



U.S. Department  
of Transportation  
Federal Highway  
Administration

# HEARING DISORDERS and COMMERCIAL MOTOR VEHICLE DRIVERS

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6. Abstract <p>Since the establishment of the Federal Highway regulatory system, people with specific disabilities have been excluded from driving in interstate trucking for public safety reasons. Persons with severe hearing loss have been prohibited from operating commercial motor vehicles in interstate activity. This restriction is now being reevaluated by the Office of Motor Carriers.</p> <p>In this report, a literature review of hearing and driving is presented; examining the role of hearing in the driving task, noise levels in truck cabs, hearing loss in truck drivers, the relationship between hearing loss and accidents, hearing screening tests, and existing hearing standards in force in the individual states and several foreign nations. An assessment of the estimated risk that might be associated with licensing hearing-impaired drivers follows, as well as an evaluation of the current means for testing hearing in the CMV context and a summary of a workshop on hearing disorders and commercial driving.</p>			
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Hea rin g Dis or de rs a nd  
C O M M E R C I A L M O T O R V E H I C L E D R I V E R S

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## Table of Contents

I.	Introduction .....	I-1
II.	Literature Review .....	II-I
	A. The Role of Hearing in Driving .....	II-5
	1. Hearing and the Driving Task .....	II-6
	2. The Driving Environment .....	II-10
	3. Noise Levels in Truck Cabs .....	II-11
	4. Implications of the Noise Environment for the Role of Hearing in Driving .....	II-16
	5. Hearing Loss in CMV Drivers .....	II-22
	6. Reducing Noise in the Driving Environment .....	II-26
	7. Devices That Compensate for Lack of Audibility .....	II-26
	8. Effects of Noise on Performance .....	B-29
	B. Hearing Loss and Accidents .....	II-35
	C. Screening Auditory Capabilities .....	II-45
	D. summary .....	II-52
III.	Review of Existing Hearing Standards for CMV Drivers .....	III-1
	A. state Regulations for CMV operation .....	III-2
	B. Foreign Regulations for CMV Operation .....	III-14
	C. Hearing Standards Employed by Private Trucking Firms.. ..	II-24
	D. Hearing Regulations in Other Industries .....	III-25
IV.	<b>Risk Assessment.....</b>	<b>IV. 1</b>
V.	Assessment of the Adequacy of the Present Hearing Standards .....	V-1
VI.	Preliminary Recommendations .....	VI-1
VII.	Summary of the Workshop, “Hearings Disorders & CMV Drivers” .....	VII-1
VIII.	Glossary .....	VIII-1

## List of Figures

Figure 2-1.	The Haddon Matrix and the Role of Hearing in CMV Driving . . . . .	II-9
Figure 2-2.	Implications of the Noise Environment for the Role of Hearing in Driving . . . . .	II-16
Figure 3-1.	Intrastate Regulations Concerning Hearing . . . . .	III-3
Figure 3-2.	Intrastate Licensing of Deaf Drivers . . . . .	III-4
Figure 3-3.	Intrastate Licensing of Hearing-Impaired Drivers . . . . .	III-5
Figure 3-4.	Canadian Vehicle Classification . . . . .	III-15
Figure 4-1.	Medical Conditions and Their Possible Effects on Driving Ability . . . . .	IV-3
Figure 4-2.	Medical Conditions and Driving . . . . .	IV-3
Figure 4-3.	Interventions to Reduce the Crash Risk of Hearing-Impaired Drivers . . . . .	IV-30

## List of Tables

Table 2-1.	Studies Examining Noise Levels in Tractor Cabs . . . . .	II-15,
Table 2-2.	Mean Hearing Level Thresholds by Driving Exposure and Frequency . . . . .	II-25
Table 2-3.	Compensation Mechanisms by Degree of Hearing Impairment . . . . .	II-28
Table 2-4.	Noise and Industrial Accidents . . . . .	II-31
Table 2-5.	Studies Evaluating Accident and Violation History Among Hearing- Impaired Drivers and a Comparison Group . . . . .	II-44
Table 3-1.	License Status of Existing Drivers Who Develop Hearing Impairment . . . . .	III-6
Table 3-2.	Proof of Medical Examination Required to Obtain a License. . . . .	III-7
Table 3-3.	Provincial Regulations Regarding Hearing and CMV Driving . . . . .	III-17
Table 3-4.	Regulations, Licensing Restrictions, and Screening Procedures among Responding Nations . . . . .	III-20
Table 3-5.	<del>Hearing</del> Requirements for Selected Aviation-Related Occupations . . . . .	IJI-26
Table 4-1.	The Haddon Matrix and the Hazards Related to Hearing Loss in CMV Driving . . . . .	IV-5
Table 4-2.	Prevalence of Self-Reported Hearing Loss by Age . . . . .	IV-15
Table 4-3.	Number of CMV Drivers With Hearing Impairment . . . . .	IV-16
Table 4-4.	<b>The</b> Deaf Population in the United States.. . . .	IV-17
Table 4-5.	Number of Licensed “Deaf” Drivers Expected if Regulations Were Changed . . . . .	N-18
Table 4-6.	Crash Rate Estimates for CMV Drivers . . . . .	N-21
Table 6-1.	Alternative Actions . . . . .	VI-8

## I. INTRODUCTION



As a result of the Americans With Disabilities Act (1990)<sup>1</sup>, many individuals are re-examining the blanket restrictions that some industries impose on persons with disabilities. This new act was framed to provide and increase work opportunities for persons who had previously been disqualified from employment, by appropriately modifying the work environment and offering assistive technology. With the loosening of employment restrictions, however, there is some concern that public safety may be compromised. Clearly, the decision to allow someone to work must be balanced with the safety of the general public.

To evaluate the balance between individuals' rights and public safety, scientists have begun to use risk assessment methods. Risk analyses use the best possible data from the scientific literature to evaluate, for example, the change in risk that might occur with a change in regulation. These risk projections are then provided to decision makers who are responsible for determining if the risks are acceptable and manageable. By integrating the best possible data that can be brought to bear on a specific question concerning regulation, the risk assessment **approach maximizes both individuals' rights and public safety.**

Recently, we evaluated the impact of a change in Federal interstate commercial motor vehicle (CMV) regulations on persons who used insulin for diabetes. To date, all insulin-using individuals have been refused the opportunity to drive in interstate commerce. The primary findings of our risk assessment study were that insulin-using individuals would be four times more likely to have crashes than those without diabetes. However, with proper screening, it would be possible to reduce the risk to at most twofold. Also, because of both the low prevalence of diabetes and social discouragement factors, the number of drivers expected to be licensed within the first 5 years of a change would be low (1,240). Based, in part, on these findings, licensing restrictions for insulin-using drivers are being reconsidered.

We are now considering the impact of potential regulation changes on a second disability hearing impairment. At present, people with severe hearing loss and total deafness are excluded from interstate driving of commercial motor vehicles. As with restrictions on diabetes, the blanket restriction on CMV driving is now being evaluated by the Federal Highway Administration (FHWA). In this current review, we present models of investigation, a literature review, and estimates of risk. From this material, we provide a risk assessment for discussion.

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<sup>1</sup> Americans With Disabilities Act § 302(a), 102(b)(5)(A)(1990).

## II. LITERATURE REVIEW

We approach the review of the literature in much the same manner as we did the diabetes evaluation, marshaling the best available data and facts to establish as accurate a risk analysis investigation as possible. The first order of business is to define what hearing impairment means, as the definition can differ depending upon the context in which it is considered.

The determination of whether or not someone has a hearing impairment can be done in a crude manner, either by questioning a person on a survey or by directly asking him or her if he or she can hear you when you speak. More precise estimates, though, are available from pure-tone threshold tests. A normal-hearing person is thought to be able to hear sounds below 20 decibels hearing level (db HL) across a range of frequencies (250,500, 1,000,2,000,4,000, 8,000 hertz (Hz)). Someone with a hearing impairment may not be able to detect sounds until they reach anywhere from 25 db HL to 110 db HL. This loss in hearing sensitivity may appear at one frequency, a group of frequencies, or the entire range. Newby (1979) outlined the degree of severity of hearing loss as presented below (based on the average of pure-tone thresholds at 500, 1,000, and 2,000 Hz). The level of impairment in hearing that is meaningful, though, will vary by the issue in which it is applied (office of Technology Assessment 1986).

0 to 20 db	normal
20 to 30 db	slight
30 to 45 db	mild
45 to 60 db	moderate
60 to 75 db	severe
75 to 90 db	profound
90 to 110 db	extreme

But to what does the term “hearing impairment” actually refer? The American Speech-Language Hearing Association 1981 (ASHA 1981) reports that hearing impairment or hearing loss usually denotes a change for the worse in auditory structure or auditory function, outside the range of normal hearing. A person with 85 to 90 db HL hearing loss is considered functionally deaf. The distinction between the deaf and hard of hearing is an important one; it will come up in many future discussions regarding driving and the impact of hearing loss. The definition of “deaf” is quite variable. Traditionally, though, a deaf individual is defined as someone who is not able to use auditory input as a mode of communication, or, as the Conference of Executives of American Schools for the Deaf puts it, “those in whom the sense of hearing is nonfunctional for the ordinary purposes of life” (Newby, 1979). The hard of hearing would generally encompass those with hearing disability not falling within the definition of deafness.

## Driving and Hearing Regulation History

The majority of the states impose few restrictions on the licensing of persons with hearing impairments for automobile driving. However, there has been a long history of concern about licensing people who cannot hear. The first state to allow the deaf to hold licenses was Pennsylvania in 1923 (Finesilver 1962a). Deafness was originally included as one of the exclusionary criteria when the State began to issue licenses based on compulsory testing. However, as Finesilver reported, a very hands-on approach was used to overcome the burdens of this law. A deaf pastor took the then governor of Pennsylvania for a 30-minute ride, demonstrating to him that deaf people could drive. The governor then disregarded the reports of his safety committee and allowed persons with hearing impairment to drive. Fortunately, in the years since, a somewhat more scientific approach is beginning to take place to balance the individual benefits of driving with public safety.

Since the establishment of the Federal highway regulatory system; people with specific disabilities have been excluded from driving in interstate trucking for public safety reasons. Hearing loss above a defined level was considered to be a specific exclusionary criterion. However, as we will note, this decision was based on sparse, preliminary data.

In 1976, the FHWA was petitioned by the State of Wisconsin to permit deaf drivers to operate in interstate trucking. The State argued that (1) safe driving is almost totally dependent on visual acuity and alertness, (2) safety records of deaf drivers are superior, and (3) noise levels in large over-the-road tractors render hearing totally insignificant as a safety factor (FHWA 1976). Fifty comments were filed in response to the proposition to change the regulations; 34 (68%) were opposed to permitting deaf drivers on the road, and 10 (20%) were in support of 'the idea (FHWA 1976). We will review in separate sections the literature that was discussed in these comments. Ultimately, the State's petition was denied, and the docket was closed. The primary rationale for this action was that previous research had not shown that the blanket restriction against the employment of the deaf was inadequate. To quote from the report:

Research studies have shown studies favoring and opposing deaf drivers' driving records. While the possibility exists that the current standards are more stringent than required relaxation of these standards to permit experimental examination of this possibility is not considered to be in the public interest.

Further justification provided was that the hearing standards in use screened out individuals with certain pathologic conditions that might increase the risk of crash, such as conditions related to the loss of balance. It also was concluded that hearing was needed in noisy environments and that it was necessary for drivers to receive auditory feedback.

In this report; we offer an overview of the possible mechanisms by which noise and hearing might affect truck driving. The first area we examine is the degree to which hearing is needed in the driving task. Opinions range widely on this issue. Some believe driving is a purely visual task; some believe hearing is essential. We present data examining the role of

hearing in driving and the possibility that a noisy environment reduces the significance of hearing loss for driving.

We also review the well-documented contribution of truck driving to noise-induced hearing loss (NIHL). It is not our intent to discuss the standards for noise in a cab, as our focus is exclusively on the contribution of hearing loss to the risk for crashes. We also present information concerning NIHL in order to estimate the numbers of people with hearing loss who may come up to be licensed. Most hearing-impaired people seeking licenses are likely to be existing truck drivers, many of whom have developed occupation-related hearing loss.

We discuss how noise affects performance. The noise sources in a truck range from the truck itself to radio entertainment. We give an overview of the industrial literature, reviewing the specific effects of noise upon tasks that have a bearing on driving. We then summarize the limited research that has been conducted in other industries, where noise levels and the contribution of hearing loss have been assessed in relation to industrial accidents.

This background material sets the stage for the primary component of Task A, that of evaluating the direct evidence linking hearing loss to accidents. We next discuss the screening techniques available to test for hearing impairment. Finally, we discuss the hearing regulations used for intrastate drivers, drivers with private employers, and employees in other industries.

## A. The Role of Hearing in Driving

Injuries from motor vehicle accidents represent large economic and medical burdens. A tremendous amount of effort has gone into research to identify the means to reduce these burdens. One direction in this effort has been toward the recognition that the actions of the driver play a large role in accidents; to that end, the components of the driving task have been studied. Safe driving depends upon the driver's ability to receive messages from the environment, interpret them, and adjust to them (Wagner 1962).

Four senses are likely to influence the driver's ability to receive messages: vision, hearing, touch, and smell (Platt 1962). Henderson and Burg (1974) concluded that vision makes up most of the driving task. What role does hearing play in driving, and what auditory capabilities are required of a person driving a truck? Henderson and Burg suggest that hearing plays a small role in the driving task. However, they state that more research is needed to document the role of hearing and auditory stimuli in driving safety.

Under the current Federal guidelines, persons who are deaf or who suffer from moderate to extreme hearing loss cannot be licensed to operate commercial motor vehicles in interstate commerce. Two petitions to change this regulation have come forward over the years. Several arguments have been presented by those who sought to change the rule: (1) safe driving is almost all visual and hearing plays a small role; (2) noise levels in trucks render hearing insignificant as a safety factor due to masking; and (3) impaired drivers can compensate for their deficiencies. Both petitions, though, were turned down. The Federal Highway Administration concluded that hearing is important when a driver must act on emergency sounds or improper mechanical sounds and when a driver needs to communicate; noise levels are not high in all driving situations; and the literature suggests that accidents are higher among deaf drivers than non-deaf drivers (FHWA 1976).

Indeed, interviews found that truck drivers themselves feel that hearing provides a margin of safety in CMV operation (Henderson and Burg 1973) and that there are times when drivers hear hazards before they see them (FHWA 1976). However, the same drivers were unable to quantify the degree to which hearing is important, and the majority said that most malfunctions that create sound also cause vibrations; vibrations that a person with or without hearing impairment could sense.

Thus, the issue remains open for debate. We examine the role of hearing in driving by reviewing the literature concerning the driving task and the driving environment, and examining how hearing and auditory signals enter into driving. Other topics of interest include the noise levels in truck cabs and whether a noisy environment reduces the role of hearing in driving. noise-induced hearing loss in CMV drivers, means to reduce noise in the truck cab, devices to compensate for the lack of audibility, and the influence of noise on performance.

## 1. Hearing and the Driving Task

The items of interest for this review center around two questions: (1) How does hearing relate to driving safety; and (2) If hearing is eliminated, how does the loss of hearing affect driving performance? At present, there are few scientific data directly pertaining to these questions. Summaries from two previous reviews (Henderson and Burg 1973, Booher 1978) have concluded that the specific auditory requirements necessary for safe driving are not entirely known. Moreover, the relationship between hearing loss and the ability to drive safely is not well defined (Burg 1970).

Four senses are likely to have some role in the driving task: vision, hearing, touch, smell (Platt 1962). From all indications, though, it appears that vision is the sense of primary importance. A report by Henderson and Burg (1974) found that vision makes up over 95 percent of the driving task from a sensory Perspective. Most licensing agencies test or require testing for visual acuity, but they rarely test for auditory or olfactory abilities. Additionally, it is recognized that driving is possible with only the visual sense in functional order (Platt 1962).

While hearing is not nearly 'as important as vision for the. driving task, some reports indicate that hearing may be helpful for safe driving.. Finesilver (1962b) writes of an incident where a deaf driver was cited for "taking the right-of-way from an emergency vehicle." Roydhouse (1967) described an incident where a, deaf driver stopped his truck too close to a railways line and was' struck by a railcar. Petersen (1978) details one experience in which a deaf driver's brake line came loose and air leaked out unbeknownst to the driver.'

Despite such case reports, the direct relationship between the ability to hear and safe driving remains ill-defined. Henderson and Burg (1973) provide the most specific and comprehensive look at this matter with respect to CMV operation. Their report assessed the hearing requirements of CMV driving by modeling and rating auditory stimuli, interviewing current CMV drivers, and passenger observations of truck operations.

In the first part of their evaluation, Henderson and Burg reviewed the driving task from the viewpoint of hearing and defined four categories of auditory stimuli that might be important to truck driver safety. These categories included warning or attention-getting stimuli (horns,' sirens, whistles); feedback stimuli (the response from the engine when acceleration is undertaken); other sounds that are quickly identifiable (e.g., air brakes); and other sounds that are not quickly identifiable (e.g., metal rubbing against a tire). These stimuli were then considered across three driving environments (high-noise, low-noise, and quiet), and driving behaviors that might occur in each of the scenarios above were rated for their importance to the driving task. The results suggested that hearing makes its greatest contribution in off-the-road tasks in quiet environments, such as during a vehicle inspection.

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<sup>1</sup> He was able to stop the vehicle with the emergency brake, and no accident occurred.

<sup>2</sup> Judgment was made on whether hearing made the performance of a specific task easier or whether absence of sound affected performance.

Next, Henderson and Burg interviewed CMV operators for their opinions on the contribution of hearing to specific driving elements. The following factors were surveyed: (1) the use of hearing during the pre-trip inspection (when thumping tires, checking brake air lines, or listening to engine start and warm up); (2) the importance of “auditory cues” during operation (for monitoring the engine, transmission, exhaust system, drive line, and tire performance and for identifying load shifts and equipment breakdowns); and (3) the importance of hearing for gathering information that originates outside the truck (horns, sirens, etc). The interviews indicated that:

... drivers obtain very little, if any, useful information about the environment external to the truck... by means of audition. The most important use of the sense of hearing in driving is in monitoring the proper functioning of one's own vehicle and, to a lesser extent, to guide the driver in the proper use of his vehicle.

Last, the importance of hearing to the driving task was examined by observation of driver behavior during CMV operation. The observers, in general, found that the hearing sense did not provide input of significant value to the driving task and that sounds originating from outside the vehicle could not be heard. However, the observers mentioned that they might not have encountered all aspects of the driving task. On the basis of their work, Henderson and Burg hypothesize that the importance of hearing for driving may arise only in rare instances, such as during critical driving phases or emergency responses

While there is likely to be no complete model for indexing all situations in which auditory stimuli would be important in CMV driving, the literature focuses on the importance of hearing in the following situations: (1) potential situations requiring audition of warning signals (sirens, horns, and sounds at railway crossings); (2) potential vehicle function problems requiring audition (e.g., malfunctions of the engine, brakes, and/or tires); (3) vehicle inspection; and (4) communication (Platt 1962, Wagner 1962, Henderson and Burg 1973, Henderson and Burg 1974).

Figure 2-1 presents an overview of these four items in the context of driving safety, specifically the development of road crashes. This characterization follows the orientation of the Haddon matrix for improving highway safety. In this matrix, Haddon (1972) has proposed that highway crashes can be reduced by appropriate intervention at any of three crash phases (before a crash, during a crash, or after a crash) or in any of three driving elements (human, vehicular, or environmental).

A number of possible scenarios are shown in Figure 2-1 with respect to hearing and driving. The primary concerns expressed in the literature over the role of hearing in driving safety fall within the pre-crash phase. In this phase, for example, the concern is that a hearing-impaired driver will be unable to interpret sounds during a vehicle inspection that, if found and corrected, could prevent the onset of a crash or that he or she will be unable to hear warning sounds related to an approaching vehicle or train, or those related to the failure of a mechanical component on the truck. The understanding is that perception of these sounds could prevent a crash.



While warning signals can be significant when viewed by themselves, the matrix shows that they should also be considered within the environment in which they occur. Noise levels in the truck cab (when in operation) could conceal sounds originating from outside the vehicle or possibly those generated from within the vehicle. Even when the vehicle is stopped, weather conditions or the level of background noise could influence the interpretation of sounds important to the inspection process.

Last, independent of the matrix, drivers with hearing impairment may be able to compensate for their loss (Finesilver 1962, Roydhouse 1967, Schein 1968, Burg 1970). As Roydhouse (1967) insinuates, the visual attentiveness and road sense of deaf drivers may be more pronounced because of their lack of hearing. One report in the literature supports this thought. When a tire was rubbing against a piece of steel on a truck, the deaf driver was able to smell the burning rubber and stop the vehicle before a problem occurred (Peterson 1978).

Figure 2-1.

The Haddon Matrix and the Role of Hearing in CMV Driving

		Factors		
		Human	Vehicular	Environmental
Phases (while driving)	Pre-Crash (while stopped)	inaudibility of sounds due to hearing impairment	* sound as a primary indicator in vehicle <b>inspection</b>	* masking of sounds due to background noise
		* inaudibility of sounds due to hearing impairment	* <b>warning sounds from</b> mechanical malfunction	* warning sounds from sirens, horns, trains * masking of sounds due to truck cab noise
	Crash			
	Post-Crash	* hearing loss poor communication		* masking of sounds due to background noise

## 2. The Driving Environment

Determination of whether or not a driver will perceive an auditory stimulus is dependent on a number of factors in the environment, including the nature of the warning signal and the noise environment in which it occurs (Henderson and Burg 1973). Of particular interest for CMV drivers is the noise environment in which they operate.

The noise environment can affect the driver, and possibly his performance, through three mechanisms: masking, temporary threshold shift ('TTS), and noise-induced hearing loss. The interaction of these three mechanisms may produce a greater decrease in communication ability than any single influence. A single noise can mask or hide the audibility of other sounds. Masking can lead to situations where a hearing driver is essentially deaf to auditory signals. TTS or temporary hearing loss results from moderate exposure to extremely high levels of noise. It generally disappears within several hours if exposure is discontinued. While present, 'TTS can produce not only a reduced signal, but a distorted signal, making communication more difficult. Noise-induced hearing loss (NIHL), though, is permanent hearing loss. 'Repeated exposure to high levels of noise over long periods of time can lead to NIHL. If the driver suffers from either (TTS) or NEIL, he may not be able to hear certain signals while driving.

We know quite a bit about the potential influence of masking in CMV operation from studies in controlled environments. For example, low-frequency sounds mask high-frequency sounds more effectively than the reverse. Also, the closer two sounds are in frequency, the more effectively they mask each other. These observations, however, may not translate directly to the driving environment. In the driving arena, we are dealing with both complex signals (warning signs) and complex masking signals (noise). The masking sound can be variable and partly controlled by the driver (whether the windows are up or down, whether the radio is on or off, how fast the vehicle is moving). Additionally, as Henderson and Burg (1973) point out, it may be important to hear a sound that is added to the sound environment or one that is deleted from the sound environment. Shuhnan (1971) reported that it is more difficult to recognize the deletion of a sound than the addition of a sound.

Our knowledge of the effect of masking in CMV operation is greater than that. More research is needed to investigate the meaningfulness of these forms of hearing loss in the driving environment, and one must first have some understanding of what takes place in the noise environment of a truck cab.

### 3. Noise Levels. in Truck Cabs

A number of reports have established that long-term exposure to excessive noise can lead to hearing loss (NIH 1990). On the basis of these studies, the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) established noise exposure standards for workers in the early 1970s. Under these standards, noise exposure for an 8-hour work day must not average more than 90 decibels on the A-weighted network db(A). Also, the maximum exposure allowed decreases linearly with exposure time, so that the limit for a 10-hour work day (a common shift for truck drivers) should not exceed an average of 88.2 dB(A) (Close & Clarke 1972).

An interior noise regulation (49 CFR 393.94) was introduced in 1973 by the Department of Transportation in order to reduce tractor cab interior noise levels and control the loss of hearing among (DOT) truck drivers. Under the protocol of the Occupational Safety and Health Act passed by the Congress in 1970, the working conditions of CMV drivers are under the jurisdiction of the Office of Motor Carrier (OMC) in the FHWA (Durham 1981) and not the OSHA. The current OMC regulations on interior noise levels state that "the interior sound level at the driver's seating position of a motor vehicle must not exceed 90 db(A)" average of 90 db when measured in a stationary test with the doors, windows, and vents closed and having all power-operated accessories turned off. A 2-db tolerance over this sound limitation is permitted to allow for variations in testing conditions (49 CFR 393.94). This program identified the three most noise-producing parts of a truck as the engine, the exhaust, and the tires.

A review of the studies that have examined noise levels in truck cabs under real operating conditions suggests that noise levels in commercial truck cabs exceed 90 db for substantial portions of driving time. Even the most recent U.S. studies, which include newer truck models, reported mean noise levels averaging around 90 db(A) when driving with the windows open and radios off (Kam 1980. Reif 1980. Hessel 1982). A study in France (Pachiaudi 1987) reported lower noise levels than the earlier U.S. studies; they found mean levels of 81.2 db(A) with radio on and windows open. However, it is not clear whether the interior noise level standards in the two countries are comparable.

A second message confirmed by the literature is that the noise environment of the truck cab can vary considerably. A number of factors had some influence on the noise levels recorded in these reports: whether the radio was on or off; whether the window position was open or closed, what type of engine was in the truck; and the type of truck. For example, if radios are on, they are usually played at volumes that add from 3 to 8 db to the noise levels in the cab (Hessel 1982). Also it appears that closing the windows decreases noise by up to 4 db(A) and Tyler (1973) reported that 4-cycle trucks were much noisier than 2-cycle trucks. The type of truck driven is relevant in that only 40% of those persons holding a commercial driver's license operate large semi-trailers. Other factors were also likely to have some influence on the sound levels recorded, although the level of their effect was not known. These include whether the air conditioner was on or off, the degree of soundproofing in the vehicle, and the road surface on which the vehicles were driven.

Finally, it is important to recognize that the studies presented are not directly comparable because the methods, trucks, and testing conditions used varied greatly across the reports. It is

known, for instance, that noise-level measurements differ by the technique applied to measure db levels in the research (e.g., where the microphones are placed and the length of time noise is monitored). Another methodological problem in most of the studies was the testing of a small number of a variety of trucks. Small samples leave little room to determine, statistically, whether certain kinds of trucks are noisier than others.

Despite their limitations, these reports suggest that the noise environment of the CMV driver exceeds on average 90 db(A). Additional concern is raised over the value of the current standards, as additional elements under the driver's control, such as the radio, air conditioner, and window position, clearly have an opportunity to raise the db level of the truck cab above the statutory limits. Thus, the current interior noise standards could very well be "inadequate to protect not only the driver's hearing, but his job security as well," as Durham (1981) implies.'

Table 2-1 provides an **overview** of these studies, indicating the number of trucks tested, types of trucks were tested, **frequency** of noise measurement, testing conditions, and noise levels at each ear with windows up and windows down (ii known). Unless otherwise noted, tests were conducted with radios off and minimal conversation during testing. One must be cautioned, however, that (the cab environment) in today's trucks may differ from the truck cab environment of the models studied.

A detailed review of the relevant literature, follows.

#### Priede (1967)

Based on an in-depth study of noise sources in truck cabs, Priede (1967) reported that the engine is the main source of interior cab noise. Most cab noise is low-frequency noise of up to 200 Hz caused by wheel and engine rotation. A fair amount of noise is also due to "diesel knock" in the 700 to 2,000 Hz range (the range in which the human ear is most sensitive). As engine speed increases, so does the noise level in the truck cab, especially in the high-frequency ranges.

#### Emme (1970)

Emme conducted continuous over-the-road recording in an unspecified number of commercial vehicles on actual runs. With the windows open, noise exceeded 100 db(A) for the **majority of an hour** (55 minutes). Little difference was noted with the windows closed (noise **exceeded 100 db(A) for** 25 minutes out of every 30 minutes monitored). Noise levels rarely **dropped below 90 db(A)** during the testing runs. Variability in testing conditions existed from **truck to truck because** they were tested on actual runs.

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3 Regulation 49 CFR 391.41(11) prohibits drivers with significant hearing loss from being licensed.

#### Close and Clarke (1972)

In this report, the former Bureau of Motor Carrier Safety measured sound levels in 16 truck c a b s . Six tests were conducted per truck: stationary low-idle, stationary vehicle acceleration, stationary high-idle, city start-up, maximum vehicle acceleration up to 35 mph, and maximum deceleration. Each test was conducted with windows open and with windows closed; radios were always off. Noise levels were measured with microphones at ear level and 6 inches to either side of the driver. Maximum noise levels for each test varied from 84 to 99 db(A). The authors conclude that the data, combined with drivers' reports, suggest that the highest noise levels are at the left ear when the windows are open.

#### Hutton (1972)

Hutton reported on the exposure to interior noise in five cab-over-engine trucks (gas turbine and diesel engines). The interior noise levels for the diesel trucks studied (number unspecified) varied from 87 to 96 db(A) 50% of the time. Values for the gas turbine engines were substantially lower. The influence of variations in terrain driven, traffic conditions, and driving patterns on interior noise was not considered.

#### Tyler (1973)

In 1969-70, Gulf Oil measured noise levels in truck cabs in order to design their specifications for custom-ordering trucks. They found that noise levels are 15 db(A) higher when driving in heavy traffic with windows and vents open. Noise levels in 4-cycle engine vehicles exceeded 90 db(A) for 30% of driving time (it was not specified whether this was with windows opened or closed); noise levels in 2-cycle engine trucks exceeded 90 db(A) about 10% of the time. Several means of reducing noise levels in 4-cycle trucks were tested, and it was determined that the percentage of time with noise above 90 db(A) could be reduced to less than 10% by installing any of a number of readily available, low-cost devices which can reduce noise levels. A maximum level of 83 db(A) was recorded when the most effective noise reduction techniques were used together with closed windows and vents.

#### Kam (1980)

Kam tested noise levels in 20 two-ton trucks as they drove 360 miles, non-stop, at 45 mph with no radio speakers on. All trucks were of the same design and model year. Noise measurements were made by microphones clipped to the left collar of the driver's shirt and evaluated with the windows open and closed. For the 10 trips with open windows, noise levels averaged 90 db(A), bordering on the maximum 8-hour OSHA limit. For the 10 trips with closed windows, noise levels averaged 69.6 db(A). Noise levels were approximately 5 db(A) higher at the left ear than at the right ear when the windows were open and approximately 2 db(A) higher at the left ear when the windows were closed.

#### Reif, Moore, and Steevensz (1980)

Reif, Moore, and Steevensx argue that noise levels measured at points some distance away from the driver do not provide accurate measures of the driver's exposure levels. Using microphones placed in the driver's ears, they studied continuous noise levels in 58 trucks driving in city and freeway traffic. Noise levels were also measured at 6 inches to the right of the

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This is the only study to report such a large difference between windows open and closed

driver's ear. All trucks but one (a 1968 model) were built from 1971 to 1978 and had Z-cycle or 4-cycle engines.

Tests were made with open windows, radios off, and minimal conversation between the driver and accompanying research technician. Results showed a decrease in noise levels from the left ear to the right ear, and to the center of the cab. For freeway driving with windows open, noise levels at the left ear ranged from 87 to 96 db(A),<sup>5</sup> at the right ear from 85 to 94 db(A), and in the truck center from 82 to 91 db(A).<sup>6</sup> Noise levels were slightly lower on highways, and slightly lower still for city driving. Additional tests were conducted in 8 trucks with the use of a CB radio. To hear the CB, the volume was such that noise levels increased by 2.7 db(A) at the right ear. On average, the sound level at the left ear was approximately 6 db(A) higher than that measured 6 inches from the right ear.

Hessel, Heck and McJilton (1982)

Noise levels in 8 diesel engine tractors, model years 1972 to 1977, were studied. Noise exposure was measured for 30 minutes, with a sound-level meter positioned at ear level in the passenger's seat, and for the entire driving shift (from 7 to 10 hours) with a dosimeter that was attached to the driver's sun visor. The trucks were driven in the highest gear, with the radio off, the driver's window open, and the passenger's window part open. Routes were on dry, level, concrete roads, usually interstate highways.

Noise levels measured with a sound level meter averaged 83.4 db(A). Noise measured with a dosimeter averaged 88.6 db(A). The higher dosimeter readings may have been due to the presence of non-standard noises when the sound level meter was turned off (e.g., acceleration up hills and starting from a dead stop). They are probably more typical of a driver's actual noise exposure. In six tractors, the mean noise level exceeded 90 db(A) (measured with a dosimeter). The authors found that noise levels increased by 3 to 8 db(A) when a CB or AM radio was used and that noise levels decreased by 1 to 4 db(A) when windows were closed.

Pachiaudi (1987)

Pachiaudi examined noise levels in 41 truck cabs in France. He found that noise levels in cabs with the radio on and the windows open averaged 81.2 db(A). . Four db were attributed to the radio and three db to the open window. Many of the 250 drivers who were tested in this study suffered from hearing loss. This was surprising, as noise levels in the trucks tested were below levels believed to induce hearing loss. It was possible, though, that the damage seen was due to the use of noisier trucks in earlier years.

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<sup>5</sup> As it is not explicitly stated, we assume that the reported noise levels are the mean levels for the trip.

<sup>6</sup> Noise levels were not broken down by model year or engine type (2-cycle or 4-cycle).

Table 2-1.

Studies Examining Noise Levels in Tractor Cabs

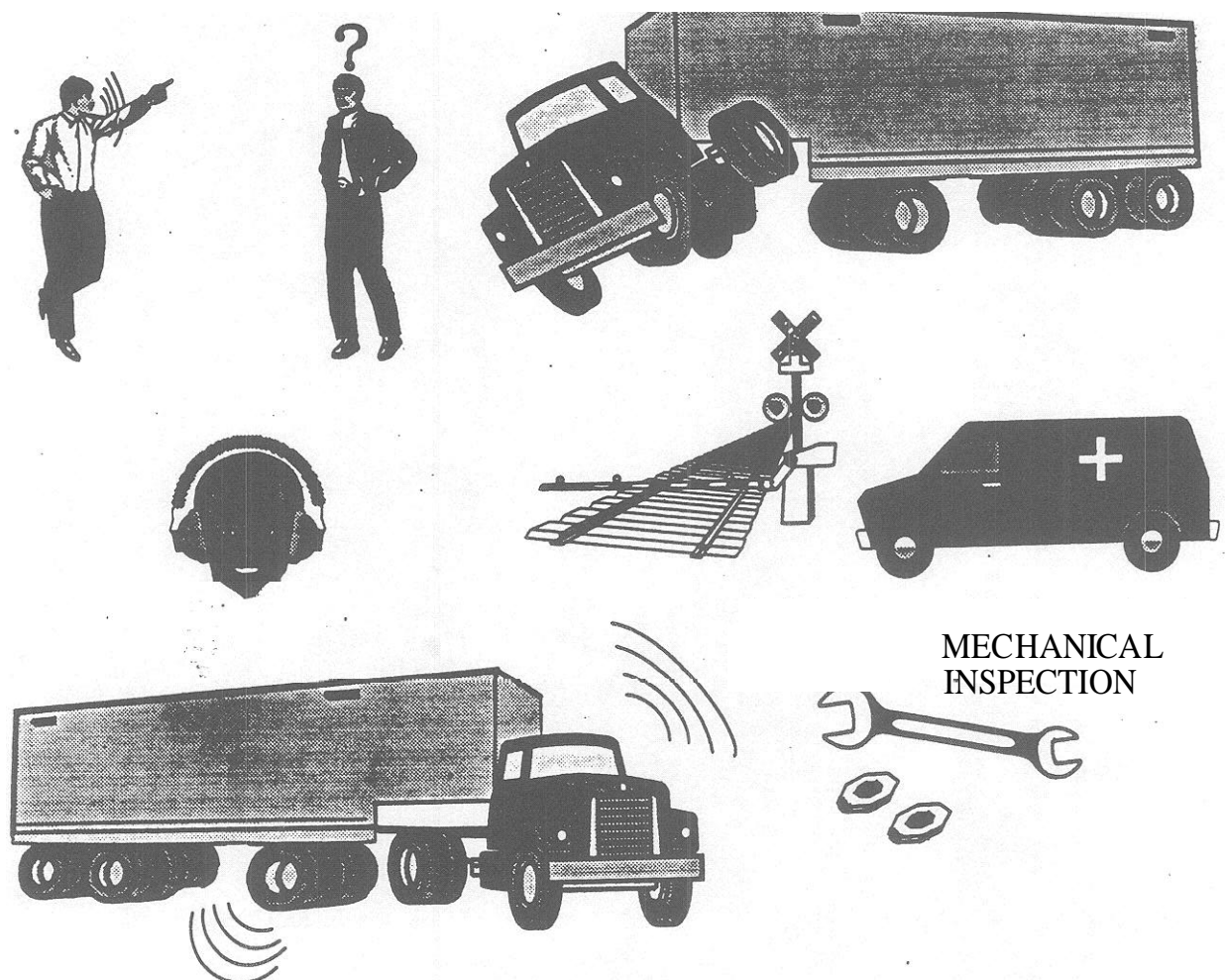
Authors	Year	Number of Trucks	Trucks Studied	Testing Conditions	Measurement Frequency	Noise Levels[db(A)]			
						Window Open		Window Closed	
						left ear	rightear	left ear	right ear
Close, et al.	1972	16		Stationary, Acceleration, Deceleration	•Continuous •Reported maximum level	w-95	85-95	84-98	88-95
Kam	1980	20	2-ton trucks	Freeway driving	•Continuous •Reported mean noise level	90		69.6	
Reif, et al.	1980	58	Model years: 1971-1978 (one 1968): Canada	City, highway, and freeway driving	*Continuous microphone in ear *We report ... for free way	87-96	85-94		
Hessel, et al.	1982	8	Model years: 1972-1977	Highway driving	*Continuous *Reported mean level	88.6		84.6-87.6	
Pachiaudi	1987	41	Model years not provided France	Real traffic conditions	*Continuous -Not separate for left right ears	77.1		74	
Tyler	1973	4-cycle engine cabs have noise > 90 db(A) 30% of the time; 2-cycle engine cabs have noise > 90 db(A) 10% of the time							



#### 4. Implications of the Noise Environment for the Role of Hearing in Driving

If tractor cab noise levels are sufficiently high, it is possible they may interfere with the driver's ability to hear warning signals, and vehicle malfunctions and with ability to communicate, even if the driver has no hearing impairment. Certain evidence supports this view. Henderson and Burg (1973) reviewed the available literature and concluded that high noise levels in commercial trucks may mask sounds that could be important to the driver. They found, in general, that truck cab noise levels in 1973 were high enough that it would have been difficult for a truck driver to hear automobile horns and emergency sirens at any distance where they can act to prevent a crash. Communication also may be masked by noise (Hinchcliffe 1958, Jones 1983). Lipscomb (1982) provides a comprehensive overview of the variables associated with driving that influence the audibility of warning signals. An overview of the impact of the noise environment on recognition of sounds by CMV operators follows. Figure 2-2 portrays the issues relevant to the discussion: the audibility of warning sounds, the audibility of vehicle malfunction, vehicle inspection, communication, noise levels in the truck cab, and hearing protection.

Figure 2-2. Implications of the Noise Environment for the Role of Hearing in Driving



## The audibility of warning signals in the truck cab

Warning signals as diverse as automobile horns, truck horns, emergency vehicle sirens, train horns, and railroad crossing bells have been identified as potentially important to driver safety. A number of factors, though, affect their perceptibility to the driver in the tractor cab. The intensity level, frequency, and distance and direction of the sound source must be defined before one can predict the audibility of the sound that arrives at the truck cab. Background noise may be sufficiently high to mask the detectability of warning sounds. Distance is particularly important in determining the usefulness of a signal. A driver must be able to hear a signal at a distance that allows him to react to the signal. A warning that is heard at the last moment may be of limited practical value. The noise characteristics of the tractor cab (window position, radio playing) also affects the ability to hear a warning signal, as does the hearing sensitivity of the driver.

Understanding the detectability of warning signals based on listener characteristics (e.g., hearing loss) and the listening environment (noise level, spectrum, etc.) allows a "prediction" of whether a driver can respond to a warning signal in a timely manner (Larouche 1991). This type of "prediction" is largely controlled by the noise environment. The truck cab listening environment varies, though, and it is difficult to agree on an average condition.

Most data on audibility of warning signals relate to automobiles. The sound environment of the automobile, however, is not directly comparable to that in a truck cab. Henderson and Burg (1973) provided some careful calculations to relate the findings of automobile studies to those which might be expected under the same conditions in a truck cab. They accomplished this by comparing the average noise level expected in each environment. These comparisons are provided in part below.

### Automobile Horns

Callaway (1951) investigated the acoustic characteristics of various types of automobile horns. The energy level in automobile horns was found mainly at the lower frequencies (160 to 380 Hz). The overall and octave-band sound pressure levels were measured at various distances. By comparing the loudness of these electrically driven horns with the loudness level inside a car travelling at 40 mph on a smooth surface with the windows closed, Callaway concluded that the horn could be heard at 50 feet and possibly at 100 feet. Henderson and Burg (1973) manipulated these data for the louder noise environment of large trucks and concluded it is doubtful that an automobile horn could be heard by the driver of a large truck at any distance beyond 6 to 18 feet under ~~similar circumstances~~. These distances have no practical warning value for a truck driver regardless of his or her hearing sensitivity.

### Sirens

Puswell and Aulwurn (1971) investigated the audibility of emergency vehicle sirens from inside an automobile. The authors considered the location of the sound source, music from the radio, vehicle speed; and roadway type and concluded that the interior noise level of the automobile was an important factor in the ability to detect sirens at various distances. The detection distance is significantly shorter at highway speeds than at city traffic speeds, and music in the vehicle reduced the ability to hear an approaching siren. Henderson and Burg (1973)

calculated that this would mean a distance of 100 to 125 feet for a commercial motor vehicle. This distance may not be sufficient for a truck driver to respond adequately.

Skeiber, Mason, Potter (1978) examined existing audible warning signals, determined their operational limitations, and documented how best to optimize them without increasing community noise annoyance. Measurements were made of interior noise of automobiles and commercial vehicles, and of the sound characteristics of a variety of sirens. The authors conclude that a wide range of sound levels are necessary to provide adequate aural warning for many potentially dangerous situations. Warning distances were very short except under the quietest conditions, Sound levels of sirens needed to be 10 db higher than the noise background to be detected.

The value of the warning sound in eliciting a response, though, may differ depending on a vehicle is relative to the vehicle emitting the siren. Puswell and Aulwurn (1971) found greater audibility of sirens approaching from the sides rather than from the front or back. However, Henderson and Burg (1974) reported that a warning signal from a vehicle that is travelling in the same direction as the base car can be heard in sufficient time to elicit a successful response. Warning signals also can be heard with less difficulty by drivers whose vehicles are stopped.

Reporting on the relative utility of audible warning devices on emergency vehicles, Potter and colleagues (1977) commented that the present level of audible warning emitted by emergency vehicles was not adequate to warn drivers in traffic. Several changes in the warning signal were recommended, including a more forward radiation of the signal and a higher frequency sound (3,000 Hz). Because most of the noise in an automobile or truck is in the low-frequency range, a higher-frequency sound may be slightly more audible. However, NIHL often may include loss at 3,000 Hz and may interfere with this audibility for a fair number of CMV drivers.

#### Railway Warning Signals

There are few studies on the role that auditory signals play in alerting drivers of an approaching tram (Lerner 1990). Aurelius and Korobow (1971) evaluated the audibility of railroad warning signals (horns, bells, whistles) for drivers of both automobiles and trucks and found that such signals did not provide adequate warning at sufficient distances, regardless of the driver's hearing sensitivity. Based on analytical and experimental data, they reported that a mean signal intensity of 87 db was required outside an automobile for a train horn to be heard. As the Federal Railroad Administration requires a horn sound level of at least 96 db(AA) at 100 feet forward of the train, and because sound intensity reduces with distance, the sound level 400 feet from the train could be about 84 db(A) in some instances (Lerner 1990).

Higher signal intensity levels may be required for trucks. While interior noise levels in truck cabs were not measured, the experiments of Aurelius and Korobow suggest that noise in the cab could have a degrading effect on the perception of horns, whistles, and bells. The use of radios, for example, resulted in even shorter detection distances for railway warnings among automobile drivers. Mortimer (1988) summarized this information and concluded that most motor vehicle drivers "receive information on the presence of a train through tram horns . . . only a few seconds before the train reaches the crossing."

Whether or not short detection distances increase the risk for accidents is not clear. Current Federal regulations specify the proper approach for large trucks at railway crossings.

Drivers of trucks carrying hazardous materials must stop their vehicles at crossings and listen and look in both directions for an approaching train. When it is safe to do so, the driver may proceed across the tracks without changing gears when crossing the tracks (49 CFR 392.10). Drivers of other trucks generally do not have to come to a complete stop at crossings, but must drive at a rate of speed that will permit the truck, if necessary, to be stopped before reaching the nearest rail and a speed that will allow due caution to determine that the course is clear (49 CFR 392.11).

An evaluation of motor vehicle accidents at highway-railroad grade crossings in Florida, though, suggests that the auditory warning provided by a train horn can alert drivers with normal hearing and dramatically improve crossing safety. When the impact of a nighttime ban on the use of train horns at highway-railroad grade crossings was surveyed, it was observed that more crashes occurred at crossings in which the ban was in effect than at crossings where horns were sounded (FRA — 5 December 1991). This study by the Federal Railroad Administration conservatively estimated a 128 to 167% increase in accidents due to the lack of a train horn. The report, however, did not mention if any of the accidents involved commercial motor vehicles. It is possible, given the noise levels of tractor cabs, that the ban could have had little effect on accidents involving trucks and trains.

The fact that this was a nighttime ban is of additional interest, as the visual warning to the driver is likely to be diminished. Only a light may be visible from the train, as opposed to the train itself. This study might suggest that without adequate visual warning, auditory warning may become important for the prevention of crashes.

#### The audibility of vehicle functions in the truck cab

There are indications that hearing may be important in monitoring the proper functioning of the truck during long-haul operations. Sounds from the engine, gears, brakes, and tires may provide clues to their malfunction. Mechanical noises such as these could prompt an inspection that would prevent an accident. The relative value of these sounds for truck safety, however, remains unknown. Thus, much of what we know about the role of hearing in the perception of vehicle malfunction is speculative,

No data exist that describe the degree to which hearing is required to recognize vehicle malfunctions. While not being able to hear unusual engine noises or warning buzzers could increase the risk for accident in and of itself, there are reports that suggest the hearing-impaired may still be able to recognize inappropriate vehicle functioning. Woods (1978) commented that the deaf have increased sensitivity to feel and handling. The deaf truck driver, hence, could be able to feel the vibration associated with engine problems. The group of truck drivers interviewed by Henderson and Burg (1973) also indicated that most changes in sound that occur while driving are accompanied by a tactile sensation. Visual gauges also exist for many vehicle functions.

There also are no data available regarding the audibility of the mechanical noises of malfunction in the noise environment of the truck cab. It is likely that aural perception of engine or brake malfunction for those without hearing loss could be affected by the noise levels present in the tractor cab. This would vary depending upon, for example, whether the window was up

or down, the radio on or off, and truck speed. However, Henderson and Burg (1973) point out that truck drivers should be able to hear above interior noise levels when the truck is stopped or traveling at slow speeds in the city.

### Vehicle inspection and the role of hearing

There also are indications that hearing may be necessary for preventive maintenance, or vehicle inspection. Current Federal standards place a great deal of significance on CMV inspection. Drivers must display the knowledge and skills to inspect safety-related parts and understand the effects of undiscovered malfunctions on safety (49 CFR 383.111). Hearing may be required, for example, in the pre-trip inspection to “determine that required alarms and emergency devices automatically deactivate at the proper pressure level” (49 CFR 383.113). The study by Henderson and Burg in 1973 also stressed the importance of hearing in the pre-trip inspections with regard to checking for air leaks in the braking system or tires. There are no data, however, to evaluate the importance of hearing for the inspection task.

It is possible that a driver may be able to compensate for lack of hearing in the inspection process by relying upon other senses. Vibrations and gauges may compensate for the detection of some malfunctions. However, certain sounds, such as small air leaks and sounds emitted from rod bearings, may not be felt through visual tactile means. It also is apparent in the trucking industry of today that some drivers do not conduct the pre-trip inspection; mechanics do. Thus, with a lack of relevant studies, it remains difficult to pinpoint the exact magnitude to which hearing would be important for the inspection process, other than to point out that it may be required in certain situations.

### Communication and the role of hearing

Communication may be vital to safe CMV operation. Federal regulations state that all interstate drivers must be able to read and speak English. The ability to hear is likely to have some impact on effective communication. Safety in a truck before and after an accident, for example, may depend on the ability to understand speech to some degree. Before an accident, a truck driver could receive a warning over a CB radio regarding upcoming road and traffic conditions. The warning is verbal with no visual input. Also, after an accident or in an emergency, it may be important for the truck driver to use both oral (speaking) and aural (hearing) communication.

Other scenarios described in the literature where aural communication might be important for CMV operation include interaction with a second driver and the reception of docking and unloading instructions. Woods (1978) commented that Rhode Island disallowed licenses for deaf truck drivers because “the deaf individual cannot hear verbal warnings and directions when backing into congested areas.” The ability to hear may affect communication relevant to CMV operation, but, again, there have been no studies to document how and to what extent lack of hearing affects safety through this mechanism.

Little attention has been given to the audibility of speech communication in the noise environment of the truck cab. Jones (1983) writes that communication becomes more difficult in noisy environments and cites a study that found that speech sounds must increase by 3-5 db(A)

for each 10 db(A) increase in background noise. He concludes that for sustained conversation, a limit on background noise of 70 db(A) is recommended. Research also has shown that low-frequency sounds (250 to 1,000 Hz) contain the most speech energy, but it is the high-frequency sounds (2,000 to 4,000 Hz) that contain the most critical information for speech intelligibility. These high frequencies are also the frequencies most affected by NIHL. A person with NIHL will have a diminished hearing ability for sounds at high frequencies (4,000 to 8,000). Truck drivers similarly report a loss in the ability to understand speech immediately after driving (consistent with the effects of temporary threshold shift). For example, a truck driver, in a personal communication to the DOT, stated that after driving, the likelihood of miscommunication in providing directions over the telephone increased.

Kramer and Arbuster (1982) report that, in a well understood situation, people can communicate, even if the environment itself is not conducive to communicating (e.g., fire fighters yelling instructions during a fire.). Persons in such situations already have a sense of what will be communicated. This may or may not directly apply to the situation of a CMV crash.

## 5. Hearing Loss in CMV Drivers

There is no question that exposure to noise causes hearing loss (NIH 1990; Jones 1983). Moderate exposure leads to TTS — hearing impairment that disappears within several hours. Repeated exposure over long periods can lead to NHHL — permanent hearing impairment. The Federal Railroad Administration acknowledged the problem of noise in 1983 when it adopted modified OSHA standards for railroad workers.

The first sign of NIHL is usually loss of hearing at fairly high frequencies, in the range of 3,000 to 6,000 Hz, with a peak loss of around 4,000 Hz. Additional exposure leads to loss of hearing above and below these frequencies.

There are both primary and secondary risk factors for NIHL. These risk factors need to be considered when evaluating studies that examine NIHL. Driving exposure may not be the only high-noise situation a driver encounters. The table below provides a description of these primary and secondary risk factors for NIHL.

Primary Risk Factors	Secondary Risk Factors
Occupation	Medical History
Military	Conductive Hearing Loss
Hobbies	Anatomic/Genetic
Medication	Medication
Age	Diabetes
Residence	Cholesterol Elevation
Outdoor Activities	Cigarette Smoking
	Hypertension

Based on the tractor cab noise levels presented earlier, CMV driving can be a major risk factor for NIHL. This is of primary importance for the risk assessment, because the likely pool of people who would be affected by regulations concerning hearing and licensing would almost exclusively be those individuals already driving CMVs (total number: 5.5 million — FHWA estimate). The literature clearly demonstrates that there is a high degree of hearing loss among CMV drivers (Truckie 1974, Nerbonne 1975, Dufresne 1988). The type of hearing loss seen was similar for all truck drivers: hearing sensitivity was at a relatively high threshold (Nerbonne 1975, Dufresne 1988) and at a frequency of 3 to 6 kilohertz (kHz) with a peak loss at around 4 kHz. The greatest loss of hearing was found in the left ear.

What is critical, however, is to be able to document the incidence and prevalence of NIHL among CMV drivers. Data concerning self-reported hearing loss from the National Health Interview survey reveal that 2.9% of those engaged in the transport industry (excluding railway) had hearing loss. This estimate must be qualified in that the definition of the transport industry was broad. Many other occupations besides CMV driving were included. Self-reported hearing loss may underestimate prevalence because individuals are not always aware of the hearing loss,

or they may not choose to report a hearing problem. Age and duration of exposure are additional factors to consider.

A more precise estimate has, been published by Backman (1989), in Finland, who evaluated, cross-sectionally, the frequency of self-reported hearing loss in professional drivers. Overall, the frequency of hearing loss increased from 8% in the youngest drivers, aged 30 to 34, to 17% among the oldest drivers, aged 50 to 54, with an overall prevalence of 13%. These rates are similar to those reported among metal assembly workers and other occupations (Talbot 1985).

Using data from the U.S. Health Interview Survey and the Finnish reports, we can estimate the prevalence of self-reported hearing loss among the 5.5 million U.S. interstate drivers. On the low end, we could estimate that there would be approximately 159,500 licensed drivers with hearing impairment (5.5 million x .029). This assumes that the prevalence of hearing loss among CMV drivers would be similar to that for persons in other transportation industries. On the high end, we can use the information available from Finland, where the prevalence of hearing loss among professional drivers was 13%. This would result in an estimate of 715,000 CMV drivers with impairment (5.5 million x .13). Whether we arrive at 159,500 or 715,000, it is clear that a large number of CMV drivers are estimated to have hearing loss.

If one is more interested in estimating the numbers of new (incident) cases of hearing loss among truck drivers, we can approximate this figure using the data from Finland. Between the ages of 30 and 34 and 50 and 54, the prevalence of hearing loss rose from 8% to 17%. Thus, during the 20 years between 34 and 54, an additional 9% appeared to develop hearing loss; roughly a .0045% increase each year. This figure can be translated into a crude incidence rate for the CMV drivers. Therefore, the estimated number of new cases of hearing loss among CMV drivers each year between the ages of 34 and 54 would be 2.7 million drivers (35 to 54 yrs.) X .0045 = 12,150. We would thus expect that if current regulations were effective, 12,150 licenses could be taken away each year from the current pool of truck drivers.

This figure assumes that these CMV drivers would be identified as hearing-impaired with a proper hearing test. Whether or not this would occur in practice is not clear. Some of these drivers might pass the recommended hearing screening (49 CFR 391.41), as even fairly advanced NIH: will not produce worse than a 40-db HL average threshold at 500, 1,000 and 2,000 Hz. These same drivers would probably fail the forced-whisper test. Enforcement of the hearing regulations can also vary among private employers.

To evaluate what the practices may be regarding hearing in CMV drivers, we contacted approximately 45 private trucking companies to determine the number of drivers who failed their DOT physicals at renewal because of hearing. A random sample of large interstate trucking firms was chosen from the Official Motor Carrier Directory, 1991 ed. Every seventh company that owned 1,000 or more tractors was selected. To attain information from at least 30 companies, each fourth company that owned 500 or more tractors was also selected. This selection provided 30 companies owning at least 500 tractors.



The director of personnel or safety was contacted in each company and asked the following questions: How many drivers are employed by your company? Are all drivers subject to the Federal medical standards? Have any drivers failed the DOT physical at renewal? How many? Have any of your drivers failed the DOT physical due to hearing impairment? How many? What is the outcome of failing a DOT physical?

The results of this informal survey were as follows:

Number of companies contacted	30
Total number of employed drivers	66,364
Mean number of drivers per company	2,213
Total number of drivers that failed DOT physical at renewal due to hearing	32
Crude rate of failure due to hearing	48/100,000

This investigation provided useful information. First of all, by comparing the expected number of hearing-impaired CMV drivers with the number failing the DOT physical due to hearing, one can see that of the 159,000 to 715,000 CMV drivers expected to have hearing impairments, only an estimated 2,640 (55 million X .00048) are being screened out of the driving population. This translates into .4% to 1.7% (2,640/715,000 to 2,640/159,000) of the hearing-impaired CMV drivers.

According to this information, nearly 99% of hearing-impaired CMV drivers are licensed and driving. The question then remains as to the safety of hearing-impaired drivers. It may be that their driving records equal, if not exceed, those of normal hearing CMV drivers, assuming that a CMV driver would not remain employed with an unsafe driving record. On the other hand, this may reflect lack of enforcement of the hearing regulations. Further investigation would be necessary to determine which, if any, of these reasons would explain the existence of 156,360 to 712,360 hearing-impaired CMV drivers.

We recognize that both the prevalence estimates and the incidence estimates are crude and are likely to be underestimates. It is also important to remember that NIHL increases exponentially with age. There will be few drivers at the younger ages with NIHL. However, with many years of exposure to noise, the numbers with NIHL will increase substantially as evidenced by the 9% increase seen in Finland. There is little question that there are a very large number of current CMV drivers who have some form of hearing impairment, and that each year a large number of new cases of hearing impairment will occur in the pool of CMV drivers. The number of these drivers who are excluded from licensing, though, appears to be very small.

A brief description of the literature regarding NIHL among truck drivers follows.

Mackie (1974)

The hearing effects of noise on commercial drivers were measured secondarily in a study by Mackie and colleagues (1974). Forty-five drivers with a mean age of 45 years and an average driving experience of 26 years were tested in a study which sought primarily to examine the effects on noise on driver performance. Hearing tests showed that many of the drivers already suffered from extensive hearing loss. When compared to data that were corrected for expected hearing loss due to age, the results suggested that the permanent hearing loss the truck drivers suffered from was NIHL. A direct evaluation for NIHL, though, was not conducted.

Nerbonne and Accardi (1975)

Nerbonne and Accardi studied 85 U.S. drivers who had been driving a truck for at least 1 year. The drivers ranged in age from 23 to 45, with a mean age of 33.6 years. Twenty-eight potential subjects were excluded because of: (1) exposure to other excessive noise environments, (2) a history of ear damage, (3) use of ear protection while driving a truck, or (4) air-bone gaps indicating conductive hearing loss. Pure-tone hearing tests were conducted on the drivers. Test results showed hearing loss at 4 kHz in drivers who had driven at least 15 years. While the hearing levels of drivers with less than 15 years' experience were in normal ranges, there was some loss of hearing around 4 kHz. These results are consistent with NIHL patterns. Table 2-2 below depicts the mean hearing level thresholds present in these drivers by years of driving exposure and frequency. A decrease in hearing level thresholds was observed with increasing driving experience at each frequency. Regardless of driving experience, hearing was better in the right ear than in the left, consistent with other studies that show that noise is higher at the left ear. Hearing loss increased with the driving experience.

Table 2-2. Mean Hearing Level Thresholds by Driving Exposure and Frequency  
(in decibels)

YEARS OF EXPOSURE	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	8,000 Hz
1 - 7	9	6	5	19	19
8 - 14	12	7	8	24	20
15+	14	9	14	33	23

Dufresne, Alleyne, and Reesal (1988)

Dufresne, Alleyne, and Reesal reviewed 602 NIHL worker's compensation claims filed over a 4-year period in Alberta, Canada. A graph of the audiograms of the 10 truck drivers who had filed claims was compared to a graph of the audiograms of the entire sample. Both graphs showed a sharp dip between 4 and 6 kHz. The truck drivers' audiograms differed from the entire sample in that hearing loss was more pronounced in the left ear than in the right. This is probably due to the added noise caused from driving with open windows in a fast-moving vehicle.

## 6. Reducing Noise in the Driving Environment

A number of interventions can reduce the potential harmful effects of noise in the tractor cab. The most common are the use of hearing protection devices (HPDs) and soundproofing of the truck cab. HPDS (individually fit earplugs, earmuffs, etc.) reduce all sounds in the driving environment, including noise and signals that may be of interest to the driver. The use of hearing protection devices can be compared with inducing a temporary hearing loss for the purpose of increasing comfort in a noisy environment.

Because hearing protection may reduce the audibility of certain sounds, there is some concern that hearing protection may contribute to accidents by interfering with speech communication (Wilkins 1982), the ability to detect horns, or the ability to localize incoming sounds. A survey by Karmy and Coles (1976) found that more than one-half of those questioned thought that it was more difficult to hear warning sounds with hearing protection. Persons with NIHL may be at a particular disadvantage when wearing hearing protection (Wilkins 1982). Persons with NIHL wearing protection may not be able to hear warning signals; while normal-hearing people wearing protection could. This scenario, though, is completely dependent on the frequency and intensity of the signal. Recently, linear earplugs have been developed that reduce all frequencies equally, thereby maintaining the signal-to-noise ratio for the user. Suter (1989) reported that hearing protectors may adversely affect speech recognition for moderately to severely hearing-impaired listeners because some speech sounds may fall below the level of audibility.

Preliminary evidence from industrial cohorts suggests that there is no increase in accident risk among those who wear protection devices. Cohen (1976) and Schmidt (1980) both found a significant reduction in the number of injuries reported after introduction of a hearing protection program in a noisy environment. It is not clear from the reports if hearing protection was the sole reason for the reduction in mishaps. In a more comprehensive study, Moll van Charante (1990) reported that the use of hearing protection had no noteworthy association with shipyard accidents.

Body soundproofing, which is becoming more common in automobiles and trucks, is another means to reduce noise. Tyler (1973) explored a number of mechanisms to reduce truck cab noise, varying from the application of layers of fiberglass in the truck cab to the use of mufflers to the use of polyurethane foam as an insulating material. The most effective means of achieving noise reduction was achieved through a combination of techniques. AU means were considered relatively inexpensive to provide.

There has been some concern here, as well, that soundproofing could further diminish outside sounds (e.g., sirens, horns). Newer cars with better soundproofing, for example, have poorer detection distances for railroad warning signals (Aurelius and Korobow 1971). At the same time, though, Aurelius and Korobow report that, overall, masking by engine noise appears to be a more important factor than body soundproofing. The real impact of soundproofing on motor vehicle collisions, however, remains unknown.

## 7. Devices That Compensate for Lack of Audibility

A number of devices have been developed to help the hearing-impaired driver overcome the handicap as it relates to the normal activities of daily living. Many with hearing impairment may choose not to use these devices, but a hearing screening test can identify those persons who need to use special devices to ensure safe operation of a vehicle. The following devices have been recommended to hearing-impaired and deaf drivers:

1. Assistive mirrors, most often two side mirrors and a rearview mirror. A number of states already require the use of assistive mirrors for their hearing-impaired CMV drivers licensed in intrastate commerce.

2. An enhanced visual turn indicator. The enlarged design of the indicator theoretically prevents the hearing-impaired driver from driving with the turn signal on.

3. An alerting device that provides a visible warning when it detects sirens, horns, and other loud road noises. This visual warning signal for sirens and other noises is generally mounted on the dashboard. The device can be set at various levels of sensitivity. In a noisy environment, though, the device has to be set to a fairly poor sensitivity setting to prevent it from going off continuously. Recently developed devices have tried to overcome this limitation. Traffic-warning signals, for example, normally have a sharp line spectrum in the frequency domain, while ambient traffic noise is &e-band random noise. This difference can permit the detection of the warning signals in a noisy environment. Miyasaki and Ishida (1987) have developed and reported on one such traffic-alarm sound monitor. While they found that the device was satisfactory for siren detection, it was not satisfactory for the detection of alarm signals at a railway crossing.

4. Hearing aids. Lee and colleagues (1981) reported on the speech discrimination and effectiveness of hearing aids in listening conditions similar to those encountered by a transit operator. They concluded that individuals with hearing impairment (even those who used hearing aids) do not perform as well in noise as their normal-hearing counterparts. They also concluded that hearing aids could amplify unwanted noise. This study and other similar reports, though, are flawed from their lack of attention to audibility. Simply placing a hearing aid on an individual does not guarantee that you have made sounds audible. Much more in-depth, specific testing is required before any conclusion can be made. Also, given the circuitry available, a hearing aid can be configured in such a way as not to contribute to NIHL.

~~Gross~~ suggests that hearing aids could reduce the occurrence of crashes (if the lack of hearing is related to crashes). However, no data exist for these devices or assistive mirrors, turn signals, alerting devices, and linear earplugs that demonstrate their effectiveness in preventing accidents among hearing-impaired individuals.

Other forms of compensation that may be employed by a hearing-impaired individual or an individual whose hearing is masked by noise during truck operation include: visual awareness, tactile response, and olfactory sensitivity. The ability to use intersensory information to compensate for lack of audibility may be influenced by degree, type, and onset of hearing loss. On the other hand, the deaf driver may experience less fatigue due to noise exposure because he

or she does not hear the noise. There are no data specifically related to this issue. A summary of advantages, disadvantages, and compensations of congenitally deaf, adventitiously deaf, and hard-of-hearing persons is shown in Table 2-3 below.

Table 2-3.

Compensation Mechanisms by Degree of Hearing Impairment

	<b>Congenitally Deaf</b>	<b>Adventitiously Deaf</b>	<b>Hard-of-Hearing</b>
<b>Disadvantages</b>	-no audition -no verbal communication	-no audition	-limited audition -possible sound distortion
<b>Advantages</b>	-no noise fatigue	-no noise fatigue -speech -lip reading	-speech -lip reading
<b>Compensations</b>	-visual dependence -cochlear implant -written communication -gestural communication -olfactory -tactile	-visual dependence -cochlear implant -written communication -gestural communication -olfactory -tactile	-speech -lip reading -hearing aid -high signal sensitivity -less signal; sensory ratio

## 8. Effects of Noise on Performance

There is little question that exposure to noise causes hearing loss (NIH 1990; Jones 1983). Noise, though, has also been linked with other effects, such as interference with communication and physiological disorders (Hinchcliffe 1958, Jones 1983, NIH 1990) which could, in themselves, lead to accidents. As mentioned before, speech sounds must increase by 3 to 5 db(A) for each 10-db(A) increase in background noise (Jones 1983). The added effort needed to converse in noisy environments can cause fatigue, anxiety, and stress. Additionally, hearing loss can lead to psychological and cognitive dysfunctions (NIH 1990). These effects will vary greatly among individuals.

Less well known is the impact that noise may have upon job performance. There is some suggestion that noise has a detrimental influence on work output and efficiency (Hinchcliffe 1958). Other studies have investigated the association between noise and industrial accidents. Most have found that noise is related to industrial accidents. However, study design and methodologic limitations in these reports raise some concern over whether noise is a causal factor in accidents. A review of this issue will be presented later.

### Effects of noise on driving performance

Whether noise has an effect on driving performance is difficult to determine. Studies suggest that the effects of noise on performance may be highly task-dependent. In a review of this literature, Jones (1983) reports that noise does not interfere with the detection of single-source signals, but does interfere when the task requires attention to several sources. Similarly, Finkelman (1977) studied eight college-aged automobile drivers and found that noise did not affect driving performance in a single-task situation. However, when a second task was added, the number of pylon errors was substantially higher in the noise environment.

Most of these studies, though, were conducted in either laboratory or test track settings. The tasks undertaken in such situations may not be comparable, in terms of complexity, to driving a truck on an interstate highway. The only appropriate way to determine whether noise in truck cabs adversely affects drivers' performance is to conduct a controlled study with truck driving as the task. One study (Mackie 1974) attempted this and found no indication that higher noise levels resulted in more driving errors among CMV operators. It also found that defining and measuring valid performance criteria for truck driving were difficult, implying that the results of performance studies can differ by the performance criteria selected.

It is apparent that more research is needed to investigate the effects of noise on driving performance. The research to date suggests that performance in a noisy environment may not be impaired until complex or multiple tasks are encountered. However, these results were obtained from studies conducted in well-controlled environments. It may be difficult to extrapolate these findings to the driving tasks encountered in routine CMV operation. A look at the relevant studies follows.

Finkelman (1977)

The effect of noise on driving performance was evaluated in eight volunteers (five men, three women) ages 18 to 23 years, who were tested on 16 driving runs each on a set course marked with pylons. Four tasks were undertaken by each subject four times: (1) driving the course without noise, (2) driving the course with 93-db(A) white noise, (3) driving the course without noise, but with delayed digit recall, and (4) driving the course with noise and delayed digit recall. Driving performance was assessed by the number of pylon errors and the driving time to complete the course. One practice run was permitted for each subject.

No real difference was found in pylon errors between runs with noise and runs without noise when driving was the sole task to perform. The runs with noise took only a little longer to complete. However, when a second task (delayed digit recall) was added, meaningful differences were observed between the runs with noise and the runs without noise. Both pylon errors and driving time were greater in the runs with noise.

Mackie, O'Hanlon & McCauley (1974)

This study evaluated, in part, the effects of noise and vibration on driving performance among CMV operators. Forty-five drivers, ages 27 to 64, with a mean age of 45 and an average of 26 years of driving experience, participated in the study. Many of the drivers appeared to suffer from extensive NIHL. The authors produced different noise and vibration levels by varying the type of vehicle and road conditions used. A standard tractor cab and a "quiet" truck (a truck specially designed for low noise and vibration) were used on three driving routes which varied from 313 to 428 miles. Sound measures in the trucks were taken once an hour. The average noise readings in the quiet truck were 74 db(A). Noise levels in the standard tractors were similar to those found by Close & Clarke (1972), with a mean of approximately 86 db(A). In the high-noise situation (standard tractors on very rough roads) noise levels averaged 99 db(A).

Performance measures evaluated included steering wheel motion, vehicle speed, accelerator motion, brake activation, and driver errors. Steering wheel motion turned out to be a poor measure of performance because it was heavily dependent on the road conditions driven. Vehicle speed was also a questionable performance measure since, by design, the vehicle speed of the trucks could not vary considerably on the highways. There were very few driver errors and no indications that higher noise levels resulted in more errors. There also was no evidence that different noise and vibration levels affected fatigue.

In all, the study found no relationship between noise levels and commercial truck driver performance, but it is difficult to place high confidence in these results due to a number of methodological constraints. Many drivers, for instance, suffered from NIHL. Fatigue was self-rated by the drivers. The number of drivers evaluated in each vehicle and road condition category was not mentioned.

Noise and industrial accidents

To evaluate the significance of hearing in motor vehicle accidents, one can also look at the relationship between noise and industrial accidents. Many hypothesize that noise may be a cause of accidents, because it hinders communication and masks warning signals (Wilkins 1982). Indeed, case reports show that masking leads to accidents in noisy, industrial environments.

(Wilkins 1982). Hearing protection devices, which may decrease hearing ability, may also be related to accidents.

Noise is commonly implicated as a cause of industrial accidents (Wilkins 1982), but few studies provide evidence to evaluate its impact on large numbers of people. Of the evaluations completed to date, three (Kerr 1950, Cohen 1973, Moll van Charante 1990) suggest that high levels of noise are associated with industrial accidents, while two (Lees 1980, Straub 1974) found no relationship. Table 2-4 portrays the data relevant to these reports. Two other studies (Cohen 1976, Schmidt 1980) provide evidence that personal hearing protection devices may decrease the risk for accidents in high-noise environments. The combined evidence suggests that noise could be a contributory factor in industrial mishaps, but the evidence at this point is not entirely convincing.

It remains particularly difficult to interpret these studies, because of their methodological constraints. The fundamental limitations include the failure to adjust the findings for the independent effects of confounding variables on accidents, the poor manner in which noise exposure was assessed, and the failure to distinguish the influence of hearing loss on accidents from the influence of noise. Confounding variables such as age, experience, workshift, and the workplace environment could be related to industrial accidents irrespective of the effects of noise. It is important to consider these factors when evaluating the influence of noise on accidents. Many studies, though, have not controlled for their external effect.

Second, the measures of noise exposure undertaken in the following reports have been very poor. Most of the reports published have defined noise exposure from company records or by the factory department in which the individual worked. These measures are very indirect techniques for assessing noise exposure and, as such, may not provide accurate measures of the noise levels where the participants actually worked. Third, some reports have failed to conduct pure-tone, audiometric examinations to test for the level of hearing impairment in the surveyed populations. Moreover, when audiometric exams were conducted in one report, the examiners did not test for hearing sensitivity in the higher frequencies where the influence of NIHL can be seen. Some or all of the accidents may have been due to the effects of NIHL rather than to noise itself.



Table 2-4.

Noise and Industrial Accidents

Study	Time	Industry	Accidents		Noise Levels		Units	Comments
			High noise	Low noise	High	Low		
Kerr, 1950	1 yr	electronics	correlation: $r=-0.42$		not presented		-	-12,060 employees
Cohen, 1973	5 yrs	manufacture (plant A)	9.0	0.4	95+ dBA	<80 dBA	average per worker over 5 yrs	-1,000 workers -matched on age and work experience -not matched on work environment
		(plant B)	1.7	0.7				
Lees, 1980	15 yrs	?	0.64	0.62	90+ dBA	<85 dBA	incidence/exposure year	-140 "industrial" workers -matched on age, exposure period, and duration of employment
Moll van Charante 1990	3.5 yrs	shipyard (no hearing loss)	1.83 <sup>1</sup>	1.00 <sup>2</sup>	82+ dBA	<82 dBA	odds ratio	-600 workers -matched on age -other factors were controlled for in the analysis
		(hearing loss)	1.80	4.25 <sup>1</sup>				

<sup>1</sup>  $P < 0.05$

<sup>2</sup> Reference value

The individual contribution of noise and NIHL to industrial mishaps remains poorly defined. Moll van Charante and colleagues (1990) provide the best evidence to date to describe their influence on accidents, Workers with hearing levels at less than 20 db had a significantly higher risk for injuries and accidents when exposed to high noise levels (.82 db) than when exposed to lower noise levels. However, workers with hearing levels at more than 20 db had a lower risk for accidents in high-noise than in low-noise environments. Noise, then, may have an adverse impact only on those with minimal or no hearing loss (i.e., those who can hear it).

While the evidence concerning noise and industrial accidents supports the idea that the ability to communicate and hear warning signals could be important for accident prevention, the methods used in many of the studies to arrive at this conclusion were significantly flawed. Thus, again, it appears that more research is necessary to elicit the true relationship of noise to industrial accidents, as well as the concomitant relationship of NIHL. A more detailed description of the studies on industrial accidents follows.

#### Kerr (1950)

Kerr conducted a study to identify variables that may be associated with accident proneness in factory departments in the Camden Works of RCA. He compared 53 accident-prone and non-accident-prone departments, based on annual accident rates. Of the 40 variables investigated, Kerr found four significant correlations with accidents, one of which was a high mean noise level. However, no mention was made of the characteristics of the People within each department, such as age, sex, race, experience, or working shifts. Because of this, and the design of the study, it is difficult to determine if noise was a causal factor in accidents in this factory.

#### Cohen (1973)

Cohen compared the medical disorders, absences, and job accidents of workers exposed to high noise levels (>95 db) and low noise levels (< 80 db). This retrospective study used data from 500 worker files of two manufacturing plants and was double-blind to eliminate recorder bias. Workers in the high- and low-noise-level groups of each plant were matched for age, work experience, and work shift. The results suggested that workers in low-noise areas were less likely to have accidents than those in high-noise areas. The exclusion of workers with hearing problems from the study may have had some influence on the results.

#### Lees (1980)

Lees ~~performed~~ conducted cohort study of 140 industrial workers to examine the level of noise exposure in relation to absenteeism and accidents. Persons were placed in two groups: those exposed to 85 db(A) or less for 15 years, and those exposed to 90 db(A) or more for a period of 3 to 15 years. Both groups were matched by age, exposure period, and length of employment. Lees reviewed medical records to determine the frequency with which selected medical factors were related to noise. Initial analysis of the data showed higher rates of motor vehicle accidents in the high-noise cohort. However, no relationship was found between noise exposure and accidents on the job. The incidence rate of motor vehicle crashes was seven times higher for men on rotating shifts. When adjusted for shiftwork, the relationship between noise and motor vehicle crashes disappeared. The motor vehicle accident data also were not adjusted for the effects of sex or driving exposure.

#### Moll van Charante (1990)

Moll van Charante conducted a case-control study on the risk for injuries and accidents in 600 male shipyard workers in order to identify factors that may interfere-with the perception of warning signals. Workers who had been injured in the past 3.5 years were matched by age with workers who had not been injured. The results were based on a questionnaire that had a response rate of 88%, the injury registry records of the shipyard, annual audiometric tests that screened across frequencies of 250 to 8,000 Hz and noise surveys conducted 3 years previously. Alcohol consumption, average hearing thresholds greater than 20 db HL, and loud noise exceeding 82 db(A) were safety hazards for the workers identified by univariate analysis. In multivariate analysis, 43% of the injuries at the shipyard were attributed to the combination of noise and hearing loss. Those workers with minimal or no hearing loss (thresholds less than 20 db HL) had a significant risk for injuries and accidents when exposed to high noise levels (greater than 82 db(A)). Noise levels greater than 82 db(A) however, did not appear to pose a threat to the safety of workers with hearing losses of more than 20 db HL. At noise levels under 82 db(A), though, persons with extreme hearing impairment were 4.2 times more likely to be involved in an industrial accident than those without hearing loss.

#### Straub (1974)

Straub examined the industrial medical records of 52 heavy-metal fabrication workers to investigate associations between their work-related injuries and hearing levels. He divided the group into those with hearing levels poorer than 40 db HL and those with hearing levels better than 25 db HL. Also, he matched the groups for sex, age, race, job, and years of experience. The results of the study showed no significant difference in the frequency of work-related injuries between the two groups. The study suffers important limitations in the small sample size the use of self-reported injury data with no mention of reporting rates, and the use of data from audiometric test that average the results of the frequencies only at 500, 1,000, and 2,000 Hz. Current literature clearly states that the onset of industrial hearing loss is initially found between 3,000 and 6,000 Hz.

#### Moll van Charante (1991)

In a follow-up study, Moll van Charante examined factors that may influence the perception and the processing of sensory receptions, including the effects that high noise levels had on the reduction of posture control and its subsequent effects on the risk for industrial accidents at the same naval shipyard. In this retrospective, age-adjusted case-control study of 106 workers, a at&graph was used to measure posture control in silence and in high noise levels **exceeding 93 db(A)**. The question was posed whether hearing loss could affect posture control, which could then in turn affect the risk for injuries. No significant difference in posture control was found between those workers who had experienced previous injuries and the controls. Also, no relationship between posture control and hearing loss was found according to the audiometry results. Possible confounding factors of this study are the relatively young age of the sample (mean age. 37 years), and the possible recall bias in regard to lifestyle.

## B. Hearing Loss and Accidents

Employment opportunities for hearing-impaired persons have been restricted in a number of sectors under the pretext that hearing is required for job performance or that a higher risk for occupational accidents may exist. The accident risk associated with hearing loss is not entirely clear, but mention is often made that hearing-impaired persons may not be able to hear sounds that signal danger or be able to communicate with others in emergency situations. At present, we know very little about the accident experience of hearing-impaired drivers. This pertains to both automobile and CMV drivers.

One reason we know little about the role of hearing loss in CMV accidents is that persons with extreme hearing impairment are restricted from operating commercial motor vehicles in interstate commerce. Under the current regulations (49 CFR 391.41), a person must perceive a forced-whisper voice in the better ear at not less than 5 feet (with or without a hearing aid) or, if tested by an audiometric device, must not have an average hearing loss in the better ear of greater than 40 db HL at 500, 1,000, and 2,000 Hz to be eligible for interstate licensure.

Licensing for private automobile drivers who are deaf or hearing-impaired is more commonplace. Data on the accident experience of these drivers, then, could provide some information regarding the effect of licensing hearing-impaired persons for interstate operation. However, a number of limitations in the studies on automobile drivers affect the interpretation of results. These include weaknesses in the definition of hearing impairment, definition of accidents, sources of hearing-impaired drivers, and study designs used.

Problems in the comparison of results between studies arise because the definition of hearing impairment differed in each investigation. Some studies relied on self-reported hearing loss measures. This is likely to be much less accurate as a measure of hearing loss than those studies based on audiometric or forced-whisper testing. Similarly, the classification of hearing loss by the forced-whisper test is much less accurate than the categorization by standardized audiometric methods.

No standard definition of a road crash has been implemented in the literature. Thus, a number of different definitions of road accidents have been described: fatal crashes, police-reported accidents, self-reported accidents, tow-away crashes, and injury-producing crashes. The collisions described below with respect to hearing impairment have been confined to police-reported, self-reported, and injury-producing accidents. This comparison among the studies is, again, difficult because of the differences in the definition of accidents employed.

Each accident definition also entails special circumstances regarding hearing impairment. For example, many non-fatal accidents are not reported to State and local authorities (WHO 1979, Greenblatt 1981, National Center for Statistics and Analysis 1984). Persons with hearing impairment may be reluctant to report accidents that may result in a medical examination or a loss of driving privileges. In this sense, the proportion of accidents reported to licensing authorities could differ between hearing-impaired and normal-hearing populations. Accidents involving hearing-impaired drivers may also be more likely to be reported by the police or other

drivers simply because a handicapped driver was involved and out of concern over public safety (Pinesilver 1962a, Coppin 1964).

There is some evidence from the literature that moving vehicle violation rates for deaf drivers may not be reliable. Roydhouse (1967) presented case reports to point out that violations may be pursued more aggressively among deaf drivers than normal-hearing drivers, because of concern for public safety. Schein (1968), though, hypothesizes that it could be possible that law enforcement officials may be more lenient with deaf persons. Indeed, evidence from a study by Cook (1974) suggests "a certain amount of leniency on the part of law officers when arresting a hearing-impaired person for other than major violations." There were more individuals in the hearing-impaired group who had violations that went without infraction than in the hearing population (31% vs 9%  $p < 0.01$ )

The possibility that violation records could be severely influenced by external factors hints that more faith should be placed in accident statistics rather than violation statistics regarding deaf drivers. Accidents are a more severe endpoint than violations (particularly accidents resulting in substantial property damage or injury) and may be more likely to be reported because of their severity and their implication for public safety. Thus, they are likely to have more validity than violation rates.

Self-reported road crashes include, by definition, only those collisions that the respondents have reported on surveys and questionnaires. Accidents defined in this way may be underreported to the extent that individuals may conceal events that reflect unfavorably upon their experience (Elbel 1960). Last, injury-producing accidents, such as those taken from hospital and health care records, include only accidents that result in injury serious enough to warrant medical attention. Minor accidents and crashes that produce only property damage may not be included under this classification scheme.

The populations from which the hearing-impaired individuals were identified also varied among the studies and, depending upon the source, may have biased the results. Cohorts have been selected from licensing records, deaf organizations, driver improvement programs, deaf schools, and surveys of deaf informants.

Some reports have focused on persons who were known by their respective licensing agencies to be deaf or hearing impaired. They would be known, for the most part, either by medical examination upon license application or by police reports. Some research suggests, however, that relatively few persons with medical impairments are identified to the authorities by medical personnel (Waller 1965). Individuals identified by police records have also been generally involved in a previous accident or moving violation. Thus, they may be more prone to crash. Individuals identified from licensing agencies, then, may not be representative of the hearing-impaired population.

Other studies have evaluated persons identified from rosters of deaf organizations and driver improvement programs. Persons belonging to deaf clubs may be quite different from those who are not members. Schein (1968) found that persons in higher socioeconomic groups were more likely to join than those in lower income groups. He also noted that only 50% of the deaf population may belong to a deaf organization. These groups, then, may not be representative of