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John A. Volpe National Transportation Systems Center

Emissions Impacts on Driver Safety

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13. ABSTRACT (Maximum 200 words)

The Federal Motor Carriers Safety Administration (FMCSA) is concerned that truck drivers' exposure to high levels of air pollutants and mobile air toxics for potentially long periods of time, may lead to acute and/or long term cognitive impairments as a result. The goal of this project was to compile existing information addressing the following question: *Does exposure to diesel exhaust at levels found in cabs affect driver safety performance by affecting driver sleep, alertness, reaction time, fatigue levels, or judgment-making abilities?* To determine whether such an effect exists, the Volpe National Transportation Systems Center conducted expert interviews to obtain insight into the question and searched the environmental and medical literature. The results of these activities are reported here.

The results of the expert interviews and literature search highlighted the fact that very little is known regarding the cognitive impact of exposure to diesel exhaust emissions. Certainly, the potential for an effect exists, but cognitive ability is generally confounded with other "lifestyle" factors for truck drivers (e.g., fatigue, shift work). Consequently, the question will be difficult to answer. Challenges for future research are identified.

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1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
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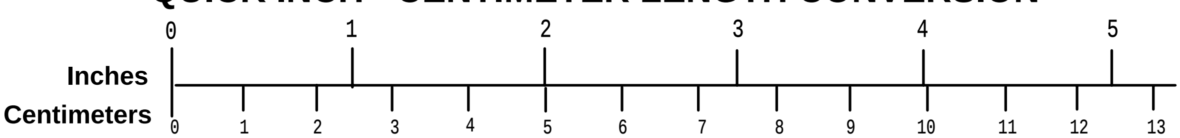

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PREFACE

This report was prepared by the Human Factors Division of the Office of Aviation Programs at the John A. Volpe National Transportation Systems Center, United States Department of Transportation. This research was conducted with funding from the Federal Motor Carriers Safety Administration (FMCSA); Michael Johnsen served as the project manager. The authors wish to thank Michael Johnsen, Jose Mantilla, and Paul Zebe for their direction and guidance in the development of this report. Special thanks also go to Christopher Zevitas for his help identifying experts to interview, to the researchers who participated in the interviews, and to Marilyn Gross for her assistance in conducting the literature review.

The views expressed herein are those of the authors and do not necessarily reflect the views of the Volpe National Transportation Systems Center, the Research and Innovative Technology Administration, or the United States Department of Transportation.

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EXECUTIVE SUMMARY

The goal of this project was to compile existing information regarding whether driver performance is affected by exposure to diesel exhaust emissions at levels found in cabs. The health effects of exposure on the cardiovascular and pulmonary systems are well documented, but there is a lack of understanding regarding the potential cognitive effects of diesel exhaust emissions exposure. The Federal Motor Carriers Safety Administration (FMCSA) is concerned that truck drivers' exposure to high levels of air pollutants and mobile air toxics for potentially long periods of time, could influence their safety and affect their sleep, alertness, or judgment. To address this issue, the Volpe National Transportation Systems Center conducted expert interviews to obtain insight into the issue and searched the environmental and medical literature for relevant research. The results of these two activities are reported here. Challenges to future research are also noted.

Expert Interviews

Ten researchers from the Environmental Protection Agency (EPA), Harvard School of Public Health, and Wright Patterson Air Force Base participated in the interviews. The researchers noted that there is a dearth of literature addressing the cognitive effects of diesel emissions. Instead, human studies have generally addressed the effects of diesel exhaust on pulmonary and cardiovascular health, and animal studies have typically focused on the neurotoxic effects of exposure. Most researchers acknowledged that there is a cause for concern; several studies have shown high concentrations of particles at hot spots such as truck stops and major freeways. However, little is known whether cognitive ability would be impaired as a consequence, and the consensus reached by the researchers interviewed was that such a question would be difficult to answer.

Literature Review

A review of the environmental and medical literature identified only three studies that directly examined the cognitive impacts of diesel exhaust exposure. Two of these studies focused on the chronic effects of exposure to diesel exhaust emissions and reported impairments in cognitive ability – as indicated by decrements in memory, problem solving, and reaction time – as a consequence. However, the level of exposure leading to the impairment was not measured, and the extent of the impairment (i.e., whether it is long-lasting or temporary) was not clear. Only one study measured and controlled for exposure, but its focus was on the health effects of acute, short-term exposure, particularly for those with sensitivity to chemicals. The results showed no effect on cognitive ability due to exposure between those who were chemically sensitive versus those who were not, although the former group reported more symptoms (e.g., dizziness, nausea, fatigue) than the latter group. However, performance differences within a group before, during, and after exposure were not compared as part of the study.

The literature search was expanded to include research that examined the cognitive impacts to chemicals in diesel exhaust or substances that could have similar cognitive effects as diesel exhaust, but no clear conclusions could be drawn from these studies. With respect to the literature on the cognitive effects of chemicals in diesel exhaust, the only studies found addressed the effects of carbon monoxide exposure. In these studies, exposure was generally acute and short-term. The cognitive impact of carbon monoxide exposure varied depending on the task; performance on vigilance and tracking tasks showed no effect of exposure and time estimation was impaired slightly, but performance on complex tasks requiring abstract thinking and manual dexterity or performing two tasks concurrently was impaired. Consequently, carbon monoxide could impair driver judgments at high levels of exposure, but it is not clear whether such levels are encountered in the typical driving environment. It is also important to consider that the level of carbon monoxide to which drivers are exposed fluctuates greatly due to weather and traffic.

With respect to the literature for substances that could have similar cognitive consequences as diesel exhaust, a body of research addressing the cognitive effects of exposure to jet fuel vapors was considered potentially relevant, since both jet fuel and diesel are fuel oils and hence, closely related. Much of this research was the result of the military's concern that such exposure could lead to errors by pilots in navigation and communication. Studies addressing this issue focused on the chronic, long-term effects of exposure, i.e., over weeks in the case of animal studies and years for human studies. While animal studies examining the neurobehavioral consequences of jet fuel vapor exposure showed only short-term effects of exposure on behavior and brain development, the results of human studies examining the consequences of occupational exposure to jet fuel showed more lasting effects. Exposed workers had more variable performance on complex tasks compared to non-exposed workers and greater performance decrements on simple tasks. However, the degree to which exposure to diesel emissions has similar consequences as exposure to jet fuel vapors is unknown.

Challenges to Future Research

The results of the expert interviews and literature search highlight the fact that very little is known regarding the cognitive impact of exposure to diesel exhaust emissions. One reason for this is that the question is a difficult one to answer.

First, cognitive ability is influenced by external stressors; for the truck driver, lifestyle factors (e.g., long hours, shift work) have significant impacts on cognitive functioning. Consequently, the specific impacts of diesel exhaust emissions exposure could be difficult to isolate and measure. Second, a good metric of cognitive ability that would be sensitive to the effects is needed. Results from the literature examining the effects of carbon monoxide exposure show varying levels of cognitive impairment depending on task complexity.

Third, a dose-response effect of exposure on cognition would be difficult to determine. To measure the effects of acute, short-term exposure, cognitive tests would need to be administered at the time of exposure, but there are no easy methods to track drivers' exposure in real-time, and capturing drivers at the time of exposure would be methodologically challenging. To measure the chronic effects of long-term exposure, an estimate of the level of diesel exhaust emissions to which drivers are exposed over time would be needed. Developing a model to determine these estimates would require a large data collection effort to consider all factors that moderate exposure (e.g., commodity, length of haul).

One interesting approach is to examine whether there are any biological indicators (e.g., blood markers) of cognition. No such markers have yet been identified, and establishing the relationship between biological markers and cognitive ability would be a significant task.

While controlled laboratory studies and animal studies offer an alternative to occupational studies in a complex real-world environment, it is not clear whether the results from these basic research studies would generalize to the truck driving population. The results of human laboratory studies would still need to be considered with other important lifestyle factors that influence cognitive ability, and animal studies would be limited to addressing the effects of diesel emissions exposure on basic cognition, whereas much of the skills required in driving in order to maintain safety require a high level of cognitive functioning.

Thus, any research to be conducted would be costly, difficult to implement, and any effects difficult to measure. Although the potential for an effect exists, it is important to note that the harmful effects of emissions are being addressed in other ways. The EPA is establishing a comprehensive national clean diesel initiative to reduce emissions from diesel engines in the heavy-duty commercial motor vehicle fleet through the use of high-efficiency catalytic exhaust emission control devices or comparably effective advanced technologies. It is hoped that when the program is fully implemented and the fleet of older engines has fully turned over (by 2030), the benefits of this initiative will be evidenced by the improved health and safety of all drivers.

1 INTRODUCTION

The Federal Motor Carriers Safety Administration (FMCSA) is concerned that truck drivers, who are exposed to diesel emissions for potentially long periods of time and over many years, may suffer acute and/or long term cognitive impairments as a result. Measurements of diesel exhaust in cabs of idling trucks and in "hot spots" where many trucks idle (e.g., overnight at truck stops or waiting at a border crossing) show levels of air pollutants and mobile air toxics that exceed federal health standards. The health impacts of diesel exhaust exposure have generally focused on its cancer-related effects and impact on cardiovascular and pulmonary function. Less is known regarding the impact of diesel exhaust exposure on cognition. Thus, FMCSA sponsored the Volpe National Transportation Systems Center (Volpe Center) to compile existing information that addressed the role (if any) of these pollutants in affecting 1) driver alertness, reaction time, and fatigue; and 2) the quality of sleep drivers experience in cabs with elevated levels of emissions. Specifically, the question of interest addressed was: *Does exposure to diesel exhaust at levels found in cabs affect driver safety performance by affecting driver sleep, alertness, reaction time, fatigue levels, or judgment-making abilities?*

The Volpe Center conducted two tasks. One task was a series of *expert interviews* to obtain insight into the question. The other task was a *literature search* of environmental and medical literature to determine whether any studies were conducted that examined the cognitive impacts of diesel exposure. The literature search included neurological studies, studies related to specific chemicals found in diesel exhaust, and studies examining the cognitive effects of substances that could have similar effects as diesel exhaust (e.g., jet fuel).

This report presents the results of this effort. Section 2 provides a summary of the expert interviews and Section 3 presents an overview of the literature review findings. Detailed notes from each interview and an annotated bibliography of the literature identified in the review are provided in Appendix A and Appendix B, respectively. A summary of the findings and challenges for future research are identified in Section 4.

2 EXPERT INTERVIEWS

The Volpe Center conducted interviews with neurotoxicologists, engineers, and medical professionals for their insight regarding the cognitive effects of diesel exhaust exposure. This section describes the methodology for the interviews and presents a summary of the interview discussions. Notes from each interview are provided in Appendix A.

2.1 Participants

Ten subject matter experts participated in the interviews, as listed below:

- EPA: Vernon Benignus, William Boyes, Ian Gilmour, Chad Bailey
- Harvard School of Public Health: Tom Smith, Eric Garshick, Jaime Hart
- United States (U.S.) Air Force, Wright Patterson Air Force Base/Science Applications International Corporation (SAIC): Gail Chapman, Palur Gunasekar, Shawn McInturf, and Haviland Steele

The participants were identified through recommendations from the Environmental Protection Agency (EPA), FMCSA, and the Volpe Center, as well as through a review of the relevant literature (see Section 3).

The first interviews were conducted with researchers at the U.S. Environmental Protection Agency (EPA). FMCSA identified three experts as a starting point: Vernon Benignus, William Boyes, and Chad Bailey. Vernon Benignus and William Boyes are neurotoxicologists with knowledge regarding the neurobehavioral effects of organic compounds and solvents. They recruited Ian Gilmour, a research biologist, to participate in the discussion to provide input on the health effects of air pollutants. Chad Bailey is an environmental scientist with knowledge on the health effects of diesel emissions.

During the course of the EPA interviews, it was recommended that the Volpe Center contact researchers at the Harvard School of Public Health to discuss their large-scale cohort study examining the occupational health effects of diesel exhaust emissions on truck drivers. It was not known whether the Harvard study addressed cognitive ability, however. Environmentalists at the Volpe Center also felt that researchers at Harvard would have insight into the problem and provided the initial contacts for Tom Smith, a Professor of Industrial Hygiene in the Department of Environmental Health, and Eric Garshick, an Assistant Professor at Harvard Medical School, both involved in the cohort study.

Finally, the results of the literature review, conducted concurrently with the interviews, indicated that research sponsored by the military might shed some light on the problem. In particular, the U.S. Air Force had conducted studies examining the neurobehavioral effects of exposure to jet fuel vapors. Because diesel exhaust and jet fuel are closely related, it was of interest to determine if the effects of exposure from jet fuel vapors might be similar to that expected from exposure to diesel exhaust emissions.

2.2 Method

To structure the interviews, six questions of interest were identified by the Volpe Center in conjunction with FMCSA:

1. Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver’s ability to drive safely?
2. Do you think there is any chance that there could be an effect such as this?
3. Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?

4. If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?
5. What factors should be considered in this research?
6. Can you recommend anyone else we should contact regarding this research?

The interviews were generally conducted as informal discussions. During the interview, experts were asked to discuss their research examining the health effects of diesel exhaust or similar substances or to discuss their interest in the topic.

2.3 Results

The researchers interviewed noted that there is a paucity of literature examining the cognitive effects of diesel emissions. Only two studies were known to be of potential relevance: one that examined the neurobehavioral effects of occupational exposure by railroad workers and electricians to diesel exhaust (see Kilburn, 2000; note that this study was identified by FMCSA in their earlier review) and one that considered the likelihood of reporting Gulf War syndrome symptoms after exposure to diesel fuel vapors (see Fiedler, et al., 2004). A third study noted by some researchers to be of interest, although not directly relevant to cognitive functioning, was a recent finding that particulate matter can migrate from nasal passages to the brain when it is inhaled (in particular, manganese). However, it was not clear from the research whether these particulates would have any impact on neurological functions.

Other research examining the health effects of diesel exhaust emissions has tended to focus on the cardiovascular or pulmonary effects. In the laboratory setting, these studies are conducted with healthy young adults or mild asthmatics, who inhale low levels of diesel exhaust fumes and then perform physical tasks. In the field, several occupational studies have measured the level of diesel emissions in vehicles and examined its effect on drivers. In one study, for example, the level of diesel emissions in patrol cars of North Carolina state troopers was measured and the health effects were evaluated with respect to the state troopers' blood profiles, blood pressure and heart rate. The results of the study identified cardiac consequences of the troopers' occupational exposure to diesel emissions (see Riediker, et al., 2003, 2004).

With respect to the trucking industry, the Harvard School of Public Health is conducting a large study addressing the health effects of occupational exposure to diesel emissions. Specifically, the study examines the relationship between lung cancer and diesel and vehicle emissions exposure. Researchers have collected measurements for particulates at various trucking terminals, and a database is being developed so that exposure can be estimated based on workers' job title, work location, and terminal site. The results of the study so far have shown that there is an increased risk of lung cancer, cardiac mortality, and accidental death.

The discussions highlighted the fact that exposure to diesel emissions can occur in several ways. Of particular concern to FMCSA is the air quality in "hot spots", where trucks may park for an extended period of time with their engines idling. Several research studies have focused on one interchange in Tennessee along Interstate-40 and Watt Road, where there are three truck stops with an overall capacity for 700 overnight trucks. As part of the studies, the air quality at these truck stops and in cabs have been measured and modeled. The measurements showed high concentrations of particulate matter during the nighttime hours when there were more diesel trucks idling and the atmosphere was at its meteorological low, and during the winter months. Models of air quality show that truck stops represent islands of high concentration among low background areas. There is also a consistent finding showing that the concentration of very fine particles coming out of exhaust tailpipes is ten times higher along major freeways compared to urban background air. Other studies examining the levels of different particulate mixture components (i.e., soot, carbon) also show a steep gradient along major freeways.

Researchers were divided regarding whether there could be a cognitive effect of diesel emissions. Neurotoxicologists interviewed generally thought that an effect was possible; in fact, the EPA is proposing a series of animal studies to examine the neurophysiological and cognitive effects of diesel exposure. Animal studies provide a means for drawing clear conclusions between a neurotoxin and behavior, without influences by external sources. However, medical researchers were more cautious, acknowledging that cognitive issues are generally confounded with “lifestyle” factors for truck drivers (e.g., poor sleep). As a result, if cognitive impairments were found, it would not be clear whether the impairment was the result of exposure to diesel exhaust emissions or other external stressors.

2.4 Conclusions

If any research were to be conducted for FMCSA on the cognitive impact of diesel emissions, it would be important to consider factors that could be measured empirically and variables that could moderate the results. Both real-time exposure and cognitive ability are difficult to measure. A series of studies would be needed to identify markers of exposure and biological indicators of neurocognitive functioning. Additionally, it would be important to consider the method of exposure; inhalation is only one form and drivers may absorb diesel through the hands. The dose and level of exposure could vary depending on the source, magnitude and length of time of exposure.

Several agencies are interested and in a position to conduct this kind of research should new studies be proposed by FMCSA. The EPA and military are best suited for conducting animal studies. For human studies, the Harvard School of Public Health has established relationships with trucking companies, unions, and management, and could expand their current study to measure the cognitive impacts of diesel exhaust exposure.

3 LITERATURE REVIEW

A literature review was conducted on neurological studies and studies relating to the specific chemicals found in diesel exhaust that examined the *cognitive* impacts of diesel exhaust exposure (e.g., driver alertness, reaction time, fatigue levels, sleep-disruption, or judgment-making abilities). Literature addressing the potential cancer risks of diesel exhaust emissions exposure or its cardiovascular or pulmonary effects was not included in the scope of the review. The methodology for the literature search and a summary of the findings are presented in this section. An annotated bibliography, providing details for each of the studies discussed, is included as Appendix B. Note that while the literature review focused only on the those studies that addressed the cognitive effects of diesel exhaust emissions exposure, Appendix B presents a larger view of the problem and includes references for studies that addressed the non-cognitive health effects of diesel exhaust exposure and for studies that measured air quality in general traffic and "hot spots" since it was expected that this research might also be of interest to the reader.

3.1 Method

The review searched the environmental and medical literature and included the following nine sources:

1) Transportation Research Information Service (TRIS)/National Transportation Library (NTL)
2) Defense Technical Information Center (DTIC)
3) Center for Disease Control (CDC)/National Institute of Occupational Safety & Health (NIOSH)
4) Medline
5) National Institute of Environmental Health Sciences
6) EPA
7) EbscoHost and InfoTrac (indexes to a variety of journals)
8) Health Effects Institute
9) Assorted links from Internet search engines (e.g., Google)

The focus was on those studies examining the *cognitive* effects of diesel exposure rather than examination of cancer risks or cardiovascular or pulmonary functions.

3.2 Results

The results of the literature search consisted of neurological studies and research related to chemicals found in diesel exhaust and similar substances. An overview of the findings is presented in the three following sections. Section 3.2.1 addresses research on diesel exhaust exposure. Because so little literature specifically addressing the cognitive impact of diesel exhaust exposure was found, the literature search was expanded to consider research examining the cognitive impacts of exposure to chemicals found in diesel exhaust, based on the "Partial List of Chemicals Associated with Diesel Exhaust" specified by the U.S. Department of Labor (see www.osha.gov/SLTC/dieselexhaust/chemical.html). Of these chemicals, only studies were found addressing the cognitive effects of carbon monoxide exposure, and an overview of these findings are provided in Section 3.2.2. Finally, the literature search also considered the cognitive effects of substances that could have similar effects to diesel exhaust. In particular, the literature review identified a body of research addressing the cognitive effects of exposure to jet fuel vapors. Both jet fuel and diesel are fuel oils, so the two were considered to be closely related. Additionally, because diesel vapors from unburned fuel can be a component of diesel exhaust, findings from the literature regarding the cognitive impairments due to jet fuel vapors were expected to be potentially relevant. This is discussed in Section 3.3.3.

3.2.1 Diesel Emissions Exposure

The literature review identified only three studies that directly examined the cognitive impacts of diesel exhaust exposure, none of which were focused specifically on truck drivers. Two of these studies addressed the chronic effects of long-term exposure and reported impairments in cognitive ability. In the first study, Kilburn (2000) examined whether diesel exhaust-exposed workers had more impairment in central nervous system functions than non-exposed workers. Performance on neurophysiological and neuropsychological tests for 10 railroad workers and six electricians (the chemically-exposed workers) was compared to a control group with no known history of exposure. The results showed impairments in neurobehavioral functions for the diesel-exposed workers relative to the control group and suggested that a link between diesel-exhaust exposure and impairment to the central nervous system (including cognitive functioning) may be present. Specifically, diesel-exhaust exposure led to cognitive decrements in memory, problem solving, reaction time and neurological impairments in vision and balance.

In the other study, Maruff, et al. (1998) addressed the neurological and cognitive consequences of chronic petrol sniffing. Blood tests, neurological tests, and psychological tests were performed on 34 *non-sniffers* who had never sniffed petrol, 33 *current sniffers* who had sniffed petrol for at least six months and were currently and actively sniffing; and 30 *ex-sniffers*, who had sniffed petrol for at least six months but had not sniffed petrol in the six -month period prior to the study. The psychological test results showed better performance for non-sniffers on pattern and spatial recognition and paired association learning, particularly as the number of patterns increased, relative to current sniffers and ex-sniffers. Additionally, non-sniffers showed higher performance than current sniffers on visual search as the number of distractors increased. The findings suggest that petrol sniffing may compromise neurological and cognitive functions but that their effects may be reduced over time with abstinence.

While chronic exposure to diesel exhaust emissions has been found to impair cognitive functioning, less known are the effects of acute, short-term exposure. This was the focus of a study by Fiedler, et al. (2004), which assessed the health effects of acute exposure to diesel vapors with acetaldehyde on Gulf War veterans under stressful and non-stressful conditions. Participants were classified as being *ill*, based on criteria for chronic fatigue syndrome and self-reported chemical sensitivity, or *healthy*. They were exposed for 50 minutes in a controlled environment facility to 5 parts per million (ppm) diesel vapor, simulating typical exposure concentrations in garages where diesel and other fuels are used, with 0.5 ppm concentration of acetaldehyde added to simulate the soldiers' environmental conditions. Subjective reports of symptoms and performance on a dual-task driving task, with and without stressors, were compared for the two groups of Gulf War veterans before, during, and after exposure. The results indicated that although ill Gulf War veterans reported more severe symptoms than healthy Gulf War veterans as a result of the exposure (e.g., difficulty concentrating, disorientation, dizziness, and headaches), there was no performance difference attributable to cognitive ability between the two groups, as measured by the dual-task driving simulation test. However, it is important to note that there was no control group (i.e., a "no exposure" condition), nor was performance within a group compared before, during, or after exposure.

Thus, the results of the literature review suggest that cognitive impairment may result from chronic exposure to diesel exhaust emissions (Kilburn, 2000 and Maruff, et al., 1998), but the level of exposure leading to the impairment was not known, and the extent of the impairment (i.e., whether it is temporary or not) is not clear. The one study that did measure and control for exposure showed that chemically-sensitive participants were more likely to report symptoms than healthy participants after acute exposure, but reported no difference attributable to cognitive ability between the two groups (Fiedler, et al., 2004). However, it was not clear whether there were performance differences within a group as a consequence of exposure.

3.2.2 Carbon Monoxide Exposure

Studies addressing the cognitive effects of carbon monoxide exposure were primarily conducted in controlled laboratory environments. In the studies, exposure was considered with respect to its short-term, acute effects and measured as a function of the concentration level (in parts per million, ppm) and/or via participants' carboxyhemoglobin (COHb) levels, a measure of the amount of carbon monoxide and hemoglobin in red blood cells when carbon monoxide is inhaled. The concentration levels tested vary from 0 ppm to 200 ppm, with COHb levels ranging from less than 1% (with no exposure) to 10% and higher. Subjectively, participants reported symptoms such as headaches at high levels of exposure (Stewart, et al., 1970; Stewart, et al., 1973). Objectively, the results of these studies generally showed no effects on monitoring (Horvath, Dahms, and O'Hanlon, 1971) and tracking (Hanks, 1970; Mikulka, et al., 1970; O'Donnell, et al., 1971) tasks and small effects on time estimation abilities (Beard and Wertheim, 1967; Bunnell and Horvath, 1988). Of concern, however, are studies that show the potential for memory deficits and impaired cognitive functioning on more complex tasks such as abstract thinking and manual dexterity (Amitai, et al., 1998; Ryan, 1990; Stewart, et al., 1970) and dual task performance (Milhevic, Gliner, and Horvath, 1983).

With respect to driving performance, the effects of carbon monoxide exposure are not as clear. Wright, Randell, and Shephard (1973) showed that a 3.4% increase in COHb levels (achieved through carbon monoxide exposure at levels of 100 ppm for 2 hours) could impair judgments while driving. Additionally, COHb levels upwards of 11% created some "tunnel vision", with drivers focusing more on information in the forward field of view and less on information at the periphery (McFarland, 1973). However, it is not clear whether the levels of carbon monoxide to which drivers are exposed while on the road are equivalent to those used in the studies. In fact, one report that noted the carbon monoxide level in cars indicated levels of less than 25 ppm (Mayron and Winterhaller, 1976), although the level of exposure fluctuates due to weather and traffic.

It is worth noting that there were no negative consequences of carbon monoxide exposure on sleep (O'Donnell, Chikos, and Theodore, 1971); participants exposed to carbon monoxide experienced more "deep sleep" than those who were not exposed, with no impact on cognitive functioning.

3.3.3 Other Substances

Anecdotal reports by pilots complaining of nausea, poor coordination, short-term memory loss, and "slow thinking" after short-term acute exposure to jet fuel led to concerns that exposure to jet fuel vapors could result in pilot errors in navigation and communication (Davies, 1964; Porter, 1990; Smith, et al., 1997). Basic research investigating the consequences of exposure to jet-fuel vapors has generally focused on the consequences of chronic exposure, measured in weeks for controlled animal studies and years for human studies. The results of animal studies indicated short-term neurological and behavioral effects (e.g., during exposure or initially during postnatal development) without any long-term consequences (Mattie, et al., 2001; Nordholm, 1998). However, human studies suggest more permanent neurological effects. Three studies directly examined the prevalence of cognitive deficits on aircraft factory workers with long-term exposure to jet fuel (Knave, Mindus, and Struwe, 1979; Knave, Persson, Goldberg, and Westerholm, 1976; Knave, et al., 1978), the results of which suggest a link between exposure and cerebellar functioning (Ritchie, et al., 2001). The results show more symptoms of exposure (e.g., dizziness, headache, nausea, respiratory tract inflammation, chest palpitations) reported by workers with high exposure compared to workers with lower levels or no exposure. Exposed workers showed greater variability in performance on psychological tests of complex reaction time and greater performance decrements on tasks of simple reaction time and perceptual speed (Knave, Mindus, and Struwe, 1979; Knave, et al., 1978). Neurological tests on workers with high and low levels of exposure showed no differences due to level of exposure (Knave, Persson, Goldberg, and Westerholm, 1976). The extent to which jet fuel vapors and diesel exhaust have similar effects is not known, however.

3.3 Summary

The review of the environmental and medical literature identified only three studies that directly examined the cognitive impacts of diesel exhaust exposure. Two of the three studies reported impairments in cognitive ability as a result of *chronic* exposure, but the level of exposure resulting in the impairment was not measurable, and whether the impairment was temporary or long lasting is not clear. Only one study controlled for exposure, but its focus was on determining the effects of *acute* diesel emissions exposure, particularly for those with chemical sensitivity. The results of the study showed no difference in cognitive ability due to exposure between chemically-sensitive participants and healthy participants, but no comparison of cognitive performance before, during, or after exposure within a group was conducted.

The literature search was expanded to include research that examined the cognitive effects to chemicals in diesel exhaust or substances that could have similar cognitive effects as diesel exhaust. With respect to the former, only studies addressing the cognitive effects of carbon monoxide exposure were identified. While carbon monoxide may impair driver judgments, it is not clear whether the level of carbon monoxide to which drivers are exposed is significant enough to cause such impairments. With respect to the latter, research examining the cognitive effects of exposure to jet fuel vapors was considered to be potentially relevant since both jet fuel and diesel are components and fuel oil and diesel exhaust emissions also contain a mixture of gases and vapors. The results of these studies showed no long-term neurobehavioral consequences of chronic exposure to jet fuel vapors in animals but more lasting effects in humans. However, the degree to which jet fuel vapors and diesel exhaust vapors have similar effects is not known.

4 SUMMARY AND CHALLENGES FOR FUTURE RESEARCH

The goal of this project was to determine whether truck drivers' exposure to diesel exhaust emissions at levels found in cabs affects cognitive ability. A series of expert interviews was conducted and the environmental and medical literature was reviewed to answer this question. Unfortunately, no conclusive answer was found; the potential for an effect exists, but the question is difficult to answer empirically. The results are summarized below and challenges to future research are discussed.

4.1 Summary

The consensus of the experts interviewed was that the effects of diesel exhaust emissions exposure on the cardiovascular and pulmonary system are well-known, but it is not clear whether a cognitive impact exists. While an effect is possible, a clear link between the two would be difficult to measure empirically. This may account for the lack of literature that directly addressed the cognitive effects of diesel emissions exposure. The literature review identified only three studies. While the results of those studies suggested that chronic exposure to diesel exhaust could affect memory, problem solving, and reaction time, the level of exposure resulting in the impairment and the severity of the impairment, was not defined.

Research examining the cognitive effects of exposure to chemical components of diesel exhaust (i.e., carbon monoxide) and to substances that could have similar effects as diesel exhaust emissions (i.e., jet fuel vapors) was also considered. The literature addressing the cognitive-related health effects of chemical components in diesel exhaust was limited to research on carbon monoxide exposure. Carbon monoxide impaired performance only slightly on simple tasks (e.g., vigilance and tracking tasks), but more significantly on complex tasks, such as abstract thinking. However, the studies addressing carbon monoxide exposure were generally conducted in controlled laboratory environments, and whether levels of exposure in the typical driving environment are as high as those used was not clear. The literature examining the cognitive effects of exposure to jet fuel vapors was considered to be potentially relevant since diesel and jet fuel are closely related. Controlled animal studies and occupational studies on human participants showed contradictory results; the effect of exposure on animals had only short-term neurological effects, which dissipated once exposure ceased, but the results of human research studies showed long-term impairments.

4.2 Research Challenges

The expert interviews and literature search highlighted the fact that little is known regarding the cognitive effects of diesel exhaust emissions exposure. The results identified several challenges to conducting further research. Specifically, any research to address this issue would be costly and difficult to implement and any effects difficult to measure for a number of reasons.

First, it is difficult to isolate the cognitive effects due to diesel emissions exposure from the cognitive effects of other stressors, such as lifestyle (e.g., long hours, shift work). Second, a good metric of cognitive ability that would be sensitive to the effects is needed. Research addressing the cognitive impacts of carbon monoxide exposure showed varying results depending on the difficulty of the task.

Third, a good dose-response effect of diesel emissions exposure on cognition would be methodologically difficult to collect. To measure the effects of acute, high-dosage exposure, cognitive tests would need to be administered at times of exposure, but the level of exposure is variable due to factors such as the traffic, weather, and time of day. There are no easy methods to track drivers' exposure to concentration of particles over time, and capturing drivers at the time of exposure to evaluate their cognitive ability would be a challenge. To measure the chronic effects of long-term exposure, an estimate of the level of diesel exhaust emissions to which drivers are exposed over time would be needed. Developing a model to determine these estimates would require a large data collection effort to consider factors that moderate exposure (e.g., commodity, length of haul).

One interesting approach for future research is to examine whether there are any biological indicators (e.g., blood markers) of cognition. That is, inflammatory markers in the blood that might indicate cognitive impairments. The Harvard School of Public Health is currently collecting biological data from truck drivers as part of a cohort study examining the non-cognitive health effects of diesel emissions exposure on the population. Although no biological markers for cognition have yet been identified, the Harvard School of Public Health could begin to examine whether such a marker exists and establish a relationship between a specific inflammatory marker and cognitive ability. This would be a significant task, however.

Additionally, the results from the cohort study conducted by the Harvard School of Public Health could be used to estimate drivers' level of exposure over time. Researchers are measuring concentrations of particulate matter at trucking terminals and in cabs (with body worn monitors). This data could be used to develop a model of exposure, and the model considered with respect to the overall cognitive effects of the truck driver lifestyle. Further refinements to the model could examine the contribution of other moderating variables; for example, the combined effects of aging and exposure by comparing data on cognitive ability collected from truck drivers with cognitive data collected from gerontology studies. Similar to the previous proposal, developing such a model and deriving any valuable data would be a long-term effort.

Several other options for basic research should be noted, although it is also important to consider that results from these controlled laboratory studies may not generalize to the truck driving population. A laboratory study is feasible; healthy participants can be exposed to diesel exhaust emissions at levels that would be representative of that encountered at truck stops and complete a series of tasks. The level of impairment and the extent of the impairments (i.e., how long it lasts) could be measured. However, the results would still need to be considered with respect to other important lifestyle factors that influence cognitive ability. Animal studies are also possible and could serve as a starting point for determining whether a clear link between cognition and diesel exposure exists. However, animal studies could measure only performance on simple tasks, and much of the skills required in driving in order to maintain safety require a high level of cognitive functioning. Consequently, the question of whether or not the results would generalize remains. It is possible that these basic human and animal studies could provide the basis for a model that examines the contribution of acute and chronic exposure to diesel exhaust to cognitive ability.

If FMCSA determines that additional research is needed, several organizations would be interested in assisting in the effort. The Harvard School of Public Health could expand their current occupational study to address whether a cognitive effect of diesel exhaust emissions exposure exists. Harvard researchers have established relationships with several trucking companies and are traveling to terminals to collect information on exposure levels and biological data from truck drivers. As noted above, they could begin to examine whether a biological marker for cognitive ability exists and determine what tasks to administer to measure neurocognitive functioning. For basic research, the EPA is well suited to conducted animal studies; in fact, the EPA's 5-year plan proposes animal studies to examine the effect of diesel emissions exposure.

4.3 Conclusion

Unfortunately, the question regarding whether diesel exhaust emissions exposure affects cognition will remain unanswered for a while to come. The potential for an effect exists, but a clear answer is difficult to obtain. The harmful effects of emissions are being addressed in other ways, however. The EPA is establishing a comprehensive national clean diesel initiative to reduce emissions from the over 11 million diesel engines in the heavy-duty commercial motor vehicle fleet. Standards set forth by this initiative are anticipated to reduce nitrous oxide (NO_X) and particulate matter emissions from heavy duty engines by 90% and 95% below current standard levels, respectively, through the use of high-efficiency catalytic exhaust emission control devices or comparably effective advanced technologies. These new standards will significantly reduce drivers' exposure to emissions as they are phased in between 2007-2010. The public health and environmental benefits of the program will come at an average cost increase of about $2,000 to $3,200 per new vehicle in the near term and about $1,200 to $1,900 per new vehicle in the long term.

However, these standards may only offer a short-term solution. Estimates show an increasing trend of truck vehicle miles traveled (TVMT). In 2005, the Energy Information Administration estimated that truck drivers traveled an average of 230 million miles, with an annual growth rate of 2.2%. Consequently, it is not known whether the benefits from the EPA's clean diesel initiative will be offset by an increase in the number of heavy-duty commercial motor vehicles in the long-term. It is hoped that when the program is fully implemented and the fleet of older engines has fully turned over (by 2030), the reduction in NO_X, non-methane hydrocarbon and particulate matter emissions will be evidenced through the improved health and safety of all drivers.

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APPENDIX A. NOTES FROM EXPERT INTERVIEWS

Interviewee(s): Vernon Benignus, William Boyes, Ian Gilmour **Date**: March 6, 2007

1. **Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver's ability to drive safely?**

No. Will Boyes has examined the effects of air pollution on animals with particular focus on the effects of the organic compounds. He is aware of primarily animal studies looking at the neurotoxic effects of diesel, rather than the cognitive effects. Recent studies looking at the effects of exposure on humans have included a meta-analysis examining the neurological effects of exposure to specific organic compounds. While these studies have not specifically examined the effect of diesel, the hydrocarbons in the fluids tested may have similar effects on the central nervous system (CNS) as the hydrocarbons in diesel exhaust, e.g., CNS-depressant properties. A recent finding is that particulate matter may be able to migrate from nasal passages (when inhaled) into the brain. This research has been done primarily on specific metals, e.g., manganese.

Ian Gilmour discussed new research that has examined the specific effects of the different chemical components in diesel exhaust on pulmonary health (specifically, asthma). He noted that there are eight labs that are conducting human-diesel inhalation studies but these studies are focused on the effects of diesel on the pulmonary and cardiovascular systems. These studies are conducted with healthy young adults or with mild asthmatics who are asked to inhale diesel (in the amount that may be typical of daily exposure) and asked to perform physical tasks. Researchers then examine lung function, cardiac output, heart rate, etc. No studies have specifically looked at the cognitive effects on sleep.

Other studies: Monitoring of North Carolina state troopers and air pollution levels in the patrol cars and associated the two with cardiac and respiratory functions.

2. **Do you think there is any chance that there could be an effect such as this?**

Yes. In the EPA's 5-year research plan, there is an item to conduct animal studies to examine the neurophysiology or cognitive deficits with exposure to diesel, e.g., by placing trained rats into Skinner boxes in inhalation chambers where volatiles are trapped and testing their cognitive and neurological functions.

3. **Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?**

There are several initiatives underway to look at "hot spots" at or near roadways and highways and to look at children's exposure to diesel exhaust as a cause of asthma.

4. **If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?**

Federal agencies should conduct the programs to leverage with existing research programs. The Health Effects Institute was noted. This organization receives funding from EPA and automotive and trucking industries.

Interviewee(s):	Vernon Benignus, William Boyes, Ian Gilmour	**Date**:	March 6, 2007

5. What factors should be considered in this research?

Research may be conducted using a controlled exposure (i.e., a laboratory study including control groups) to determine the specific effect of chemicals or a field study in which occupational participants are monitored in their work environments and compared with workers in similar occupations who have only normal exposure to diesel exhaust.

6. Can you recommend anyone else we should contact regarding this research?

- For information on human studies: Bob Devlin (devlin.robert@epa.gov, 919.966.6255); Michael Madden (919.966.6257)
- Eric Garshick, Harvard School of Public Health. Epidemiological studies examining whether there is a link between diesel exposure and cancer.

Interviewee(s):	Chad Bailey	**Date:**	March 6, 2007

1. **Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver's ability to drive safely?**

No, but there have been several other studies looking at the cardiac and pulmonary effects of diesel exposure (e.g., lung cancer, asthma) in trucking terminals, truck yards, truck stops and in the railroad industry examining exposure in locomotive cabs.

- The Harvard University School of Public Health conducted an epidemiological study systematically evaluating emissions exposure of truck drivers at the five largest unionized trucking firms and the rate of lung cancer. A similar study was conducted looking at the exposure risk to rail workers.
- A study conducted in the state of North Carolina examined the effects of diesel exposure on state troopers. Researchers measured the troopers' blood pressure and heart rhythm and collected blood draws before and after their shifts and found increased heart rate variability in young police officers, and in cars with higher concentration of higher particulate matter. Additionally, the blood profile showed signs of inflammation, suggesting that there were cardiac consequences.
- Kilburn conducted a small study examining the effects of diesel exposure on 10 railroad workers and six electricians and suggested that there may be neurobehavioral impairments resulting from diesel exposure.
- Another study looked at the likelihood of Gulf War syndrome resulting from breathing fuel vapors.
- NIOSH has conducted worksite health hazard evaluations, e.g., a long-term miner study looking at lung cancer.
- Vernon Benignus and Will Boyes published a paper addressing toluene exposure. Although toluene is not in diesel exhaust, if a fuel truck operator is routinely unloading fuel from a tank truck, it's possible that s/he could be exposed early on, and this could influence choice reaction time.
- Other studies have examined the chemicals to which people in petroleum distribution chain are exposed, e.g., Dave Verma at McMaster University looked at tank truck drivers' exposure to vapors.

2. **Do you think there is any chance that there could be an effect such as this?**

Yes.

3. **Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?**

Exposure to diesel emissions can occur in a variety of scenarios. For example, for a less-than-truckload company, exposure can occur at the truck terminals at the origin and destination points where there is lots of diesel activity in the truck yard or from engines on the dock. Once the truck is moving, exposure can occur on secondary roads, freeways, etc., with the most direct exposure at overnight locations (e.g., a truck stop).

Several studies have measured exposure to diesel in Tennessee along Interstate-40 and Watt Road. There are three truck stops here with a capacity for 700 overnight trucks. As part of the Watt Road Environmental Laboratory Initiative, the air quality at this truck stop and in truck cabs has been measured. The results of these studies indicate that high concentration of particulate matter was found during the nighttime hours, when there were more diesel trucks idling and the atmosphere was at its meteorological low, and during the winter months, when more trucks are idling.

Additionally, researchers from Oak Ridge National Labs (John Storey, Jim Parks) collected a wide range of emissions measurements, which Chad Bailey is modeling. The modeling results show that truck stops represent islands of high concentration among low background areas. Other studies have looked at typical concentrations of air pollutants found on freeways and roadsides; data is being collected in California by USC and UCLA, and in the New York area by the University of Rochester, Albany. There is a consistent finding showing that along freeways, the concentration of very fine particles coming out of exhaust tailpipes is a tenfold higher along major freeways compared to urban background air. Studies that have looked at other component of particulate mixture (soot, carbon) also show a steep gradient along major freeway.

4. If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?

Academia would be well-equipped to conduct some of the research, e.g., through Industrial Hygiene and Occupational Health departments at Harvard University, University of Michigan, UCLA, and UC-Berkeley. Other organizations who might be able to assist are the Health Effects Institute (HEI) and NIOSH-CDC. Other experts in the field are Vern Benignus and Will Boyes.

5. What factors should be considered in this research?

6. Can you recommend anyone else we should contact regarding this research?

- Eric Garshick, Harvard School of Public Health. Epidemiological studies examining whether there is a link between diesel exposure and cancer.
- Byron Bunker (emissions engineer): 734.214.4155

Other discussion topics

<u>What is the impact of regulations that may be enacted?</u> The concentration of particulate mass and the numbers of particles will decrease as a result of these standards. Reducing the sulfur in the base fuel will reduce ultrafine matter. With respect to soot, the new standards are expected to require manufacturers to use particle traps, so that emissions may not be an issue.

Interviewee(s): Thomas Smith, Harvard University **Date**: April 4, 2007

The Harvard School of Public Health is conducting a cohort study to examine the relationship between lung cancer and diesel and vehicle emissions exposure in the trucking industry. The cohort contains drivers, dock workers, mechanics, hostlers, and clerks from four large trucking companies. As part of the study, over 4,000 measurements of particulates were collected at various trucking terminals with different levels of operations. This data is being used to create a database of exposure to estimate exposure based on job title, work location, and terminal site. The results of the study so far have shown that there is an increased risk of lung cancer, cardiac mortality, and accidental death in this population.

1. **Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver's ability to drive safely?**

No, much of their work has focused on measuring exposure at different work locations for different types of workers at various terminal sites.

2. **Do you think there is any chance that there could be an effect such as this?**

There could be an effect, but it is much more difficult to quantify than disease.

3. **Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?**

Measurements of air quality in truck cabs have been collected as part of their study. No "hot spots" were found, per se, but measurements suggest that truck drivers' exposure is primarily the result of traffic emissions from other cars. That is, addressing the effects of exposure to traffic emissions may be more feasible than addressing the effects of exposure to diesel, specifically. However, exposure levels are sporadic, e.g., occurring only if the driver is following close to another car or truck. <u>Note that most of the drivers in their study are not long-haul drivers and do not sleep in their trucks.</u>

4. **If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?**

The Harvard School of Public Health has a good working relationship with trucking companies and Teamsters, with whom they have current partnerships. A study to address the cognitive effects of diesel emissions exposure could be developed in conjunction with these organizations.

5. **What factors should be considered in this research?**

- Symptoms of exposure
- Genetic responses/blood markers
- The development of tasks that are sensitive enough to measure differences in cognitive performance

6. **Can you recommend anyone else we should contact regarding this research?**

- Eric Garshick, Harvard School of Public Health
- Mark Weiskopf, Harvard School of Public Health (neurophysiologist who could help generate tasks for measuring cognition at terminals)

Interviewee(s):	Eric Garshick and Jaime Hart, Harvard School of Public Health	**Date**:	April 6, 2007

1. **Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver's ability to drive safely?**

There are organic compounds in exhaust that with enough exposure could have effects. There is literature addressing emissions exposure from school buses, and a birth cohort study in the New York area that examined the effect of PAH (polycyclic aromatic hydrocarbons) exposure on neurocognitive performance in schools. No one has yet looked at the neurocognitive effects of emissions on truck drivers.

2. **Do you think there is any chance that there could be an effect such as this?**

It is hard to tell. The cognitive issues may be confounded with other "lifestyle" factors (e.g., poor sleep, obesity), and it will be necessary to disentangle the various neurocognitive effects. Additionally there are many ways to measure cognition.

3. **Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?**

4. **If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?**

The Harvard School of Public Health has established relationships with trucking companies, unions, and management. Most truck drivers in their study are willing to participate in research studies, particularly if they are paid to do so. Most of their truckers in their study are not long-haul drivers and do not sleep at truck stops. Instead, the drivers' companies often pay for a hotel on overnight trips.

5. **What factors should be considered in this research?**

The question currently asked is too broad and needs to be focused by determining what can be measured empirically. First, exposure can be measured in several ways. A pilot study may be needed in which several markers are collected (e.g., elemental carbons, organic vapors) to determine which markers to use and which might have the most impact on cognition. $200k is a reasonable budget for such pilot study. Second, a method for measuring the neurocognitive impact will need to be devised. A pilot study could be conducted to test the protocol at local terminals before expanding it to larger terminals. Collecting blood samples to determine the presence of "inflammatory markers" may also be useful, especially if a correlation can be demonstrated between these markers and impaired cognitive response.

It may also be interesting to examine the effects of exposure versus lifestyle, or to rephrase the question to consider the risk factors of neurocognitive effects.

6. **Can you recommend anyone else we should contact regarding this research?**

Interviewee(s):	Haviland Steele, SAIC Dr. Gail Chapman, Dr. Palur Gunasekar, Dr. Shawn McInturf, Wright Patterson Air Force Base	**Date:**	April 12, 2007

1. **Are you aware of any research on the effects of diesel emissions (preferably at levels a driver might be exposed to) on alertness, decision-making, or sleeping, or any other impacts that could affect a driver's ability to drive safely?**

The military has extensively examined the effects of exposure to jet fuel vapors because the potential for neurobehavioral effects was noticed. Shawn McInturf assisted in the data collection of eye-blink conditioning data on rats in one study that examined whether exposure to jet fuel resulted in any cerebellum deficits. The results showed differences in eye-blink responses among rats with high exposure to jet fuel vapors versus those with low exposure. A subsequent study examined the effect of jet fuel exposure on the rats' circadian rhythms, but the data collected showed no overall effect. With respect to diesel exposure, animal models have shown cardiovascular effects.

2. **Do you think there is any chance that there could be an effect such as this?**

It is not clear; it would be important to measure the concentration levels at hot spots to determine what levels are inhaled. If these numbers are significant, then additional research may be needed to determine the cognitive impact.

3. **Some existing research suggests that there are elevated levels of emissions in truck cabs that exceed Federal agency standards. Are you aware of any research that has examined ambient air quality in 'hot spots' where trucks might park or inside truck cabs?**

4. **If primary research needs to be conducted (in the absence of existing research) what vehicle would be appropriate (Federal agency or organization with expertise in this field)?**

Most of the toxicology research conducted at Wright Patterson Air Force Base consists of animal studies. These animal studies could be used to develop clear conclusions regarding a link between diesel exposure and cognition. Stressors could also be introduced to examine their effects.

Human body exposure studies, if needed, would be better conducted by the EPA. Wright Patterson AFB has not conducted toxicology studies on humans, and if they are needed, IRB approval could take up to a year to obtain.

5. **What factors should be considered in this research?**

Driver exposure may occur in various ways (e.g., inhaled from the air, absorbed from the hands). The dose and effects of exposure may vary depending on the source and length of time of exposure. Also, consider whether there are any biomarkers (e.g., blood markers) that could be indicative of cognitive deficits.

6. **Can you recommend anyone else we should contact regarding this research?**

- John Hinz, U.S. Air Force
- Laurie Roszell, U.S. Army
- Dave Mattie, U.S. Air Force

APPENDIX B. ANNOTATED BIBLIOGRAPHY

The annotated bibliography is organized into five sections. The first three references the literature addressing the cognitive effects of exposure to diesel exhaust (B.1), carbon monoxide (B.2), and jet fuel vapors (B.3) respectively. Each of the studies in these sections is described in a table that highlights the following:

- the purpose of the study,
- the number of participants,
- the method and level of exposure,
- the task participants performed,
- the results of the study, and
- implications of the research.

Because the literature review identified research that addressed other aspects of diesel exhaust exposure, two additional sections in the annotated bibliography are included. Section B.4 lists literature identified in this search and in the Project Plan Agreement (PPA) that addresses other health effects of diesel exhaust exposure, e.g., on cardiovascular and pulmonary functions. The purpose of each study and an overview of the findings are provided for each article in Section B.4. Finally, Section B.5 contains literature addressing measurements of air quality in general traffic and in “hot spots.” Because these studies do not address any health effects, only the purpose is noted.

B.1 Cognitive Effects of Diesel Exposure

Title:	**Responses to controlled diesel vapor exposure among chemically sensitive Gulf War Veterans**		
Author(s):	Fiedler, N., Giardino, N., Natelson, B., Oteenweller, J.E., Weisel, C., Lioy, P., Lehrer, P., Ohman-Strickland, P., Kelly-McNeil, K., and Kipen, H.		
Journal:	*Psychosomatic Medicine*, 66, 588-598	**Year:**	2004
Purpose:	To evaluate the health effects of exposure to diesel vapors with acetaldehyde on Gulf War veterans under stressful and non-stressful conditions		
Participants:	19 healthy Gulf War veterans and 12 ill Gulf War veterans (based on criteria for chronic fatigue syndrome and self-reported chemical sensitivity, as indicated by sensitivity to 5 or more of 8 chemicals and 1 or more lifestyle change due to chemical sensitivities)		
Exposure:	Participants were seated in a controlled environment facility (CEF; a 7.3'x 9'x13.6' stainless steel chamber) and exposed to 5 ppm diesel vapor, simulating typical exposure concentrations in garages where diesel and other fuels are used, with 0.5 ppm concentration of acetaldehyde added to simulate the soldiers' environmental conditions.		
Task:	The experiment was divided into four phases: pre-exposure, exposure, 30-minutes post-exposure, and 1-hour post exposure. • In the pre-exposure phase, participants performed tasks to collect baseline data in a "clean air" environment. Participants completed a questionnaire indicating whether they experienced specific symptoms related to eye irritation, anxiety, somatic health (e.g., numbness/tingling, back pain, muscle aches), respiration, and cognition (disorientation, dizziness, ability to concentrate) and general symptoms related to exposure volatile organic compounds (e.g., headache, fatigue, lightheadedness, drowsiness, nausea), and provided ratings on the environmental quality, odor intensity, and odor irritation. Participants also performed a dual-task driving simulation test, in which they responded to a central task when a "safe" condition was present (e.g., white head lights in the left lane) and a peripheral task when a critical stimulus appeared (e.g., a stop sign). These tasks took approximately 50 minutes. • In the exposure phase, participants were exposed to diesel vapors. After 25 minutes, participants performed a Stroop task, which was used as a psychological stressor. Participants then completed the symptom and environmental questionnaires and the dual-task driving simulation test. • Thirty minutes post-exposure, participants completed the symptom and environmental questionnaires and performed the dual-task driving simulation test. • One hour post-exposure, participants completed the symptom and environmental questionnaire.		
Results			
Ill Gulf War veterans indicated more severe symptoms, e.g., difficulty concentrating, disorientation, dizziness, and headaches, than healthy Gulf War veterans. These symptoms are consistent with physiological data showing reduced end-tidal CO_2 levels and hyperventilation. Other symptoms experienced by ill Gulf War veterans included increased drowsiness and increased fatigue with prolonged exposure relative to the healthy veterans. However, despite these differences in the subjective ratings, there was no performance difference on the dual-task driving simulation test between the two groups. It is important to note that the veterans were given only a single exposure and that there was no control group that did not experience no exposure, apart from the baseline data collected before the exposure to diesel, so the results could reflect a stress resulting from anticipating the odor.			
Implications	Persons with chemical intolerances are more likely than those without those same intolerances to hyperventilate as a result of exposure to general chemicals. The authors hypothesize that the ill Gulf War veterans may have exhibited a conditioned response (e.g., hyperventilating) to the odor of diesel fumes, possibly the result of associating the odors with the Gulf War. Thus, veterans' anxiety about chemical exposures due to previous illness may lead to chronic anxiety and contribute to the occurrence of general somatic symptoms such as fatigue when exposed to these chemicals.		

Title:	**Effects of diesel exhaust on neurobehavioral and pulmonary functions**		
Author(s):	Kilburn, K.H.		
Journal:	*Archives of Environmental Health*, 55(1), 11-17	**Year:**	2000
Purpose:	To examine whether diesel exhaust exposure causes impairment in central nervous system functions		
Participants:	16 chemically-exposed workers: 10 railroad workers (between 43 – 60 years old) and 6 electricians (between 42 – 56 years old). A control group consisted of 159 males with no known exposure to chemicals.		
Exposure:	Exposure level varied. The 10 railroad workers had a range of 15-40 years of experience as diesel mechanics or train crewmen. The 6 electricians were working in a contained space with exhaust from idling diesel engines pouring into the space		
Task:	Participants completed a self-administered questionnaire and a set of neurophysiological and neuropsychological tests measuring reaction time, balance, visual functioning, memory, dexterity, coordination, decision making, and peripheral sensation and discrimination.		
Results			
The group of diesel-exposed workers showed impairments on neurobehavioral functions relative to the control group, with abnormalities slightly higher in the railroad workers with longer-term exposures. Specifically, the tests showed decrements in balance, reaction time, blink reflex latency, problem solving, perceptual motor functions, and verbal and visual memory recall. Pulmonary test also showed that 10 of the diesel-exposed participants had airway obstructions, and 10 had chronic bronchitis, chest pain, tightness, and hyper reactive airways.			
Implications	There may be a link between diesel-exhaust exposure and impairment to the central nervous system (including cognitive functioning). Specifically, diesel-exhaust exposure led to cognitive decrements in memory, problem solving, reaction time and neurological impairments with respect to vision and balance. Similar impairments were noted regardless of exposure time (i.e., exposure for 1 year versus 25 years).		

Title:	**Neurological and cognitive abnormalities associated with chronic petrol sniffing**		
Author(s):	Maruff, P., Burns, C.B., Tyler, P., Currie, B.J., and Currie, J.		
Journal:	*Brain*, 121, 1903-1917	**Year:**	1998
Purpose:	To examine the effects of chronic petrol sniffing on neurological and cognitive performance		
Participants:	34 non-sniffers, 33 current-sniffers, and 30 ex-sniffers		
Exposure:	Non-sniffers had never sniffed petrol; current sniffers had sniffed petrol for at least 6 months and were currently and actively sniffing; and ex-sniffers had sniffed petrol for at least 6 months but had not sniffed petrol in a 6-month period prior to the study		
Task:	Blood tests; neurological examination; psychological testing of motor function, simple and choice reaction time, visual search pattern recognition, spatial recognition, pattern-location paired-associate learning, visual attention, drawing and copying		
Results			
Results of the psychological testing indicated that current-sniffers performed poorer than non-sniffers on tasks of visual search as the number of distractors increased, pattern and spatial recognition, and paired association learning and memory tasks (particularly as the number of patterns increased). Ex-sniffers showed poorer performance on pattern and spatial recognition and paired associate learning tasks (similar to current-sniffers, this deficit was seen as the number of patterns increased) relative to non-sniffers. Performance speed did not vary among the three groups, suggesting that the cognitive deficits found were not due to an inability to perform the tasks.			

Title:	**Neurological and cognitive abnormalities associated with chronic petrol sniffing**		
Author(s):	Maruff, P., Burns, C.B., Tyler, P., Currie, B.J., and Currie, J.		
Journal:	*Brain*, 121, 1903-1917	**Year:**	1998
Implications	Neurological and cognitive function is compromised with petrol sniffing but their effects may be reduced with abstinence.		

B.2 Cognitive Effects of Carbon Monoxide Exposure

Title:	**Neuropsychological impairment from acute low-level exposure to carbon monoxide**		
Author(s):	Amitai, Y., Zlotogorski, Z., Golan-Katzav, V., Wexler, A., and Gross, D.		
Journal:	*Archives of Neurology*, 55, 845-848.	**Year:**	1998
Purpose:	To examine the effect of acute low-level carbon monoxide exposure on cognitive functioning		
Participants:	92 students; 45 in the experimental group (6 of which were smokers) and 47 in the control group (8 smokers)		
Exposure:	Participants in the experimental group were exposed to carbon monoxide from kerosene stoves in their dormitory rooms for a period of 1.5 to 2.5 hours. The exposure level ranged from 17-100 ppm resulting in COHb levels ranging from 1% to 11%.		
Task:	Participants completed five tests measuring short-term and long-term semantic and figural memory; visuomotor coordination; visuospatial organization and constructional skills; auditory memory, attention, and concentration; spatial planning; and verbal memory and learning abilities.		
Results			
Low level exposure to carbon monoxide impaired short- and long-term memory, visuomotor coordination, visuospatial planning and construction, and temporospatial orientation.			
Implications	Carbon monoxide exposure was linked to cognitive decrements in memory, learning, attention, tracking, abstract thinking, and visuospatial planning and processing.		

Title:	**Carbon monoxide exposure and cerebral function**		
Author(s):	Beard, R.R. and Grandstaff, N.		
Journal:	*Annals of the New York Academy of Sciences*, 174(1), 385-395	**Year:**	1970
Purpose:	Summarize the literature regarding the effects of carbon monoxide on cerebral function		
Results and Implications	Many studies have examined the effects of carbon monoxide on cerebral brain function without clear results. Testing in different environments can modify behavioral patterns, and the minimal dose needed to produce a demonstrable effect has varied.		

Title:	**Behavioral impairment associated with small doses of carbon monoxide**		
Author(s):	Beard, R.R. and Wertheim, G.A.		
Journal:	*American Journal of Public Health and the Nation's Health*, 57 (11), 2012-2022	**Year:**	1967
Purpose:	Examine the effects of carbon monoxide on rats, monkeys, and humans to determine behavioral changes		
Experiment 1			
Participants:	18 young adult, non-smoking, university students		
Exposure:	Carbon monoxide was administered in concentrations of 0, 50, 100, 175, and 200 parts per million		
Task:	Participants were presented with two tones; the first was one second long and the second varied between 0.675 seconds and 1.325 seconds. Participants judged whether the length of the second tone was the same as, shorter, or longer, than the first by pressing one of three levers.		
Results			

Title:	**Behavioral impairment associated with small doses of carbon monoxide**		
Author(s):	Beard, R.R. and Wertheim, G.A.		
Journal:	*American Journal of Public Health and the Nation's Health*, 57 (11), 2012-2022	**Year:**	1967

Participants showed no overt changes in motor behavior, but judgments of time intervals, as measured by the ability to discriminate the length of two successively presented auditory tones, were impaired as a result of exposure to all carbon monoxide concentrations. Accuracy decreased as the carbon monoxide concentration exposure increased, and this performance decrement in judgment precision was similar for small and large differences in tone duration. Ninety minutes of exposure was sufficient to cause significant decrement with 50ppm, with shorter times needed for higher concentrations.	
Experiment 2	
Participants:	Rats
Exposure:	0, 250, 500, 750, 1000 ppm
Task:	Rats were trained to press levers to obtain food pellets or water (reinforcement) at fixed time intervals, e.g., the rat was rewarded with a food pellet three minutes after the previous pellet was delivered. Rats learn that pressing the level soon after the reinforcement is delivered is useless but increases the rate of lever pressing as the end of the fixed time interval approaches.
Results	
Ninety minutes of exposure to carbon monoxide at a concentration level of 50 ppm led to decrements in discriminating the relative length of auditory tones. Recovery from carbon monoxide exposure was quick, however, suggesting that the performance decrement was not related to the amount of carbon monoxide hemoglobin in the blood. Additionally, carbon monoxide exposure impacted the rats' ability to discriminate time.	
Implications	Low levels of carbon monoxide exposure may impact complex tasks such as time estimation, with performance decrements occurring faster for higher levels of carbon monoxide. Studies with rats showed similar effects of carbon monoxide exposure on time judgments. It is possible that these decrements in time estimation may lead to errors in speed estimation. However, this hypothesis is based on intuition rather than empirical evidence and needs testing.

Title:	**Interactive effects of physical work and carbon monoxide on cognitive task performance**		
Author(s):	Bunnell, D.E. and Horvath, S.M.		
Journal:	*Aviation, Space, and Environmental Medicine*, December, 1133-1138	**Year:**	1988

Purpose:	To evaluate the effects of carbon monoxide exposure and physical work on cognitive performance
Participants:	11 men and 7 women ranging in age from 18-29 years old
Exposure:	~0.7-1%, 7%, and 10% COHb Blood samples were collected prior to the study to determine the amount of carbon monoxide required to reach the target COHb levels. Participants breathed oxygen for 3 min, and then breathed a mixture of carbon monoxide and oxygen for 5 min. Participants were then taken to an experimental chamber, with 45 ppm carbon monoxide in the 7% COHb condition and 65 ppm in the 10% COHb condition.
Task:	Participants sat or exercised in the experimental chamber for 50 minutes. In the exercise condition, participants walked on a treadmill at either 35% or 60% of their maximum aerobic capacity. Participants then set for 5 min before completing five cognitive tasks measuring spatial processing, psychomotor tracking, short-term memory, arithmetic reasoning, visual search, and response inhibition. Participants then completed the Environmental Systems Questionnaire in which they indicated the extent to which they felt specific somatic systems during exposure.

Title:	**Interactive effects of physical work and carbon monoxide on cognitive task performance**		
Author(s):	Bunnell, D.E. and Horvath, S.M.		
Journal:	*Aviation, Space, and Environmental Medicine*, December, 1133-1138	**Year:**	1988
Results			
Participants reported no increase in symptoms with increasing levels of COHb, suggesting that participants could not tell when they were exposed to carbon monoxide. A cognitive effect of carbon monoxide exposure was reported in participants' responses to the second of two sequentially presented Stroop tasks, such that participants were hindered in their ability to learn a new response set. There was also an interaction of COHb level and exercise on visual search performance, with high levels of work (i.e., 60% exertion) at elevated COHb levels resulting in poorer performance.			
Implications	COHb levels as high as 10% can be tolerated, even with physical work, with minor performance decrements in cognitive function		

Title:	**Human performance of a psychomotor test as a function of exposure to carbon monoxide**		
Author(s):	Hanks, T.G.		
Journal:	*Annals of the New York Academy of Sciences*, 174(1), 421-424	**Year:**	1970
Purpose:	Determine whether carbon monoxide exposure in traffic affects driving judgment and control		
Participants:	Nonsmoking, healthy young male university students (Note: the number of participants was not specified)		
Exposure:	0, 25, 50, 75, and 100ppm carbon monoxide. Breath samples measured for carbon monoxide content before exposure and every 30 minutes during exposure, which lasted 4½ hours.		
Task:	Critical tracking task		
Results			
There was no effect of carbon monoxide exposure on tracking performance.			
Implications	Exposure to carbon monoxide at levels up to 100 ppm (14.6% CoHB) did not result in decrements in tracking performance		

Title:	**Neurorimaging, cognitive, and neurobehavioral outcomes following carbon monoxide poisoning**		
Author(s):	Hopkins, R.O. and Moon. F.L.M.		
Journal:	*Behavioral and Cognitive Neuroscience Reviews*, 5, 141-155	**Year:**	2006
Purpose:	To report on neurological and cognitive impairments resulting from carbon monoxide poisoning		
Results and Implications	The focus of this review was on the effects of carbon monoxide-poisoning. The literature shows that carbon monoxide-poisoning leads to impairments in memory, executive function, mental processing speed, intellectual function, and attention, but the onset and severity of the impairments vary from individual to individual. Thus, a consistent pattern of cognitive deficits due to carbon monoxide-poisoning has not been found. There is no consistent criterion for characterizing less severe carbon monoxide poisoning, e.g., carbon monoxide exposure. COHb levels range from 1% to 15%, with few studies assessing the cognitive effects.		

Title:	**Carbon monoxide and human vigilance**		
Author(s):	Horvath, S.M., Dahms, T.E., and O'Hanlon, J.F.		
Journal:	*Archives of Environmental Health*, 23, 343-347	**Year:**	1971
Purpose:	To determine whether the levels of carbon monoxide found in the urban atmosphere affect visual vigilance		
Participants:	10 healthy males between 21 and 34 years old		
Exposure:	The experiment consisted of three test sessions, one week apart. Participants inhaled a different gas mixture in each session, containing 0, 26, or 111 ppm carbon monoxide. During exposure, participants breathed the gas mixture for one hour before performing a monitoring task. Participants were also exposed to the gas while performing the task. COHb levels approached 0.8% in the control condition, 2.3% with 26 ppm exposure, and 6.6% in the 111 ppm condition.		
Task:	Participants were asked to perform a monitoring task that required them to judge and discriminate between visual light signals and nonsignals. In the first part, participants were shown 10 signals interspersed among 50 nonsignals. In the second part, they were shown 10 signals within 290 nonsignals for four 15-minute periods.		
Results			
There was no effect of carbon monoxide exposure in monitoring task performance at when the exposure level was 26 ppm relative to the control condition (0 ppm). Carbon monoxide exposure at 111 ppm (COHb levels of 6.6%) increased the effects of monotony and led to accuracy decrements in detecting signals over the two-hour period. Heart rates and respiratory functioning was not affected.			
Implications	Carbon monoxide exposure combined with monotony during driving could lead to less efficient performance of routine tasks and inability to cope with unexpected events.		

Title:	**Carbon monoxide: A danger to the driver?**		
Author(s):	Mayron, L.W. and Winterhalter, J.J.		
Journal:	*Journal of the Air Pollution Control Association*, 26(11), 1085-1088	**Year:**	1976
Purpose:	To determine carbon monoxide levels at intersections, busy streets and expressways, and in cars		
Method:	Measured carbon monoxide levels in the inside of an idling car from the driver's seat, in ventilating air entering the car, and in the ambient air at busy traffic locations and intersections		
Results			
Measurements of carbon monoxide, collected in Southern California under standard driving conditions generally show levels less than 25ppm carbon monoxide. The highest concentration of carbon monoxide measured was 45ppm for a 3-minute period. High concentrations (3-5%) of carboxyhemoglobin (resulting from exposure to 18-32 ppm carbon monoxide) may have adverse effects on the detection of small environmental changes. However, the impact on driving performance is not clear. The effect of carbon monoxide levels found in cars is dependent on how much time the driver spends in his/her car at one time and cumulatively. Carbon monoxide levels were measured in 51 cars; two were extremely high (70ppm and over 100ppm), and 9 had levels higher than the 8-hour standard of 9ppm. This ambient air standard may be exceeded regularly, depending upon wind direction, wind strength, and traffic density. Readings of carbon monoxide levels in ventilating air ranged from 2 to 36 ppm. In traffic, the carbon monoxide level varied from 25ppm to a high enough level to produce nausea and dizziness when traffic was stop-and-go. At busy intersections, the values of carbon monoxide ranged from 3-60 ppm. The main predictor of carbon monoxide levels is traffic delay. The actual amount of exposure to the driver is unknown.			
Implications	It is not clear whether carbon monoxide exposure leads to car accidents, but measurements of carbon monoxide levels in cars suggest that it may be a contributing factor.		

Title:	**Low level exposure to carbon monoxide and driving performance**		
Author(s):	McFarland, R.A.		
Journal:	*Archives of Environmental Health*, 27, 355-359	**Year:**	1973
Purpose:	Examine the effects of low levels of carbon monoxide on human performance and on driving		
Participants:	27 participants ranging in age from 20-50 years old		
Exposure:	17% COHb, 11% COHb, and no carbon monoxide exposure A blood sample and alveolar sample were collected at the start of the experiment to determine initial COHb levels. Participants were then given normal room air or a mixture of 700 ppm carbon monoxide using a 500-liter gasometer; participants exhaled into a second gasometer to measure the amount retained. Each participant was exposed to carbon monoxide until one of the three levels was reached.		
Task:	In the first phase of the study, participants completed laboratory tests measuring psychomotor reactions in dual-task performance, dark adaptation and glare recovery, peripheral vision, and depth perception. In the second phase, participants drove an automobile on an unopened, divided highway.		
Results			
The psychomotor task required participants to respond to concurrent tasks appearing in the central field of vision and in the periphery. Performance on the central task showed no effect of carbon monoxide exposure, but performance on the peripheral task showed evidence of attentional lapses; participants failed to respond to the peripheral task if it appeared close in time to the central task more frequently at COHb levels of 17% and less so at 11%. There was no clear effect of carbon monoxide exposure on dark adaptation or glare recovery. The peripheral vision task required participants to look directly at a point while responding to lights in different patterns presented at 10º, 20º, and 30º from the center field of view. The results showed that participants missed more lights that appeared at a 20º point from the line of sight at a 17% COHb level than under control conditions. There was no difference at other levels or at other points. There was no difference in depth perception as a function of COHb levels. Participants' visual information processing while driving was measured using a visual interruption apparatus that consisted of a helmet with a translucent face shield which moved up and down. While participants generally required more visual information at higher speeds (i.e., 50 mph) than lower speeds (i.e., 30 mph), under conditions of carbon monoxide exposure, participants required more roadway viewing at higher speeds than without carbon monoxide.			
Implications	COHb levels of 11% and 17% have slight effects on visual information processing, leading drivers to focus more attention on information in the forward field of view and consequently, miss information in peripheral vision.		

Title:	**Carbon monoxide exposure and information processing during perceptual-motor performance**		
Author(s):	Mihevic, P.M., Gliner, J.A., and Horvath, S.M.		
Journal:	*International Archives of Occupational and Environmental Health*, 51, 353-363	**Year:**	1983
Purpose:	Examine the effects of carbon monoxide exposure on dual-task motor performance		
Participants:	16 participants between 20 to 36 years old		
Exposure:	Participants were seated in an 1.85 m x 1.85 m x 2.46 m chamber with clear walls. Carbon monoxide was mixed into the air stream from a tank containing 10% carbon monoxide in nitrogen (approximately 100 ppm).		

Title:	**Carbon monoxide exposure and information processing during perceptual-motor performance**		
Author(s):	Mihevic, P.M., Gliner, J.A., and Horvath, S.M.		
Journal:	*International Archives of Occupational and Environmental Health*, 51, 353-363	**Year:**	1983
Task:	Participants were seated in the environmental chamber for 2 ½ hours. In the first 1½-hour, participants sat in the chamber. In the last hour, participants completed a reciprocal tapping task, the reciprocal tapping task in conjunction with a digit identification task, and the reciprocal tapping task in conjunction with a digit subtraction task. In the reciprocal tapping task, participants tapped a stylus alternatively between two metal targets on a board. The task difficulty was manipulated by varying the width of the target (0.35 or 0.75cm) and the distance between the targets (5.2, 10.2, 20.5, or 41.0 cm). In the digit identification task, participants were asked to verbally identify the digit (from 0 – 9) that appeared on a circular display, mounted on the board used for the tapping task, showed digits from 0 – 9. In the digit subtraction task, participants subtracted the digit that appeared from 100. Participants completed the tasks in room air and carbon monoxide conditions, the order of which was counterbalanced).		
Results			
Performance on the primary tapping task did not vary as a function of whether it was performed alone or in conjunction with the secondary digit manipulation task (digit identification or digit subtraction). However, performance on the secondary digit manipulation task was higher when it was performed alone than performed in conjunction with the primary task. Carbon monoxide exposure served as a stressor which led to performance decrements on the digit manipulation task at moderate levels of difficulty on the primary tapping task relative to regular room air exposure. There was no difference in primary task performance as a function of carbon monoxide exposure during the digit identification task.			
Implications	Carbon monoxide exposure had minimal effects on motor performance. However, there is some evidence to suggest that as task difficulty increases – hence increasing the attentional demands, carbon monoxide exposure may contribute to deficits if other tasks are performed concurrently.		

Title:	**The effect of carbon monoxide on human performance**		
Author(s):	Mikulka, P., O'Donnell, R., Heinig, P., and Theodore, J.		
Journal:	*Annals of the New York Academy of Sciences*, 174(1), 409–420	**Year:**	1970
Title:	**Low level carbon monoxide exposure and human psychomotor performance**		
Author(s):	O'Donnell, R.D., Mikulka, P., Heinig, P., and Theodore, J.		
Journal:	*Toxicology and Applied Pharmacology*, 18, 593-602	**Year:**	1971
Purpose:	Determine the effects of carbon monoxide exposure on time estimation, tracking, and ataxia		
Participants:	9 male students between 19 and 22 years old		
Exposure:	Experiments were conducted in the Thomas Domes at Wright-Patterson Air Force Base. The domes are enclosed environments, in which air flow at a rate of 40 ft^3/min allows the atmosphere to change completely in a 20-minute time period. There were five exposure levels – 0, 50, 125, 200, and 250 ppm carbon monoxide, resulting in mean COHb levels of 0.96% at no exposure, 2.98% at 50 ppm, 6.64% at 125 ppm, 10.35% at 200 ppm, and 12.37% at 250 ppm.		

Title:	**The effect of carbon monoxide on human performance**		
Author(s):	Mikulka, P., O'Donnell, R., Heinig, P., and Theodore, J.		
Journal:	*Annals of the New York Academy of Sciences*, 174(1), 409–420	**Year:**	1970
Task:	Participants completed 3 3-hour sessions at carbon monoxide-levels of 0, 50, and 125 ppm. Participants were given a 15-minute rest period and then asked to complete a series of tracking and time estimation tasks. In the tracking task, participants manipulated a control stick to keep a needle on a display dial from going off scale. In the time estimation task, participants estimated 10 second time-intervals for a 3-minute time period by tapping on an electric switch. At the end of the exposure period, blood samples were collected, and participants completed the Pensacola Ataxia battery, which comprises of a set of balancing tasks.		
Results			
The results showed no effect of carbon monoxide exposure on tracking performance or time estimation ability; rather performance on the tasks improved over time. Additionally, carbon monoxide exposure did not affect participants' balance.			
Implications	Low levels of carbon monoxide exposure do not lead to a performance decrement		

Title:	**Effect of carbon monoxide exposure on human sleep and psychomotor performance**		
Author(s):	O'Donnell, R.D., Chikos, P., and Theodore, J.		
Journal:	*Journal of Applied Physiology*, 31(4), 513-518	**Year:**	1971
Purpose:	To analyze the effects of carbon monoxide exposure on sleep patterns and subsequent performance		
Participants:	4 non-smoking, male Air Force personnel with altitude training		
Exposure:	Exposure was conducted in the Thomas Domes at Wright-Patterson Air Force Base. Participants slept for nine nights in the Thomas dome. The first four nights were used to adapt the participant to the dome. Over the next five nights, participants were presented with two exposures, either to 75 of 150 ppm carbon monoxide. Each "exposure" night was followed by one night of "clean air", and the final night served as a control condition where no carbon monoxide was given. Carboxyhemoglobin levels reflected a relationship with the level of carbon monoxide exposure; 0.6% in the control condition, 5.9% in the 75-ppm condition, and 12.7% at 150 ppm.		
Task:	Electrophysiological measures were collected each night. In the mornings, participants performed a series of performance tasks to measure visual function (e.g., critical flicker fusion), mental arithmetic, tracking performance, and time estimation.		
Results			
There was no effect on sleep. In fact, participants experience more periods of "deep sleep" and less light sleep under carbon monoxide exposure than in the control condition. Performance measurements also showed no effect of carbon monoxide exposure.			
Implications	Carbon monoxide did affect sleep, increasing the amount of deep sleep, but these changes did not affect subsequent cognitive functioning.		

Title:	**Memory disturbances following chronic, low-level carbon monoxide exposure**		
Author(s):	Ryan, C.M.		
Journal:	*Archives of Clinical Neuropscyhology*, 5, 59-67	**Year:**	1990
Purpose:	Demonstrate transient decrements in cognitive function may occur with carbon monoxide exposure		
Participants:	48-year old right-handed married female with a 3-year history of headaches, lethargy, and memory problems		
Exposure:	Approximately 180 ppm carbon monoxide, possibly due to exposure from her furnace		
Task:	Pittsburgh Occupational Exposures Test Battery, which consisted of a set of cognitive tests including incidental memory (requiring recall of digit-symbol pairs), recognition of recurring words, verbal learning (requiring learning pairs of unrelated words), word association, symbol digit learning, short- and long-term memory (copy a design and recall it 30 minutes later)		
Results			
Prior to exposure, the subject held a job that required heavy concentration and memory skills, but following exposure, the subject was not able to track verbal information and visual information presented within 30 minutes. While it cannot be ruled out that the subject is suffering from a medical disease that disrupts memory, it is more likely that this memory deficit is due to a three-year low-level carbon monoxide exposure.			
Implications	Long duration exposure to low-levels of carbon monoxide could lead to decrements in concentration and memory.		

Title:	**Experimental human exposure to high concentrations of carbon monoxide**		
Author(s):	Stewart, R.D., Fisher, T.N., Baretta, E.D., and Herrmann, A.A.		
Journal:	*Archives of Environmental Health*, 26, 1-7	**Year:**	1973
Participants:	6 healthy male volunteers		
Exposure:	13 carbon monoxide exposure levels ranging from 1,000 ppm for 10 min to 30,400 ppm for 1 min. COHb levels ranged from 3.2% to 15.2%.		
Task:	A physical examination was performed to collect baseline information including cardiovascular data (ECG) at rest and after 3-minutes of exercise on a stationary bicycle and blood samples. During exposure, participants sat in a slightly reclined position, and their heart rate, respiratory rate, brain activity (EEG), and visual evoked response (VER) were monitored. Following exposure, participants were given 100% oxygen for 20 minutes. A physical examination was performed again 16 hours after exposure and one week following exposure.		
Results			
Two participants reported headaches following high levels of exposure (15,000 ppm for 2 min and 30,000 ppm for 1 min resulting in COHb levels of 11.6% and 9.1%) and one noted a pounding sensation (35,600 ppm for 45 seconds). There was no change in participants' cardiovascular function (ECGs), blood pressure, heart rate, or brain activity (EEG) following exposure.			
Implications	Carbon monoxide was rapidly absorbed during exposure, and this abrupt increase (as measured by the COHb concentration) led to headaches in three participants. There was no change in cardiovascular, respiratory, or brain activity.		

Title:	**Experimental human exposure to carbon monoxide**		
Author(s):	Stewart, R.D., Peterson, J.E., Baretta, E.D., Bachand, R.T., Hosco, M.J., and Herrmann, A.A.		
Journal:	*Archives of Environmental Health*, 21, 154-164	**Year:**	1970
Participants:	18 healthy males ranging from 24 – 42 years old		
Exposure:	< 1, 25, 50, 100, 200, 500, and 1,000 ppm for 30 minutes to 24 hours		
Task:	Blood samples were collected, and participants completed tasks to measure time estimation, reaction time, hand steadiness, manual dexterity, brain activity, visual activity, and cardiovascular activity.		
Results			
The data showed no subjective symptoms or objective evidence of decrements in task performance during exposure levels less than 100 ppm of carbon monoxide over an 8-hour period (a COHb saturation of 11% to 13%). Carbon monoxide exposure at a level of 200 ppm for four hours (leading to a COHb level of 15% to 20%) led to reports of headaches in the final hour, but there was no change in task performance. Exposure to higher carbon monoxide-levels (500 and 1,000 ppm, COHb saturation close to 30%) also led to subjective reports of headaches, the onset of which typically occurred within 1-2 hours of exposure, with minimal levels of exertion increasing the pain. At these higher levels of carbon monoxide exposure, changes in participants' visual evoked response (VER) and poorer manual dexterity were noted.			
Implications	Poorer dexterity at high levels of carbon monoxide exposure (i.e., 1,000 ppm) could potentially lead to mechanical driving errors (e.g., shifting gears).		

Title:	**Carbon monoxide and driving skills**		
Author(s):	Wright, G., Randell, P., and Shephard, R.J.		
Journal:	*Archives of Environmental Health*, 27, 349-354	**Year:**	1973
Purpose:	To examine the effect of carbon monoxide exposure on tasks of driving skill		
Participants:	50 adult volunteers		
Exposure:	Half the participants breathed in 80 ml of carbon monoxide, added to a rebreathing system at a 2% concentration level, and the other half received no exposure (control group)		
Task:	Before exposure, the level of carboxyhemoglobin in the blood was measured using a rebreathing method. Participants then completed a set of driving tests evaluating brake reaction time, night vision, glare vision, glare vision recovery, hand steadiness, and depth perception followed by a period on the driving simulator. Participants were then randomly distributed into two groups, with some receiving carbon monoxide (experimental condition) and some clean air (control condition). Participants then repeated the driving tests and simulation task.		
Results			
Carbon monoxide exposure increased COHb levels by 3.4% relative to initial values. This difference led to significant performance decrements in the driving simulator for participants in the experimental condition post-exposure. When comparing performance pre-and post-exposure, the control group (no exposure) exhibited more careful driving habits (e.g., releasing the parking break, using the turn signals). The exposure group, however, showed less improvements with respect to their previous performance and when compared to the performance of the control group. These performance decrements are attributed to impaired judgment due to a lack of cerebral oxygen. There was no effect on performance on the driving tests due to carbon monoxide exposure.			
Implications	A 3.4% increase in carboxyhemoglobin levels may be expected through carbon monoxide exposure to 100 ppm for two hours or 50 ppm for five hours. Truck drivers, regularly exposed to exhaust fumes, may experience these high carbon monoxide concentrations, which may impair safe driving habits.		

B.3 Cognitive Effects of Exposure to Jet Fuel Vapors

Title:	**Jet Fuel Intoxication**		
Author(s):	Davies, N.E.		
Journal:	*Aerospace Medicine*, May, 481-482	**Year:**	1964
Purpose:	To report a case of in-flight intoxication due to jet fuel		
Participants:	32-year old male Air Force pilot		
Exposure:	Pilot flying a T-33A (two seated jet trainer) was exposed to what was estimated to be 3000 to 7000 ppm JP-4 fuel vapors for approximately 7 minutes		
Task:	Flight from Craig Air Force Base, Alabama, to Dover Air Force Base, Delaware, with an emergency landing at Dobbins Air Force Base, Georgia		
Results			
At 15,000 feet, pilot began to feel groggy and switched regulator to 100% oxygen. At 20,000 feet, he felt weak and decided to land as quickly as possible. Symptoms showed a slight stagger in his gait, mild headache, slurred speech, and mild muscle weakness.			
Implications	There are large individual differences with respect to hydrocarbon intoxication. Mild symptoms include giddiness, slurred speech, poor coordination, nausea, and mild euphoria. These may be followed by a headache, mild depression, throat irritation, or staggering. Severe cases lead to dyspnea, cyanosis, and coma.		

Title:	**Long-term exposure to jet fuel** **An investigation on occupationally exposed workers with special reference to the nervous system.**		
Author(s):	Knave, B., Persson, H.E., Goldberg, J.M., and Westerholm, P.		
Journal:	*Scandinavian Journal of Work Environment and Health*, 3, 152-164	**Year:**	1976
Purpose:	To examine the effects of long-term exposure to jet fuel on the nervous system		
Participants:	29 aircraft factory workers, of which 13 were considered “heavily exposed” and 16 were considered “less heavily exposed”		
Exposure:	All had been exposed for at least 5 years of employment. The "heavily exposed” group experienced continuous exposure to high concentrations of jet fuel fumes for several hours every day, for at least 20-30 minutes each time. The “less heavily exposed” group reported a more intermittent pattern of exposure than the heavily exposed group, with several days of heavy exposure followed by weeks or months without exposure.		
Task:	Participants provided a personal history (heredity, previous health, occupational history, smoking, symptoms, etc.) and completed a neurological examination.		
Results			
All participants in the heavily exposed group reported symptoms of exposure consisting of dizziness (77%), headache (23%), nausea (31%), respiratory tract irritation (46%), and palpitations and pressure on the chest (23%). In the less heavily exposed group, 44% of the participants reported symptoms, ranging from dizziness (31%), headache (31%), nausea (13%), respiratory tract irritation (19%), and palpitations and pressure on the chest (13%). There were no significant differences found between the two groups from the neurological tests, but it is likely that there current sample was too small to show such an effect. A comparison of the jet fuel exposed workers to several other occupational groups (workers in a storage battery factory, workers in heavy metals industry) showed an increase in symptoms of neurasthenia (a lack of the central nervous system’s energy reserves) and polyneuropathy (a neurological disorder in which the peripheral nerves throughout the body malfunction).			

Title:	**Long-term exposure to jet fuel** **An investigation on occupationally exposed workers with special reference to the nervous system.**		
Author(s):	Knave, B., Persson, H.E., Goldberg, J.M., and Westerholm, P.		
Journal:	*Scandinavian Journal of Work Environment and Health*, 3, 152-164	**Year:**	1976
Implications	Heavily exposed workers were more likely to report symptoms of exposure than less heavily exposed workers. Additionally, jet fuel exposed workers were more likely to report symptoms of potential neurological disorders than a reference group of non-jet fuel exposed workers. However, information regarding the fuel concentrations in the air when the symptoms occurred was not available.		

Title:	**Neurasthenic symptoms in workers occupationally exposed to jet fuel**		
Author(s):	Knave, B., Mindus, P., and Struwe, G.		
Journal:	*Acta Psychiatry Scandinavia*, 60, 39-49	**Year:**	1979
Title:	**Long-term exposure to jet fuel** **II. A cross-sectional epidemiologic investigation on occupationally exposed industrial workers with special reference to the nervous system.**		
Author(s):	Knave, B., Olson, B.A., Elofsson, S., Gamberale, F., Isaksson, A., Mindus, P., Persson, H.E., Struwe, G., Wennberg, A., and Westerholm, P.		
Journal:	*Scandinavian Journal of Work Environment and Health*, 4, 19-45	**Year:**	1978
Purpose:	To examine the effects of long-term exposure to jet fuel on the nervous system		
Participants:	30 jet fuel exposed workers and 30 nonexposed workers (control)		
Exposure:	Mean exposure time for experimental group was 17.7 years and control group was 19.8 years. Measured by time of employment, analysis of work practices, and measurements of airborne fuel contents during exposure		
Task:	Interviews; psychological tests of reaction time addition, simple reaction time, memory, manual dexterity, and perceptual speed; and neurophysiological measurements (EEGs)		
Results			
Only four participants in the exposure group did not indicate any symptoms on exposure. Twenty-one of the 30 participants in the exposure group indicated they had experienced symptoms such as dizziness, headache, nausea, respiratory tract symptoms, palpitations, and thoracic oppression. Thirteen of the participants indicated feeling fatigued while working with jet fuel and in the evenings. A comparison of symptoms reported between the two groups also showed that those in the exposed group reported more depression, lack of initiative, palpitations, and sleep disturbances. The psychological test results showed participants in the exposure group had poorer performance on reaction time and perceptual speed tasks (i.e., those tasks with high attentional demand) but no difference attributable to exposure on memory or manual dexterity.			
Implications	Exposure in the work context studied here was relatively stable. 87% of the participants in the experimental group reported recurrent symptoms due to exposure (depression, fatigue, lack of initiative, dizziness were most common). Additionally, psychological testing showed greater variability in performance for participants in the experimental group relative to the control group for complex reaction time, greater decrement in performance over time on tasks of simple reaction time, and poorer perceptual speed performance.		

Title:	**Developmental neurobehavioral effects on JP-8 jet fuel on pups from female Sprague-Dawley rats exposed by oral gavage**		
Author(s):	Mattie, D.R., Cooper, J.R., Sterner, T.R., Schimmel, B.D., Bekkedal, M.Y.V., Bausman, T.A., and Young, S.M.		
Journal:	United States Air Force Research Laboratory	**Year:**	2001
Purpose:	To examine the effects of prenatal JP-8 exposure on central nervous system development		
Participants:	140+ female rats		
Exposure:	0, 325, 750, 1500 mg/kg JP-8 daily by gavage (minimum of 35 female rats in each condition)		
Task:	Tests of neurobehavioral development were conducted on the 68 litters consisting of 4 male and 4 female pups. Pups performed tasks requiring them to turn over, raise their head, swim, and complete a water maze.		
Results			
The results showed no difference in neurobehavioral development on simple tasks (e.g., turning over and raising one's head) or in completing the water maze. However, dose-related effects were found for swimming ability, such that pups exposed to jet fuel showed poorer performance initially than non-exposed pups although performance between the two groups equalized over time. This result suggests that exposure to jet fuel may delay brain development in areas of motor coordination, but that these effects disappear at later ages.			
Implications	Exposure to JP-8 jet fuel may delay cerebellum development in pups but this effect is not lasting.		

Title:	**Cognitive neurobehavioral toxicity assessment of three hydrocarbon fuels**		
Author(s):	Nordholm, A.F.		
Journal:	U.S. Army Medical Research and Materiel Command: Fort Detrick, Maryland	**Year:**	1998
Purpose:	Examine the effects of jet fuel exposure (JP-8, JP-4, and JP-5) on rats to determine neurobehavioral changes		
Participants:	32 Sprague-Dawley rats		
Exposure:	Whole-body inhalation of JP-8 (1.0 mg/L±10%) or JP-5 (1.2 mg/L±10%) vapor for 6 hours/day, 5 days/week for 6 weeks; to JP-4 (2.0 mg/L±10%) vapor for 6 hours/day for 14 days; or to a control condition. Concentrations were representative of real world vapor exposures experienced by operational military. Rats were rested 14-65 days after exposure to minimize the neurobehavioral effects resulting from physiological irritance or stress during exposure and to examine the presence of neurobehavioral deficits resulting several weeks post-exposure.		
Task:	Neurobehavioral Toxicity Assessment Battery (NTAB), which consisted of 10 tests that evaluated muscle strength, locomotion, physical fatigue, nociception (i.e., pain perception), auditory brainstem function, short-term memory, emotional depression, spatial localization, short-term memory, central nervous system sensitization, and social behavior.		

Title:	**Cognitive neurobehavioral toxicity assessment of three hydrocarbon fuels**		
Author(s):	Nordholm, A.F.		
Journal:	U.S. Army Medical Research and Materiel Command: Fort Detrick, Maryland	**Year:**	1998
Results			
In the “long-term” (i.e., 60 days), exposure to the vapors led to no changes in neurology or behavior. However, 14-days post-exposure to JP-4 vapor for 6 hours/day led to a significant decrease in the rats’ response to pain, their acoustic startle response, and locomotion, and a significant increase in approaching “novel” food stimulus; this finding is consistent with an increase in dopamine and/or serotonin levels in the brain. Exposure to JP-8 also resulted in a significant increase in approaching “novel” food stimulus and significant increase in muscle strength, consistent with changes in the dopamine and DOPAC levels in several brain regions. JP-5 exposure led to no significant deficits on the NTAB tests. Exposure to the vapors reduced weight gains relative to rats in the control group; during exposure, rats in the experimental conditions weighed less than the control groups, but recovered their weight rapidly once the exposure period ended.			
Implications	Exposure (of rats) to JP-4, JP-6, or JP-8 vapors from 14-30 days may cause neurological and behavioral changes. Increased dopamine and/or serotonin levels due to JP-4 and JP-8 exposure have cognitive implications although it is not clear what that effect is. The results suggest that JP-4 has the greatest risk on neurological functioning and behavior, with the effect of JP-8 being greater than or equal to that of JP-5. Additional research is needed to determine if these humans will experience these same effects.		

Title:	**Audiological and vestibulo-oculomotor findings in workers exposed to solvents and jet fuel**		
Author(s):	Ödkvist, L.M., Arlinger, S.D., Edling, C., Larsby, B., and Bergoltz., L.M.		
Journal:	*Scandinavian Audiology*, 16, 75-91	**Year:**	1987
Title:	**Audiological findings in solvent-exposed workers**		
Author(s):	Bergoltz., L.M. and Ödkvist, L.M.		
Journal:	*Acta Otolaryngologica Supplementum*, 412, 109-110	**Year:**	1984
Purpose:	Examine the effects of occupational exposure to solvents/jet fuel on the central and peripheral nervous systems		
Participants:	3 participant groups: (A) 16 participants with diagnosis of solvent-induced psychoorganic syndrome based on neurophysiological and psychological testing (B) 7 participants with suspected psychoorganic syndrome (neurasthenic symptoms) but normal findings on psychological tests (C) 8 participants with significant exposure to jet fuel but free from psychoorganic syndrome		
Exposure:	(A) Participants were paint mixers, construction painters, spray painters, printers, and truck drivers with a range of exposure from 9 – 40 years. All participants had been free from exposure for at least 2 years (B) House painters, spray painters, and tanker drivers with a range of exposure time from 5 – 30 years (C) Aircraft mechanics with a range of exposure from 15 – 41 years		
Task:	Audiological and vestibular tests		

Title:	**Audiological and vestibulo-oculomotor findings in workers exposed to solvents and jet fuel**		
Author(s):	Ödkvist, L.M., Arlinger, S.D., Edling, C., Larsby, B., and Bergoltz., L.M.		
Journal:	*Scandinavian Audiology*, 16, 75-91	**Year:**	1987
Results			
The test results suggest potential disturbances in the central nervous system as a consequence of exposure to solvents. In particular, participants' performance on the test suggest that greater exposure increases the likelihood of lesions in the auditory cortex and brainstem. Decrements in performance were found on those tests evaluating the functional state of the cerebellum rather than tests of simple reflexes.			
Implications	The results suggests a dose-effect relationship with greater levels of exposure resulting in an increased likelihood of psychoorganic syndrome and neurasthenic symptoms.		

Title:	**Aviators intoxicated by inhalation of JP-5 fuel vapors**		
Author(s):	Porter, H.O.		
Journal:	*Aviation, Space, and Environmental Medicine*, July, 654 – 656	**Year:**	1990
Purpose:	To report two cases of inhalation of JP-5 fuel vapors		
Participants:	Two pilots (instructor and student)		
Exposure:	Two pilots were exposed to jet fuel vapors in a T-34C, unpressurized aircraft		
Task:	Radio instrument night-training flight		
Results			
Pilots reported irritation to the eyes and euphoria (even after the instructor pilot notified the student pilot of the emergency), and experienced difficulty walking after exiting the aircraft and filling out familiar forms. Both appeared fatigued but a physical examination indicated that they were normal.			
Implications	Pilots have reported JP-5 exposure-related symptoms such as transient memory loss (e.g., difficulty remembering emergency procedures), lightheadedness, and "slow thinking". Jet fuel exposure has led to errors by experienced pilots in navigation and communication.		

Title:	***Biological and Health Effects of JP-8 Exposure***		
Author(s):	Ritchie, G.D., Bekkedal, M.Y.V., Bobb, A.J., and Still, K.R.		
Journal:	Naval Health Research Center Detachment Toxicology: Wright Patterson Air Force Base, OH	**Year:**	2001
Purpose:	To summarize the human, animal, and in vitro studies examining the biological and neurological health effects due to acute or long-term exposure to JP-8 and its chemical constituents		
Implications	Long-term occupational exposure to JP-8 jet fuel vapors could lead to deficits in cerebellar functioning (e.g., eye-blink responses, balance).		

Title:	**Effect of chronic low-level exposure to jet fuel on postural balance of U.S. Air Force Personnel**		
Author(s):	Smith, L.B., Bhattacharya, A., Lemasters, G., Succop, P., Puhala II, E., Medvedovic, M., and Joyce, J.		
Journal:	*Journal of Occupational and Environmental Medicine*, 39(7), 623-632	**Year:**	1997
Purpose:	To examine the effect of low-level exposure to JP-8 jet fuel vapors on postural stability		
Participants:	27 United States Air Force aircraft maintenance personnel (20 male, 7 female) served in the		

Title:	**Effect of chronic low-level exposure to jet fuel on postural balance of U.S. Air Force Personnel**		
Author(s):	Smith, L.B., Bhattacharya, A., Lemasters, G., Succop, P., Puhala II, E., Medvedovic, M., and Joyce, J.		
Journal:	*Journal of Occupational and Environmental Medicine*, 39(7), 623-632	**Year:**	1997

	experimental group; 25 unexposed participants (14 male, 11 female) from the military, university, and other sources served as the control group
Exposure:	8-hour breathing zone samples were collected from each participant in the occupational group
Task:	Postural sway, measured on a force platform, to determine the effects of the proprioceptive, visual, and vestibular systems on balance. Participants stood on the platform with their eyes open and closed and then stood on a 4-inch foam over the platform with their eyes open and closed.
Results	
Participants balance decreased (i.e., sway increased) as exposure level increased. The neurotoxic effect of jet fuel vapor exposure could be seen at low-levels of exposure (e.g., the level received when opening a storage tank).	
Implications	The effect of jet fuel vapor inhalation on proprioception has safety consequences, e.g., for workers in dark areas and slippery surfaces. Long-term exposure could lead to degraded neurological functions.

B.4 Other Health Effects of Diesel Exposure

Title:	**Environmental and clinical investigation of workmen exposed to diesel exhaust in railroad engine houses**		
Author(s):	Battigelli, M.C., Mannella, R.J., and Hatch, T.F.		
Journal:	*Industrial Medicine and Surgery*, March, 121-124	**Year:**	1964
Purpose:	To investigate the clinical and physiological effects of diesel exhaust exposure on railroad workers		
Notes:	Physical examination, chest x-rays, ECGs, spirometry, and medical histories were collected for 364 railroad workers (210 exposed engine repairmen, 154 railroad workers). The results showed no differences in pulmonary functions or chest abnormalities due to exposure.		

Title:	**Health problems resulting from prolonged exposure to air pollution in diesel bus garages**		
Author(s):	El Batawi, M.A. and Noweir, M.H.		
Journal:	*Industrial Health*, 4, 1-10	**Year:**	1966
Purpose:	To evaluate environmental conditions in two bus garages and to examine the effect on workers' health		
Notes:	Measurements of gases and vapors in the garages were below the known threshold levels. 161 workers were examined to determine the health effects. Workers complained of irritation of the eyes (42%) and throat (19%) from gases and fumes, dyspepsia (25.5%), and cough and sputum (10.6%). Clinical examination indicated that 13.7% of the workers showed signs of upper respiratory tract disease, 8.7% had chronic bronchitis, and 4.3% had asthma. These levels are higher than those found in similar working groups without diesel exposure (8.9% for URT, 5.6% chronic bronchitis, and 1.1% asthma). The number of cases of gastritis and peptic ulcer was also higher than expected (14.3%). Finally, 29.8% of workers had high blood pressure (over 150 mmHG systolic and 80mmHG diastolic); for those working night shifts, the rate was 39.6%.		

Title:	**Acute changes in pulmonary function in salt miners**		
Author(s):	Gamble, J., Jones, W., Hudak, J., and Merchant, J.		
Journal:	*Industrial Hygiene for Mining and Tunneling – Proceedings of an ACGIH Topical Symposium* (11/6-7/78), 119-128	**Year:**	1978
Purpose:	To examine dose-response relationship of particulate and/or NO_2 exposure over work shifts		
Notes:	There was no relationship found between pulmonary function due to particulate and/or NO_2 exposure		

Title:	**Epidemiological-environmental study of diesel bus garage workers: Chronic effects of diesel exhaust on the respiratory system**		
Author(s):	Gamble, J., Jones, W., and Minshall, S.		
Journal:	*Environmental Research*, 44, 6-17	**Year:**	1987
Purpose:	To determine the relationship between diesel exposure and respiratory symptoms, cardiac function, and pulmonary function in diesel bus garage workers		
Notes:	Diesel-exposed workers had a higher prevalence of coughing, phlegm, and wheezing than a comparison group, but there was no association with length of time in the occupation. Pulmonary function decreased as tenure increased. There was no effect found on cardiac function.		

Title:	**Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects**		
Author(s):	Health Effects Institute	**Year:**	1995
Purpose:	To evaluate the evidence examining the potential that diesel emissions cause cancer and to identify information gaps in the literature		
Notes:	Epidemiologic data suggests a weak association between diesel exposure and lung cancer, but it is not clear what the relative risk of diesel exposure is with respect to other lifestyle factors (e.g., smoking, asbestos, diet). Additionally, no studies provide exposure information, i.e., a measurement of exposure for the time period most relevant to the development of lung cancer. Developing markers to measure diesel emissions exposure would help establish a risk assessment for lung cancer.		

Title:	**Acute overexposure to diesel exhaust: Report of 13 cases**		
Author(s):	Kahn, G., Orris, P., and Weeks, J.		
Journal:	*American Journal of Industrial Medicine*, 13, 405-406	**Year:**	1988
Purpose:	To determine the risk of overexposure and its health effects		
Notes:	13 incidents of overexposure at five underground coal mines were identified. Twelve miners reported mucous membrane irritation, headaches, and feeling light-headed. Eight miners indicated feelings of nausea; 4 reported feeling “high” and experiencing heartburn; 3 reported weakness, numbness and tingling in extremities; 2 reported chest tightness; and 2 reported wheezing. These symptoms were resolved within 1-2 days.		

Title:	**Historical estimation of diesel exhaust exposure in a cohort study of U.S. railroad workers and lung cancer**		
Author(s):	Laden, F., Hart, J.E., Eschenroeder, A., Smith, T.J., and Garshick, E.		
Journal:	*Cancer Causes Control*, 17(7), 911-919	**Year:**	2006
Purpose:	To develop a profile of exposure in the railroad industry and to estimate lung cancer risk associated with the exposures		
Notes:	After adjusting for time and differences in the probability and intensity of exposure, the data showed an increased risk of lung cancer deaths for diesel-exposed railroad workers than non-exposed workers		

Title:	**Diesel exhaust inhalation causes vascular dysfunction and impaired endogenous fibrinolysis**		
Author(s):	Mills, N.L., Törnqvist, H., Robinson, S.D., Gonzalez, M., Darnley, K., MacNee, W., Boon, N.A., Donaldson, K., Blomberg, A., Sandstrom, T., and Newby, D.E.		
Journal:	*Circulation,* December 20/27, 3930-3936.	**Year:**	2005
Purpose:	Examine the effects of diesel exhaust inhalation on cardiovascular function (endothelial vasomotor and fibrinolytic function)		
Notes:	30 healthy, male nonsmokers, aged 20-38 years old, were exposed to diesel exhaust generated by an idling Volvo diesel engine. Inhalation of diluted diesel exhaust led to impairments in human vascular functioning, with as little as 1 hour of exposure.		

Title:	**Airway inflammation following exposure to diesel exhaust: a study of time kinetics using induced sputum**		
Author(s):	Nordenhäll, C., Pourazar, J., Blomberg, A., Levin, J-O., Sandström, T., and Ädelroth, E.		
Journal:	*European Respiratory Journal*, 15, 1046-1051	**Year:**	2000
Purpose:	Examine the time kinetics of airway inflammation following exposure to diesel fuel		
Notes:	15 healthy nonsmoking volunteers were exposed to diesel exhaust generated by an idling Volvo diesel engine. Participants alternated between moderate levels of exercise and rest periods for 15-minute intervals. Sputum induction, performed 6 hours and 24 hours after each exposure, showed that diesel exposure led to a time-dependent inflammatory response in the airways.		

Title:	**Urbanization and traffic related exposures as risk factors for schizophrenia**		
Author(s):	Pedersen, C.B. and Mortensen, P.B.		
Journal:	*BMC Psychiatry*, 6(2)	**Year:**	2006
Purpose:	To explore the urban-rural difference in schizophrenia by examining whether traffic-related exposure increases the risk of the disease		
Notes:	Initial examination of the data suggested that geographical proximity to the nearest major road and degree of urbanization had significant effects on the risk of developing schizophrenia. With respect to the former, higher risk levels were found in children living 500-1000 meters from the nearest major road; with respect to the latter, children living in the capital city at the time of their 15th birthday had a greater risk of schizophrenia compared to children living in rural areas. However, further analysis indicated that the degree of urbanization accounted for the effect of geographical distance. That is, traffic-related exposure (e.g., to carbon monoxide, benzene) does not explain urban-rural differences in schizophrenia risk		

Title:	**Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first three years of life among inner-city children**		
Author(s):	Perera, F.P., Rauh, V., Whyatt, R.M., Tsai, W.Y., Tang, D., Diaz, D., Hopener, L., Barr, D., Tu, Y.H., Camann, D., and Kinney, P.		
Journal:	*Environmental Health Perspectives*	**Year:**	2006
Purpose:	To evaluate the effects of prenatal exposure to urban air pollutants on child mental and psychomotor development		
Notes:	Three-year olds with high levels of prenatal exposure to polycyclic aromatic hydrocarbons (PAHs) received lower scores on tests of their mental development than those with lower levels of exposure. This exposure could lead to performance deficits in language, reading, and math in early school years. There was no effect of PAH-exposure on cognitive development observed for children under 3 years of age, nor were there any effects seen with respect to psychomotor development and behavioral issues.		

Title:	**An experimental investigation in animals of the functional and morphologic effects of single and repeated exposures to high and low concentrations of carbon monoxide**		
Author(s):	Preziosi, T.J., Lindenberg, R., Levy, D., and Christenson, M.		
Journal:	*Annals of the New York Academy of Sciences*, 174(1), 369-384	**Year:**	1970
Purpose:	To examine the pathological effects of carbon monoxide and to determine what levels of carbon monoxide in the atmosphere are safe if continuously exposed using animals (dogs)		

Title:	**Coal miners exposed to diesel exhaust emissions**		
Author(s):	Reger, R., Hancock, J., Hankinson, J., Hearl, F., and Merchant, J.		
Journal:	*American Occupational Hygiene*, 26 (1-4), 799-815	**Year:**	1982
Purpose:	To examine differences in respiratory symptoms and pulmonary function between diesel-exposed and non-diesel exposed coal miners.		
Notes:	Underground miners and surface workers at diesel-use mines reported more coughing and phlegm than the control group of non-diesel exposed workers and showed patterns consistent with small airways disease. However, because miners' exposure time and exposure level to diesel emissions is low, no clear link between the health effects and diesel emissions could be made.		

Title:	**Particulate matter exposure in cars is associated with cardiovascular effects in healthy young men**		
Author(s):	Riediker, M., Cascio, W.E., Griggs, T.R., Herbst, M.C., Bromberg, P.A., Neas, L., Williams, R.W., and Devlin, R.B.		
Journal:	*American Journal of Respiratory Critical Care Medicine*, 169, 934-940	**Year:**	2004
Purpose:	To understand the cardiovascular effects of occupational exposure to particulates ($PM_{2.5}$)		
Notes:	Nine young (23 to 30 years old), nonsmoking, North Carolina State Highway Patrol troopers were monitored over 4 days, while working a 3pm to 12am shift. Blood samples were collected before the first shift and 10 to 14 hours after each shift, and the troopers wore electrocardiogram monitors throughout their shift. Air-quality monitors were installed in their vehicles to measure $PM_{2.5}$ levels. The results showed that $PM_{2.5}$ exposure was associated with changes in heart rate variability and inflammatory and coagulatory responses in blood markers.		

Title:	**Diesel Asthma: Reactive airways disease following overexposure to locomotive exhaust**		
Author(s):	Wade III, J.F. and Newman, L.S.		
Journal:	*Journal of Occupational Medicine*, 35(2), 149-154	**Year:**	1993
Purpose:	Report of three cases of railroad workers who developed asthma from diesel exhaust inhalation		

B.5 Measuring Air Quality

Title:	**Heavy-Duty Vehicle Idle Activity and Emissions Characterization Study**		
Author(s):	Baker, R., Ahanotou, D., and Allen, J.D.		
Journal:	N/A	**Year:**	2004
Purpose:	To refine the Texas Commission on Environmental Quality's statewide On-Road Heavy-Duty Vehicle (HDV) Extended Idling Activity Database and Emissions Inventory for different source generators. Truck idling was characterized at different time scales and annual emissions projected through 2030		

Title:	**Methodology for evaluating mobile source air toxic emissions: Transportation project alternatives**		
Author(s):	Claggett, M. and Miller, T.L.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1987, 32-41.	**Year:**	2006
Purpose:	To present a method for computing and evaluating mobile source air toxics (MSATs) emissions among a group of transportation project alternatives		

Title:	**Variability of mobile air toxic emissions factors with MOBILE6.2**		
Author(s):	Claggett, M. and Miller. T.L.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1987, 103-109	**Year:**	2006
Purpose:	To discuss the range of mobile source air toxic (MSAT) emissions factors produced by the MOBILE6.2 model as a function of calendar year, ambient temperature, fuel (gasoline), Reid vapor pressure, and vehicle speed		

Title:	**Air quality measurements inside diesel truck cabs during long term idling**		
Author(s):	Doraiswamy, P., Davis, W.T., Miller, T.L., Lam, N., and Bubbosh, P.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1987, 82-91	**Year:**	2006
Purpose:	To measure air quality inside and outside diesel truck cabs for different truck types in extended idling conditions		

Title:	**Integrating geographic information systems for transportation and air quality models for microscale analysis**		
Author(s):	Hallmark, S. and O'Neill, W.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1551, 133-140	**Year:**	1996
Purpose:	To apply geographic information system (GIS) tools to microscale air quality analysis		

Title:	**Patterns of Drivers' Exposure to Particulate Matter**		
Author(s):	Krausse, B. and Mardaljevic, J.		
Journal:	*Spatial Planning, Urban Form, and Sustainable Transport*. In K. Williams, Ed., (pp. 151-167). Ashgate: Burlington, VT.	**Year:**	2005
Purpose:	To evaluate drivers' exposure to particle emissions in urban traffic conditions		

Title:	**Exposure of trucking company workers to particulate matter during the winter**		
Author(s):	Lee, N.K., Smith, T.J., Garshick, E., Natkin, J., Reaser, P., Lane, K., Lee, H.K.		
Journal:	*Chemosphere*, 61, 1677-1690	**Year:**	2005
Purpose:	To analyze air pollutant concentrations in the workplaces of various trucking companies during the winter		

Title:	**Study of exhaust emissions from idling heavy-duty diesel trucks and commercially available idle-reducing devices**		
Author(s):	Lim, H.		
Journal:	*United States Environmental Protection Agency* (EPA420-R-02-025)	**Year:**	2002
Purpose:	To understand exhaust emissions and fuel consumption due to long-duration idling in different weather conditions and accessory loads		

Title:	**Project level carbon monoxide hot-spot analysis for level of service D intersections**		
Author(s):	Meng, Y. and Niemeier, D.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1641, 73-80.	**Year:**	1998
Purpose:	To present a screening methodology for modeling carbon monoxide concentrations at level of service D intersections using meteorological situation-orientated reference charts		

Title:	**Characteristics and emissions of heavy-duty vehicles in Tennessee under the MOBILES model**		
Author(s):	Miller, T.L., Davis, W.T., Reed, G.D., Doraiswamy, P., and Fu, J.S.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1842/2003, 99-108	**Year:**	2003
Purpose:	To compare characteristics of heavy-duty vehicles in the state of Tennessee with that described by national data in the MOBILE6 model and to propose a new method for classifying vehicles		

Title:	**Corrections to mileage accumulation rates for older vehicles and the effect on air pollution emissions**		
Author(s):	Miller, T.L., Davis, W.T., Reed, G.D., Doraiswamy, P., Tang, A., and Sanhueza, P.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1750, 49-55	**Year:**	2001
Purpose:	To present a model for predicting average cumulative mileage for older vehicles to be used in estimating emissions levels		

Title:	**Effect of county-level income on vehicle age distribution and emissions**		
Author(s):	Miller, T.L., Davis, W.T., Reed, G.D., Doraiswamy, P., and Tang, A.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1815, 47-53.	**Year:**	2002
Purpose:	To analyze trends in the types and ages of vehicles driven in Tennessee relative to national data and to average personal income		

Title:	**Diesel truck idling emissions – measurements at a $PM_{2.5}$ hot spot**		
Author(s):	Miller, T.L., Fu, J.S., Hromis, B., Storey, J.M.E., and Parks, J.E.		
Journal:	*Proceedings of the Transportation Research Board 86th Annual Meeting*	**Year:**	2007
Purpose:	To measure ambient concentrations of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} at the Watt Road interchange on I-40 in Knoxville, TN. There are three large truck stops at this interchange, with up to 400 trucks idling at night and 20,000 trucks traveling by day.		

Title:	**Diesel truck idling emissions – mobile source air toxics measured at a hot spot**		
Author(s):	Parks, J.E., Storey, J.M.E., Miller, T.L., Fu, J.S., and Hromis, B.		
Journal:	*Proceedings of the Transportation Research Board 86th Annual Meeting*	**Year:**	2007
Purpose:	To measure mobile source air toxics (MSATs) emissions (e.g., formaldehyde, acetaldehyde, acrolein, and other species collected on di-nitrophenyl hydrazine (DNPH) filters) at the Watt Road interchange on I-40 in Knoxville, TN.		

Title:	**Travel characteristics of urban freight vehicles and their effects on emission factors**		
Author(s):	Protopapas, A., Chatterjee, A., Miller, T.L., and Everett, J.		
Journal:	*Transportation Research Record: Journal of the Transportation Research Board*, 1941, 89-98	**Year:**	2005
Purpose:	To analyze and compare data for different commercial vehicle usage classes to develop input parameters for the MOBILE6 model		

Title:	**Mass, surface area and number metrics in diesel occupational exposure assessment**		
Author(s):	Ramachandran, G., Paulsen, D., Watts, W., and Kittelson, D.		
Journal:	*Journal of Environmental Monitoring*, 7, 728-735	**Year:**	2005
Purpose:	To evaluate diesel exposure using three different metrics (aerosol mass, surface area, and number concentration) using three different occupational groups (bus drivers, parking garage attendants, and mechanics)		

Title:	**Exposure to particulate matter, volatile organic compounds, and other air pollutants inside patrol cars**		
Author(s):	Riediker, M., Williams, R., Devlin, R., Griggs, T., and Bromberg, P.		
Journal:	*Environmental Science and Technology*, 37(1), 2084-2093	**Year:**	2003
Purpose:	To understand the potential occupational exposure of North Carolina Highway State troopers to air pollutants by measuring the average pollutant levels inside patrol cars		

Title:	**The mobile source effect on curbside 1,3-butadiene, benzene, and particle-bound polycyclic aromatic hydrocarbons assessed at a tollbooth**		
Author(s):	Sapkota, A. and Buckley, T.J.		
Journal:	*Journal of the Air and Waste Management Association*, 53, 740-748	**Year:**	2003
Purpose:	To measure human exposure (to benzene and 1,3-butadiene) with respect to vehicle volume and class		
Notes:	Vehicles with more 2 axles produced higher levels of air pollutants than 2-axle vehicles (9 times more benzene, 32 times more 1,3-butadiene, and 60 times more particle-bound PAH)		

Title:	**Exposure to Diesel Exhaust Emissions on Board Locomotives**		
Author(s):	Seshagiri, B.		
Journal:	*American Industrial Hygiene Association Journal*, 64, 678-683	**Year:**	2003
Purpose:	To measure elemental carbon concentrations of diesel exhaust emissions in train cabs		

Title:	**Overview of particulate exposure in the U.S. trucking industry**		
Author(s):	Smith, T.J., Davis, M.E., Reaser, P., Natkin, J., Hart, J.E., Laden, F., Heff, A., and Garshick, E.		
Journal:	*Journal of Environmental Monitoring*, 8, 711-720	**Year:**	2006
Purpose:	To measure occupational exposure to diesel exhaust and other common environmental pollutants at various work sites (e.g., terminal sites, office, dock area, shop areas)		

Title:	**Mobile source air toxics from idling trucks – A report from the Mexican Border**		
Author(s):	Storey, J.M.E., Lewis Sr., S.A., Zietsman, J., Villa, J.C., and Forrest, T.L.		
Journal:	*Proceedings of the Transportation Research Board 86th Annual Meeting*	**Year:**	2007
Purpose:	To estimate idling emissions (in particular MSATs and diesel PM) from trucks crossing at the El Paso – Ciudad Juarez border		

Title:	**Particulate matter and aldehyde emissions from idling heavy-duty diesel trucks**		
Author(s):	Storey, J.M.E., Thomas, J.F., Lewis Sr., S.A., Dam, T.Q., Edwards, K.D., DeVault, G.L., and Retrossa, D.J.		
Journal:	2003 SAE World Congress (SAE Technical Paper Series 2003-01-0289), Detroit, MI, March 3-6, 2003	**Year:**	2003
Purpose:	To measure diesel emissions from in-use idling trucks at the Aberdeen Test Center and to examine the impact of idle reduction technologies on emission levels		

Title:	**A simultaneous job- and task-based exposure evaluation of petroleum tanker drivers to benzene and total hydrocarbons**		
Author(s):	Verma, D.K., Cheng, W.K., Shaw, D.S., Shaw, M.L., Verma, P., Julian, J.A., Dumschat, R.E., and Mulligan, S.J.P.		
Journal:	*Applied Occupational and Environmental Hygiene*, 1, 725-737	**Year:**	2004
Purpose:	To evaluate petroleum tanker drivers' exposure to benzene per task (e.g., loading, unloading, and travel) and on a full-shift basis		

Title:	**Diesel exhaust exposure in the Canadian railroad work environment**		
Author(s):	Verma, D.K., Finkelstein, M.M., Kurtz, L., Smolynec, K., and Eyre, S.		
Journal:	*Applied Occupational and Environmental Hygiene*, 18(1), 25-34	**Year:**	2003
Purpose:	To investigate occupational exposure to diesel exhaust in the railroad industry. Specifically, to collect and measure elemental carbon levels in diesel exhaust and compare it to other industries		

Title:	**A comparison of sampling and analytical methods for assessing occupational exposure to diesel exhaust in a railroad work environment**		
Author(s):	Verma, D.K., Shaw, L., Julian, J., Smolynek, K., Wood, C., and Shaw, D.		
Journal:	*Applied Occupational and Environmental Hygiene*, 14(10), 701-714	**Year:**	1999
Purpose:	To evaluate sampling methods for measuring diesel exhaust in the railroad environment		

Title:	**Comparison of daytime and nighttime concentration profiles and size distribution of ultrafine particles near a major highway**		
Author(s):	Zhu, Y., Kuhn, T., Mayo, P., and Hinds, W.C.		
Journal:	*Environmental Science and Technology*, 40(8), 2531-2536	**Year:**	2006
Purpose:	To measure the concentration and size distribution of ultrafine particles near major highways during the day and at night		

Title:	**Toxic Gases In Heavy Duty Diesel Truck Cabs**		
Author(s):	Ziskind, R., Carlin, T., Axelrod, M., Allen, R.W., and Schwartz, S.H.		
Journal:	FHWA-RD-77-139	**Year:**	1977
Purpose:	To measure in-cab concentrations of carbon monoxide, nitric oxide, and nitrogen dioxide.		