrations above 10 mg/L are invariably under the influence and their driving skills are affected.

KEYWORDS: forensic science, toxicology, toluene, impaired driving, driving under the influence of drugs, inhalant abuse, drug recognition expert

Toluene is an aromatic hydrocarbon solvent present in many household and industrial chemicals, including cleaning solvents, paints and paint strippers, and glues. Toluene-containing products are abused for their euphoric, disorienting, and intoxicating effects, in a practice known as "huffing" or "solvent sniffing" in which the subject inhales the fumes from a solvent-soaked rag or bag (1). As these materials are readily and inexpensively obtained, the practice of solvent abuse is widespread, particularly among school-aged children, and youths without the means to buy alcohol. A recent study reports lifetime rates of inhalant use in 5th, 7th, and 9th grade children in the United States and Australia approaching or exceeding the rates of marijuana use (2). The intoxicating effects of toluene including impairment of cognitive and psychomotor functions would be expected to result in deficits in driving performance. There have been a few reports of the specific appearance, driving behavior, and performance of individuals intoxicated as a result of toluene inhalation, which have included quantitative analysis of toluene in blood samples. We describe a series of toluene-related impaired driving cases, in which driver behavior and performance in standardized field sobriety tests (SFST) or Drug Recognition Expert (DRE) examinations (four cases) were reported.

Methods

Blood samples were screened by Enzyme Multiplied Immunoassay Technique (EMIT®, SYVA/Siemens, Deerfield, IL) for cocaine metabolite, opiates, benzodiazepines, barbiturates, cannabinoids, amphetamines, phencyclidine, propoxyphene, methadone, and tricyclic anti-depressants. Acidic and basic extracts were prepared and screened by gas chromatography with flame ionization, mass selective, and nitrogen/phosphorus detection according to methods described elsewhere (3). Volatiles were screened and quantitated by gas chromatography with headspace autosampling, and the identity of aromatic hydrocarbons confirmed qualitatively by headspace gas chromatography with full scan mass selective detection. Standards were prepared fresh because toluene is lost from specimens by diffusion into headspace, by absorption into rubber stoppers, and possibly by other mechanisms (4–6). Toluene stock standard solutions were prepared in methanol (10%), and diluted out in deionized water to concentrations of 8.6, 21.5, 43, and 86 mg/L. Blood (0.2 mL) or aqueous standard and internal standard solutions (2.0 mL) (0.3 mL *n*-propanol and 20 g sodium chloride, diluted to 2 L with deionized water) were dispensed into headspace vials, and sealed with 20 mm Teflon-lined caps. Samples were analyzed by gas chromatography (6890 gas chromatograph, Agilent, Santa Clara, CA) on a 30 m DB-ALC-1 0.53 mm i.d., 3 μm film thickness (J&W/Agilent). The method has a limit of detection of 0.5 mg/L, and a limit of quantitation of 2 mg/L, and was linear up to 86 mg/L (R^2 = 0.995). The procedure was free from interferences from other common volatile organic solvents, including benzene and *o*-, *m*-, *p*-xylenes. Toluene was baseline resolved from the internal standard (*n*-propanol) with a relative retention time of 1.31.

Case Reports

Six drivers suspected of driving under the influence were contacted by police officers of various agencies in the State of Washington. The following observations were recorded, and results of the DRE examinations are listed in Table 1. Table 1 also records the time difference between arrest and blood collection, when known.

Case 1

A 37-year-old male subject was contacted by police after being involved in a single vehicle collision in a parking lot. He had a

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TABLE 1—*Subject information, DRE findings and toxicology results.*

	Expected DRE Clues for Inhalant Category	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
Age	–	37	56	25	25	43	30
Gender	–	M	M	M	M	M	M
Blood toluene conc. (mg/L)	–	12	45	17	29	17	29
Elapsed time between arrest and blood draw*	–	>2 h 7 min	2 h 9 min	>2 h 9 min	37 min	>49 min	>1 h 51 min
Other drugs present	–	None	None	None	None	Bupropion† Quetiapine	None
Clues of horizontal gaze nystagmus	Present	6 of 6	6 of 6	4 of 6‡	n/a	n/a	6 of 6
VGN	Present (high dose)	No	No	No	n/a	n/a	No
Pupil size (normal 3.0–6.5 mm)§	Norm/dilated	Dilated 5.5/8.5/6.0	Constricted 2.5/3.5/1.5	Dilated 7.5/10.5/6.5	n/a	n/a	Normal 5.0/7.0/5.0
Can converge pupils	No	No	No	No	n/a	n/a	No
Pupil reaction to light	Slow	Slow	Slow	Normal	n/a	n/a	Normal
Pulse (normal 60–90 bpm)	Elevated	Elevated (74/70/72)	Elevated (84/86/82)	Elevated (100/100/86)	n/a	n/a	Elevated (88/110/100)
Blood pressure (normal 120–140/70–90)	Elevated	Elevated (158/100)	Elevated (160/90)	Elevated (160/80)	n/a	n/a	Normal (110/78)
Body temperature (normal 98.6°F)	Normal	Low (95.6°F)	Low (97.3°F)	Low (97.6°F)	n/a	n/a	Low (97.3°F)
Muscle tone	Flaccid	Normal	Normal	Normal	n/a	n/a	Normal

*In cases where the time of the blood draw was not recorded, times reflect time between driving and completion of evaluation.
†Urine positive.
‡Subject unable to keep eyes open to complete test.
§Measurements reflect pupil sizes in room light, near dark, and indirect light.

strong chemical odor and appeared dazed and confused. He had slurred speech, slowed responses, and performed poorly on field sobriety tests. He admitted to having been inhaling "brake cleaner" prior to the collision. The DRE officer's opinion was that he was under the influence of an inhalant. A blood sample was collected and screened for common drugs and metabolites, and volatiles. The blood was positive for toluene at a concentration of 12 mg/L. No other drugs were detected.

Case 2

A 56-year-old male subject was stopped for failure to maintain his vehicle within his lane. He was described as having a strong chemical odor, was confused and disoriented, was unable to answer simple questions, and repeatedly fell asleep during the police interview. He was examined by a DRE officer who developed the opinion that the subject was under the influence of a central nervous system (CNS) depressant and narcotic analgesic. Blood was collected and tested positive for toluene at a concentration of 45 mg/L. No other drugs were detected.

Case 3

A 25-year-old male was contacted by police officers for driving into oncoming traffic. A DRE exam was performed during which the subject performed poorly in SFSTs. He was noted to have slurred speech, appeared confused, laughed frequently, and walked into a wall during the walk-and-turn test. He had a strong chemical odor, and rubber cement residue was observed in both nostrils. The DRE developed the opinion that he was under the influence of an inhalant. Blood was collected and tested positive for toluene at a concentration of 17 mg/L. No other drugs were detected.

Case 4

A 25-year-old male subject was contacted by police after being involved in a car versus fence collision. He was observed at the scene by an officer to pour toluene onto a rag and inhale the fumes, and continued to inhale until he passed out. Accordingly, no examination or SFSTs were conducted. He had a strong chemical odor and later admitted to having been doing this for 5 years. A blood sample was collected and tested positive for toluene at a concentration of 29 mg/L. No other drugs were detected.

Case 5

A 43-year-old male subject was contacted by police after running a red light. He performed poorly in SFSTs, displaying poor balance and coordination, and slow reactions. He was described as having a strong glue-like odor about his person, and he related to officers a history of huffing gasoline and glue. He had had multiple contacts with police following this behavior. Blood was collected and tested positive for toluene with a concentration of 17 mg/L. Bupropion and its metabolites, and quetiapine were detected in the urine.

Case 6

A 30-year-old male was stopped by police for weaving and making an improper turn. A DRE officer examined the subject who performed poorly in SFSTs, had slurred speech and poor coordination, and his face, hands, and shirt were covered in gold paint. He had a very strong chemical odor on his person, but denied having been inhaling the paint. The DRE officer developed the opinion

that the subject was under the influence of an inhalant. Blood was collected and found to have a toluene concentration of 29 mg/L. No other drugs were detected.

The blood toluene concentrations had a median value of 23 mg/L (range 12–45 mg/L, mean 25 mg/L, SD 12.1 mg/L). Table 1 records the physiological responses of the subjects where these were evaluated by a DRE officer. Subjects uniformly displayed horizontal gaze nystagmus, but not vertical nystagmus. Pupil size was highly variable ranging from constricted to dilated. None of the subjects was able to converge their gaze (cross their eyes). Pulse and blood pressure were generally elevated, consistent with the DRE matrix. Muscle tone was described as normal in each case. Body temperature, as measured in the ear, was consistently low by a degree or more. Other major distinguishing features of toluene intoxication cases are the indicia of solvent abuse such as paint or glue on the hands, face, and clothing, and the strong odor of solvents or chemicals on the subject's body, clothing, and breath.

Discussion

Toluene intoxication presents as typical CNS depressant intoxication, with light headedness, disinhibition, excitability, and impulsive behavior (1). Miyazaki et al. described a toluene-related dissociative "twilight state" characterized by disordered consciousness, during which actions can be performed without conscious volition and immediately forgotten (6). Other effects including reduced consciousness, slurred speech, dizziness, ataxia, and disorientation can occur with more intensive use. Subjects in this series consistently displayed these effects, manifested as confusion and disorientation, loss of coordination, poor balance, sleepiness, and inability to follow instructions.

The time between driving and blood draw was not well documented in every case, but was typically of the order of 2 h when a DRE evaluation was conducted. This is an important factor because the early distribution/elimination half life of toluene is of the order of 1–2 h (7), meaning that the blood toluene concentrations at the time of driving most likely were considerably higher than at the time of blood collection. Furthermore, other researchers (4,5,8) have noted that toluene is unstable in, or lost from, stored specimens over a period of weeks, even when frozen (−25°C). This should be taken into account when evaluating quantitative toluene results from medicolegal samples, in that the measured result most likely would underestimate the actual concentration at the time of driving.

Baselt (9) reviewed toluene concentrations encountered in various populations, citing Lush (10) who reported that in a population of solvent abusers in Scotland, those with blood toluene concentrations of 0.4–1.0 mg/L had noticeable odors of solvents on their breath. Those with concentrations between 1.0 and 2.5 mg/L showed increasing signs of intoxication, and 50% of abusers with blood toluene concentrations between 2.5 and 10.0 mg/L were hospitalized, showing signs of marked intoxication, including hallucinations. Subjects with concentrations above 10.0 mg/L were unconscious, and in some cases died. These concentrations are noticeably lower than the ones reported here and by other workers, for equivalent effects (6,7,11), raising questions about the reliability of their quantitative method. Park et al. (11) reported that toluene concentrations in blood of abusers arrested for glue sniffing ranged from 0.2 to 74.7 mg/L, with a median of 2.4 mg/L (mean 10.8 mg/L, SD. 3.9 mg/L). Garriott (7) reported toluene concentrations in six solvent abusers who habitually inhaled toluene in a prison workshop, with immediate collection of specimens, of between 9.8 and 31.4 mg/L. None exhibited distress, but all showed moderate signs of intoxication including slurred speech, slow unsteady movements, and an impaired ability to concentrate. The highest blood toluene concentration in a living abuser identified in our review of the literature was in a population of toluene-abusing street youth in Brazil, one of whom achieved a blood toluene concentration of 83.7 mg/L (median for population 15.3 mg/L) (12).

Blood toluene concentrations in individuals deliberately abusing toluene for its CNS effects are markedly different from individuals occupationally exposed. For example, Nise and Orbaek (13) reported median end of week/preshift blood toluene concentrations of 0.04 mg/L, range 0.0–0.28 mg/L in rotogravure printing workers who were occupationally exposed. Brugnone (14) reported median end of work-shift blood toluene concentrations of 0.41 mg/L (range 0.09–0.77 mg/L) in 52 rotogravure workers. Thiessen et al. (12) identified 2.6 mg/L as the likely upper limit for accidental exposure.

Miyazaki et al. (6) attempted to correlate blood toluene concentrations with the presence or absence of signs and symptoms in solvent abusers. They reported that nine of 51 subjects with solvent sniffing histories and blood toluene concentrations reported physical signs ("twilight state," slurred speech, staggering, tremors), although of subjects with concentrations 9.9 μg/g and higher (n = 7), six had physical symptoms but none had neuropsychiatric effects (hallucinations or delusions). Only three of 44 subjects with concentrations less than 9.9 μg/g displayed physical effects.

Gjerde et al. (8) reported on drivers driving under the influence of toluene in Norway. A series of 114 drivers who tested positive for toluene at concentrations above 0.09 mg/L had a mean blood toluene concentration of 10.1 mg/L (109 μM), with a range from 0.09 to 21.5 mg/L. The authors note that almost all drivers with blood toluene concentrations greater than 9.3 mg/L (100 μM) were considered impaired following an evaluation by a physician. However, intoxication can occur with lower concentrations and any delay in taking a sample will mean that the measured concentration will not reflect the amount present in the blood at the time of driving. The authors do not describe the specific appearance or symptomology of the drivers. The elimination rate of toluene is multi-phasic and the elimination rate constant may be concentration dependent. However, the early phase elimination half-life rate is rapid (49.3–53.5 min) (7), and the fact that concentrations determined at the time of sample collection may differ substantially from those at the time of driving, is a significant factor to be considered in interpreting toluene-impaired driving cases.

In our six case series, the concentrations of toluene in the blood are considered to be well in excess of occupational exposure, and consistent with known toxic effects. The lowest blood toluene concentration measured in these six subjects was 12 mg/L, and that subject showed clear evidence of impairment consistent with CNS depression, with many of the expected signs present (staggering gait, slurred speech, and "twilight state"). The symptoms were generally as expected from the DRE matrix, with pulse and blood pressure elevated, and a lack of convergence. Contrary to the DRE protocol, vertical gaze nystagmus was not observed in any subject, body temperature tended to be low rather than normal, muscle tone was normal rather than flaccid, and pupil size was highly variable. The blood toluene concentrations in all cases were consistent with abuse, and could not be accounted for by occupational exposure. Toluene concentrations above 10 mg/L were consistent with the range documented by other workers for impairment. The observations in these cases confirm that recreational abuse of toluene causes impairment in the skills necessary for safe driving.

References

1. Williams JF, Storck M. Inhalant abuse. Pediatrics 2007;119(5):1009–17.
2. McMorris BJ, Hemphill SA, Toumbourou JW, Catalano RF, Patton GC. Prevalence of substance use and delinquent behavior in adolescents from Victoria, Australia and Washington State, United States. Health Educ Behav 2007;34(4):634–50.
3. Akins B, Miranda E, Lacy JM, Logan BK. A multi-drug intoxication fatality involving Xyrem® (GHB). J Forensic Sci 2009 (in press).
4. Gill R, Hatchett SE, Osselton MD, Wilson HK, Ramsey JD. Sample handling and storage for the quantitative analysis of volatile compounds in blood: the determination of toluene by headspace gas chromatography. J Anal Toxicol 1988;12(3):141–6.
5. Saker EG, Eskew AE, Panter JW. Stability of toluene in blood: its forensic relevance. J Anal Toxicol 1991;15(5):246–9.
6. Miyazaki T, Kojima T, Yashiki M, Chikasue F, Tsukue I. Correlation between ''on admission'' blood toluene concentrations and the presence or absence of signs and symptoms in solvent abusers. Forensic Sci Int 1990;3:169–77.
7. Garriott JC, Foerster E, Juarez L, de la Garza F, Mendiola I, Curoe J. Measurement of toluene in blood and breath in cases of solvent abuse. Clin Toxicol 1981;18(4):471–9.
8. Gjerde H, Smith-Kielland A, Normann PT, Morland J. Driving under the influence of toluene. Forensic Sci Int 1990;44(1):77–83.
9. Baselt R. Disposition of toxic drugs and chemicals in man, 7th ed. Foster City, CA: Biomedical Press, 2005.
10. Lush M, Oliver JS, Watson JM. The analysis of blood in cases of suspected solvent abuse, with a review of results during the period October 1977 to July 1979. Croom Helm, London: Forensic Toxicology, 1979;304–13.
11. Park SW, Kim N, Yang Y, Seo B, Paeng KJ. Toluene distribution of glue sniffers' biological fluid samples in Korea. J Forensic Sci 1998;43(4):888–90.
12. Thiesen FV, Noto AR, Barros HM. Laboratory diagnosis of toluene-based inhalants abuse. Clin Toxicol 2007;45(5):557–62.
13. Nise G, Orbaek P. Toluene in venous blood during and after work in rotogravure printing. Int Arch Occup Environ Health 1988;60(1):31–5.
14. Brugnone F, De Rosa E, Perbellini L, Bartolucci GB. Toluene concentrations in the blood and alveolar air of workers during the workshift and the morning after. Br J Ind Med 1986;43(1):56–61.

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