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The Response of the Intoxilyzer 5000® to Five Potential Interfering Substances

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ABSTRACT: A study was conducted of potential vapor phase interferents which could be present on human breath and also be capable of inducing a false-positive response for ethanol on the evidential infrared-based breath testing device, the Intoxilyzer-5000. This involved preparation and validation of a range of vapor standards, which were introduced to the instrument using a dynamic flow double-bubbler system. Potential interferents were chosen on the basis of both their infrared signatures and their general availability, and included toluene, *m*-xylene, *o*-xylene, methanol and isopropanol. All compounds tested were found to be capable of inducing false-positive readings for ethanol in a highly reproducible manner, as a result of which it has been possible to derive precise least-squares equations describing the ethanol readout expected for any given blood concentration of toluene, *m*-xylene, *o*-xylene, methanol and isopropanol. The likelihood of an interference compromising the integrity of the analysis is related to both the toxicological significance and prevalence of a given blood concentration of each solvent, and the point at which the instrumental interference light is triggered in each case.

KEYWORDS: forensic science, forensic toxicology, Intoxilyzer 5000, breath-alcohol, breath-ethanol, DUI, evidential breath analysis, interferents, IR, isopropanol, methanol, toluene, *m*-xylene, *o*-xylene

Widespread use of breath analysis instruments to detect motorists driving while over the legal alcohol limit has led to concern about possible interferences to these devices from substances other than ethanol, which may also be present in exhaled air. In some cases, this question has been responsible for legal challenges to prosecution, especially in jurisdictions where breath ethanol measurements alone are taken to be sufficient evidence for fine or conviction.

One such instrument, specifically designed to accurately quantify breath ethanol concentrations, is the Intoxilyzer 5000 (CMI Inc., Owensboro, KY). This instrument is used in the United States, Canada, South Africa, Finland, Sweden, Norway, various other countries in Europe, and also in New Zealand, where this study was carried out. One aim of this study was to characterize in detail the response of the Intoxilyzer 5000 to five common industrial solvents-toluene, *m*-xylene, *o*-xylene, methanol, and isopropanol.

To use the Intoxilyzer 5000, subjects provide breath samples through a heated tube located at the left front corner of the instrument. Internally, the breath path travels across the instrument before entering the heated sample chamber located at the rear. Once the chamber is filled to a constant concentration, the measurement is made and recorded. Measurement is based on the attenuation of three wavelengths of an infrared (IR) beam directed from one end of the sample chamber to a detector at the other end.

Despite their good track-record in providing accurate determination of breath alcohol concentrations in almost all cases (a fact made apparent by cross-reference with GC analyses of corresponding blood samples), the results of ethanol measurements made by IR instruments have been challenged in legal proceedings on the basis that on a given occasion, some specified interfering substance may have been present in the subject's breath sample. In such cases, the specified interfering substance may be blamed either for the entire ethanol reading, or for elevating the true ethanol reading. For the most part, such IR instruments are specifically designed to account for the commonest potential interferent, acetone. Thus, in the Intoxilyzer 5000, use is made of the differential responses of a 3-channel system based on three distinct wavelengths of IR energy: specifically, 3.80, 3.48, and 3.39 μm. The 3.48 and 3.39 μm wavelengths correspond to the two C-H vibrational stretching modes of ethanol at 2873.56 cm^{-1} and 2949.85 cm^{-1} respectively. The lower energy 3.80 μm wavelength is used to set the baseline and corresponds to 2631.58 cm^{-1}. Although IR absorption at 3.48 and 3.39 μm occurs for both ethanol and acetone, this occurs with different efficiencies between wavelengths, and a difference amplifier system is used to automatically subtract any response due to acetone. Whether ethanol, acetone, or a combination of the two are present in the system, the output responds only to ethanol.

However, it is still possible that in a few cases, less common substances than acetone which absorb IR energy in a similar region to the two C-H vibrational stretching modes of ethanol may give rise to significant interferences. For this to occur, the following three criteria would have to be met: Firstly, the substance in question would have to absorb IR energy at the 3.48 μm and 3.39 μm wavelengths at similar relative photon-capture efficiencies (between the two wavelengths) to the ethanol molecule. In other words, the ratio of the two peaks would have to be much the same for the interferent as it is for ethanol, or the IR instrument will detect its presence. Secondly, because the sample being analyzed is always breath, the substance must have sufficient vapor pressure to pass from the blood into the breath and remain detectable—it must be a fairly volatile compound. The third prerequisite is more of a practical matter, in that the substance would have to be at a sufficiently low blood (toxicological) concentration as to allow the subject to drive an automobile.

A further consideration in selecting potential interferents for

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study is the likelihood and degree of exposure of certain subgroups of the population to various 'unusual' compounds. The most common scenarios for exposure to volatile organic substances would be in occupational settings involving solvents (such as industrial spray-painting and cleaning operations), cases of solvent abuse, and cases involving ingestion of low-grade alcohols (such as methylated spirits). Based on these considerations, the following list of compounds have been suggested as potential interfering substances: toluene, *m*-xylene, *o*-xylene, methanol, and isopropanol. The IR spectra for these substances all indicate significant absorption bands in the 3.48 and 3.39 μm wavelength regions (1).

In this study we characterized the response of the Intoxilyzer 5000 to these five common industrial solvents. As far as the authors are aware, the closest previous study carried out along these lines is that of Cowan et al. (2) who investigated the response of the Intoxilyzer 4011AS-A to eleven possible interfering substances, including toluene, methanol, and isopropanol. The 4011AS-A is the predecessor to the 5000 model and lacks the 3.80 μm baseline wavelength. Sample vapors of a set concentration were introduced to the Intoxilyzer 4011AS-A instruments using a slightly different methodology to that used in this study, particularly with respect to solutions immiscible with water. In this study we have extended the previous work by characterizing the instrumental responses over a full range of concentrations for each chemical, allowing for the first time the precise prediction of expected interferences corresponding to given concentrations in the blood.

Throughout this paper, use of the term 'interference' refers to the meaning of the term as applied in Analytical Chemistry; namely, as the raw response in instrumental output to any substance other than the analyte (ethanol). In some cases, the presence of an interference will be successfully detected by the instrument, and in some cases it will remain undetected. The significance to attach to undetected interferences depends on further factors, such as the likelihood that a given substance will be present on human breath. Thus, interpretation is still the province of the expert witness.

Materials and Methods

The dual bubbler system of Hill and Powell (3) (Fig. 1) was selected and optimized for dynamic production of precise vapor standards and their introduction into the Intoxilyzer as human breath surrogates.

Two standard Dreschel bottles were used for the dual bubbler system. Aliquots (pure or diluted) of the liquid to be vaporized are placed in both bottles. A stream of oxygen-free nitrogen is passed through the first bottle and then onto the second bottle at a flow rate of 2.5 L/min^{-1}. The first Dreschel bottle is set at 40°C, and the second bottle at 34°C (the approximate temperature of human breath as it leaves the mouth). Stirred/thermostated water-baths provide the temperature control for both Dreschel bottles. Polystyrene insulation was also used in order to keep the water-bath temperatures stable to ±0.25°C. The exact temperature of the second water bath was also monitored using an accurately calibrated digital thermistor probe.

After emerging from the second Dreschel bottle, the sample vapors are directed through a short heated (44°C) length of tubing directly into the breathing intake port of the Intoxilyzer-5000. It was necessary to heat the tube to avoid condensation of the sample vapor occurring after leaving the second bottle. Control of concentration is achieved by direct dilution of the solution in the Dreschel bottles (using the appropriate solvent). This method has also been used by Burnett (4), who bubbled hydrogen through saturating vessels containing solutions thermostatted at 25°C. Concentrations of vapor in the gas stream can be calculated from a knowledge of the solute's gas-liquid partition coefficient as it applies to the particular solvent used, and/or on the basis of Raoult's Law.

Accuracy of the delivery system was established by use of aqueous ethanol standards, based on pre-calibration of the instrument for ethanol using a standard Smith & Wesson breath simulator. Ethanol standards were prepared by adding a certain volume of AR grade ethanol to a certain volume of distilled water in the two Dreschel bottles. The exact temperature of the second water bath determines the concentration of the ethanol in the vapor phase and thus the concentration passed to the Intoxilyzer, and this was calculated using the Dubowski equation (5). Ethanol standards with calculated theoretical vapor concentrations of 0.042, 0.076, 0.168, and 0.252 g/210 L were prepared and passed through the delivery system in its definitive configuration to the Intoxilyzer. Under these conditions, there was very good agreement between observed ethanol readings on the Intoxilyzer 5000 and values calculated according to the Dubowski equation, with observed figures being on average only 0.43% higher than calculated values. These results were taken to imply that our system for producing vapor phase standards performs well and delivers accurate concentrations.

Determinations of isopropanol and methanol were both carried out at eight different concentrations, covering the concentration ranges which correspond to the non-lethal blood concentration ranges found in the literature. Each of these eight concentration determinations were themselves performed in triplicate (using three different solutions, rather than one solution three times). Depletion of the solutes from the standard solutions can occur (and could be directly monitored on the Intoxilyzer) if the bubbling is extended to more than a few minutes. Cowan et al. (2), using a breath simulator for preparation of standards, overcame this problem by re-routing the Intoxilyzer exhaust tube to the pump inlets. In this study, the volumes of solution used and time scales were such that measurements were always taken before the onset of any solute depletion.

Toluene and the xylenes are not water soluble. Therefore, in order to obtain a range of concentrations of toluene and the xylenes directly from solutions, a solvent suitable for diluting these must be used. Vapor concentrations of toluene and the xylenes may be calculated using partition coefficients (applicable to the specific solvent/solute pair), but these are not always available, and experimental determination can be protracted. Alternatively, if the solute and solvent share similar chemical structures (and are unlikely to interact in solution), the theoretical vapor concentration can be calculated by applying Raoult's Law followed by the Ideal Gas Law. Raoult's Law, which relates the vapor pressure of a component to its mole fraction in solution, is used to establish the partial pressure of the solute above each two component system (see for instance (6)). It applies to binary solutions where the solution is a single phase (i.e., gas, liquid, or solid), and a usual precondition of its legitimate use is that the solvent component must be in excess and the solute only a minor component. The Ideal Gas Law, which can be rearranged to express moles per unit volume in terms of pressure and temperature, is then used to calculate actual concentration figures (in g/210 L).

Similar molecules (e.g., benzene and toluene) obey Raoult's Law over the whole range, and are said to form nearly ideal solutions. In order to make use of Raoult's Law, and also be of use in this study, the diluting solvent chosen for use with toluene and the xylenes had to adhere to the following three criteria.

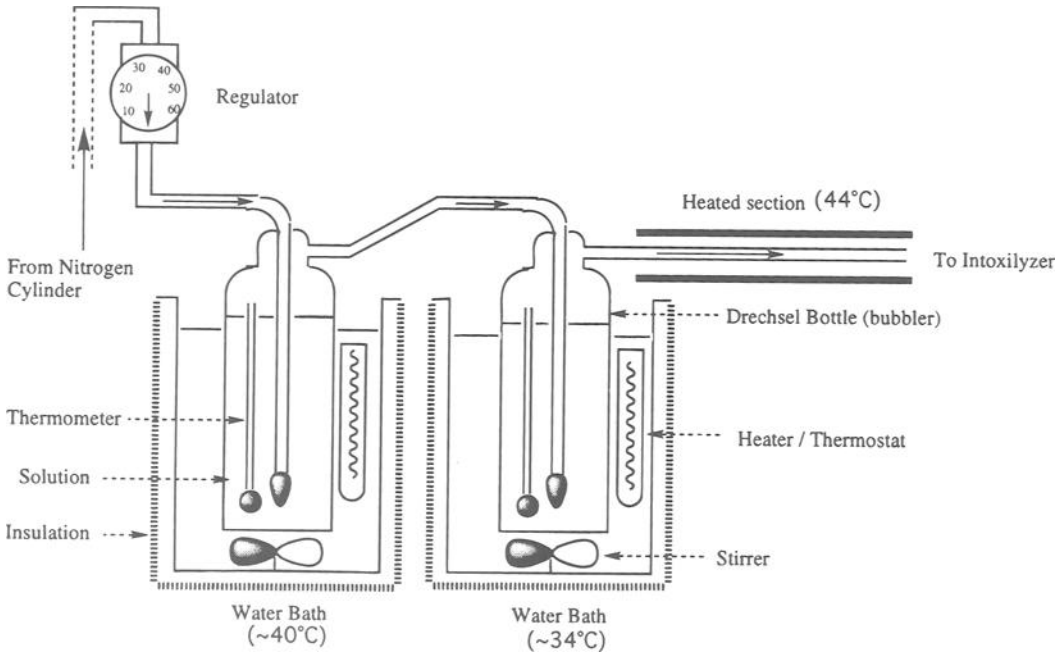

FIG. 1—*Schematic of the dynamic dual-bubbler system used for producing vapor-phase standards of accurately-known concentration.*

These are: (a) miscibility with toluene, *o*-xylene, and *m*-xylene, (b) structural similarity to the structures of toluene and the xylenes, and (c) low or negligible potential to act as an interferent in its own right: the diluting solvent must not possess significant IR absorption bands close to the 3 bands used by the Intoxilyzer, and should also be of comparatively low volatility.

Acetophenone was found to be a particularly suitable solvent. It fulfils the first two criteria in that it is miscible with toluene and the xylenes and it is structurally similar. It does possess a small IR absorption in the region of interest; however, the combination of the small size of this IR band and the low vapor pressure of the compound mean that this interference is not significant, pure acetophenone giving an average reading of only 0.002 g/210 L on multiple passes through the Intoxilyzer. This background value was considered acceptably low (for instance, it represents only 2% of a 0.084 g/210 L reading) and was simply subtracted from all toluene and xylene readings.

The validity of the Raoult's Law/Ideal Gas Law estimation for a toluene/acetophenone mixture was confirmed by preparing a toluene/acetophenone solution in the relevant concentration range and determining the solution to vapor concentration ratio (the partition coefficient) using Gas Chromatography-Mass Spectrometry (GC-MS). A Hewlett Packard (5970) mass detector, quadrupole design, interfaced to a HP 5890A GC was used to obtain mass spectra. Selected ion mode (SIM) was used. The positive m/z 91.00 ion was used as a diagnostic for toluene. The column used was a HP-1 (Cross-linked Methyl Silicone Gum) 50 m × 0.2 mm × 0.33 μm film thickness capillary column. The toluene concentration of the solution used was 5.2014 g/L^{-1}; 1 μL of this solution was automatically injected into the column and the m/z 91.00 ion of toluene selected for peak integration. This procedure was repeated ten times. For experimental determination of toluene in the vapor phase above the solution, a stoppered test-tube was partially filled with the toluene solution, placed in a waterbath at 34°C and left for approximately 5 min to allow for vapor equilibration. 500 μL of the vapor was withdrawn from the test-tube using a gas-tight syringe and manually injected into the column. The 91.00 ion was selected for peak integration. This procedure was also repeated ten times. Using the theoretical method of determination (Raoult's Law/Ideal Gas Law) the vapor-to-solution ratio is calculated to be 7.187. The average of the experimentally determined (GC-MS) vapor-to-solution ratios was 6.808. These two values are considered to be in good agreement considering the technical challenges inherent in the GC-MS determination of toluene in acetophenone, and the fact that manual gas phase injections were used for the headspace analysis (some vapor may have been lost by condensation).

Determinations of toluene were carried out at ten different concentrations using acetophenone as the diluent, covering the concentration ranges which correspond to the non-lethal blood concentration ranges found in the literature. Determinations of *m*-xylene and *o*-xylene were carried out at nine and five different concentrations, respectively, using acetophenone as the diluent, covering the concentration ranges which correspond to the non-lethal blood concentration ranges found in the literature. In all cases, determinations at each concentration value were themselves performed in triplicate. As with the water-soluble compounds, this involved using three different solutions, rather than one solution three times.

Non-lethal blood concentration ranges reported in the literature for the five substances under analysis are presented in Table 1, along with the corresponding blood/air partition ratios from the literature at specified temperatures (7–15). Partition ratios given are averages of the literature values. There is some variation in the terminology used in the literature for partition ratios, with the terms 'blood/air ratio' and 'blood/breath ratio' often being used interchangeably. Also, some ratios are determined at 37°C and some at 34°C (with the latter figure being nearer to the temperature of human breath). For consistency, we refer to all such partition ratios as 'blood/air' ratios throughout the text. The methodology outlined and results obtained all relate to the particular Intoxilyzer

TABLE 1—*Ranges of the five compounds in blood and breath reported in cases of exposure, and air/blood partition ratios.*

Interferent	Blood/air Partition Ratios	Blood Ranges mg/L^{-1}	Breath Ranges μg/L^{-1}	Breath Ranges g/210 L	References
Toluene	15 @ 37°C	<0.1–92	0.067–6133	0.00001–1.29	2,7–14
m-Xylene	27.72 @ 37°C	0.87–40	31–1443	0.007–0.303	7,9,13,15
o-Xylene	26.55 @ 37°C	0.87–40	33–1507	0.007–0.316	7,9,13,15
Isopropanol	1372 @ 34°C	0.96–4400	0.7–3207	0.0001–0.673	2,13
Methanol	2788 @ 34°C	117–6300	42–2260	0.009–0.475	2,12,13

5000 VA instrument tested in this study, which has the serial number SN 66-004114.

Results

All substances tested were found to interfere to varying degrees. Summaries of the actual interferent concentrations versus apparent ethanol concentrations registered on the Intoxilyzer 5000 are provided in Tables 2 to 6.

The Intoxilyzer 5000 is designed to detect interferences on the basis of deviations in the relative ratios of the IR peaks. The exact point at which this mechanism first triggers depends on the relative proportions of the IR bands in the interfering compound. For toluene, an interference is registered at toluene concentrations somewhere between 0.192 and 0.290 g/210 L, whereas for

TABLE 2—*Actual toluene concentrations and resultant apparent ethanol concentrations.*

Toluene Conc. in Solution (g/L^{-1})	Toluene Concentration in Vapor (μg/L^{-1})	Toluene Concentration in Vapor g/210 L	Apparent EtOH Concentration (μg/L^{-1})	Apparent EtOH Concentration g/210 L
0.04	11.3	0.002	34	0.007
0.22	56.9	0.012	65	0.014
0.43	116	0.024	88	0.018
1.56	412	0.087	139	0.029
3.47	913	0.192	228	0.048
5.20	1380	0.290	276*	0.058*
6.94	1830	0.384	380*	0.080*
10.4	2730	0.573	535*	0.112*
15.6	407	0.855	783*	0.164*
26.0	6860	1.44	1290*	0.271*

*Interference message triggered on the Intoxilyzer readout.

TABLE 3—*Actual* m-*xylene concentrations and resultant apparent ethanol concentrations.*

m-Xylene Conc. in Solution (g/L^{-1})	m-Xylene Concentration in Vapor (μg/L^{-1})	m-Xylene Concentration in Vapor g/210 L	Apparent EtOH Concentration (μg/L^{-1})	Apparent EtOH Concentration g/210 L
0.04	3.46	0.001	24	0.005
0.43	35.2	0.007	45	0.009
1.56	125	0.026	57	0.012
3.46	280	0.059	100	0.021
5.19	420	0.089	144	0.030
6.91	558	0.117	199	0.042
10.4	839	0.176	279*	0.059*
15.6	1250	0.263	426*	0.089*
25.9	2070	0.435	712*	0.150*

*Interference message triggered.

TABLE 4—*Actual* o-*xylene concentrations and resultant apparent ethanol concentrations.*

o-Xylene Conc. in Solution (g/L^{-1})	*o*-Xylene Concentration in Vapor (μg/L^{-1})	*o*-Xylene Concentration in Vapor g/210 L	Apparent EtOH Concentration (μg/L^{-1})	Apparent EtOH Concentration g/210 L
1.58	104	0.022	59	0.012
5.28	349	0.073	118	0.025
7.04	466	0.098	161	0.034
15.8	1040	0.218	320*	0.067*
26.4	1770	0.372	528*	0.111*

*Interference message triggered.

TABLE 5—*Actual isopropanol concentrations and resultant apparent ethanol concentrations.*

Isopropanol Conc. in Solution (g/L^{-1})	Isopropanol Conc. in Vapor (μg/L^{-1})	Isopropanol Conc. in Vapor g/210 L	Apparent EtOH Concentration (μg/L^{-1})	Apparent EtOH Concentration g/210 L
0.04	23.5	0.005	8	0.002
0.20	118	0.025	50	0.011
0.39	235	0.049	92*	0.019*
0.79	470	0.099	175*	0.037*
1.57	940	0.197	364*	0.076*
3.14	1880	0.395	717*	0.151*
4.71	2820	0.592	1130*	0.237*
6.28	3760	0.790	1530*	0.321*

*Interference message triggered.

TABLE 6—*Actual methanol concentrations and resultant apparent ethanol concentrations.*

Methanol Conc. in Solution (g/L^{-1})	Methanol Concentration in Vapor (μg/L^{-1})	Methanol Concentration in Vapor g/210 L	Apparent EtOH Concentration (μg/L^{-1})	Apparent EtOH Concentration g/210 L
0.04	12.3	0.003	12	0.003
0.20	61.3	0.013	90	0.019
0.40	123	0.026	170	0.036
0.79	245	0.051	326	0.068
1.58	490	0.103	632	0.133
3.17	980	0.206	1250	0.263
4.75	1470	0.309	1880	0.395
7.91	2450	0.515	3090	0.649

NB.—Interference message not triggered over concentration range studied.

m-xylene the mechanism triggers somewhere between 0.117 and 0.176 g/210 L (Tables 2 and 3). For methanol, the interference mechanism is not triggered over the entire range of concentrations investigated (Table 6). It should be noted that our uncertainty over exactly where the inbuilt interference mechanism first activates is simply a result of the fact that instrumental response was measured at discrete jumps in concentration: the actual point of its activation can therefore lie anywhere between the concentration the interference message is first registered, and the next highest concentration figure.

The data given in Tables 2 to 6 are plotted together for purposes of comparison in Fig. 2, which is a summary of the relative responses of the Intoxilyzer 5000 to the five interfering substances.

Direct comparison of the slopes in Fig. 2, which represent instrumental sensitivity to each interferent, should be moderated by consideration of where the interference message is triggered for each substance, and what the possible ranges of each are on human breath. For instance, although toluene shows the smallest slope on this graph, it is likely to be a significant interferent, because the interference light on the Intoxilyzer is not triggered until a fairly high concentration is attained, and such concentrations have been reported to exist on human breath without fatal effects.

A summary of the mathematical relationships between apparent ethanol readings and blood interferent concentrations is presented in Table 7. The high degree of linearity of these relationships (R^2 values range from 0.998 to 1.000) makes it possible to calculate with reasonable certainty the concentration of each non-ethanolic substance required to have been present in the blood in order to result in a given (but spurious) ethanol reading.

The following example is intended as an illustration of how these relationships may be of use. Suppose a defence lawyer claims that an ethanol reading of a certain value obtained on the Intoxilyzer-5000 was in fact due to methanol, and blood-screening was not undertaken. Prosecution can now test the likelihood of this conjecture by a simple calculation of just how much methanol would have been required to give such an observed (but spurious) ethanol reading. From this point they can then counter-argue that for a given methanol concentration to register on the Intoxilyzer as the ethanol reading observed, the blood methanol levels would have had to have been so high to cause specific observable toxicological effects (such as unconsciousness or death)—effects which were in fact not observed.

One factor which should be taken into account when interpreting

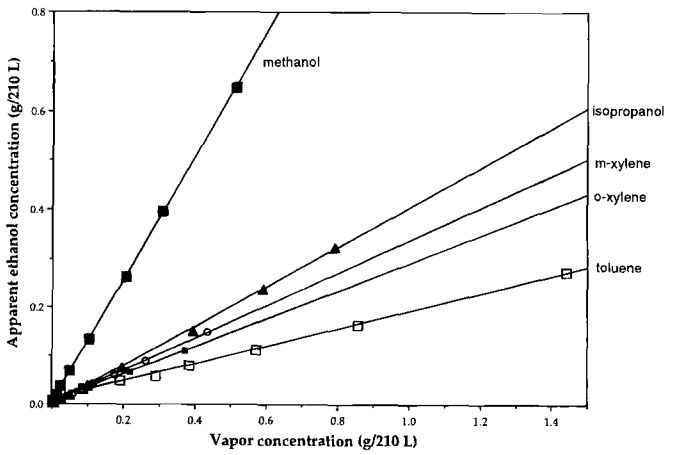

FIG. 2—*Summary of relationships between the vapor concentrations of each compound and the apparent ethanol readings observed.*

the results is that particular Intoxilyzer 5000 instruments may be preset with an inbuilt margin-of-error facility. For instance, those in New Zealand operational use (legal limit 400 $\mu g/L^{-1}$ or 0.084 g/210 L) are set in such a way that if a subject induces an instrumental response corresponding to a breath concentration reading of between 400 and 439 $\mu g/L^{-1}$, then the actual recorded value is given as 400 $\mu g/L^{-1}$.

Discussion

Toluene

In discussing the results from the previous section it must be kept in mind that only non-lethal concentrations of each compound are relevant, because subjects with lethal concentrations are likely to be incapable of driving (and in any case have more serious concerns). Non-lethal concentrations along with the corresponding effects, however, are relevant in establishing whether a subject would be capable of driving or not at a specific concentration. Non-lethal blood toluene concentrations reported in the literature range from 0.0225 mg/L^{-1} up to 31.4 mg/L^{-1} (Table 1).

In the case of the latter figure, which is the most extreme case of non-lethal intoxication found in the literature, the elevated toluene levels were due to glue-sniffing (11). The effects of this concentration on the subject were similar to those produced by moderate alcohol intoxication. This blood toluene concentration of 31.4 mg/L^{-1} would translate to a breath toluene concentration of 0.439 g/210 L on the basis of the reported blood/air toluene partition ratio of 15:1. Experimentally, a vapor concentration of 0.439 g/210 L should give an apparent ethanol reading on the Intoxilyzer of 0.090 g/210 L (calculated using the inverse of the least squares relationship for toluene given in Table 7) without actually having consumed or inhaled any ethanol whatsoever. This will not actually occur, however, because the inbuilt interference mechanism on the Intoxilyzer is triggered between 0.048 and 0.058 g/210 L (Table 2). When this occurs, the numerical result is printed, but is followed two lines lower by the message "Interference" and the test is automatically aborted. The result of the test is given in a box at the bottom of the printout as "Incomplete Test." The numerical result therefore can not be used for evidential purposes.

In both occupational exposure and solvent abuse cases it would seem that interference from toluene would be most likely to cause problems when a subject has also consumed a moderate amount of alcohol. Toluene alone can account for somewhere between 0.048 and 0.058 g/210 L of the ostensible ethanol reading without causing the interference mechanism to trigger (Table 2), and this value would be below most legal thresholds. However, if the signal resulting from toluene is augmented by the presence of genuine ethanol, the readout could exceed legal limits without activating the interference mechanism. For instance, a reading of 0.126 g/210 L could result from the combination of 0.046 g/210 L as a spurious ethanol response from toluene and 0.080 g/210 L from genuine ethanol. Additionally, the idea that a spray painter who is occupationally exposed to toluene might visit a tavern for liquid refreshments on the way home is not one which is beyond the realms of probability. The significance of these results will differ in different jurisdictions.

Xylenes

Although the interferences of both *m*-xylene and *o*-xylene with the Intoxilyzer 5000 were studied separately, a literature survey on fatal and non-fatal blood and breath concentrations produced

TABLE 7—*Least-squares relationships which can be used to calculate the blood concentrations which would have been required to produce given apparent ethanol readings.*

US Units: Observed reading in g/210 L yield blood concentrations in mg/L. *Interferent*	*Least Squares Equation*			R^2
Toluene:	blood toluene concn.	=	−4.21 + (397 × (observed reading))	0.999
m-Xylene:	blood *m*-xylene concn.	=	−1.17 + (397 × (observed reading))	0.998
o-Xylene:	blood *o*-xylene concn.	=	−2.39 + (446 × (observed reading))	1.000
Isopropanol:	blood isopropanol concn.	=	31.80 + (16166 × (observed reading))	0.999
Methanol:	blood methanol concn.	=	−28.57 + (10540 × (observed reading))	1.000
Conventional SI Units: Observed reading in μg/L yield blood concentrations in mg/L. *Interferent*	*Least Squares Equation*			R^2
Toluene:	blood toluene concn.	=	−4.24 + (0.08332 × (observed reading))	0.999
m-Xylene:	blood *m*-xylene concn.	=	−1.23 + 0.08348 × (observed reading))	0.998
o-Xylene:	blood *o*-xylene concn.	=	−2.42 + 0.09367 × (observed reading))	1.000
Isopropanol:	blood isopropanol concn.	=	34.85 + 3.3889 × (observed reading))	0.999
Methanol:	blood methanol concn.	=	−27.29 + 2.2117 × (observed reading))	1.000

mostly cases involving a mixture of the three isomers (*ortho*, *meta*, and *para*-xylene). This is because an industrial-grade mixture of the three xylenes (rather than one of the individual isomers) is commonly found in occupational settings; however, *m*-xylene is usually the predominant component of this mixture.

Gamberale et al. (16) discussed subjects exposed to xylene concentrations of 435 mg/m^{-3} and 1300 mg/m^{-3} while at rest, and a concentration of 1300 mg/m^{-3} while exercising. The resultant breath concentrations were 0.016, 0.045, and 0.066 g/210 L, respectively. The xylene used for the study was the mixture of the three isomers (with the predominant form being *m*-xylene).

From this work it has been determined that experimentally, vapor concentrations of 0.016, 0.045, and 0.066 g/210 L would produce apparent ethanol readings of about 0.008, 0.018, and 0.025 g/210 L without the interference mechanism being triggered (Table 3). Although 0.025 g/210 L is still less than many legal limits, it could still be an issue of concern if a subject undergoing a breath test had also consumed enough ethanol to produce a combined reading above these values. An assumption is made here that the three-isomer xylene mixture on the subject's breath interferes in a similar manner to that of *m*-xylene. This would seem reasonable given that the interference results for *o*-xylene are similar to those for *m*-xylene (Tables 3 and 4; Fig. 2).

Isopropanol

Isopropanol triggered the interference message at a low apparent ethanol reading of between 0.011 and 0.019 g/210 L (Table 5). It would therefore be unlikely for isopropanol to be mistaken for ethanol, although it could conceivably still contribute a small part to an ethanol reading. This has been observed by Hak (17), in simulation trials on the Intoxilyzer 5000C, where a combination of 1 g/L^{-1} ethanol and 0.25 g/L^{-1} isopropanol was found to sometimes result in an "Interferent" message and sometimes result in the test reading being recorded as genuine. However, because isopropanol is largely converted to acetone as it is being oxidized, the breath of a person who had consumed enough isopropanol to produce a significant apparent ethanol concentration on the instrument would also contain acetone. The Intoxilyzer 5000 is designed to specifically detect and subtract any response specifically due to acetone, and display the interference message for high levels of acetone in excess of 0.168 g/210 L (R. Gainsford, E.S.R., Gracefield, Wellington, N.Z., personal communication). Hence, the response of isopropanol and acetone will be due to isopropanol only assuming that acetone subtraction is exact.

In one reported case (18), the blood isopropanol concentration of an alcoholic was found to be 1000 mg/L^{-1} after ingestion of isopropanol. This corresponds to a breath concentration of 0.153 g/210 L, and would produce an apparent ethanol reading on the Intoxilyzer of 0.060 g/210 L. This would trigger the interference mechanism and an incomplete test would be recorded.

Methanol

Methanol is probably the most likely substance to be mistaken for ethanol. The interference message was not triggered over the entire range of the Intoxilyzer (0–0.630 g/210 L). Using combinations of ethanol and methanol, Hak (17) also reported general failure to trigger the "Interferent" message except when using a solution of 0.5 g/L^{-1} methanol and 0.5 g/L^{-1} ethanol, when the message was triggered occasionally.

A methanol poisoning outbreak in Kentucky (19) produced blood methanol concentrations between 300 to 2000 mg/L^{-1}. This range corresponds to a breath concentration range of 0.023 to 0.151 g/210 L using the blood/air partition ratio of 2788:1 (Table 1). The resulting apparent ethanol readings on the Intoxilyzer would be from 0.031 through to 0.192 g/210 L respectively, and the interference mechanism would not be triggered. Most of the patients within this blood methanol concentration range were alert and oriented on admission to hospital.

Because the initial narcotic effects of methanol are mild compared with ethanol, and the characteristic toxic syndrome may not appear until 6–30 h after ingestion (20), a person could have quite a high blood methanol concentration early on in the metabolism process and still be capable of driving. Unfortunately most cases of methanol poisoning have only been discovered in the late stages of metabolism when the toxic signs have become obvious.

The most readily available form of methanol likely to be involved in cases of domestic consumption is probably methylated spirits ('meths'), which is about 95% ethanol. After ingestion of methylated spirits, symptoms of methanol toxicity are unlikely to become noticeable until all the ethanol is metabolized. This is because ethanol competes with the enzyme system responsible for methanol metabolism and it is the metabolite of methanol (formic acid), rather than the methanol itself, which is highly toxic. For this reason, a subject may still appear reasonably alert and oriented. The response

TABLE 8—*Comparison of interference results from the Intoxilyzer 4011AS-A and the Intoxilyzer 5000.*

Interferent	Vapor Conc. (g/210 L)	Intoxilyzer 4011AS-A		Intoxilyzer 5000	
		Apparent Conc. (g/210 L)	Interference Light Trigger Point*	Apparent Conc. (g/210 L)	Interference Light Trigger Point*
Toluene	0.331	0.060	0.029	0.070	0.048–0.058
m-Xylene	—	—	—	—	0.042–0.059
o-Xylene	—	—	—	—	0.034–0.067
Isopropanol	0.152	0.342	0.029	0.059	0.011–0.019
Methanol	0.079	0.229	NT†	0.102	NT†

*Specified in terms of the apparent ethanol reading (g/210 L).
†NT = Not triggered.

to a test taken on the Intoxilyzer at this time would mainly represent the ethanol content (about 95%), which will persist in the blood stream for a number of hours after ingestion. Therefore interference by methanol from methylated spirits is unlikely to be a significant problem, and would be important only in cases in which it had contributed to the ethanol reading recorded as being just above the legal limit. Occupational exposure however, could still be a problem, and it would be advisable to corroborate claims that the subject may have been exposed to methanol in the workplace.

Comparison with Previous Work

A comparison of the results obtained from this study on the Intoxilyzer 5000 with those obtained on the Intoxilyzer 4011AS-A by Cowan et al. (2) are presented in Table 8. In this Table, we have calculated (from the data in Table 7) concentration values in our study which would correspond to the single concentrations of toluene, isopropanol, and methanol measured in the earlier study.

Comparison of the results of the two studies suggests that the degree of interference for isopropanol and methanol is significantly less in the case of the 5000 model while the degree of interference for toluene is worse. The former two results are probably due to the changes in programing of these devices, the 5000 being more modern and, presumably, better programed to meet the problems of interferences (the extra 3.80 μm wavelength is not considered to be the reason for the improved specificity). Also the results would be affected by the "fine" adjustment of the acetone subtraction system and other specific voltages (17). By contrast, the Intoxilyzer 4011AS-A study (apparently) shows that the earlier instrument is less sensitive to toluene than the Intoxilyzer 5000. This result is in conflict with those for isopropanol and methanol, and is likely to be an artefact of the experimental methodology employed in the earlier study which involved preparation of toluene/water mixtures by premixing toluene with a small amount of ethanol. This procedure is unusual, and is not likely to have significantly increased the miscibility of toluene in aqueous solutions. The resultant toluene-water suspension is likely to have produced gas standards of substantially lower concentration than assumed on the basis of the toluene/water partition coefficient (which applies to lower-concentration aqueous solutions of toluene in which the solute is genuinely dissolved). Thus it would seem probable that the results of the earlier work represented an underestimate of the extent of toluene's interference on the Intoxilyzer 4011AS-A.

If the toluene results from the earlier study are excluded, it can be seen that overall the Intoxilyzer 5000 is significantly better at minimizing the effect of interferences than the earlier model. The false-positive readout figures in the Intoxilyzer 5000 for isopropanol and methanol have been reduced to 17 and 45% of their earlier values, respectively.

Conclusion

The results of this study clearly indicate that all five substances tested for potential interference with the Intoxilyzer 5000 will interfere to some degree. Even so, the performance of this instrument is significantly better than that of the earlier model Intoxilyzer 4011AS-A. Four of the five compounds (toluene, the two xylenes, and isopropanol) are registered by this version of the Intoxilyzer as interferences by the instrument at given points in their concentration ranges, and one (methanol) is not. From the point of view of where this interference mechanism is triggered, the compounds can be ranked in terms of their probability (if present) of causing an undetected false-positive reading for ethanol in this order: methanol >> toluene > the xylenes >> isopropanol. This ranking must be moderated by both the likelihood of each compound actually being present, which is idiosyncratic and case-specific, and (where it is present), the typical non-fatal concentrations reported in cases of exposure. For instance, methanol ingestion and intoxication is (fortunately) known to be comparatively rare, but there is quite a reasonable likelihood that glue-sniffers, home hobbyists using toluene-based glues, or workers in the painting industry would contain toluene on their breaths at concentrations above (endogenous) background levels.

Overall, risk of misinterpretation is limited to a few compounds, and will probably only occur in unusual circumstances, but prosecuting officers should be aware of these. In practice, the frequency with which misinterpretation may occur is likely to be quite low, since operational evidence is that methanol and toluene are only infrequently detected in blood samples.

Acknowledgments

The authors would like to extend special thanks to Allan Stowell, Ross Gainsford, and Andrew Winther of the toxicology section of *ESR*: Forensic at Gracefield, Wellington, for their expert advice and assistance during this project. We also thank the New Zealand Police for the loan of an Intoxilyzer 5000 to us for a period of several months.

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ERRATA

Erratum/Addendum to: Murphy GK. Fatal air transport accidents involving athletic teams from the United States. J Forensic Sci 1997;42(1,Jan):75–9.

• One such accident involving significant loss of life was inadvertently omitted from this paper. On February 15, 1961, a Sabena Airlines Boeing 707 carrying the entire United States World Figure Skating team to the World Championships in Prague crashed near Brussels, Belgium. Eighteen American skaters, along with sixteen officials, coaches and family members, 27 other passengers, and a crew of 11, were killed, a total of 72 deaths. The cause of this crash is not known to me.

Reference

Mitch D. A tragedy remembered. Skating Magazine 1986;Feb: 34–41 and 66–68.

Editor's Note: Any and all future citations of the original paper should read: Murphy GK. Fatal air transport accidents involving athletic teams from the United States. [published erratum/addendum appears in J Forensic Sci 1998;5(May)] J Forensic Sci 1997;42(1,Jan): 75–9.

Erratum/Correction:

• An error in the values in one of the columns of one table in the following previously published paper require correction: Caldwell JP, Kim ND. The response of the Intoxilyzer 5000® to five potential interfering susbstances. J Forensic Sci 1997 Nov (6):1080–87. Below is reprinted Table 8 in its entirety from the above paper with the corrected values.

TABLE 8—*Comparison of interference results from the Intoxilyzer 4011AS-A and the Intoxilyzer 5000*

		Intoxilyzer 4011AS-A		Intoxilyzer 5000	
Interferent	Vapor Conc. (g/210 L)	Apparent Conc. (g/210 L)	Interference Light Trigger Point*	Apparent Conc. (g/210 L)	Interference Light Trigger Point*
Toluene	0.331	0.054	0.029	0.070	0.048–0.058
m-Xylene	—	—	—	—	0.042–0.059
o-Xylene	—	—	—	—	0.034–0.067
Isopropanol	0.152	0.101	0.029	0.059	0.011–0.019
Methanol	0.079	0.086	NT†	0.102	NT†

* Specified in terms of the apparent ethanol reading (g/210 L)
† NT = not triggered

Any and all future citations of the above-referenced paper should read: Caldwell JP, Kim ND. The response of the Intoxilyzer 5000® to five potential interfering susbstances. [published erratum appears in J Forensic Sci 1998 May;43(3)] J Forensic Sci 1997 Nov;42(6): 1080–87.

Erratum:

• The author's name should have been William Tompson, not Lawrence D. Muller in the Table of Contents for March issue of J Forensic Sci for correspondence of: Additional commentary on Budowle B, Lindsey JA, et al. validation and population studies of the loci LDLR, GYPA, HBGG, D7S8, and Gc (PM Loci), and HLA-DQ-α using a multiplex amplifications and typing procedure'', J Forensic Sci 1995;40:45–54.