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Recreational Noise Exposures at Motorsport Events

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RECREATIONAL NOISE EXPOSURES AT MOTORSPORT EVENTS

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ABSTRACT

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Noise induced hearing loss (NIHL) is a type of hearing loss that after repeated exposure to high levels of sound for extended periods of time can result in damage to the fragile structures of the inner ear. Hearing changes caused by NIHL could be temporary or permanent. Hazardous noise levels in the workplace environment have been known to cause NIHL over time. Therefore, governing agencies have noise standards that have been enacted to decrease the risk of developing NIHL in the workplace. The Occupational Safety and Health Administration, Mine Safety and Health Administration, and the Federal Railroad Administration are examples of these governing agencies. In addition, the National Institute for Occupational Safety and Health and the World Health Organization have provided best practice guidelines for prevention of NIHL by establishing permissible noise exposure criteria. Hazardous noise exposure is not only confined to the workplace but can be found in a variety of non-occupational settings including recreational activities. Occupational and non-occupational noise exposures are cumulative throughout a lifetime. However, there are no limits to reference for recreational exposures. Common recreational activities include target shooting, attending concerts, and attending motorsport or other sporting events among others.

The motorsport industry is growing and includes countless aficionados partaking in motorsport events. Both recreational and occupational noise exposure studies have documented the risk for NIHL among individuals involved in motorsports. The range of sound pressure levels were between 63 dBA to over 100 dBA across studies investigating motorcycles, snowmobiles, stock cars, F1, monster trucks and tractor pulls (Bess & Poynor, 1974; Buhr-Lawler, 2017; Dolder et al., 2013; Jordan et al., 2004; Kardous & Morata, 2010; Moore, 2014; Morley et al., 1999; Rose et al., 2008; Ross, 1989; Van Campen et al., 2005). Hot rodding is a unique motorsport among other types that has not been evaluated for noise exposure of drivers, spectators, and event personnel. Due to an increasing number of individuals with NIHL, it is important that additional research is conducted to evaluate the noise exposures from motorsports that are contributing to this health issue. Development of prevention strategies and hearing conservation programs for individuals involved in motorsports is warranted. Recommendations for future directions and hearing health promotion activities targeting this population are provided. Audiologists can play a key role in the prevention of NIHL resulting from motorsport noise exposure by providing hearing conservation services, monitoring for auditory damage, and education for motorsport enthusiasts and employers.

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CHAPTER I

REVIEW OF THE LITERATURE

Introduction

This review of the literature covers aspects of noise exposure as related to recreational noise exposures during motor sporting events. The demographics and risk of noise-induced hearing loss (NIHL) from motorsports is included. A background on motorsports and descriptions of hot rod associations is described. Various types and methods of noise measurement are discussed in addition to the factors that affected these measurements.

Motorsports

Motorsport racing events can be seen around the world and are a part of the popular and sporting cultures for social and economic reasons. A Global Consumer Survey estimated that 1.3 million households had individuals “who attended any auto racing track event in the U.S.” in the year of 2018 (Lange, 2021, p. 1).

Economic Impacts

One part of motorsport is auto-racing, which has been ranked among some of the most popular sports in the United States (Gough, 2018). Auto-racing motorsport competitions can be split into two sets of vehicle classes: open-wheel and enclosed-wheel racing. Globally, open-wheel racing is headed by the Formula series (which includes Formula 1), while in the United States, open-wheeled racing is led by the Indy Car series, most widely known as the Indianapolis 500. Among Formula 1 motor sports race teams, Ferrari reached revenues of around $349 million in 2016 (Gough, 2018).

Enclosed-wheel racing includes sports car racing, stock car racing, and touring car racing. The National Association for Stock Car Auto Racing (NASCAR) is the leading organizer of stock car racing and is one of the world's most valuable sports event brands. The highest valued NASCAR team is Hendrick Motorsports, while the Daytona 500 is stock car's highlight event. The brand value of Daytona 500 in 2017 was $140 million and in 2018, television viewership for Daytona 500 in the United States stood at around 9.3 million (Gough, 2018, para. 3-4).

Potential positive economic effects of motorsports have been documented. According to Gough (2018), global annual sponsorship spending in motorsports amounted to over $5 billion. Another example of a positive economic effect from motorsports was documented in a study by Connaughton and Madsen (2007) who examined the economic impact of the motorsports industry in North Carolina for 2005. They found the total economic impact to be $5.9 billion in increased total output, 27,252 in increases employment, nearly $1.7 billion in increased total employee compensation, and close to $2.8 billion in increased total value added.

From a global perspective, Angus et al. (2007) reported that in 2005, the motorsport industry was worth approximately £50 billion (approximately $55 billion) and represented 0.23% of global gross domestic product, there were approximately 600 race circuits, 56 global motorsports events, and, on average, more than 52 million viewers watched each Formula 1 Grand Prix.

Taken altogether, motorsport can be seen as a major global industry with significant economic, cultural, and entertainment aspects. Additionally, future research into the sustainability (i.e., some aspects including natural-ecological systems, human-health/knowledge, social-organizations/government systems, manufactured-existing tools/infrastructure, and financial-money/stocks) of motorsport is warranted as current academic literature pertaining to motorsport and sustainability is very limited (Dingle, 2009).

Types of Motorsports

Dingle (2009) described the diversity of motorsport racing and how the term could be described:

> The term 'motorsport' encompasses a range of major categories of racing. For four-wheeled vehicles alone there are a multitude of forms: formula one, Indy car, stock car, tally, drag racing, go-karts, dune buggies and trucks are just some. Motorbikes race in several varieties, including superbikes, motocross, quad bikes and the derivative snocross competitions. While motorsport is principally a land-based activity, it also extends to onshore and offshore speedboat racing. Many categories of motorsport are further divided into sub-categories – on-road or track racing and off-road racing. Within each major category, motorsport is further divided into a range of competitions according to body type, engine capacity and vehicle manufacturer, each with their own idiosyncrasies and technical requirements. (p. 76)

Street Racing. The term 'street racing' might have multiple meanings. It could potentially refer to races occurring in closed circuits on regular streets in a scheduled race (e.g., NASCAR or Indy racing). A second definition might refer to illegal races that occur spontaneously between drivers who decide to challenge one another during normal driving. Illegal races might also be well organized by "meets" or "clubs" that have events scheduled and publicized by word of mouth. A final definition of street racing could involve a sole driver exceeding speed limits or racing against the clock. Street racing has been documented to be associated with injuries or deaths of participants, passengers, spectators, and/or pedestrians. In

1998, street racing was added as a driver factor to the Fatality Analysis Reporting System form that codes factors related to fatal crashes in the United States, the District of Columbia, and Puerto Rico. In addition, other illegal activities have been identified with street racing including impaired driving, illicit gambling, and noise complaints among others. There are very limited official statistics on street racing offenses and related collision due in part to different jurisdictional operational definitions. However, through social surveys, the prevalence of young male drivers partaking in street racing is between 18.8% and 69% with drivers being from various international jurisdictions. Another finding from the limited evidence on street racing suggested it has increased in the last decade with media attention and public concern on the rise (Vingilis & Smart, 2009).

Armstrong and Steinhardt (2006) provide definitions to differentiate between street racing and “honing,” which is generally activities such as burnouts and unnecessary speeding or acceleration by an individual or by a group. However, both terms of street racing and hooning are not mutually exclusive and are often used interchangeably. The authors explained that formal “anti-hooning” legislation has been passed in four Australian states and New Zealand. This legislation forbade activities such as racing, creating unreasonable noise or smoke, and causing deliberate loss of traction. Within this study, Armstrong and Steinhardt conducted an examination of the experiences and perceptions of young people regarding “hooning behavior” and legislative reforms through a combination of focus groups, email responses, and message board feedback. The authors reported six key themes identified in responses: group processes, defect notices, police attitudes, media perceptions, illegal behaviors, and “anti-hooning” legislation.

Hot Rodding. There are various meanings for the terms hot rods, hot rodding, and hot rodders, which could be defined in several dictionaries as slang. In general, hot rods can be thought of as automobiles that are typically classic American cars that have been modified or built in a particular way either for racing, touring, or for purely aesthetic purposes. Balsley (1950) stated, “The hot-rod culture is committed to the everlasting modification of what it casually calls Detroit iron -the American production car” (p. 354). Furthermore, Balsley summarized that any car when rebuilt by a hot rodder could be assigned to one of the four following categories of design listed numerically and increasing (lowest to highest) in rank:

4. Changes are done only to the exterior of the car with accessories from manufacturers and the engine remains substantially unaltered.

3. Changes are made to the engine to increase horsepower and acceleration while ornamentation may still be used.

2. The car is stripped of all chromium and ornaments, roadability and safety are increased, and all changes made are practical for everyday use.

1. The top ‘rank’ is classified as cars that are streamlined to run only at top speed with many of their owners being innovators and designers in the hot-rod field.

In the 1930s prior to WWII, racing was occurring on southern California’s dry lakes. Popularity of this racing increased but with few established rules; accidents and injuries were common and police authorities were threatening to shut down the events. What resulted was several clubs joining in an interest of organization and safety to what became known as the Southern California Timing Association established in 1937. Some actions the association took included banning some types of cars as dangerous, formal technical committees to examine cars before they raced, controlling spectator access, complying with police and highway patrol, as well as creating competition by awarding points for places in races (Moorhouse, 1991).

The hot-rodding subculture boomed in the 1940s. The launch of *Hot Rod Magazine* occurred in 1948, lending itself to become a place for archives of American hot rodding and a guide for the hot-rodding industry. The hot-rodding subculture has developed into a number of established businesses, entertaining "show and shine" car show events, drag racing, and motorsport events (Dixon, 2007). Dixon (2007) summarized, "Hot rodding is not an inexpensive hobby, but the development of a lifestyle. Enthusiasts will hock personal possessions and work extra hours to establish themselves as hardcore hot-rodders. This subculture is articulated through car clubs and associations coast-to-coast" (p. 24).

Associations. A plentiful number of car clubs and associations have been created around the hot rod culture including the National Hot Rod Association (NHRA, 2019), Goodguys Rod & Custom Association (Goodguys, 2019), and the National Street Rod Association (NSRA, 2019). The Hot Rod Industry Alliance is a section of the Specialty Equipment Market Association (2019, which is dedicated to preserving and promoting the hot rod industry.

Founded in 1951, the NHRA (2019) is a drag racing governing body and the largest auto racing organization in the world. It has over 40,000 drivers in its rosters (NHRA, 2019). Goodguys, an association founded in 1983, has over 70,000 active global members today and is anchored by Goodguys Gazette Magazine. They self-report to be the largest motorsports organization in the world dedicated to the preservation and growth of the classic and late model hot rodding community. Goodguys considers itself a market leader in the automotive aftermarket industry. They host 18 events across the country with a projected total attendance of over two-million for 2019 (Goodguys, 2019). The NSRA (2019) hosts a number of Hot Rod and Muscle

Car shows in the United States. In the Hot Rod Industry Alliance biannual report of 2017, the hot rod industry was reported to be a $1.26 billion enterprise (Specialty Equipment Market Association, 2019).

In summary, motorsports and hot rod racing are a major part of the popular and sporting culture that continues to thrive. Membership in hot rod associations and clubs demonstrate that individuals might be partaking and attending events such as drag racing and motorsport events. These events generate high sound levels and might put individuals at risk of NIHL and tinnitus.

Noise-Induced Hearing Loss and Tinnitus

Cochlear damage and hearing loss can result from exposure to excessive noise and is known as NIHL. Noise-induced hearing loss typically begins as decreased hearing sensitivity in the 3,000 to 6,000 Hz frequency range, which is referred to as a 'noise notch' on the audiogram if hearing thresholds are better for the lower and higher test frequencies. If noise exposure continues over time, the notched configuration broadens and eventually disappears as the hearing loss progresses to include lower and higher test frequencies. Noise-induced hearing loss is influenced by the characteristics of the noise (i.e., frequency spectrum) and the acoustical transmission characteristics of the ear canal and middle ear (Gates et al., 2000). The hearing changes caused by NIHL can be temporary or permanent. Temporary threshold shift is a decrease in hearing sensitivity that typically returns to the previous level after a set period of a few minutes to a few hours. On the other hand, a permanent threshold shift is an irreversible decrease in hearing sensitivity (sensorineural hearing loss) that could be caused by repeated exposure to hazardous noise levels over time (National Institute for Occupational Safety and Health [NIOSH], 1998). Gates et al. (2000) retrospectively examined the 15-year change in audiometric thresholds of 203 men and found the effects of noise damage might continue long after noise exposure had stopped. They further stated that the mechanism for this finding was unknown but presumably resulted from prior noise-induced damage to the cochlea.

The workplace environment is a known setting that might have hazardous noise levels, which could potentially lead to NIHL over time. Because of this, governing agencies have established noise standards to reduce the risk of NIHL in the workplace. The Occupational Safety and Health Administration (OSHA, 1983), Mine Safety and Health Administration (MSHA,1999), and the Federal Railroad Administration (FRA, 2006) are examples of these governing agencies. Furthermore, NIOSH (1998) and the World Health Organization (WHO, 2019) have provided best practice recommended guidelines for permissible noise exposures.

Hearing loss caused by exposure to non-occupational noise is called sociocusis and includes recreational and environmental noises (i.e., loud music, firearms, and household power tools). Additionally, combined exposures to noise and certain physical or chemical agents (i.e., vibration, organic solvents, carbon monoxide, ototoxic drugs, and certain metals) appear to have synergistic effects on hearing loss. Passchier-Vermeer and Passchier (2000) found sufficient scientific evidence to show noise exposure could induce non-auditory effects beyond hearing impairment. These non-auditory effects included hypertension and ischemic heart disease, annoyance, sleep disturbance, and decreased school/work performance. They further stated that noise exposure is on the increase, especially in the general living environment, indicating it would be a major health problem in the 21st century.

Factors Influencing the Risk of Noise-Induced Hearing Loss

The effect of noise on hearing is influenced by the following factors: the temporal pattern of noise, the level of the noise, the duration of the noise, the spectral characteristics of the noise, and concomitant exposures including chemicals.

Temporal Pattern of Noise

The temporal pattern of noise is the way sound is distributed in time and can be characterized as continuous noise, intermittent noise, time-varying noise, or impulse noise. Continuous noise has negligibly small fluctuations of sound level within a period. Intermittent noise is when large differences in sound level occur with periodic interruptions of relative quiet or low-level sounds between noise episodes. Time-varying noise is when the noise level varies substantially but there are no significant quiet periods. Impulse noises are very short bursts of noise lasting less than one second characterized by sharp rise and rapid decay times such as gunfire (Madison, 2014; NIOSH, 1998).

Level of the Noise

To determine the risk of NIHL, the level of noise is an important factor to consider. As the level of the noise increases, the risk of NIHL increases. Sound pressure level (SPL), expressed in decibels (dB), is a measure of the amplitude of pressure change that produces sound. This amplitude is perceived by the listener as loudness or the level of the noise. The sound level meter is the basic measuring instrument for measuring sound levels in dB SPL. According to NIOSH (1998), the level of concern for noise when determining risk of NIHL is 85 dBA (A-weighted) as this level is considered hazardous to working adults and is known to contribute to NIHL. The determination of this level is driven by the selection of an exposure limit. The exposure limit depends on the maximum acceptable occupational hearing loss (i.e., the fence) and the percentage of the occupational noise-exposed population for which the maximum acceptable occupational hearing loss would be accepted. The fence is usually defined as the average hearing threshold level (HTL) for two, three, or four audiometric frequencies. Excess risk is the difference between the percentage that exceeds the fence in an occupational-noise-exposed population and the percentage that exceeds the fence in an unexposed population. Material hearing impairment is a term that means a person's average HTLs for both ears exceed 25 dB at certain audiometric frequencies. As defined by NIOSH (1998), material hearing impairment is an average of the HTLs for both ears that exceed 25 dB at 1000, 2000, 3000, and 4000 Hz. Based on this definition, the excess risk is 8% for workers exposed to an average daily noise level of 85 dBA over a 40-year working lifetime. Referenced in Tables 3-4 from NIOSH is the estimation of the percent of excess risk of material hearing impairment at age 60 after a 40-year working lifetime across different models.

Duration of the Noise

The duration of the noise must be considered along with the level of the noise to fully determine if the noise is hazardous. The combination of noise level and time or (duration) is termed exposure. Noise exposures that no worker should exceed are referenced by NIOSH's (1998) Table 1-1 using a specific exchange rate. The exchange rate is an increment of decibels that requires the halving of allowable exposure time for equivalent exposures. This is discussed further under the noise measurement section of this paper.

Spectral Characteristics of the Noise

The spectral characteristics, the frequency content, of noise depend on the type of noise and the source. A complex sound could have a wide range of frequencies while other sources might have fewer frequencies with tonal characteristics. The filtering of frequency content of a noise is used to compare the effect of the noise on the human ear and is known as frequency weighting. Fletcher and Munson (1933) demonstrated that the human ear is most sensitive to frequencies between 2000 and 5000 Hz and has good sensitivity between 100 and 10,000 Hz. One method of frequency weighting is to use A-weighting (dBA), which represents the response of the human ear at low to moderate levels of intensity and gives a good estimation of the threat to human hearing. Occupational Safety and Health Administration (1983), MSHA (1999), FRA (2006), WHO (2019), and NIOSH (1998) required that occupational noise exposure measurements are conducted using A-weighting instrumentation settings. Other types of weighting are Z-weighting and C-weighting. C-weighting allows capture of more low frequency sounds and slightly more of the high frequencies than A-weighting (Madison, 2014). Z-weighting is essentially an "unweighted" measurement.

Concomitant Exposures

As mentioned earlier, combined exposures to noise and certain physical or chemical agents (i.e., vibration, organic solvents, carbon monoxide, ototoxic drugs, and certain metals) appear to have synergistic effects on hearing loss (NIOSH, 1998). In a study by Gwin et al. (2005), NIOSH conducted a series of surveys to evaluate occupational exposure to noise and potentially ototoxic chemical agents among members of a professional stock car racing team. Exposure assessments included site visits to the team's race shop and a "worst-case scenario" racetrack. Area samples were collected to measure exposures to potentially ototoxic chemicals including organic compounds (typical of solvents), metals, and carbon monoxide. Organic compound concentrations and levels of lead and other metals were either not detected or were extremely low, and well below any occupational exposure criteria. Carbon monoxide levels never exceeded the eight-hour exposure criteria (OSHA PEL of 200 parts per million [ppm], the NIOSH REL of 100 ppm, the American Conference of Governmental Industrial Hygienists' threshold limit values of 50 ppm, or the NIOSH recommended ceiling limit at the race shop. Gwin et al. discussed how "hazardous noise and chemical exposures have not been empirically studied. Moreover, the effects of these agents on hearing, communication, and job performance are unknown” (p. 406). This further highlighted the need for noise exposure studies in automobile racing events. Noise exposure data for the noise survey from the first part of this study are provided in the Motorsport Noise Exposure in the Stock Cars subsection.

Noise-Induced Tinnitus

Tinnitus is one of the major symptoms accompanying NIHL. It is described by ringing, buzzing, roaring, or other sounds an individual hears that do not have an external physical source. Furthermore, tinnitus is very heterogeneous in nature with symptoms and degree of severity varying from person to person and even fluctuating within the same individual. The exact loci of where tinnitus is generated in the auditory system has yet to be determined and could be different on a case-by-case basis. There is no current curative treatment for tinnitus but many management strategies have helped those dealing with handicaps from tinnitus including but not limited to behavioral therapy approaches, sound therapy options, and stimulation methods. Tinnitus could be caused by NIHL and might be prevented if proper steps are taken to protect hearing sensitivity from dangerous noise exposures.

Occupational and recreational noise exposure levels could potentially be intense enough to cause permanent damage to the cochlea (e.g., NIHL) and noise-induced tinnitus. In a retrospective study by Griest and Bishop (1998), tinnitus was evaluated as a potentially early indicator of permanent hearing loss in a population of noise exposed workers. Data were examined from 91 male employees working in environments with noise levels ranging from eight-hour time weighted averages of 81-101 dBA over a period of 15 years. The results indicated the prevalence of tinnitus increased more than two and a half times for workers experiencing maximum threshold shifts of 15 decibels or greater in hearing level (dBHL). One limitation pointed out by Griest and Bishop in the design of this study was workers were required to recall non-work exposures over a substantial period of time, raising concerns of the reliability of their responses. Additionally, the authors emphasized the non-work exposures were important and needed to be included as a determining factor for NIHL and tinnitus.

Axelsson and Prasher (2000) described that one of the most common causes of tinnitus was noise exposure and noise-induced permanent tinnitus (NIPT) could derive from occupational noise exposure, leisure noise, or acoustic trauma. In occupational NIPT, the time between the start of noisy work and the appearance of tinnitus is long (e.g., years) but with leisure noise and acoustic trauma, the time between exposure and tinnitus is frequently very short or immediate. The researchers further stated through their review of literature that although NIPT from occupational noise is decreasing in clinical practice, it is more common that young individuals report tinnitus from exposure to leisure activities such as concerts and discos.

The prevalence of leisure noise-induced tinnitus among 518 Flemish young adults (between the ages of 18-30 years old) as well as the relation with sociodemographic factors, health-related variables, and attitudes and beliefs towards noise were examined by Degeest et al. (2016). This study was a cross-sectional study using a self-administered questionnaire. The noise-related activities analyzed were categorized as watching movies or plays, visiting nightclubs or music venues, attending musical concerts or festivals, listening to personal music players through headphones, listening to a home stereo or radio, attending sport events, using noisy tools, practicing a musical instrument, occupational noise, playing in a band or orchestra, or other noisy leisure-time activities. A 68.5% overall prevalence of temporary tinnitus was observed and at least 6.4% of the young adults in the study sample reported chronic tinnitus in at least one ear. Higher levels of leisure noise were independently associated with chronic tinnitus. The results from this study were considered by the authors to underpin the importance of educating young adults about the risks of loud noise exposure during leisure activities with special attention to tinnitus as a sign of overexposure and the importance of hearing protection devices (HPDs).

Noise Exposure Measurement Techniques

Purposes of Noise Measurement

Within a workplace, the purposes of noise measurement might include the following: to quantify the workers' exposure and identify those who exceed noise criteria levels, to assess the noise situation for engineering and administrative controls, and to measure ambient sound levels in audiometric rooms. Workers' noise exposures must be quantified to know the needed attenuation required from HPDs, for education and motivation for use of HPDs, and participation in hearing conservation programs (HCPs; Moritz, 2014). Other effects such as speech interference and annoyance are other areas of interest that can be assessed with noise measurements (Murphy et al., in press). Public health efforts have expanded beyond the occupational setting and focus on quantifying hazardous sound levels and permissible exposures over a lifetime, as those by WHO described previously.

Instrumentation

The sound level meter (SLM) and the noise dosimeter are instruments for measuring noise. To comply with regulatory requirements, instruments for noise measurement must conform to appropriate standards (within the United States). Sound level meters should comply with the American National Standard Institute's (ANSI) specification for sound level meters (2022b). Noise dosimeters should comply with ANSI's specification for personal noise dosimeters (2022a) and OSHA (1983) regulations. Calibration of instruments should comply with ANSI'S (2022b) specification for acoustical calibrators (Moritz, 2014).

Sound Level Meters

Murphy et al. (in press) stated, “Nearly all instruments used for noise analysis have evolved from the basic sound level meter (SLM), which senses acoustic pressure and indicates the output as frequency-weighted, time-averaged sound pressure levels in decibel units” (p. 32). Sound level meters are commonly used in industry for conducting area noise measurements to determine noise levels of machines or work areas. These area noise measurements can be used to create a noise contour map of an industrial plant, as an educational tool for HCPs, and to identify major sources of noise for engineering and administrative controls. Sound level meters may be used to measure sound levels and periods of time an employee is exposed to noise with documentation in a log in a method called task-based noise exposure assessment. Other important uses of SLMs include measuring area noise levels and background noise levels in audiometer rooms, for calibration of audiometers, and assessing the need for engineering controls (Moritz, 2014).

Two types of sound level meters most often used in industry are the precision sound level meter (Type 1) and the general-purpose meter (Type 2). The type or quality of the microphone makes the difference between the two. There are certain characteristics across sound level meters including showing the sound level output in tenths of a decibel, the dynamic range is often selectable for low or high settings, and the weighting scale can be chosen to fit the appropriate measurement. For example, A-weighting might be selected for most occupational noise measurements while C-weighting can be used to determine the contribution of low-frequency noise for engineering noise control purposes. The response settings of either “slow” or “fast” could be selected, which refer to the time the meter takes to reach its final reading. For many noise exposure measurements, the slow response time constant is used. The level is averaged over a one-second period and then exponentially averaged when running in a continuously updating mode. The one-second time constant allows the instrument operator to estimate the exposure during the operation period. Madison (2014), FRA (2006), MSHA (1999), OSHA (1983), and WHO (2017) require noise exposure measurements be made with the slow time constant. For complex operations where the slow time constant might be too slow and compromise the estimate of an event, the fast response time constant is used. The level is averaged over a 0.125 second period (ANSI, 2022c). For transient events such as an automobile pass-by for assessing transportation noise, the fast setting might be an appropriate choice (Murphy et al., in press). Sound level meters might also be equipped with frequency analysis capabilities such has octave-band, one-third octave band, or narrow-band filers (Moritz, 2014).

Noise Dosimeters

The noise dosimeter is a small integrating sound level meter that automatically calculates the noise dose. Dosimeters are commonly used to measure variable sound levels over time. They are especially useful and efficient when workers are frequently moving to different areas within a workplace. This portable device with an integrated microphone is placed within the vicinity of the ear, preferably at the top of the shoulder, to collect an individual's unprotected exposure. Dosimeters can perform various functions simultaneously including "profiling" or "logging" a worker's noise exposure history, measuring, storing, and analyzing data. Some statistics of the worker's noise exposure history that could be obtained with the dosimeter include time by the minute of noise exposure, noise-level and dose at specific times, dose at the end of a period, maximum and minimum noise levels, and noise level graphic display. Noise dosimeters continuously measure sound levels in an environment and could be set to sampling parameters (acoustic metrics) for specific standards or guidelines (Moritz, 2014).

Measurement Metrics

As previously described, sound level meters and noise dosimeters measure and store a variety of acoustic metrics. Many dosimeters allow for users to change the exchange rate (3, 4, or 5 dB). The exchange rate reflects the relationship between allowable exposure times and specific noise levels. The OSHA (1983) and MSHA (1999) standards specified that noise be integrated over time using a 5 dB exchange rate, meaning an increase of 5 dBA is equivalent to a doubling of noise dose. Dose refers to the amount of noise exposure relative to the allowable exposure. For each doubling of noise dose, the allowable exposure time is halved. Hence, according to OSHA, exposure to 90 dBA is permissible for eight hours, 95 dBA for four hours, 100 dBA for two hours, and so on. Each of these noise level and permitted time of exposure is equal to a 100% noise dose. The National Institute for Occupational Safety and Health (1998) and WHO (2017) recommended a 3-dB exchange rate. Most countries and the U.S. Department of Defense use a more conservative 3 dB exchange rate (Madison, 2014).

Because sound levels are rarely constant over an entire work shift or set period of time, a time-weighted average (TWA) is used as the measurement metric. Time-weighted average is the combination of all sound intensities accumulated throughout an eight-hour work shift or time period to identify the integrated overall exposure reported in dBA. The A-weighted scale is employed during noise measurements because it closely represents the loudness perception and risk of damage to the human ear. According to NIOSH (1998) guidelines, exposures at or above an eight-hour TWA of 85 dBA (equivalent to 100% dose) is the recommended noise exposure limit (REL). On the other hand, when the noise exposure reaches an eight-hour TWA of 90 dBA or above, the permissible exposure limit (PEL) or 100% dose is reached according to OSHA (1983) standards. Additionally, the OSHA standards defined exposures at or above an eight-hour

TWA of 85 dBA as the action level (AL) and is when 50% dose is reached. At this point, implementation of a hearing conservation program and enrollment of the affected workers is essential (OSHA, 1983). When the noise dose is above 100%, it is representative of exposure levels that are dangerous to the individuals' hearing when exposed to this degree over extended periods of time.

The lower threshold level in dBA, below which the instrument does not measure, can be set in instruments. OSHA and MSHA specify a lower threshold of 80 dBA or below. Many dosimeters begin measuring at 70 dBA or below but may have range limits that prevent accurate measurements of higher sound levels (e.g. 130 or 140 dBA). Additionally, today's dosimeters can give measurements based upon fast, slow, and instantaneous response settings. Most SLMs have large dynamic ranges over which sound levels are measured accurately (up to 110 dB) (Moritz, 2014). Noise dosimetry is routinely utilized in industry and in non-occupational settings for noise exposure measurements of individuals or groups of individuals.

Noise dosimetry is meant to be a free-field measurement when used to assess the risk of NIHL. A free field measurement is when there is nothing present that would impede or have significant influence on the sound energy radiated from a source into the sound field (Murphy et al., in press). The new technology of in-the-ear dosimetry measures an individual's protected exposure under the hearing protector. In-the-ear dosimetry measures of the transfer functions of the outer ear must be considered for noise exposure measurements. A part of the transfer functions of the outer ear is the ear canal, which causes an increase in sound pressure levels for certain frequencies (resonance) due to its physical characteristics (i.e., length and structure being similar to a tube open at one end and closed at the other end).

Occupational Noise Exposure Standards and Recommended Guidelines

U.S. government standards have been developed and enforced to control levels of noise and to prevent NIHL in the occupational industry. The U.S. government enforces the following standards: OSHA (1983) 29 CFR 1910.95, MSHA (1999) Title 30 CFR Part 62, FRA (2006) 49 CFR Parts 227 and 229.

Best practice recommended guidelines, which are not enforced by a regulatory agency or by the federal government, also exist to address noise exposures. Best practice occupational guidelines were developed by NIOSH (1998). The NIOSH guidelines were based on scientific evidence and provide criteria documents “on the prevalence of hazards, the existence of safety and health risks, and the adequacy of control methods” (Centers for Disease Control and Prevention, 2014, para. 2). Recreational and occupational noise exposure guidelines are provided as well by the WHO (2019). Additionally, the WHO published guidelines for community noise “by consolidating knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in non-industrial environments” (Berglund et al., 1995, p. iii). The WHO has provided night noise guidelines and environmental noise guidelines for the European region.

U.S. Government Standards

Occupational Safety and Health Administration Standard

The Occupational Safety and Health Administration **(**1983) is part of the U.S. Department of Labor and was created after the Occupational Safety and Health Act of 1970. It was created to assure safe and healthful working conditions for individuals by setting and enforcing standards and by providing training, outreach, education, and assistance (U.S. Department of Labor, n.d.-c).

The OSHA (1983) 29 CFR 1910.95 stated that protection against the effects of noise exposure is to be provided when sound levels exceed criterion sound levels when measured on the A-scale of a standard sound level meter at slow response. When measuring for action level, all continuous, intermittent, and impulsive sound levels from 80-130 dBA are to be integrated into the noise measurements. Furthermore, the employer is required to notify the employee exposed at or above the action level (OSHA, 1983). An effective hearing conservation program is required by the employer under OSHA's standard whenever the employee noise exposures equal or exceed an eight-hour TWA of 85 decibels, which is defined as a 50% dose and referred to as the action level.

The OSHA (1983) defines a PEL of 90 dBA, eight-hour TWA integrated with an exchange rate of 5 dBA, to be a 100% noise dose. When measuring for PEL, all continuous, intermittent, and impulsive sound levels from 90-140 dBA are to be integrated into the noise measurements. When exposures reach the PEL level, engineering controls are required and hearing protection must be implemented. The ceiling limit (or slow max) is defined as 115 dBA by OSHA, meaning employees' exposure should never exceed this limit. Peak level exposures are limited to 140 dB peak SPL.

Mine Safety and Health Administration Standard

The U.S. Department of Labor's (n.d.-c) MSHA develops and enforces safety and health rules for all U.S. mines and their employees. The Mine Safety and Health Administration provides educational, technical, and other types of assistance to mine operators (U.S. Department of Labor, n.d.-c).

The purpose of MSHA's standard, Title 30 CFR Part 62, is to prevent the occurrence of and reduce the progression of occupational noise-induced hearing loss among miners (Electronic Code of Federal Regulations, 2019). It applies to all mine operators, both coal and metal and nonmetal, underground and surface operations. September 13, 2000 was the date this standard and its provisions became effective, one year from the date it was published (Electronic Code of Federal Regulations, 2019).

The AL, PEL, and ceiling limit used in MSHA's standard (Electronic Code of Federal Regulations, 2019) are identical to those used by OSHA:

> Section 62.120 of MSHA's standard requires that if a miner's noise exposure equals or exceeds the 'action level' during any work shift, it is required to enroll the miner in a hearing conservation program (HCP) that complies with Section 62.150. If a miner's noise exposure exceeds the permissible exposure level (PEL) during any work shift, Section 62.130 requires the enrollment of the miner in an HCP that complies with Section 62.150, and use all feasible engineering and administrative controls to reduce the miner's noise exposure to the PEL. Use of operator provided hearing protection must be ensured. In addition, administrative controls must be posted on the mine bulletin board and a copy is to be provided to the affected miners. (U.S. Department of Labor, n.d.-a, pp. 3-5)

Additionally, MSHA's standard includes a dual hearing protection level. It is defined as a 105 dBA eight-hour TWA integrating all sound levels from 90 dBA to at least 140 dBA. If a miner's noise exposure exceeds the dual hearing protection level during any work shift, Section 62.140 requires the employer to provide and ensure the concurrent use of both earplug type and earmuff type hearing protectors, in addition to the actions required for noise exposures which exceed the PEL (U.S. Department of Labor, n.d.-a).

Federal Railroad Administration Standard

The Federal Railroad Administration (2006) standard 49 CFR Parts 227 and 229 provide minimum health and safety occupational noise standards for railroad employees whose predominant noise exposure occurs in the locomotive cab. This standard became effective February 26, 2007. The FRA used OSHA's standard as a foundation for its own standard and adapted the OSHA rule to the unique circumstances of the railroad environment. The FRA requires railroads to limit employee noise exposure to an eight-hour TWA of 90 dBA. Also, FRA requires railroads to implement a hearing conservation program for those employees who are exposed to noise levels that equal or exceed an eight-hour TWA of 85 dBA. The FRA's doubling, or exchange, rate is 5 dBA.

The FRA (2006) established design, build, and maintenance standards for new locomotives and maintenance requirements for existing locomotives. It expected this rule would reduce the likelihood of noise induced hearing loss for railroad operating employees (FRA, 2006).

Best Practice Recommended Guidelines

National Institute for Occupational Safety and Health

The National Institute for Occupational Safety and Health (1998) is a best practices scientific organization created after the Occupational Safety and Health Act of 1970 (Public Law 91-596). Within this act, NIOSH was held responsible for:

> Recommending occupational safety and health standards and describing exposure concentrations that are safe for various periods of employment—including but not limited to concentrations at which no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience. (p. iii)

The NIOSH communicated these recommended standards to regulatory agencies such as OSHA or MSHA and to others in the occupational safety and health community.

The NIOSH (1998) recommended the following guidelines for a noise standard to protect workers from hearing losses resulting from occupational noise exposure. The NIOSH's recommended exposure limit, in place of OSHA's (1983) AL and PEL, is 85 dBA eight-hour TWA with exposures at or above this being considered hazardous. The employer is to institute a hearing loss prevention program (HLPP) and is to require workers to wear hearing protectors when any worker's eight-hour TWA exposure equals or exceeds 85 dBA. The NIOSH recommends a HLPP that includes exposure assessment, engineering and administrative controls, proper use of hearing protectors, audiometric evaluation, education and motivation, recordkeeping, and program audits and evaluations. When workers whose eight-hour TWA exposure exceeds 100 dBA double hearing protection (wearing earplugs and earmuffs simultaneously) must be worn. An exchange rate of 3 dBA is recommended by NIOSH. This means the noise exposure time is halved for each 3 dBA increase in noise level. The REL of 85 dBA for an eight-hour TWA with a 3 dBA exchange rate equals 100% noise dose. This means the equivalent noise exposure duration for an 88 dBA TWA would be four hours using the 3 dBA exchange rate. The NIOSH described a ceiling limit for exposures to continuous, varying, intermittent, or impulsive noise to not exceed 140 dBA.

World Health Organization

The World Health Organization (2019) uses evidence on the health effects of noise to identify the needs of vulnerable groups and to offer technical and policy guidance to protect health.

Occupational Noise Guidelines for Risk of Noise-Induced Hearing Loss. Concha-Barrientos et al. (2004) authored a guide for occupational health professionals to carry out more-detailed estimates of the disease burden associated with hearing loss from occupational noise at both national and subnational levels. The method used in the guide assesses exposure at two noise levels (85−90 and >90 dBA) by occupational category and economic subsector. These measurements were combined with the proportions of the working population in different occupations and subsectors and with the proportion of the working-age population that was employed by gender. The guide identified that the most appropriate exposure measurement for occupational noise was the A-weighted decibel, dBA, usually averaged over an eight-hour working day (LAeq). This was explained to be because of the strong correlation between this parameter and the ability of the noise hazard to damage human hearing. A minimum noise exposure was identified as being <85 dBA, moderately high noise exposure as 85-90 dBA, and high noise exposure as >90 dBA. Within the guide, it was stated that in most occupational settings, hearing impairment is generally defined as a binaural pure-tone average for the frequencies of 1000, 2000, 3000 and 4000 Hz of greater than 25 dBHL. This was different from the WHO definition of disabling hearing loss of permanent unaided average hearing threshold level of 41 dBHL or greater for the better ear at the four frequencies of 500, 1000, 2000 and 4000 Hz for the purposes of burden of disease assessments, referenced in Table 3 from Concha-Barrientos et al. (2004). The relative risks for hearing loss by sex, age group, and level of occupational exposure are referenced in Table 7 from Concha-Barrientos et al. (2004).

Johnson et al. (2001) reviewed exposure criteria and occupational exposure levels in a book compiled by WHO intended for occupational hygienists and other occupational health and safety personnel as an introduction to the subject. Within the chapter, the authors reviewed the history behind the use of octave band versus A-weighting, 85 dBA versus 90 dBA exposure level, and 3 dBA versus 5 dBA exchange rates as related to legislation standards, recommended guidelines, and reviews on research evidence. Examples of noise exposure criteria indicated by legislation in various countries as reported by the International Institute of Noise Control Engineering (I-INCE) are referenced in Table 4.3 from Johnson et al. (2001).

Recreational Noise Guideline for Risk of Noise-Induced Hearing Loss. A World Health Organization-International Telecommunication Union (2017) consultation on the Make Listening Safe initiative was held in Geneva, Switzerland on March 6-7, 2017. One objective of the consultation was to determine appropriate exposure limits for safe listening. Of note were the acronyms and their meanings used in describing this guideline. Leq is the equivalent continuous average noise level (dBA) measured using a 3 dB exchange rate. Lex is the equivalent continuous average noise level (dBA), measured using a 3 dB exchange rate, and normalized to an eight-hour exposure period; it might also be referred to as an La8hn or Lex8h (WHO, 2017).

Dr. Neitzel (cited in WHO-ITU, 2017) specifically addressed the question: “Are existing exposure limits for occupational noise exposure suitable for determination of risk due to recreational sound?” Dr. Neitzel identified most occupational limits as being 85 dBA Lex8h and most environmental limits as 70 dBA Leq (24).

After deliberation on posed questions and review of literature, the following outcomes were derived from the consultation. The lowest, most protective exposure limit was stated to have no associated risk. This was 75 dBA Lex8h (eight-hour exposure) or 70 dBA Leq(24) (24-hour exposure). This exposure limit was consistent with the U.S. Environmental Protection Agency (EPA, 2021) standard from 1974 and the WHO (2019) community noise limits. This limit included a margin of safety to account for vulnerable/susceptible individuals (Neitzel &

Fligor, 2017). The middle exposure limit would be associated with minimal risk and higher permissible exposure levels. This was 80 dBA Lex, 8h or 75 dBA Leq (24). This middle exposure limit reflected minimal risk and more permissible exposure, which has 1% risk of material impairment (>25 dBHL at 1000, 2000, 3000, and 4000 Hz). This middle limit was to be consistent with European Union (EU) recommendations. This exposure limit was intended to nearly eliminate the risk of measurable NIHL following a 40-year working lifetime. However, this standard might not be sufficiently protective as it did not account for lifetime exposures to noise. The highest exposure limit would have 8% risk of material impairment (>25 dBHL at 1000, 2000, 3000, and 4000 Hz). This was 85 dBA Lex, 8h or 80 dBA Leq (24) and was consistent with occupational limits outside of Europe. It was described that when referring to these grades in the standards, they could be categorized as least risk, slight risk, and higher risk (rather than less "safe").

Community Noise Guidelines. The WHO (2019) addressed increasing public complaints about excessive noise in the WHO European Region with best practice guidelines. These guidelines included WHO Guidelines for Community Noise of 1999, WHO Night Noise Guidelines for Europe of 2009, and the WHO Environmental Noise Guidelines for the European Region of 2018. The WHO described each of these guidelines as follows:

> The 1999 WHO Guidelines for Community Noise were the first WHO guidelines on the topic of noise and were a practical response to the need for action on community noise at the local level, as well as the need for improved legislation, management and guidance at the national and regional levels. (p. 5)

It should be noted that when WHO (2017) adopted the guidelines for community noise, they adopted the same EPA limit of a 24-hour Leq, or Leq (24), of 70 dBA using a 3 dB exchange rate. This limit was intended to be completely protective against any measurable hearing loss in virtually all of the population over a 40-year exposure period. These guidelines also indicated that non-occupational exposures have been noted to result in a similar amount of NIHL as occupational exposures of a similar duration and level. A difference from the EPA standard was this WHO guideline indicated maximum levels of 110 dBA Leq should be avoided to prevent acute hearing impairment (Neitzel & Fligor, 2017). The WHO (2019) explained:

> The 2009 WHO Night Noise Guidelines for Europe provide both evidence and recommendations that countries can easily use to introduce targeted limits for night noise. These guidelines support and integrate the 2002 European Union Environmental Noise Directive (2002/49/EC), which requires countries to map hotspots and reduce exposure, but does not set limit values. (para. 3)

The 2018 WHO Environmental Noise Guidelines for the European Region provided comprehensive guidance on protecting human health from harmful exposure to environmental noise (WHO, 2019). They set health-based recommendations on average environmental noise exposure of five relevant sources of environmental noise: road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise (WHO, 2019, “Policy,” para. 2-3).

WHO (2019) described:

> The WHO guidelines for community noise recommend less than 30 A-weighted decibels (dBA) in bedrooms during the night for a sleep of good quality and less than 35 dBA in classrooms to allow good teaching and learning conditions. The WHO guidelines for night noise recommend less than 40 dBA of annual average (Lnight) outside of bedrooms to prevent adverse health effects from night noise. (“Data and statistics,” para. 2)

Recreational Noise Exposure

The effects of noise on hearing of an individual are due to not only exposure in the workplace but also because of exposure to recreational or non-occupational hazardous noise levels. Another term used to describe this type of noise exposure is leisure noise. Recreational activities such as attendance to concerts, use of personal music players, and other noisy hobbies might put individuals at risk of NIHL and possibly tinnitus by adding to their overall noise exposure profile. There are currently no recreational noise exposure limits in the United States. However, the National Center for Environmental Health (NCEH, 2019) recognized that recreational activities such as motorized sporting events, sporting events, and concerts among others were sources of loud sound that might cause hearing loss, tinnitus, and/or hyperacusis with repeated exposure over time. The NCEH provided resources for the general public to access via their website. These resources included links to NIOSH information, to the American Speech-Language-Hearing Association (2021), American Academy of Audiology, and WHO to list a few (NCEH, 2019).

In response to limited studies researching recreational noise exposure, Neitzel et al. (2004) studied the effects of routine daily noise exposures resulting from non-occupational activities and their possible contribution to NIHL. In this study, 112 construction workers wore data logging noise dosimeters and simultaneously completed activity logs during two phases of data collection. Phase 1 subjects received logs listing numerous preselected occupational and non-occupational activities (involving 40 hours of consecutive noise monitoring and reporting on individual subjects). In Phase 2, subjects used free-field logs and reported non-occupational activities in greater detail (involving 96 consecutive hours of measurement). Noise exposure levels during both phases of data collection were measured using Quest Q-300 Type 2 data logging noise dosimeters. These units were configured to measure the equivalent continuous sound level, or Leq, using a slight modification of the settings specified by the 1998 NIOSH Recommended Exposure Limit (REL; 85 dBA criterion level, 3 dB exchange rate, 70–140 dBA measurement range, and fast response). The dosimeters yielded a Leq level for each one-minute interval measured. These one-minute interval noise levels, in combination with subjects' reported activities, were the basis of the activity-specific exposure level data. The noise levels measured in the current study suggested the majority of time (70% or more) spent in non-occupational activities was associated with an equivalent continuous exposure level below 70 dBA. In both phases of data collection, less than 10% of total non-occupational time was spent above 80 dBA. The activity associated with the largest percentage of minutes spent above 70 dBA and the highest mean LeqA noise level in Phase 1 was traveling in a car or bus. Routine non-occupational noise exposures contributed much less to total noise dose than occupational exposures in the subjects evaluated within this study.

Mikulec et al. (2011) quantified the noise exposure received while driving a convertible car with the top open compared to with the top closed. The researchers sought to examine if driving convertible automobiles should be added to the list of non-occupational activities that warranted recommendations for hearing protection. The cars employed for the study included 2009 Saturn Sky 2.0 Turbo, 2004 Nissan 350Z, 2001 Porsche 911 C4, 2005 Saab Aero Convertible, and a 2005 Ford Mustang GT Convertible. The study used the NIOSH REL (an eight-hour time-weighted average recommended exposure limit of 85 dB) and referred to noise of 85 dB or more to be considered as excessive. Measurements were taken by the passenger of the car using a Quest Technologies model 210 sound level meter with each data point representing the maximum reading over three seconds of noise surveillance. Measurements were taken (with the top open and with the top closed) for the three speeds: 55 mph, 65 mph, and 75 mph. Results showed the mean noise levels with the top open ranged from 85.3 dB at 55 mph to 89.9 dB at 75 mph. An average increase of 12.4-14.6 dB was observed after opening the convertible top at the tested speeds. The researchers concluded that convertible cars could be a source of noise exposure that exceeded recommended levels, especially for prolonged journeys with the top down. They suggested future research was needed to evaluate hearing damage in convertible automobile drivers including the effect of car radio usage. It should be noted that these researchers did not utilize a noise dosimeter that would integrate noise level with duration of exposure. They also did not address the issue of wind noise on the microphone of the SLM.

Skrúcaný and Kendra (2015) investigated the measurement of noise emitted from three different passenger road vehicles (Citroen Berlingo, Jaguar X-type, and a Volkswagen Polo). The researchers pointed out that nowadays limits of noise emissions are imposed on vehicles. In this study, the limits referred to were based on the Economic Commission for Europe of the United Nations for vehicle approving. The measurement device used to record sound was a Volcraft Plus SL-300 sound level meter with a measuring range of 30-130 dB. The microphone on the sound level meter had a polyurethane cover. A video car recorder, TX300 GPS camera, was used to record driving characteristics of position, accelerations, and instantaneous velocity. A combined thermo-hydro meter device was employed to measure outdoor temperature and humidity which was 8.9 °C (about 48 °F) and humidity of 54% during time of data collection. The sound level measurements were done in motion in the three vehicles in the area of and around the city of Zilina (Slovakia). Every measurement was done twice in each vehicle. Three types of measurement done were at constant speed of 50 km/h (about 30 mph) with 20-27 seconds in duration, full acceleration from 50 km/h to 90 km/h (about 60 mph), and in an urban cycle (vehicle operation in the urban area). The vehicles were fully loaded (five people). The person behind the driver manipulated the sound level meter and the measuring position was next to the driver's left ear. Peak sound levels measured were not used to draw conclusions for this study as they were only reached for one or two seconds. The evaluation of averaged measurements was used for interpretation instead. The Citroen Berlingo vehicle was the noisiest of the tested vehicles with the following average sound levels measured at constant speed of 50 km/h, acceleration from 50 to 90 km/h, and the urban cycle: 66.7, 67.8, and 65 dB, respectively. The Volkswagen Polo vehicle was the second noisiest of the tested vehicles with the following average sound levels measured at constant speed of 50 km/h, acceleration from 50 to 90 km/h, and the urban cycle: 65, 67.5, and 64.5 dB, respectively. The Jaguar X-type vehicle was the third noisiest of the tested vehicles with the following average sound levels measured at constant speed of 50 km/h, acceleration from 50 to 90 km/h, and the urban cycle: 65.7, 67.2, and 64.2 dB, respectively. The authors concluded that luxury vehicles such as the Jaguar X-type put emphasis on low noise level in the vehicle because it contributed to the driving comfort of the vehicle. Observed limitations of this study included the sound level meter settings and measurement metrics were not specified and contributing factors to noise level measurements such as driving with windows open or shut were not specified.

Motorsport Noise Exposure

Motorized vehicles have been identified as being potential sources of hazardous noise exposures. Research in the area specific to hot rod race or touring events was not developed in the literature. However, studies evaluating noise exposures or hearing loss from a variety of other recreational activities involving motorized vehicles included motorcycles, snowmobiles, stock cars, monster trucks, and tractor pulls.

Motorcycles

Ross (1989) evaluated the occupational noise exposures of motorcyclists wearing either open- or full-face helmet designs. Noise was measured with two microphones taped to the inside of the helmets with one microphone placed near the entrance of the rider's ear canal and the other near the rider's mouth (used to cue recordings during analysis). The microphones were interfaced with by a two-channel power supply and an amplifier to a two-channel miniature cassette recorder attached to a waist belt worn by the rider. The rider recorded: motorcycle speed, wind strength and direction, and position of the helmet visor. Measurements were carried during a series of runs in a town and motorway. The results were compared to the Health and Safety Executive (1976) Code of Practice for Reducing the Exposure of Employed Persons to Noise that indicated a criteria of a 90 dBA Leq 8 h with a 3 dB exchange rate. Equivalent continuous noise levels measured showed that during town driving with a full-face helmet, the range was from 63-90 dBA. During open road driving, noise levels depended on motorcycle speed. Sample Leqs ranged from 95 dBA at 30 mph to 105 dBA at 70 mph for the full-face helmet. For the open-helmet, noise levels ranged from 89 dBA at 30 mph to 98 dBA at 60 mph. Noise levels inside open helmets were found to be 7dBA less than for full-face helmet. An overall conclusion of this study was open road driving both with open- and with full-face helmets, riders were exposed to noise that could cause temporary threshold shift and permanent hearing damage.

McCombe and Binnington (1994) investigated the prevalence of NIHL in motorcycle grand prix racers. A total of 44 riders were randomly recruited and underwent interview, otological examination, and pure tone audiometry. The median age was 28 (range 18-37) years and median racing experience was 10 (range 2-21) years. Twenty riders (45%) had hearing losses greater than expected for age matched, non-noise exposed controls. The hearing deficit tended to increase with racing experience. Only 17 riders (39%) were regular users of earplugs and only nine had used them for most of their racing careers. Based on the results, the authors emphasized the need to raise awareness to this problem and increase the use of earplugs to avoid NIHL in grand prix motorcyclists.

Jordan et al. (2004) investigated under helmet, at-ear noise levels for a variety of helmet styles, motorcycle configurations, and speed gathered in on-road investigations for occupational motorcyclists. The categories of occupational motorcyclists were police, professional racer, dispatch/courier, paramedic, driving instructor, track day instructor, driving examiner, tour guides, taxis, breakdown recovery, and journalists with three participants included for each category. Miniature microphones were placed inside the helmet over the driver's ear canal opening. A digital audio tape recorder and battery were connected to microphones. A straight three mile, flat, asphalt road section of public road was selected as the test road. The rider travelled along the road at set speeds (50, 60, 70, 80, 90, 100, 110, and 120 km/h). Noise levels in excess of 105 dBA were recorded for motorcycles travelling at 70 mph. The hearing handicap in the study population ranged from 40% in professional racers and 36% in paramedics to 6% in driving instructors. All occupational motorcyclists in this study had LEPds above the second action level of the Noise at Work Regulations. The dominant noise source was the base of the helmet between the chin bar and the neck of the rider. The use of a proprietary neck seal reduced the inner helmet noise levels by around 4 dBA at 120 km/h. However, the neck seal was difficult to fit and, on several occasions, the wind pulled it from the helmet. The value of conventional hearing protectors in the reduction of noise exposure of motorcyclists was suggested by the authors to be limited due to high level of low frequency noise generated by wind turbulence and the impediment they created to use of radio communications (Jordan et al., 2004).

Carley et al. (2011) reported on the experimental measurement of motorcycle noise. Discrepancies in results for the same driving speed from previous studies that had measured noise inside a helmet were highlighted to possibly result due to the contribution of other noise sources (i.e., the engine, presence of a windshield, and the flow around the helmet). Within this study, sound pressure levels measured with extensive wind tunnel tests were conducted and compared to results from on-track data. Results showed sound pressure levels as a function of speed between on track and wind tunnel tests were comparable. Through spectral conditioning of on-track data, the contribution of engine noise to the overall noise was found to be a function of speed and more significant than previously thought. Consideration of motorcycle geometry, engine type, and environmental characteristics such as other traffic or varying wind speeds were noted to be contributing factors to the sound experienced at-ear levels. Overall, the three main contributors to at-ear noise spectra were the engine, the presence of a windshield, and the helmet.

Snowmobiles

Bess and Poynor (1974) aimed to study the effects of high-speed snowmobile engine noise on the auditory mechanism. Pre-exposure hearing tests were obtained on 21 racing drivers (42 ears) and five snowmobile mechanics (10 ears). Sound-pressure-level measurements were obtained on representative samples of high-speed engines and also on spectator areas around the racetrack. Results of this study indicated the racing snowmobiles produced intensities at ear level as great as 136 dBA (two-thirds throttle). Measurements taken within the spectator area ranged from 85 dBA to 113dBA. Such intensities were thought to be responsible for the high-frequency impairment found in all of the drivers and mechanics. Snowmobile noise levels loud enough to cause temporary hearing damage after only 120 minutes of riding were reported.

Moore (2014) investigated the noise exposure levels, knowledge, attitudes, and beliefs with regard to risk of NIHL of snowmobilers. Participants were a total of 10 adults with eight male and two females 18 years of age or older selected from a convenience sample of the Northwest Colorado Snowmobile Club. They were required to regularly participate at least five times a season to be eligible for the study. The noise measurements were obtained using a QuietDose noise dosimeter with the microphones held by medical grade tape placed in front of the individual's ear canal opening under their helmet. Dose was simultaneously calculated for OSHA PEL using a 90 dBA criterion level and a 5 dB exchange rate and the NIOSH REL using an 85 dBA criterion level and a 3 dB exchange rate. An 80 dB threshold setting was used for both OSHA PEL and NIOSH REL sampling protocols. Simultaneous dose was also calculated for OSHA AL using a 90 dB criterion level, a 5 dB exchange rate, and a 90 dB threshold setting. Survey instrumentation was used as part of the methodology including a snowmobiler data form (to record specifics on the snowmobile, helmet, and rider habits), a verbal interview of participants before and after their rides (to determine other specifics of the ride such as length, number of individuals riding, and atypical events like engine malfunction), and a health communication survey (pertaining to knowledge, attitudes, and beliefs about NIHL with key components of the Health Belief Model (HBM) integrated). A descriptive analysis was done on noise dosimetry measurements and snowmobile/rider characteristics. The results indicated all snowmobilers were over-exposed to noise while riding with helmets in this study. Under the helmet, noise exposure levels did not show adequate protection from hazardous snowmobile sounds while participants were engaged in recreational snowmobiling. The HBM survey results indicated half of the participants thought a helmet would provide protection. Also, the HBM survey showed the participants felt hearing protectors might be underutilized because of cost, communication, and comfort barriers. Regardless of the many variables between riders, all had noise hazards. Some of the riders had lower noise dose than others, which could be due to differences between the riders, equipment, and time spent riding. Also, results indicated the actual time snowmobilers spent riding, the high snowmobile noise levels, and non-use of hearing protection devices contributed to the risk of NIHL.

Stock Cars

In a study by Kardous and Morata (2010), noise exposures at three stock car racing events were conducted by researchers from the National Institute for Occupational Safety and Health (NIOSH). The selected stock car racing circuits were the Bristol Motor Speedway, Indianapolis Motor Speedway, and Kentucky Speedway. The noise assessments included area noise level measurements (in the pit area, infield, and spectator stands at the three races, and an infield garage at the Kentucky Speedway), using Quest Technologies Model 1800 and Larson-Davis System 824 type 1 sound level meters with "SLOW" response and A-weighting frequency filter; and personal noise exposure measurements (of one driver, team members and crew, and spectators during race preparation, practice, qualifications, and competition) using Quest Technologies M27 and Larson-Davis Spark 706 personal noise logging dosimeters. The dosimeters were set to measure noise exposure in comparison to the OSHA permissible exposure limit (PEL) and the NIOSH recommended exposure limit (REL). The authors provided the noise spectrum of a stock racing car (gathered using an audio tape recorder and laboratory analysis) to point out the importance of it in relation to selection of hearing protection, communication devices, and for providing effective noise control solutions. Results showed all area noise level measurements exceeded the NIOSH REL of 85 dBA, peak sound pressure levels reaching and exceeding the NIOSH and OSHA 140 dB maximum allowable exposure limit at the Kentucky and Bristol Motor Speedways. Results for personal noise dosimetry measurements at the Bristol Motor Speedway showed time-weighted averages that ranged from 96 dBA for a spectator in the stands during a race, 114 dBA for a driver inside the car during practice, measurements exceeded NIOSH REL for a driver during practice in less than a minute, within several minutes for team members, and less than one hour for spectators during the race. The authors discussed how noise levels on all three race tracks exceeded those measured in hazardous industrial environments. With stock car racing increasing in popularity, the authors further discussed the little recognition that existed of the associated noise exposure as an occupational hazard.

The National Institute for Occupational Safety and Health surveyed noise exposure for a professional stock racing team at their race shop with two site visits and during two races at Bristol Motor Speedway in a study by Van Campen et al. (2005). The purpose included assessing the level of exposures and then making initial recommendations for improved hearing protection and communication for the team. The instrumentation included a Quest Model 1800 sound level meter, which conformed to the American National Standards Institute (ANSI) Specification for Sound Level Meters (S1.4-1983, R2001) for sound level measurements and a Quest model M-27 dosimeter, which conformed to ANSI S1.251991(R1997) for personal noise dosimetry. The SLM was set to “slow” response, and “A” frequency-weighting response. For the shop measurements, the dosimeters were set to measure both the OSHA PEL (90 dBA criterion level, 5dB exchange rate, based on an 80dB recording threshold) and NIOSH-recommended exposure limit (REL; 85dBA criterion level, and 3 dB exchange rate). All dosimetry data were downloaded to a computer for analysis. The equipment used to document SPLs and noise dosimetry were factory calibrated within the previous year by the respective manufacturer. Field calibration was conducted on the survey data using a Quest CA-12B (110 dB at 1000 Hz) battery-operated calibrator. The assessments consisted of two site visits to the team's shop and two site visits to races at the track. At the shop, area sound pressure levels were measured for various work tasks (job titles were mechanic, fabricator, paint and body, suspension assembler, and team owner). Results showed equivalent levels (Leqs) ranging from 58 to 104 dBA across these work tasks. It was reported that OSHA's permissible exposure limit was never exceeded. However, in two instances, values exceeded OSHA's action level of 85 dBA for initiation of a hearing conservation program. In addition, the NIOSH recommended exposure limit was exceeded for five jobs. For the races, SPLs were reported to be averaged above 100 dBA in the pit area with peak levels reaching 140 dB SPL for every personal noise dosimetry measurement. The researchers discussed that this study provided evidence that stock racing teams were routinely exposed to extreme noise levels that might be damaging to hearing. They further discussed that the more immediate concerns included the occupational risks posed by noise-induced fatigue, stress, and miscommunication. They recommended that further analysis was needed to characterize noise exposures at other race shops and tracks, assess hearing protection devices, investigate prevalence/type/degree of hearing loss induced by extreme noise levels, and to determine if improved noise reduction could result in improved performance/safer racing conditions.

Rose et al. (2008) investigated the level of noise (in terms of intensity, frequency content, and duration of exposure) experienced by fans attending a professional stock car race (NASCAR). Data were collected at a NASCAR event at Lowe's Motor Speedway in Concord, North Carolina on May 30, 1999. Written notification was given to NASCAR officials prior to study and written acknowledgment was received. The race lasted 3 hours 58 minutes. A portable precision sound level meter with A-weighted scale was used for sound level measurements. Sound pressure levels measured at 6 meters (~20 feet) and 46 meters (~150 feet) from the track at 30 min intervals. An external filter was used at 46 meters to measure SPL at 125, 500, 2k, & 8k Hz. Sound level measurements were found to be at 46 meters, the range of SPL was 96.5-104 dBA, with the average measured level being a Leq of 100.7 dBA. At six meters, the range of SPL was 99-109 dBA with the Leq of 106.2 dBA. Four specific frequencies at 46 meters were as follows: 125 Hz: SPL range 85-101 dBA with Leq of 96 dBA, 500 Hz: SPL range of 95-105 dBA with Leq of 100.6 dBA, 2000 Hz: SPL range 75-94 dBA with Leq of 89 dBA, and 8000 Hz: SPL range 66-82.5dBA with Leq of 75.9 dBA. The researchers discussed that the front row SPL had a Leq=106.2 dBA, far less than 140 dB of immediate permanent threshold shift but temporary threshold shift still likely. By OSHA standards, this exceeded the 90 dBA time-weighted average by fourfold. A limitation of this study was the actual risk of noise-induced hearing loss could not be inferred from the findings as only levels of noise with use of a SLM were reported without exposure time. As mentioned previously, noise exposure was determined by level, duration, and spectral characteristics of the noise.

Formula 1

Dolder et al. (2013) reported noise exposures at the 2013 Montreal Grand Prix Formula 1 race. Within the background of this study, it was noted that although there were some published noise levels for some motor sport events, none were available for Formula 1 racing. Three track positions were chosen for measurement locations: location one was after a hairpin turn and part way along the longest straightway of the race (with the closest distance to the track centerline being approximately 10 m), location two was at the end of an s-turn (here the cars were traveling at lower speeds and the closest centerline of the track was approximately 34 m), and the third position was at the beginning of the same s-turn (here the cars were slowing down for the turn and the distance to the centerline of the track was approximately 20 m). The resulting metrics for the first, second, and third positions of the track were LApeak values were 139.2, 127.5, and 120.5 dB, LAeq values were 110.4, 103.1, and 97.6 dB, respectively. The OSHA PEL to calculate dose was as follows per lap with each location respectively: 3%, 2%, and 0.76% while per race, they were predicted to be 234%, 112% and 53%. The NIOSH REL to calculate dose was as follows per lap with each location respectively: 123%, 22%, and 5.6% while per race they were predicted to be 8585%, 1558% and 394%. Overall, the F1 race had average noise exposure levels of over 110 dBA and peak levels near 140 dBA. The authors concluded use of double hearing protection as indicated by OSHA would be recommended when attending this F1 race. A limitation to this study was the specific instrumentation or measurement procedures were not explicitly stated.

Monster Trucks

Morley et al. (1999) reported on a study that NIOSH investigators conducted using personal and area air monitoring for two evening monster truck and motocross shows to evaluate air concentrations of carbon monoxide (CO) and volatile organic compounds, as well as to measure noise levels in an enclosed arena. Four arena employees wore Toxilog Atmospheric Monitors (Biosystems Inc., Middlefield, Connecticut) with CO sensors during the shows. Four additional Toxilog CO monitors were used by NIOSH investigators during each show to assess spectator exposures. The four NIOSH investigators were positioned in general crowd areas around the arena. For short time periods (generally less than 15 minutes), the NIOSH investigators moved around the arena wearing the CO monitors to simulate what might occur when spectators left their seats to obtain refreshments or take breaks. The Toxilog monitors were calibrated in the laboratory according to the manufacturer's recommendations prior to use in the field. Quest Electronics Model M-27 Noise Logging Dosimeters were also worn by four arena employees. The noise dosimeters were attached to the wearer's belt and a small remote microphone was fastened to the wearer's shirt at a midway point between the ear and the outside of the employee's shoulder. Four additional noise dosimeters were used during each show to assess spectator exposures to noise as described above for the CO monitors. The four NIOSH investigators responsible for the CO monitors were also responsible for the noise dosimeters. The meters were placed on the employees generally 60 to 90 minutes before the beginning of the show (8:00 p.m.), and they wore them until 10:30– 11:00p.m., when the meters were paused and the data transferred to a computer. At the end of the show, the dosimeters were removed and paused to stop data collection. The information was downloaded to a personal computer for interpretation with QuestSuite computer software. The dosimeters were calibrated before and after the show according to the manufacturer's instructions. Three area air samples for volatile organic compounds were collected during each show using thermal desorption tubes containing three beds of sorbent materials. The crowds at the monster truck show were found to be exposed to average noise levels from 95 to 100 dBA, depending on the exchange rate used to calculate the exposures, and to short-term carbon monoxide concentrations exceeding limits intended to protect members of the general public. Specifically, the results of the noise dosimeter survey indicated employees were exposed to average noise levels during the show that ranged from 88 to 94 dBA when analyzed with a 5-dB exchange rate. The authors discussed how research had shown that simultaneous exposure to CO could increase the harmful effects of noise. They further suggested that controlling noise at the source, making hearing protection devices available, and providing educational materials about noise, CO, and their adverse effects were measures the arena management and public health agencies should consider.

Tractor Pulls

Buhr-Lawler (2017) described a tractor pull as “a motorsport event wherein trucks and tractors compete to determine the machine that can pull a heavy weight over the longest distance on a track. The trucks and tractors that compete in pulls have modified engines and/or multiple engines” (p. 213). Buhr-Lawler conducted an informal study with the aim to better understand the needs of a rural population and to determine how university outreach programs might benefit the people at an annual rural tractor pull event. The study was conducted as part of a hearing loss prevention outreach project by the University of Wisconsin–Madison audiology group at the Dairyland Super National Truck and Tractor Pull in Tomah, Wisconsin. The data were collected over three successive tractor pulls (2014 to 2016). There were three components to the study: an observation of the number of earplugs provided each year; cross-sectional recordings of sound levels during tractor pull events; and informal, qualitative discussions about attitudes toward hearing loss prevention.

In 2014, the peak sound level measured (using an iPad [Apple Inc., Cupertino, CA]) sound level measurement application Decibel 10th Professional Noise Meter (SkyPaw Co. Ltd, Hanoi, Vietnam) in the grand stands during the Light Unlimited tractor division was 110 dBA. In 2015, the peak sound level in the light tractor division was 128dBA in the front viewing area. These sound levels were measured using a 3M (St. Paul, MN) sound level meter. In 2016, measurements were conducted using a 3M sound level meter using slow-response dBA weighting at various locations on the tractor pull grounds. All 2016 sound level measurements were taken on June 24, 2016 prior to and during the 11:00 am pull that included the Light

Unlimited, Super Stock Diesel 4x4s, SuperFarm Tractors, and Mini-Rods machines. Multiple sound level measurements were taken in all conditions with the exception of the chainsaw art demonstration. The number of samples taken in each condition varied based on factors such as number and duration of pulls as well as access to locations. For example, the outreach member conducting the sound level measurements was only allowed to remain in the pit area for a few minutes prior to the competition due to safety regulations. The sound level measured in the puller area during motor warm-up was 103.8 dBA and the peak sound level was 112 dBA. In the front viewing area during pulls, the average sound level in the front viewing area was 108.6 dBA, and the peak sound level was 125 dBA. In the grandstands (the furthest seating from the competitions, estimated to be 125 to 200 feet away), the average sound level in the grandstand was 99.7 dBA and the peak sound level was 122.2 dBA.

The goal to provide Tomah Tractor Pull attendees, pullers, and workers the immediate means to protect their hearing at the event was reached. The number of earplugs distributed was 8,700 total pairs over three years. A limitation of this study was sound level measures were taken periodically for several hours but no dosimetry or long-term sound level studies were made. The general trend in attitude of tractor pull attendees, participants, and workers was toward increased acceptance of the use of hearing protection over the three years of the outreach project.

Factors Influencing Noise Exposure Measurements in Motorsports

Several studies have investigated a couple factors in relation to noise measurement: helmet use and wind noise.

Helmets

Van Moorhem et al. (1981) examined protection for hearing offered by helmets, investigating the effect helmets had on the detection of warning signals (insertion loss), and to measure noise generation by flow around a bare head. Two major types of helmets were used in the study: the Bell Star (full-face helmet) and the Bell Super Magnum (conventional helmet-using a shield, or visor and shield, or with sunglasses). For aerodynamic noise and insertion loss measurements, a one-half inch General Radio, model 1962-9601 microphone was located behind the ear of the subject while wearing one of the helmets. The microphone was then connected to a General Radio model 1933 precision sound level meter. Two test conditions were utilized for aerodynamic noise measurements: a motorcycle (Honda 350 c.c.) and an automobile (convertible Volkswagen) for a speed range of 18-28 m/s. Results showed at-ear noise levels with a helmet varied from 75-100 dBA depending on type of helmet and speed of air flow around the helmet. At-ear noise levels under no-helmet conditions were 10-20 dB higher at speeds greater than 10 m/s compared to when a helmet was worn. In addition, a helmeted rider never appeared to be at a disadvantage relative to the bare headed rider in detecting the warning signal (in the condition of a recorded siren presented at 80 dBA at speeds below approximately 14 m/s). The researchers made three general conclusions based on their findings: (a) For an unmodified/intended for street use motorcycle, noise experienced by the rider with or without a helmet on was largely generated by air flow at speeds greater than 10 m/s.; (b Aerodynamically generated noise was not likely to damage hearing of the occasional rider; and (c) Wearing one of the tested helmets with proper fit did not appear to cause a disadvantage for the ability to detect warning signals (with a signal-to-noise ratio of 1:1 as the criterion).

Kennedy et al. (2011) provided insight into the flow mechanisms responsible for the production of sound within motorcycle helmets. The researchers stated the need at the time for this study as being related to the lack of flow field surveys for helmets in the available literature. The helmet used in the study was described as a commercially available extra-large motorcycle helmet. The make and model of the helmets were not disclosed as they were covered by a confidentiality agreement. It was mounted using a mannequin head at a large wind tunnel facility at the University of Bath. The study investigated the importance of three potential sound-producing regions of the flow including the helmet wake, the surface boundary layer, and the cavity region beneath the helmet at the chin bar. To compare wind tunnel measurements to data taken on a motorcycle (where there was a contribution to the in-helmet noise from the motorcycle engine and from environmental sources), a signal conditioning procedure was applied. Doing so allowed the extraction of the "helmet only" spectrum, which contained only the noise due to flow over the helmet. Results demonstrated the helmet wake (showing to contain turbulence over a wide frequency range) and surface boundary layer flows had slight contributions to at-ear sound. The key source of noise was identified to be the cavity region around the chin bar with key factors being flow speed and helmet angle that govern the sound produced within this region. It was further stated that the geometry of this cavity region is complex and would be unique to each rider and helmet combination. Furthermore, the researchers concluded it was possible to control production of sound from this region. In addition, the researchers stated this information supported reports of noise reduction through use of a neck shield to close off this cavity.

Wind Turbulence

The presence of airflow across the microphone of a sound measurement instrument could cause artifact and error that could be introduced into the measurements. Windscreens are provided with most sound measurement instruments to reduce these effects. Windscreens are made of porous materials that serve the purpose of covering the instrument microphone to protect it from wind noise, dust, wet conditions, and damage. The condition of the windscreen must be carefully paid attention to as after extended use it might become clogged or damaged, which could result in lower sound level measurements. When airflow past the microphone exceeds about 8.9 mile/hour, wind screens become necessary. Wind noise increases as wind speed increases, reducing the ability to measure low-level sounds. When wind screens are used, the effect is the response to high frequencies is reduced (Murphy et al., in press).

Summary

Many factors need to be considered when conducting noise exposure measurements in motorsports. The research showed these factors must be considered and be controlled for as much as possible. Factors that cannot be controlled for then must be recorded as potential influencers on the data, results, and conclusions derived.

This chapter provided descriptions of the motorsports industry, NIHL and tinnitus, and an introduction to noise exposure measurement techniques. Occupational noise exposure standards and recommended guidelines were reviewed. Evidence of recreational noise exposure for individuals involved across different categories of motorsport events was cited in the reviewed literature. The next chapter focuses on the application of hearing loss prevention models and hearing conservation programs for motorsport enthusiasts.

CHAPTER II

APPLICATION TO THE FIELD OF AUDIOLOGY

Hearing Loss Prevention Models

Meinke and Stephenson (2007) discussed four models for approaching hearing loss prevention: the regulatory model, educational model, medical treatment model, and preventive medicine model. The regulatory model is dependent on government agencies collecting scientific evidence associated with NIHL and providing legal requirements for employers to protect their workers. These were reviewed under the Occupational Noise Exposure and Recommended Guidelines section of this paper. The education model is based on teaching children and adults to recognize noise hazards and how to take appropriate actions to reduce noise exposures to safe levels. In the medical treatment model, the pathophysiology and treatments of NIHL are the focus. Finally, the preventive medicine model deals with early detection and intervention, appropriate diagnosis, and rehabilitation with a patient centered approach. These four models could be used in combination when audiologists are designing their own hearing loss prevention programs.

Public Health Models of Prevention

Public health models of prevention are classified into different categories depending on the goals and methods used: primary, secondary, and tertiary strategies or models of prevention (Meinke & Stephenson, 2007). Primary strategies are defined as those intended to avoid the development of a disease before it occurs. This is accomplished by preventing hazards and alternating unhealthy or unsafe behaviors that might lead to disease or injury. Examples of methods employed to accomplish primary prevention strategies include mandates or legislation and education about safe and healthy habits. Secondary strategies aim to diagnose and treat an already existing disease when it appears to be asymptomatic or in its early stages before it progresses. An example of a method employed for secondary prevention might include regular exams and screenings for detection of the disease. Tertiary strategies focus on reducing the effects of an already established disease to restore function and reduce disease related complications. Methods employed include helping people manage the impacts of the diseases through rehabilitation programs or support groups. A combination of these health models of preventions are often needed to accomplish a significant degree of prevention and protection (Institute for Work and Health, 2015).

Primary, secondary, and tertiary strategies of prevention could be used in combination for the prevention of NIHL in the context of motorsports. Primary interventions would focus on the prevention of exposure to hazardous noise through identification of hazardous noise risk, noise control, and hearing protection. Secondary interventions would have the goal of diagnosing and monitoring motorsport enthusiasts for NIHL, training, and counseling regarding strategies to prevent progression of NIHL. Tertiary strategies might include medical or audiological intervention for NIHL.

Regulatory Hearing Loss Prevention Programs

In the United States, various federal regulatory requirements mandate occupational hearing loss prevention programs (e.g., OSHA, MSHA and FRA). However, not all noise exposures are related solely to work and could be due to recreational activities such as motorsports. Regulatory requirements that specify the noise exposure limits or implementation of hearing loss prevention programs for recreational noise exposure have not yet been developed.

However, the same framework could be useful in designing hearing loss prevention programs targeting motorsport enthusiasts. Relevant components include noise measurement, noise control, hearing protection, monitoring for auditory damage, training, and motivation.

Grange and Cotton (2004) highlighted the evolving subspecialty of motorsport medicine. Within this article, it was suggested very little has been published in the medical literature regarding motorsports including risk of hearing loss for racers. The authors recommended a medical action plan should be formulated to detail the delivery of medical care. It was explained that the components of the medical plan should include physician medical oversight, level of care, human resources, specialized medical equipment, treatment facilities, transportation resources, emergency medical operations, communications, command and control, documentation, and continuous quality improvement. These components could be integrated or considered when designing hearing loss prevention programs for motorsport enthusiasts.

As previously referenced in this paper, Buhr-Lawler (2017) provided an example of how an outreach program might be structured for a motorsport event. In this study, the author reached the goals of providing tractor pull motorsport event participants access to free disposable earplugs, implementation of an education program that encouraged the use of hearing protection into participants' personal and professional lives, and the opportunity for audiology doctoral students involved in conducting the study to experience the benefits of direct community engagement. The descriptions of already established prevention models and what has been cited in the literature could be considered as a foundation upon which to build.

Hearing loss prevention programs for motorsport enthusiasts could be built with a combination of components from the hearing loss and public health models of prevention. Specific components from the hearing loss prevention models include regulatory guidelines, education, and prevention of NIHL. As for the public health models of prevention, the specific components include primary, secondary, and tertiary strategies. The following sections detail components of what a hearing loss prevention program for motorsport enthusiasts might look like.

Noise Measurement

Measurement of noise exposure for individuals involved in motorsports serves an important role in identifying the presence of a noise hazard and if the individual exceeds noise criteria levels. For investigating the recreational noise exposure of individuals involved in motorsports, noise monitoring with the use of noise dosimeters is recommended. Instances when noise measurement might be warranted are when the individual reports loud sound exposure or communication difficulties while participating in the event. Examples of individuals from which noise measurements might be obtained from include spectators, event personnel, and drivers.

Many variables must be considered in measurement when conducting noise dosimetry. Before taking measurements, it must be decided how long to sample each event and how many samples would be needed to adequately characterize the noise exposure. For example, the audiologist might elect to measure one noise dosimetry sample obtained on a typical day at a motorsport (hotrod) event for an individual. It is recommended that noise dosimetry measurements begin as close to the start of the event and end immediately after the event has concluded for the day. Individuals should be instructed to perform regular activities and try to ignore the presence of the noise dosimeter. Individuals should also be instructed to ensure the microphone remains uncovered and to avoid hitting the microphone unnecessarily. Individuals should be advised to wear the dosimeter until the end of the day (conclusion of the event) until the audiologist personally removes the dosimeter or to contact the audiologist if the dosimeter needs to be taken off before the end of the day.

Proper calibration of the noise dosimeter must be carried out prior to and after the noise sample is collected. Examples of noise dosimeters that could be used are the doseBadge5 noise dosimeter manufactured by Cirrus Research, the Edge 5 noise dosimeter (TSI, 2022), the Spartan dosimeter (Larson Davis, 2021) or the consumer grade ER-200DW8 personal noise dosimeter manufactured by Etymotic Research, Inc. (2022). The author was most familiar with the Cirrus Research doseBadge 5 and the ER-200DW8.

The doseBadge5 clips onto the participant's clothing at both the top and bottom of the unit near the top of the person's shoulder. It is recommended the doseBadge5 be mounted close to the person's ear, typically about four to six inches to help avoid sound reflections from the head, which could affect measurements. This would hold the device securely during physical activity while participating in the event. The doseBadge5 complies with the following guidelines for overall measurements: IEC 61252:1993 +AMD1:2000—Personal Sound Exposure Meters and ANSI S1.25-1991 (R2017)—Personal Noise Dosimeters. The noise dosimeter has the capacity to run four simultaneous independent integrator channels, twp simultaneous independent peak channels, and 1:1 octave bands (63Hz to 8kHz where available). The following table summarizes noise dosimetry sampling protocol settings that could be used to simultaneously calculate noise exposures by the four independent integrator channels (i.e., virtual dosimeters).

Table 1

Noise Dosimeter Sampling Parameters

Settings	OSHA PEL	OSHA AL	NIOSH REL	WHO
Criterion Level	90 dBA	85 dBA	85 dBA	75 dBA
Criterion Time	8 hours	8 hours	8 hours	8 hours
Threshold	90 dB	80 dB	80 dB	75 dBA
Exchange Rate	5 dB	5 dB	3 dB	3 dB
Time Weighting	Slow	Slow	Slow	Slow

The doseBadge5 has a permanent “windshield” attached to the unit and the manufacturer advises against removing the protective cover. The manufacturer does not publish wind tolerances in their user manual. The normal operation of the doseBadge5 is with the windshield attached. The windshield should be used for measurements that would be collected outdoors. It is important to firmly attach the windshield as the wind tolerances of the unit could be exceeded during wind exposure while driving. Therefore, the selection of the best shoulder to hang the dosimeter might be influenced by risk of wind artifact. The doseBadge5 dosimeter has a root mean square measurement range of 60 dBA to 143 dBA and a peak measurement range of 80 dB(C) to 143 dB(C). The operating temperature of this dosimeter is -10°C to +50°C (+14°F to +122°F) and -20°C to +60°C (-4°F to +120°F) for storage. The dosimeter could operate in up to 95% non-condensing relative humidity (Relative humidity is the percentage of the total water vapor that can exist in the air without condensing and is inversely proportional to air temperature.) There are no magnets in the doseBadge5 noise dosimeter that might interfere with accurate measurements. The doseBadge5 does not display any data and it is only accessible via a

Bluetooth connection to the researcher’s smartphone or via laptop connection to the docking station. Only sound sample measurements are stored; the wearer’s voice or other sounds are not recorded.

The ER-200DW8 personal noise dosimeter complies with requirements of a Type-2 Noise Dosimeter [ANSI S1.25-1991(R2002)]. Default settings for calculating dose are calculated with the following protocol criteria: exchange rate of 3 dB, criterion level of 85 dB, threshold level of 75 dB, criterion time of eight hours, frequency A weighting, and slow response. The temperature range of operation is -10°C to +45°C (+14°F to +113°F). For accurate measurements, the 35 mm (1.4”) windscreen included with the dosimeter should be used for measurements that would be collected outdoors. The foam windscreen allows accurate measurement in winds up to 15 to 20 mph. The instrument LEDs could be taped over to avoid influencing the participants’ noise exposure due to dose percentage feedback provided by the LEDs during the event.

Results of the noise dosimetry samples could be manually transcribed onto a noise dosimetry summary data form for backup in case data are lost during the download process to a computer. The individual could be counseled regarding the noise dosimetry results at the time the dosimeter is removed.

A questionnaire could be used with individuals wearing a noise dosimeter to interview them about their motorsport event experience, the general characteristics of the event, and their concerns about hearing ability. Two forms containing potential interview questions, one for drivers (see Appendix A) and the other for the spectators or event personnel (see Appendix B) are provided as examples. The drivers could be asked to describe the general characteristics of their vehicles and their driving/event experience. Answers could be recorded in writing by the audiologist for pre-questions at the time the noise dosimeters are activated for the individual and for post-questions at the time noise dosimeters are deactivated for the participant. An alternative would be to use a web-based electronic form if wireless connectivity is available.

Noise Exposure

One challenge is determining the optimal noise exposure sampling protocol to use for characterizing the risk of NIHL for motorsport enthusiasts. The noise exposure of individuals participating in or attending a motorsport event could be measured according to the OSHA (1983) 29 CFR 1910.95 exposure standard, NIOSH (1998) exposure criteria, and to WHO (2019) recreational exposure criteria. This allows the audiologist to compare and contrast the outcomes in relation to the risk of hearing loss (e.g., greater risk of NIHL for OSHA than for NIOSH or WHO damage-risk criteria).

Analysis for the noise dosimetry measurements could then be conducted. Noise dose, TWA, and run time measurements could be quantified and compared to OSHA (1983) AL, OSHA PEL, NIOSH (1998) REL, and WHO (2019) recommended exposure limits using descriptive techniques for outcomes. Metrics utilized for descriptive analysis include LAvg/LeqA, LZPeak-peak sound pressure level, LASMax (A-weighted slow peak) and predicted time-weighted average. Results should be interpreted as specified by OSHA, NIOSH, and WHO and in terms of risk on NIHL. This could be done by determining noise dose in the context of OSHA PEL, NIOSH REL and WHO dose as more than 100% constitutes an over-exposure. An OSHA AL dose of 50% indicates the need for formal intervention by establishing a hearing loss prevention program for the individual.

Noise Control Options

Noise control should be the first order of protection from excessive noise exposure (NIOSH, 1998). Noise control aims to reduce or eliminate the source of hazardous noise exposure and prevent the noise from reaching the ears of affected individuals. These goals could be accomplished with various methods that could be applied to motorsport noise exposure. Noise control is accomplished at the source, along the path, and at the receiver (Moritz, 2014).

First, the sources of the noise must be identified (typically the engine and exhaust system). Input from the affected individuals in motorsports such as the spectators, event personnel, and drivers should always be sought as they themselves often have personal experience with the motorsport events and vehicles. Sound could also be generated from vibrating surfaces such as panels and pipes, mechanical impacts, air flow, and air compression. A frequency spectrum of the sound source could be obtained with the use of an octave band, one-third octave band, or narrow band filter capabilities available in sound level meters. Once the sources of the noise are identified, they could be rank ordered by loudness to help prioritize the sound treatment.

Treatment of the sound source could significantly reduce the intensity of the noise. Sources could be modified, redesigned, substituted, or relocated. For example, if the source of a motor vehicle is identified to be coming from the exhaust, a muffler could be added to help reduce the loudness of the noise, or relocate the exhaust port at a greater distance from the ear of the driver or passenger. Arjunan and Baroutaji (2021) investigated the sound pressure level of a Formula 3 race car and the influence of removal muffler tips. Results indicated no significant improvement in noise reduction was observed when using the muffler tips. In this case, the researchers recommended considering hearing protection for event participants and attendees.

Another example might be to replace worn bearings or other vibrating parts. Engineers and mechanics need to be consulted to maximize noise control without sacrificing performance for the driver. Although noise control is the preferred approach, it is likely the hotrodders were particularly fond of the sound and might customize the engine to enhance the sound, which might unintentionally increase the sound levels.

Treatment of the sound path entails reducing noise along its transmission from the source to affected individuals. Sound path treatment might be accomplished by using enclosures, vibration pads, or sound barriers. For example, reverberation of sound could be accomplished by covering walls with sound absorbing materials. This is less relevant for motorsport enthusiasts as the sport takes place outdoors. If the spectators are in enclosed stands, there might be an opportunity to consider acoustic treatment of the enclosure. Stands full of spectators, like at the Indy 500, likely absorb sound from the racetrack. A simple approach for spectators not seated in a stand would be to increase the distance between the sound source (cars) and themselves, which would reduce sound levels due to physical principles related to the inverse-square law.

Audiologists might gain a better understanding of noise control through workshops designed to introduce the basics. Several organizations such as the National Hearing Conservation Association, the American Industrial Hygiene Association, and the Council for Accreditation in Occupational Hearing Conservation are sources to refer for these workshops (Meinke & Stephenson, 2007).

The OSHA (1983) requires feasible engineering controls such as those listed above when noise exceeds 90 dBA TWA. The NIOSH (1998) recommends noise control when noise exceeds 85 dBA TWA. The OSHA and NIOSH criteria might be used for individuals partaking frequently in motorsport events such as event personnel and drivers. The WHO (2019) recreational noise most protective noise exposure limit of 75 dBA could be considered for spectators or other individuals involved in motorsports; however, this is likely a challenging limit to impose when considering the noise levels encountered in motor sports can range from 80-136 dBA as reviewed in Chapter I.

As discussed in Chapter I, an alternative form of noise control used in industry is "administrative" control. This is not likely to be applicable to motorsports as the drivers are not rotated during a race or event unless it is a long-distance event taking place over extended periods of time. If noise control (engineering or administrative) is not sufficient to reduce or eliminate the noise hazard, hearing protection devices could then be recommended.

Hearing Protection Devices

If used correctly, HPDs prevent auditory damage from hazardous noise exposure levels. Hearing protection devices attenuate (reduce) the amount of sound reaching the cochlea. A wide variety of hearing protection devices exist. The three basic types of hearing protection devices are earplugs that fit in the ear canal, earmuffs that fit over the entire ear, and canal caps, sometimes called semi-aural insert devices, that seal the opening to the ear canal. Earplugs might be pre-molded— they have a fixed shape such as a flanged design, or formable meaning—they are made of expandable foam. Ear plugs can be a one size fits most or custom molded to an individual's ear. Earmuffs vary by cushion and headband type. Canal caps are earplugs mounted on lightweight headbands. Furthermore, passive and active hearing protectors exist for unique listening situations. An example of passive hearing protectors are flat attenuators that reduce all frequencies equally and are sometimes referred to as "musician earplugs." Active hearing protectors use electronic circuitry to allow passage of low to moderate levels of sound and prevent amplification when sounds reach 80 to 85 dBA. Communication headsets are a good option when communication is needed for safety or performance of a task. A receiver is built into the headset that provides radio communication and attenuation in the individual's environment.

When considering HPDs for individuals in motorsports, no clear recommendations were stated within the studies reviewed. Across the studies reviewed in Chapter I, researchers recommend HPDs in general but specifics on style and type were not offered (Buhr-Lawler, 2017; Dolder et al., 2013; Kardous & Morata, 2010; Mikulec et al., 2011; Morley et al., 1999; Van Campen et al., 2005). An audiologist should investigate the needs of the individual for hearing protection in their motorsport experiences and incorporate results from noise measurements. For example, Moore (2014) recommended HPD selection for recreational snowmobilers be customized to allow for communication between riders. Furthermore, Moore suggested custom earplugs with radio connection or commercially available flat attenuation custom earplugs might be appropriate options when selecting HPDs for this motorsport population. Event personnel might find communication headsets beneficial to conduct their tasks efficiently. An example of this HPD type has been used by F1 racers and fans who like to hear the race broadcast but still want to protect their hearing (Traynor, 2011). Drivers might need to still be aware of their surroundings and find a flat attenuating hearing protector beneficial. Spectators might find traditional earplugs or earmuffs adequate. If spectators wish to hear the broadcast at large motorsport events, active earmuffs receiving AM/FM broadcasts of the race would potentially be an alternative HPD option. Howard Leight by Honeywell (2021) and 3M (2022) manufacturers make products for motorsports where the earmuff reduces the noise exposure and the electronics permit audibility of the race broadcasts or announcements. Ultimate

Hearing Protection Systems (2021) is another manufacturer offering HPD devices tailored for motorsport events including custom and foam earplugs with built in communication systems.

National Institute for Occupational Safety and Health (1998) identified the following factors that determine acceptance of hearing protectors: convenience and availability, belief that device can be worn correctly and prevent hearing loss, comfort, adequate noise reduction, and ease of fit. Audiologists need to be aware of these factors when providing an individual with HPD recommendations. The following table lists some advantages and disadvantages of hearing protector devices described by Schulz and Madison (2014). These advantages and disadvantages could be considered in the context of motorsport event personnel, drivers, and spectators.

Additional considerations an audiologist should keep in mind when recommending HPDs are the need for dual hearing protection and the limitations of noise reduction rating (NRR) listed on packaging. Dual hearing protection (earplugs and earmuffs) is recommended when the TWA exceeds 100 dBA (NIOSH, 1998). Dual hearing protection might be necessary for individuals involved in motorsports and should be recommended during high noise level exposures. The NRR rating was intended to help consumers choose an HPD by comparing attenuation values, but it does not accurately predict how much an individual would be protected in real-world use. For example, Casali and Park (1991) compared laboratory HPD attenuation results to actual protection levels achieved with identical HPD devices in the industrial setting. Overall results from this study revealed labeled noise reduction ratings overestimated the actual protection afforded in many hearing conservation programs. To accurately determine protection from HPDs, audiologists can perform hearing protector fit-testing.

Table 2

Advantages and Disadvantages of Hearing Protection Devices

Types	Advantages	Disadvantages
Earplugs	-Cooler than earmuffs -Variety of materials -Multiple sizes for different ear canals -Usually less expensive	-Attenuation depends highly on fit -Proper fitting technique can be difficult to learn -Hygiene issues in dirty environments
Earmuffs	-Easy to fit -Multiple headband types	-Can feel hot or heavy with extended use -Higher cost than earplugs
Passive HPDS	-More natural sounds -Ideal for moderate noise environments	-Lower attenuation than most earplugs -Slightly higher cost
Active HPDs	-Communication and situational awareness in quiet -Protection from impulse and high noise levels	-Cost more than passive models
Communication Headsets	-Communication in loud and changing noise -Connection to radios	-Higher cost than passive models

Note. Adapted from Schulz and Madison (2014).

Hearing protector fit-testing allows for a quantitative estimate of HPD attenuation for each individual and could guide HPD selection. Hearing protector fit-testing could be performed using several methods. An audiologist may be able to use the real ear attenuation at threshold method where the individual is asked to go through hearing threshold tests of noise at different frequencies with and without the hearing protector. Attenuation levels are then calculated by taking the differences between the open and occluded ear responses. A challenge with obtaining real ear attenuation at threshold method is that testing must be performed in a sufficiently quiet room (Berger, 1986). Another method is called field microphone in real ear that typically uses multiple microphones to simultaneously measure sound pressure levels external to the HPD and underneath the HPD in the ear canal (Biabani et al., 2017). Various commercial fit-test systems are capable of these measurements. The audiologist could then determine the personal attenuation rating of HPDs for individuals to facilitate the validation and training of the person wearing the hearing protection devices. Hearing protection fit-testing would likely need to be performed in a clinic or office setting where the audiologist has access to the needed equipment (e.g., audiometer and sound booth or fit-test system). The audiologist might consider pairing fit-testing with audiometric monitoring.

Monitoring for Auditory Damage

Gathering a case history from noise exposed individuals is the first step an audiologist should take in the monitoring for auditory damage. Individuals with a history of noise exposure commonly present with tinnitus. Hearing loss typically begins in the higher frequencies and gradually increases with continued noise exposure. It might be of use for an audiologist to employ the use of the term “sound” exposure rather than noise exposure when taking a case history to encompass the various sources and environments outside of the traditional occupational setting that might lead to NIHL including motorsports. Examples of case history questions adapted from American Speech-Language-Hearing Association (2021) to ask motorsport enthusiasts are listed in the following questions:

- Do you have ringing, buzzing, or other sounds in your ears during or after motorsport events?
- Are you exposed to excessive sound/noise when participating in motorsports?
- Do you often have to shout at the person to talk to someone who is at an arm’s length away because it is so loud around you during motorsport events?

- How often do you use hearing protection devices when exposed to excessive sound/noise during motorsport events?

Audiometry

Noise exposure has a unique pattern in the way it can affect hearing thresholds in individuals. In the early stages, it typically results in the greatest hearing loss in the 3-, 4-, or 6 kHz frequencies as compared to lower or higher frequencies (Gates et al., 2000). For this reason, it is important that audiometric pure-tone air-conduction evaluations include the inter-octaves of 3- and 6 kHz. Ideally, audiometric monitoring begins before the hazardous noise exposure by collecting a baseline audiogram. In the case of motorsports enthusiasts, individuals should not have been exposed to loud noise for 14 hours prior to the baseline testing. Audiometry should be performed to establish a baseline, monitor thresholds annually, and to inform HPD selection and verification for individuals with motorsport noise exposure. New booth-less audiometry techniques might be useful for making audiometry more accessible to motorsport enthusiasts if a sufficiently quiet test environment could be secured onsite. An example of such a system is the Wireless Automated Hearing Test System, which provides valid thresholds without the use of sound-attenuating enclosures (Meinke et al., 2017). Behar (2021) provides a review of literature on potential solutions for hearing screening strategies without the need for sound booths including the incorporation of a quiet test environment and the use of a combination of earmuffs and insert earphones, as well as the use of active noise reduction earmuffs.

Hearing Shift Criteria and Follow-Up

Occupational Safety and Health Administration (1983) defined a standard threshold shift (STS) as an average shift from baseline audiogram of 10 dB or more in the frequencies of 2000, 3000, and 4000 Hz in either ear. Determination of an STS according to OSHA is performed by adding threshold change for 2000, 3000, and 4000 Hz, dividing by three, and determining if there is a 10 dB or greater shift as compared to baseline for each ear. The NIOSH (1998) defined STS as a change of 15 dB or greater at any audiometric frequency. It is recommended the NIOSH criteria be used for audiometric monitoring of individuals with noise exposure from motorsports as they are typically exposed to carbon monoxide and fuels, which might create a synergistic effect with noise in terms of hearing loss. The synergistic effect of ototoxicants such as carbon monoxide was reported in the literature reviewed in Chapter I (Gwin et al., 2005; Morley et al., 1999). Walker et al. (2001) noted carbon monoxide and heat as the two major stressors endured by motorsport athletes. Reid and Lightfoot (2019) identified the following physiologic stressors in auto racing: mental and cardiovascular stress, heat, g force, carbon monoxide, physical exertion, noise, and fatigue. Carbon monoxide exposure is regularly present in most forms of auto racing, especially where the car has a closed cockpit and small oval racing track configurations. Having this in mind, retest could be performed immediately if a shift is observed. The NIOSH indicated STS follow up be performed within 30 days of the shift and take the actions of explaining the effects of noise, re-instruct and re-fit with HPDs, provide additional training in hearing loss prevention, and move person to quieter area if possible.

Extended High Frequency Audiogram and Otoacoustic Emissions

Other diagnostic tools could be useful when monitoring for early detection of auditory damage. Both extended high frequency audiogram (EHFA) and otoacoustic emission (OAE) testing appear more sensitive for the detection of NIHL. Extended high-frequency audiometry measures hearing thresholds at frequencies greater than 8000 Hz, up to 18000 Hz in 1.5 octave steps. Testing is performed with either circumaural or insert headphones with extended high frequency response. Somma et al. (2008) found EHFA to be more sensitive than conventional audiometry in detecting noise induced hearing loss in cement workers. Valiente et al. (2016) demonstrated the effective use of extended high frequency audiometry when conventional audiometry results are within normal range for individuals with various pathologies affecting hearing sensitivity. Audiologists must take caution when interpreting EHFA results as hearing thresholds at extended high frequencies deteriorate as a function of age and output levels are limited.

Both distortion product otoacoustic emissions and transient otoacoustic emissions provide insight into responses from the delicate outer hair cells housed in the organ of hearing, the cochlea, and are useful for early detection of NIHL in individuals (Attias et al., 2001; Marshall et al., 2001; Shupak et al., 2007). An advantage to OAE testing is it is an objective test and behavioral response is not needed from the individual. Responses from transient otoacoustic emissions testing are interpreted by evaluating the reproducibility and magnitude of the responses across frequencies relative to the noise floor. Distortion product otoacoustic emissions analysis is based on determining if the difference between the OAE response and the noise floor is at least 6 dB or greater. Then, if there is an OAE present, the audiologist must determine if the OAE is normal or abnormal by analyzing an adequate noise floor and verifying the reliability of the OAE. Once the amplitude of the OAEs is established as a baseline reference, annual monitoring could assess for decreased amplitudes beyond test-retest reliability (Marshall et al., 2001). Indications of cochlear dysfunctions could be provided by OAEs when less sensitive measures such as the pure tone audiogram show results within normal limits. Early indicators of NIHL could be provided by EHFA and OAE testing outside of conventional audiometric evaluations and allow for opportunities for intervention to prevent progression.

Education and Motivation

Training in the occupational setting is a critical part of hearing loss prevention programs. Most HLPP standards require training with specific timeliness and specific content to be included. The OSHA (1983) and NIOSH (1998) require annual training and education for all employees whose TWA exposure equals or is greater than 85 dBA. The OSHA specifies that training must include effects of noise on hearing, types of HPDS with respective advantages and disadvantages, and purpose of audiometric testing. Effective training could result in individuals making good decisions about their hearing health and taking steps to prevent the risk of NIHL. Audiologists could incorporate the aspects of training and education recommended by HLPP standards and tailor the training for individuals exposed to recreational noise in motorsports.

Educational materials should be current, relevant, and designed to engage individuals in motorsports. It is highly recommended materials be updated annually to maintain interest. Handouts and pamphlets with information on NIHL, HPDs, and monitoring for auditory damage could be provided to individuals within the audiologist's practice. Community outreach might be another opportunity to increase education and motivation. An audiologist might set up a booth at motorsport events and have information and HPDs available to hand out to individuals.

Another approach to training, motivation, and education might be accomplished by creating an adaptation of the Dangerous Decibels® program for individuals involved in motorsports. Dangerous Decibels was developed in 1999 as a public health intervention designed to educate children about noise-induced hearing loss. The program focuses on improving knowledge, attitudes, and behaviors regarding noise exposure and hearing protection strategies. Reddy et al. (2017) showed that an adaptation of the Dangerous Decibels program was effective with adults in the workplace. Dangerous Decibels educators are trained and certified as part of a two-day Dangerous Decibels Educator Training Workshop. The Dangerous Decibels website (www.dangerousdecibels.org) provides additional information regarding upcoming workshops.

Summary

This chapter offered prevention strategies for preventing NIHL in persons who drive or participate in motorsports based upon a regulatory model. The opportunity for exploring hearing loss prevention in the future might incorporate other models of prevention such as a medical model that might include the use of otoprotectants. The next chapter explores the challenges and gaps in the literature regarding the risk of NIHL in people who participate in motorsports and make recommendations for future research in this area.

CHAPTER III

CRITICAL APPRAISAL OF THE RESEARCH AND FUTURE DIRECTIONS

Assessment of Existing Noise Regulations

There are no specific recreational noise regulations for motorsports. Standards for occupational NIHL such as OSHA (1983) and the NIOSH (1998) best practice guidelines were referred to within the studies reviewed in Chapter I. These studies included the motorsports of motorcycles, snowmobiles, stock cars, Formula 1, monster trucks, and tractor pulls. Overall, there is evidence of the risk of NIHL in the participation of motorsport events for spectators, event personnel, and drivers.

Community Noise

Community noise guidelines have been developed by various organizations. As previously discussed in Chapter I, WHO (2019) recommended the following: Guidelines for Community Noise of 1999, WHO Night Noise Guidelines for Europe of 2009, and the WHO Environmental Noise Guidelines for the European Region of 2018. In the 1970s, the EPA (2021) coordinated federal noise control activities through its Office of Noise Abatement and Control. The EPA phased out the office's funding in 1982 as part of a shift in federal noise control policy to transfer the primary responsibility of regulating noise to state and local governments. The Noise Control Act of 1972 and the Quiet Communities Act of 1978 were never rescinded by Congress and remain in effect today but remain unfunded. The EPA set a 24-hour exposure level of 70 dBA as the level that would prevent measurable hearing loss in individuals over a lifetime to guide state and local governments in setting standards (EPA, 2021).

Community noise guidelines could be referred to by motorsport event organizers to determine the risk of NIHL for individuals in the community. However, these guidelines would not necessarily apply for individuals participating in the motorsport events as their respective risks for NIHL would likely to be greater given consideration of event and environmental factors of participation.

Recreational Use of Vehicles and Noise

There are no regulations or guidelines for prevention of NIHL in the recreational use of vehicles. This could lead to little recognition of NIHL as a risk and the need for prevention efforts for persons involved in motorsports. Depending on the specific population being considered such as drivers, event personnel/vendors, or spectators there would be different considerations for the application of regulations and guidelines. For example, drivers and event personnel in motorsports might most likely be considered employees under the entertainment or service industries. Then depending, on the number of employees the company has, the OSHA (1983) occupational noise exposure might apply. The OSHA injury and illness records are not required for companies with fewer than 10 employees during the calendar year (U.S. Department of Labor, n.d.-c). The OSHA occupational standard would not apply for spectators as they are not considered employees. However, the OSHA standard and recreational noise guidelines by WHO (2019) and NIOSH (1998) could be used to guide motorsport event companies and audiologists in the care for individuals participating in motorsports to ultimately raise awareness of the risk for NIHL.

Assessment of Existing Research Regarding Motorsport Noise Exposures

Research study designs differed in terms of the specific population they targeted. For example, some studies investigated the noise exposures of just the drivers while others might have included both spectator and employee exposures. Table 3 summarizes the types of motorsports that have been studied in terms of the conclusions derived and the limitations of the studies.

Table 3

Motor Vehicles and Motorsport Research Literature: Conclusions and Limitations

Topic & Study	Conclusions	Limitations
	Motorized Vehicles	
Mikulec et al. (2011)	-Convertible cars can be a source of noise over-exposure that exceeds NIOSH REL, especially for prolonged journeys with the top down.	-A Quest Technologies model 210 sound level meter was used for area sound level measurements limiting the opportunity to integrate noise level with duration of exposure in the data analysis and determination of risk of over-exposure to noise. -Issue of wind noise on the microphone of the sound level meter was not addressed and may have contributed artifact to the measurements. -Conclusions may not be generalizable to all types of vehicles driven with the top down, or all roadways or all passengers within the vehicle.
	Motorcycles	
Ross (1989)	-When open road driving with open and full-face style helmets riders were at risk for temporary or permanent hearing loss	-Results were compared to the Health and Safety Executive Code of Practice for Reducing the Exposure of Employed Persons to Noise that indicates a criteria of a 90 dBA Leq 8h integrated with a 3 dB exchange rate. This damage-risk criteria is not sufficiently protective to prevent NIHL. -Accuracy of the sound level measurements is difficult to assess. The specific microphones and their frequency response and measurement accuracy were not specified. The specifications for the recording equipment (cassette tape) were not provided and the post-processing of the recordings was not detailed.

Table 3 Continued

Topic & Study	Conclusions	Limitations
	Motorcycles	
McCombe & Binnington (1994)	45% of grand prix racers had hearing losses greater than expected for age matched, non-noise exposed controls. Riders underwent otological examination and pure tone audiometry. -There is a need to increase awareness of NIHL and use of HPDs for this population.	-No specific prevention strategies or HPD recommendations provided. -Other recreational or occupational sources of noise exposure for these racers were not investigated. Other sources of hazardous exposure may have also contributed to the presence of a NIHL. -The influence of wind noise on overall sound exposure was not well differentiated. -No specific recommendations or proposed solutions identified
Jordan et al. (2004)	-The value of conventional hearing protectors in the reduction of noise exposure of motorcyclists is suggested by the authors to be limited due to high level of low frequency noise generated by wind turbulence and the impediment hearing protectors create when using radio communications.	-No specific recommendations or proposed solutions identified.
Carley et al. (2011)	-Consideration of motorcycle geometry, engine type, and environmental characteristics such as other traffic or varying wind speeds were noted to be contributing factors to the sound experienced at-ear levels. -The three main contributors to at-ear noise spectra were identified to be the engine, the presence of a windshield, and the helmet	-SPL measurements only, duration of exposure not indicated. Therefore, unable to fully assess damage-risk for NIHL

Table 3 continued

Topic & Study	Conclusions	Limitations
	Snowmobiles	
Bess & Poynor (1974)	-Racing snowmobiles produced sound pressure levels as great as 136 dBA (two thirds throttle). -Measurements taken within the spectator area ranged from 85 dBA to 113 dBA. Such sound pressure levels were thought to be responsible for the high-frequency hearing impairment found in all the drivers and mechanics	-Pre-exposure hearing test did not indicate case history or other noise exposure sources for participants that may have contributed to the presence of NIHL
Moore (2014)	-All snowmobilers were over-exposed to noise while riding with helmets in this study. -Under the helmet noise exposure levels did not show adequate protection from hazardous snowmobile sounds.	-Due to smaller sample size, it was impossible to determine which rider characteristics lead specifically to increased noise levels and which did not. -Field data specific to mountain terrain and not transferable to riding in open/flat environments.
	Stock Cars	
Van Campen et al. (2005)	-Noise levels on all three racetracks exceeded those measured in hazardous industrial environments. -Until professional auto racing associations require the use of HPDs and establish hearing conservation programs, it will be up to responsible team owners and employees to monitor hearing and protect their hearing.	-Need to characterize noise exposure at other race shops/tracks. -No audiometric evaluations or baseline hearing tests for the participants were performed.

Table 3 continued

Topic & Study	Conclusions	Limitations
	Stock Cars	
Rose et al. (2008)	-Temporary thresholds shifts in hearing may be experienced by fans attending NASCAR races sitting at various distances from the racetrack.	- Actual risk of noise-induced hearing loss cannot be inferred from the findings as only area levels of noise were measured with use of a SLM. Exposure time was not integrated. -HPD with a noise reduction rating of at least 25 dB is recommended. However, the NRR is not a reliable measure to base HPD recommendations.
	Formula 1	
Dolder et al. (2013)	-Noise dosimetry measurements in the general audience at various locations around the track exceeded NIOSH REL and OSHA PEL criteria.	-Specific instrumentation or measurement procedures were not explicitly detailed. -Recommendation for double hearing protection does not consider factors such as communication needs of spectators or drivers.
	Monster Trucks	
Morley et al. (1999)	-Individuals attending monster truck may be exposed to hazardous carbon monoxide (CO) and noise levels. Simultaneous exposure to CO can increase the harmful effects of noise.	-CO and noise exposure were not measured for drivers. -Difficult to predict the average noise exposure for employees based on a single two-day event. More noise samples would be needed to be a “representative” across events.
	Tractor Pulls	
Buhr-Lawler (2017)	-This study establishes that hearing loss prevention outreach at tractor pulls is necessary due to the high noise levels during the competitions. -The number of earplugs distributed and the percentage of individuals who accept them indicates that this outreach is effective in the short term.	- Sound level measures were taken periodically for several hours, but no dosimetry or long-term sound level studies were made. - No data were available on the number of individuals who used the earplugs during the event.

Lack of Generalizability

It is difficult to generalize the findings of the various motorsport noise studies. First, it is difficult to generalize across exposure groups (drivers, employees, spectators). For example, one study (Van Campen et al., 2005) measured noise exposures for both drivers and employees, and sound level measurements of various fabrication and body shop machines were conducted. Bess and Poynor (1974) collected noise measurements for drivers, employees, and conducted sound level measurements in spectator areas as well. Six studies (Carley et al., 2011; Jordan et al., 2004; McCombe & Binnington, 1994; Mikulec et al., 2011; Moore, 2014; Ross, 1989) measured the noise exposures of the drivers only. Four studies were focused on spectator noise exposure (Buhr-Lawler, 2017; Dolder et al., 2013; Morley et al., 1999; Rose et al., 2008). The limited samples within each group prevented generalizing to other drivers, workers, or spectators. Second, each motorsport event was unique; no multiple studies of the same type of motorsport event would allow generalization to all events within a given category. Third, the studies were aimed at specific categories of motorsports and could not be applied to other types of motorsports that have not been investigated. For instance, results from Formula 1 races could not be generalized to other groups such as street races and so on. Fourth, the methods for many of the studies neglected to incorporate duration of exposure and this further limited the generalization of the findings. Within individual motorsport categories, there is a need for a comprehensive study design that includes an assessment of noise dosimetry, audiometry, hearing protector attenuation measures, and intervention/education effectiveness measures.

Gaps in the Existing Literature

The existing literature formed a basis to build upon in the investigation of noise exposure of motorsport enthusiasts. However, many areas need further investigation and development.

During the time this literature review was carried out, no studies investigated the categories of hot rod racing and drag racing in terms of noise exposure for enthusiasts. As revealed previously, limited studies have investigated driver, spectator, employee, and vendor noise exposures together at each type of motorsport event. Although the recommendation for HPDs was made and, in some cases, general types were suggested, specific HPD recommendations for motorsport enthusiasts were also lacking in the literature. In addition, specific HLPP recommendations for motorsport enthusiasts were not identified within the studies reviewed.

Sub-categories within each type of motorsport have yet to be investigated, i.e., motorbikes race in several varieties such as road racing, motocross, and track racing among others. Other racing categories might include kart-, truck-, rally-, street- and drag-racing. Needless to say, numerous motorsports have yet to be investigated in terms of risk of NIHL for those who engage in and attend these events.

There was a gap in terms of regulatory or racing association/owner guidance. As explained by Van Campen et al. (2005), sporting venues such as professional auto races have not historically been held to OSHA regulations so it is ultimately up to sport associations and business owners to ensure the safety of their employees.

Research Challenges

Challenges exist regarding studies investigating the noise exposure of motorsport enthusiasts. They can be grouped as intrinsic factors related to and controlled by the participant involved and extrinsic factors related to the environment in which the study is taking place and outside of the control of the participant.

Intrinsic Factors

When considering drivers involved in motorsports, an important intrinsic factor to consider is the driving style and technique. This depends on the type of racing, i.e., whether it is an endurance race versus a drag race. Generally, each driver has their own style and technique when racing or participating in motorsports. One key aspect to consider is how the driver accelerates the vehicle. Acceleration of the engine could increase the revolutions per minute as the driver shifts gears. Higher revolutions per minute usually correlate with more power being generated by the engine and this would likely result in higher levels of noise. Consequently, you might sample the same vehicle, raced by two different drivers on the same track, and get different noise exposure values. The vehicles themselves also differ so the same driver in two different vehicles on the same track might also get different outcomes. A large number of noise dosimetry samples would be needed to fully capture the range of exposures for drivers.

Another factor to consider is whether the driver wears a helmet when racing. As reviewed by Van Moorhem et al. (1981) and Kennedy et al. (2011), it was not clearly indicated that helmets were sufficient for hearing protection. However, helmets must be considered when performing noise exposure measurements and selecting appropriate HPDs.

As for spectators, vendors, or employees, one factor to consider is the relative location where they are situated during the motorsport event. For example, some spectators might be closer to the racetrack or arena while others might have seats further in the stands. Employees might be in the pit crew or they might be vendors who are situated farther from the racetrack. These individuals are likely mobile during the event and the use of noise dosimetry would be advisable rather than sound level meters for assessment of risk.

Extrinsic Factors

Environmental factors that might present as challenges to research in motorsports include weather and wind. As discussed previously, the presence of airflow across the microphone of a sound measurement instrument could cause artifact and error if introduced into the measurement. Windscreens are provided with most sound measurement instruments to reduce these effects but these are likely insufficient at high speed. Weather could impact the performance of the measurement device in terms of humidity and temperature. Specifications for instrumentation used should be considered when performing measurements outdoors.

Track design varies by the type of motorsport racing event. Open versus closed venues and groomed versus non-groomed tracks could impact noise measurements. For example, closed venues might lead to higher reverberance or reflection of sound versus an open venue. Non-groomed tracks might produce higher levels of ambient noise than groomed tracks. Exposure to carbon monoxide would likely differ between indoor and outdoor venues and should be considered when investigating the risk of hearing loss from participation in motorsport activities.

Motor and vehicle variability poses another research challenge in motorsports. Some considerations include windows open versus closed and convertible versus hard-top vehicles. Engine types and speed capacity as well as exhaust configurations could impact noise measurements.

Finally, it is important to acknowledge that every motorsport event would differ from another. The researcher could not replicate the study conditions in a laboratory or in the field. For example, each event might have a different number of cars racing or spectators at a time. The duration of the race is another consideration to keep in mind. For example, the Indy 500 race took as long as seven hours in 1911 when top speeds were 75 mph and the shortest race was in

1976, which lasted less than two hours due to rain (Martinelli, 2021). The risk of NIHL is lessened when the duration of exposure is shorter.

Altogether, many variables exist in the study of motorsport events that pose research challenges. Thus, it is of great importance to consider the documentation of these variables when conducting noise exposure measurements in motorsports. Each study could inform and build upon the previous when close attention is given to both intrinsic and extrinsic variables.

Potential Solutions and Future Directions for Research

Recreational Noise Exposure Guidelines

As stated previously, there are no official guidelines for recreational noise exposure to be used for the population of motorsport enthusiasts. However, the use of the already established OSHA (1983) 29 CFR 1910.95 exposure standard, the NIOSH (1998) exposure criteria, and the WHO (2019) recreational exposure criteria could be used.

It is rather straightforward to assume OSHA (1983) and, ideally. NIOSH (1998) guidelines for noise exposed workers would apply to the drivers and mechanics and other support personnel employed by the racing team. The vendors at racing events would also be required to implement hearing conservation programs since they fall under the “Service” category of workers covered by OSHA. There is a need to generate best practices for spectators who are potentially at risk of NIHL

Noise exposure results could be interpreted as specified by OSHA (1983), NIOSH (1998), and WHO (2019) in terms of risk on NIHL. Depending on the target population, the results could be interpreted by how applicable it is for the individual. For example, the NIOSH exposure criteria might be a good reference for drivers, employees, and vendors since they are employees while the WHO criteria could be referred to for spectators.

Efforts should be made by regulatory agencies to address recreational noise exposures to reach a broader group of people. Additionally, sport associations and business owners should be educated about the risks and ways to protect the health of their employees and motorsport enthusiasts to adhere to recommended guidelines. In this manner, attempts to reduce the incidence of NIHL could be accomplished outside of occupational settings. Strides toward this public health goal might be accomplished by audiologists serving patients who partake in motorsports as a recreational activity. There is a need for evidence-based hearing health promotion and interventions targeting these unique groups as a traditional hearing conservation program might not be practical.

Self-Monitoring of Noise Exposure

Developments in technology have increased health monitoring for consumers. For instance, smart watches can track heart rates, stress levels, steps taken in a day, and other health related activities. In terms of noise exposure monitoring, the Apple Watch SE and Apple Watch Series 4 have a Noise App that measures ambient sound levels in the environment using the microphone. When the Apple Watch detects the decibel level has risen to a level where hearing could be affected, it can notify the person (Apple Inc., 2021).

The NIOSH SLM app is another tool that could be used by individuals to monitor their own noise exposures. Jacobs et al. (2020) investigated the use of the NIOSH app on five different Apple smartphone models: iPhone 6, 6 s, 6+, 7, and 7+ without a calibrated microphones and compared the measurements to an Edge eg5 noise dosimeter to measure noise exposures in office, coffee shop, commuter train, restaurant, and spin class settings. The results indicated the NIOSH app could be used to make reasonably accurate measurements of noise in environments where noise levels exceed 75 dBA. The authors expressed that these measurements are useful as an initial exposure assessment tool but should only be used to screen out exposures that do not need further evaluation.

Access to such technology could increase the opportunities to teach people about monitoring their own noise exposures. Caution should be taken when recommending such measurements to consumers and it must be advised that these are only estimations of noise exposure. However, in this manner, individuals could make informed decisions about protecting themselves from hazardous noise.

Future Research Directions

Table 4 summarizes proposed future directions for future research based on studies reviewed in Chapter I.

Table 4

Motor Vehicles and Motorsport Research Literature: Proposed Future Directions

Topic	Study	Proposed Future Directions
Motorized Vehicles	Mikulec et al. (2011)	Evaluation of hearing loss in convertible automobile drivers.
Motorcycles	McCombe & Binnington (1994)	Raise awareness of risk of NIHL and increase use of HPDs.
	Jordan et al. (2004)	Need for HPD with radio communication for occupational motorcyclists
Snowmobiles	Moore (2014)	Need for more studies to determine whether other types of snowmobile and motorsport riders are at risk for NIHL and steps needed for prevention.
Stock Cars	Van Campen et al. (2005)	Further analysis of noise exposures at other race shops and tracks, assessment of HPDs, and determination if improved noise reduction results in improved performance/safer racing conditions.
Monster Trucks	Morley et al. (1999	Further evaluation from arena management and local public health agencies of their responsibility in informing and educating the public about the potential noise and CO exposures that they could encounter during the time spent at monster truck and motocross events.
Tractor Pulls	Buhr-Lawler (2017)	Further investigation needed to determine if the cultural attitudes toward hearing loss prevention have shifted due to the outreach efforts and if the use of hearing protection carries over into the other areas of the personal and professional lives of tractor pull attendees

Summary Statement

Several types of motorsport enthusiasts including spectators, event personnel, and drivers are generally at risk of NIHL regardless of the variables that might exist across motorsport events. The range of sound pressure values were between 63 dBA to over 100 dBA across studies investigating motorcycles, snowmobiles, stock cars, Formula 1, monster trucks, and tractor pulls (Bess & Poynor, 1974; Buhr-Lawler, 2017; Dolder et al., 2013; Jordan et al., 2004; Kardous & Morata, 2010; Moore, 2014; Morley et al., 1999; Rose et al., 2008; Ross, 1989; Van Campen et al., 2005). These outcomes supported the need to implement hearing conservation programs and hearing health promotion activities targeting these populations. Through the appraisal of existing literature and identification of future directions and proposed solutions, audiologists, event organizers, and individuals who are motorsport enthusiasts could better educate themselves and those around them about the health risk of NIHL in the recreational activity of motorsports. Audiologists can play a role in providing hearing conservation services and education for motorsport employers and individuals participating in motorsports.

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APPENDIX A

INTERVIEW QUESTIONNAIRE: MOTORSPORT DRIVERS

Motorsport Event:

Subject #____________ Date___________

In this brief interview I am going to ask you a few questions regarding your motorsport event experience, the general characteristics of the event, and your hearing-related concerns relative to noise exposure during the event.

Pre-event questions:

1. What is your age?__________
2. What is your gender?
    a. Male
    b. Female
    c. Other
    d. Prefer not to identify
3. How many years have you attended motorsport events? __________years
4. How many motorsport events a year, on average, do you attend?
    a. Less than 2
    b. 2-5
    c. 5-10
    d. More than 10
5. Do you feel that the sound levels at motorsport events might harm your hearing?

    Yes ___

    No ___
6. Do you wear hearing protection while attending the motorsport event? Yes_____ No____

    If yes, what type is used (ear plugs, ear muffs, etc.)?______________________________

    If no, why not? ____
7. Have you ever worked around high levels of noise? Yes______ No_____

If yes, what occupation___________________________

8. Do you ever have to wear ear protection (ear plugs, ear muffs, etc.) at work?

   Yes ______ No_____ If yes, what type? _________________________

9. Do you have hearing loss? If yes, do you know the cause of the hearing problem?

Vehicle/Driving Characteristics:

1. Vehicle:
   a. Year___________
   b. Make_________________
   c. Model______________
   d. Engine Type_____________
   e. Indicate location of exhaust openings:
      i. Rear end of vehicle
      ii. On the sides of the vehicle
      iii. Open header/no exhaust
      iv. Other:____________________________
   f. Windshield? Yes____ No____
   g. Muffler? Yes____ No____
   h. Driver's side window Yes____ No_____
   i. Please list any other modifications or information regarding your vehicle:

   j. What makes your engine noise louder or quieter when you drive? Please describe.

2. Do you wear a helmet?

   No___

   Yes_____ If so, may I take a picture of you wearing the helmet?

Post-event questions:

1. How would you rank the sound level of this motorsport event today in comparison to other motorsport events?
   a. Low
   b. Average
   c. High
2. Do you feel the noise levels from today are potentially hazardous to your hearing?
   a. Yes
   b. No
3. Do you feel the noise levels make the event more enjoyable?
   a. Yes
   b. No
4. Did you wear hearing protection today? Why or why not?

5. Do you have any other comments relative to noise exposure or hearing protective strategies related to your participation in the motorsport event?

6. Please report any atypical events during the motorsport event here (e.g. engine malfunction)

APPENDIX B

INTERVIEW QUESTIONNAIRE: SPECTATORS AND EVENT PERSONNEL

Motorsport Event:

Subject #____________ Date___________

Please circle one: Spectator Event Personnel Vendor

In this brief interview I am going to ask you a few questions regarding your motorsport event experience, the general characteristics of the event, and your hearing-related concerns relative to noise exposure during the event.

Pre-event questions:

1. What is your age?__________
2. What is your gender?
   a. Male
   b. Female
   c. Other
   d. Prefer not to identify
3. How many years have you attended motorsport events? __________years
4. How many motorsport events a year, on average, do you attend?
   a. Less than 2
   b. 2-5
   c. 5-10
   d. More than 10
5. Do you feel that the sound levels at motorsport events might harm your hearing?

   Yes____ No____
6. Do you wear hearing protection while attending the motorsport event? Yes_____ No____

If yes, what type is used (ear plugs, ear muffs, etc.)?_____________________________

If no, why not?____

7. Have you ever worked around high levels of noise? Yes______ No_____

   If yes, what occupation___________________________

8. Do you ever have to wear ear protection (ear plugs, ear muffs, etc.) at work?

   Yes ______ No_____ If yes, what type? _________________________

9. Do you have hearing loss? If yes, do you know the cause of the hearing problem?

Post-event questions:

1. How would you rank the sound level of this motorsport event today in comparison to other motorsport events?
   a. Low
   b. Average
   c. High
2. Do you feel the noise levels from today are potentially hazardous to your hearing?
   a. Yes
   b. No
3. Do you feel the noise levels make the event more enjoyable?
   a. Yes
   b. No
4. Did you wear hearing protection today? Why or why not?
5. Do you have any other comments relative to noise exposure or hearing protective strategies related to your participation in the motorsport event?