Garage carbon monoxide levels from sources commonly used in intentional poisoning

Neil B. Hampson, MD; James R. Holm, MD; Todd G. Courtney, BS

Virginia Mason Medical Center, Seattle, Washington U.S.

CORRESPONDING AUTHOR: Neil Hampson – *Neil.Hampson@gmail.com*

ABSTRACT

Background: The incidence of intentional carbon monoxide (CO) poisoning is believed to have declined due to strict federal CO emissions standards for motor vehicles and the uniform application of catalytic converters (CC). We sought to compare ambient CO levels produced by automobiles with and without catalytic converters in a residential garage, as well as from other CO sources commonly used for intentional poisoning.

Methods: CO levels were measured inside a free-standing 73 m3 one-car garage. CO sources included a 1971 automobile without CC, 2003 automobile with CC, charcoal grill, electrical generator, lawn mower and leaf blower.

Results: After 20 minutes of operation, the CO level in the garage was 253 PPM for the car without a catalytic converter and 30 PPM for the car equipped with one. CO levels after operating or burning the other sources were: charcoal 200 PPM; generator >999 PPM; lawn mower 198 PPM; and leaf blower 580 PPM.

Conclusions: While emissions controls on automobiles have reduced intentional CO poisonings, alternate sources may produce CO at levels of the same magnitude as vehicles manufactured prior to the use of catalytic converters. Those involved in the care of potentially suicidal individuals should be aware of this.

INTRODUCTION

From 1999-2004, the U.S. Centers for Disease Control and Prevention (CDC) estimated that carbon monoxide (CO) poisoning was a contributing factor to death for approximately 2,750 individuals in the United States annually [1]. Of those, approximately 500 deaths were accidental exposures and 2,250 intentional [1]. Intentional exposures are felt to result in a greater number of deaths because of the effectiveness of CO as a toxin; co-ingestions are commonly performed in addition to CO inhalation [2]; failure of the suicidal individual to leave the environment or seek help when poisoning symptoms develop; and conduct of the act in a place where discovery is likely to be delayed.

Interestingly, others and we have reported that the rates of both fatal and non-fatal CO poisoning from intentional exposure to motor vehicle exhaust have steadily declined since catalytic converters were mandated on U.S. automobiles in 1975 [3, 4]. Our hypothesis has been that the efficiency of catalytic converters makes it difficult to commit suicide by breathing the exhaust gas from a motor vehicle equipped with one. This study was undertaken to measure accumulated CO in a closed garage from vehicles with and without catalytic converters, as well as from other CO sources commonly used for intentional poisoning.

METHODS

Experiments were performed in a one-car detached garage constructed of wood framing, interior gypsum wallboard and external wood siding. The roof material was wood shake. Garage volume was approximately 73 m^3. CO concentrations within the garage were measured and recorded with an industrial CO gas monitor (Biosystems Toxipro-Single-Sensor Gas Monitor, Model 54-45-01D, Honeywell Inc., Morristown, New Jersey). This device has a resolution for CO of 1 PPM, a range of 0-999 PPM, and is capable of logging 8,000 data

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points measured 1 second apart or longer. The device features fully automated fresh air/zero and span calibration functions. Calibration adjustments are made automatically by the instrument and then manually verified in fresh air and subsequently with a test gas of known CO concentration (50 PPM in this case). If the fresh air readings are not 0 PPM, a calibration adjustment is made. If the functional test readings are inaccurate, a span calibration is performed. The device was suspended in the garage at a height one-half way from the floor to the ceiling. Measurements of CO concentration were recorded once per minute for 20 minutes.

Motor vehicles tested included a 1971 Volkswagen Super Beetle with a 1,500-cc displacement engine but without a catalytic converter and a 2003 BMW Z4 Roadster with a 2,500-cc engine and a catalytic converter. Both vehicles were tested at idle speed. The Volkswagen did not have a tachometer, but the normal idle speed for this vehicle is 850-900 RPM. The idle speed of the BMW was 850 RPM. Data from the Undersea and Hyperbaric Medical Society/Centers for Disease Control and Prevention national CO poisoning surveillance program conducted from 2008-2011 were used to identify the CO sources most commonly utilized after motor vehicles in intentional CO poisoning (5). In order of frequency, these included charcoal grills, gasoline-powered electrical generators, house fires, lawn mowers and snow/leaf blowers. Subsequent measurements were taken in the garage while burning a pre-packaged amount of charcoal, designed for portability (2.3 pounds) and requiring that one only light the bag to ignite it (Kingsford BBQ Bag). The burning charcoal was not taken into the garage until the paper bag had burned away and the surfaces of most briquettes were ash-gray in color, with little visible smoke production.

Also tested was a gasoline-powered electrical generator with a 196 cc four-stroke engine (Champion, model 46535). It was operated at idle speed with no load. A gasoline-powered lawn mower with a 190-cc four-stroke engine (John Deere, model 14SZ) was tested, as was a gasoline-powered leaf blower with a 27-cc two-stroke engine (Stihl, model BG45). The latter two were operated at idle speed during testing. House fire as a CO source was not tested.

RESULTS

As shown in Figure 1, operation of the idling 1971 Volkswagen produced a CO level of 253 PPM within the garage after 20 minutes, while the 2003 BMW yielded a level of only 30 PPM in the same time. Peak levels reached in 20 minutes with non-motor vehicle sources were: charcoal 200 PPM; generator 999 PPM; lawn mower 198 PPM; and leaf blower 580 PPM (Figures 2, 3). In general, CO levels rose linearly for all sources except the generator. CO levels were still increasing at the end of 20 minutes for all sources except the catalytic converter-equipped automobile.

DISCUSSION

This pilot study supports the hypothesis that intentional CO poisonings from motor vehicles are likely declining at least in part due to the Environmental Protection Agency's (EPA) U.S. Clean Air Act, originally enacted in 1970 [6], the regulations responsible for reducing vehicle CO emissions. The effectiveness of a catalytic converter is apparent in Figure 1. Not only was the CO concentration at a toxic level after operating the pre-1975 vehicle in the garage for 20 minutes, but also the concentration was continuing to increase at an approximately linear rate. Conversely, the catalytic converter-equipped vehicle produced a CO level of only 30 PPM, despite having a 66% larger engine. Furthermore, accumulation does not appear to have been continuing, as that low level was stable. It appears that equilibrium had been reached with low CO production and diffusion out through the garage structure. Gypsum wallboard has previously been demonstrated to be permeable to CO [7].

For reference with regard to ambient CO levels, the EPA has a maximum exposure limit of 9 PPM for an eight-hour period in any year, while the Occupational Safety and Health Administration's (OSHA) permissible exposure limit for CO is 50 PPM as a time-weighted average concentration over eight hours [8]. This is based upon the fact that such as exposure will yield a blood carboxyhemoglobin level of about 10%. Higher levels are considered by OSHA to be toxic. Similarly, Underwriters Laboratories requires residential carbon monoxide alarms to alarm within 90 minutes when exposed to a level of 100 PPM [8]. A level of 200 PPM may be lethal with long exposures [8].

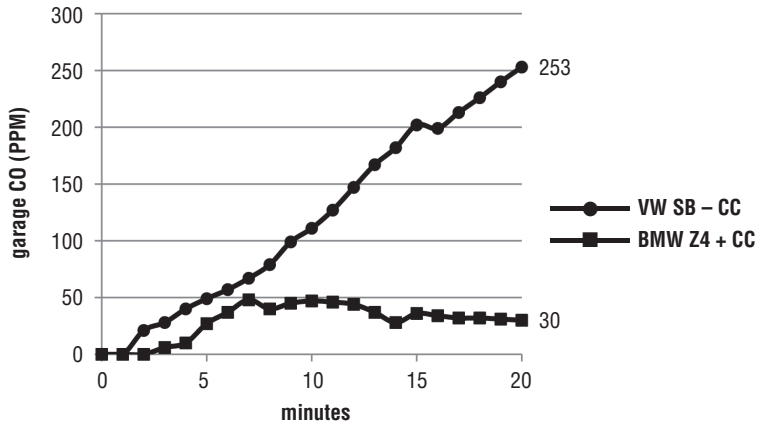

FIGURE 1. Garage CO levels measured during idling operation of a 1971 Volkswagen Super Beetle (VW SB) without catalytic converter (CC) and a 2003 BMW Z4 with catalytic converter.

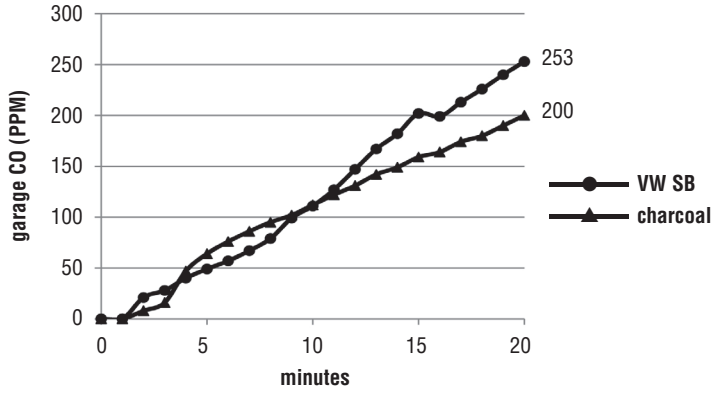

FIGURE 2. Comparison of garage CO levels measured during idling operation of a 1971 Volkswagen Super Beetle (VW SB) without a catalytic converter and burning of 2.3 pounds of charcoal briquettes.

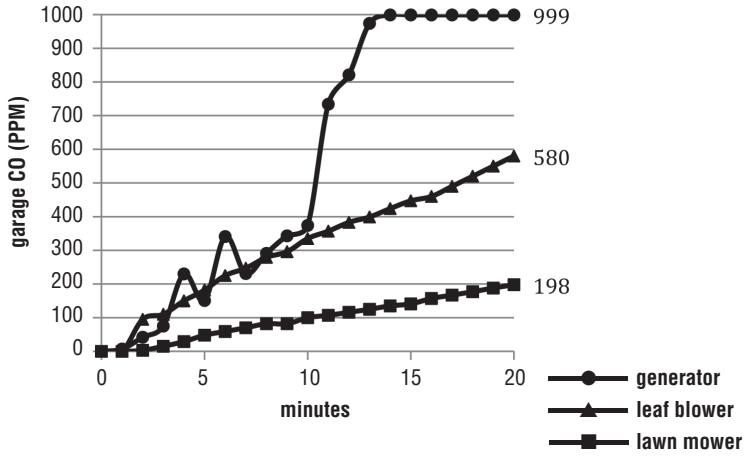

FIGURE 3. Garage CO levels measured during operation of other gasoline-powered CO sources.

It is not impossible to commit suicide by breathing exhaust gas from a motor vehicle with a catalytic converter. When a vehicle is operated in a tightly sealed space for a long time, ambient oxygen is gradually consumed, contributing to decreased engine efficiency and increased CO production. At the same time, catalytic converters, which require oxygen for their function, will begin to fail, resulting in potentially lethal CO levels. Anoxic deaths without CO poisoning have also been reported when individuals breathed only automobile exhaust, which contains low CO, high levels of carbon dioxide and low levels of oxygen [9].

As motor vehicle CO suicide becomes less prevalent because of its associated difficulties, individuals may turn to alternate CO sources. CO measurements in this study from the non-motor vehicle sources were as remarkable as those seen in motor vehicles. In East Asia, charcoal burning as a CO source for suicide has dramatically increased in popularity over the past decade [10-12]. As can be seen in Figure 2, burning a small amount of charcoal in the garage produced CO levels quite consistent with those seen from the pre-1975 automobile. In Taiwan, experimental restriction of access to barbecue charcoal has resulted in declines in both the overall suicide rate and charcoal CO suicide rate [12].

The highest garage CO level (999 PPM) was recorded after operating the gasoline-powered electrical generator for only 14 minutes. The CO measurement device used in this study has an upper limit of 999 PPM, so the true peak level is not known. It is of note that the generator was being tested at idle, under no load. Under a load, CO output would be even higher. Portable electrical generators were responsible for over 800 accidental deaths in the United States from 1999-2012 [13]. This fact has obviously not been lost on those contemplating CO suicide, as generators are occasionally utilized [5].

A variety of solutions have been proposed for the reduction of CO by generators, including: (a) incorporation of a CO sensor in the device that turns off the unit when ambient CO reaches a specified level; (b) incorporation of a catalytic converter in generators; and (c) development of a low-emission generator [14,15]. Catalytic converters contain small amounts of precious metals like platinum, palladium and rhodium. Because of this, the cost to equip a generator with one might be more than the cost of the generator itself. At this point in time, production of low-emission generators appears most likely.

The leaf blower produced about three times as much CO as the lawn mower despite having a dramatically smaller engine. This is undoubtedly an example of the difference between a two-stroke and a four-stroke engine. A two-stroke (two-cycle) engine completes two up-and-down movements of the piston for one crankshaft revolution, while a four-stroke engine requires four. As a result of design, two-stroke engines are much less efficient at burning fuel and emit more pollutants (including CO) than four-stroke engines. Note that garage CO levels were still rising at 20 minutes with both devices and equilibrium had not been reached.

Articles discussing the CO hazard of small gasoline-powered combustion engines have been published [16,17], as have articles regarding their safe use (CDC). Of course, these papers are aimed at prevention of accidental poisonings.

LIMITATIONS

There are several limitations to our study. First, it was only a pilot trial, and repetitive measurements could increase confidence in the relative values seen. Second, we tested only one model or brand of each CO source; others might behave differently, including different automobiles. We do not know if other automobiles equipped with operational catalytic converters would produce more or less CO than the vehicle tested here. Also, our CO measurement instrument reached a maximum at 999 PPM, so that we were unable to measure the CO levels produced by the generator after 14 minutes. Finally, trials were limited to 20 minutes for reasons of fire safety in light of the heat produced when operating these engines in a small enclosed space constructed of flammable materials. Because of this, we do not know the maximum CO levels that would have been achieved.

CONCLUSIONS

Findings of note from this study include the facts that (a) a vehicle with a catalytic converter produces very little CO in a closed garage; (b) the magnitude of CO production from charcoal briquettes is similar to an automobile without a catalytic converter; and

(c) non-vehicle CO sources, especially generators, can produce lethal levels if operated in an enclosed space. Those caring for potentially suicidal individuals should take these findings into consideration in their management.

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Conflict of interest statement

Authors declare no conflicts of interest exist with this submission.

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