

HEARING PROTECTION – THE ELECTRICAL HAZARD YOU DON'T “HEAR” ABOUT!

Copyright Material IEEE
Paper No. ESW2015-07

Kevin J. Lippert
Senior Member, IEEE
Eaton Corp.
1000 Cherrington Parkway
Moon Township, PA 15108
USA
KevinJLippert@Eaton.com

Amanda M. Lippert
Graduate Student
Pennsylvania State University
State College,
PA 16801
USA
amandalippert1126@gmail.com

Abstract – Many people do not understand that their hearing is a valuable, yet delicate, sense which they damage with regularity. While the sense of sight is typically recognized as delicate, and given appropriate protection considerations, the sense of hearing is not as readily apparent.

This paper will explain some of the physiological aspects which give us our hearing capabilities. It will also describe how damage to this sense may result. Examples will be cited as to why this should be considered as part of an electrical safety program, as well as potential methods for reducing the hazard.

Index Terms — arc flash, sound hazard, hearing protection

I. INTRODUCTION

According to the American Speech- Language- Hearing Association (ASHA) it is estimated that more than 28 million people in the United States have a hearing loss or deafness [1]. In regards to the workplace, loud noise is estimated to cause hearing loss in over 10 million American workers every year, despite the fact that this injury is completely preventable [2]. Additionally, the U.S. Bureau of Labor Statistics reported that hearing loss represents 12% of occupational illnesses reported in 2010 [3].

Even with these alarming statistics, many people do not understand that their hearing is a valuable, yet delicate, sense. The early warning signs (such as tinnitus or ringing in the ears) are often ignored because hearing loss is a slow and often painless process. Hearing loss frequently isn't considered an issue until it starts to interfere with one's work or social life [1, 4].

This paper will explore the physiological aspects of the hearing process in relation to the effects of hearing loss on one's personal life, the associated hearing hazards of arc flashes in the electrical industry, and identification of prevention methods.

II. PHYSIOLOGICAL ASPECTS OF HEARING

The human ear (Figure 1) is an intricate instrument that acts as a microphone for bodies to perceive the sound around them. It requires the manipulation of a physical vibration into an electrical signal, which is then translated into a nervous impulse that can be processed by the brain [5, 6]. In order to better

understand this concept, this paper will describe the hearing process in more detail.

The processing of hearing begins with the pinna, or the outer, visible portion of the ear. This is used as a funnel to capture and direct sound vibrations into the ear canal, as well as to assist in localizing sounds. Next, the sound vibrations reach the external portion of the ear canal, called the external auditory canal, which resonates and amplifies sounds [5]. The external auditory canal makes up the first 2/3 of the ear canal, and is a cartilaginous structure covered in hairy skin and protective cerumen, or ear wax [6]. The canal is curved in a slight 's' shape, as another protective measure to keep out foreign objects [5, 6, 7].

At the end of the external auditory canal, the sound vibration meets the tympanic membrane, which is commonly known as the ear drum. This marks the beginning of the middle ear, and is a very delicate structure, only 1/10th of a millimeter thick [5, 6]. This membrane, shaped somewhat like a loudspeaker cone, is covered by a thin layer of skin facing the outer ear, and a stiffening fibrous middle layer on the inner surface [5, 7]. The acoustic energy of the sound vibrations reach the tympanic membrane and, due to the slight changes in air pressure caused by the sound vibrations, cause the tympanic membrane to vibrate similarly to a drum skin, translating the acoustic energy into mechanical energy [5, 6, 7]. This movement is conducted from the tympanic membrane to the ossicles, which are the three smallest bones in the human body. These bones, the malleus, incus, and stapes, amplify (by approximately 31 dB [6]) and translate the movement of the tympanic membrane to the cochlea in the inner ear. The middle ear space containing these bones also connects to the Eustachian tube, which is the air-filled cavity responsible for maintaining consistent air pressure that is equal to the air pressure in the environment. This equalization action is more commonly known as “popping your ears” [5, 7].

Once the energy of the tympanic membrane movement has been transferred through the malleus and incus, the stapes bone advances the movements via a 'footplate' on the cochlea. This footplate is a flat bone which covers the oval window (an opening into the vestibule of the cochlea) and articulates the continued movement of the ossicles to the cochlea via the stapedio-vestibular joint [5, 6]. The cochlea is a bony, fluid-filled structure that is shaped like a snail shell. In transferring the movement of the stapes to the vestibule of the cochlea, the mechanical energy of the sound is now transferred to hydraulic

energy. It is only a 0.2 millimeter fluid movement in the cochlea that causes a neurochemical event which excites up to 30,000 hair cells. These inner hair cells in turn transduce their vibration into nerve impulses using approximately 19,000 nerve fibers which send this impulse to the brain.

As part of the inner ear, the vestibular system contained in the semi-circular canals is responsible for maintaining balance in the body. Information about both hearing and balance is sent via afferent nerves to different parts of the brain. Information from the brain is sent via efferent nerves, creating an active feedback loop. The brain's interpretation of the neural impulses produces information about frequency (pitch), intensity (loudness), and temporal aspects (e.g., timing and use of pauses) for the brain to analyze, and for the body to respond appropriately [5, 6, 7].

A. Hearing damage

As stated previously, the ear has multiple defenses to protect itself from foreign objects, including the curved shape of the ear canal, and the use of cerumen (ear wax) to protect the ear canal and ear drum. However, damage to the ear can still happen, resulting in temporary and/or permanent hearing loss. One common type of hearing loss results from damage to the outer hair cells in the cochlea [5, 6, 7].

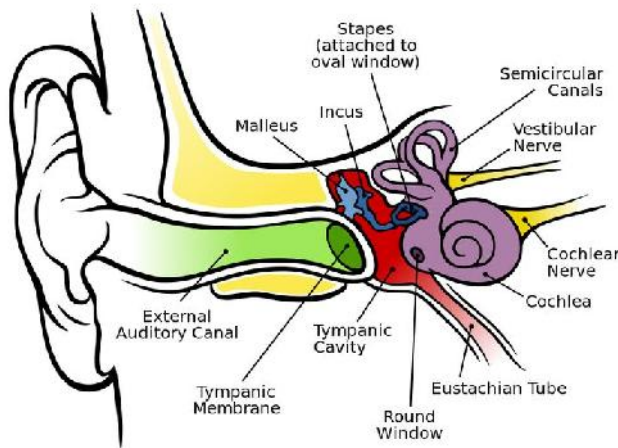


Figure 1 – Human Ear [8]

According to ASHA, there are three main types of hearing loss: conductive, sensorineural, and mixed. Conductive hearing loss involves the inability for sound energy to easily flow through the ear, such as fluid in the middle ear from allergies or a cold, swimmer's ear, punctured ear drum, etc. This type of hearing loss can be easily corrected medically or surgically [9]. Sensorineural hearing loss occurs when there is damage to the sensory hair cells located in the cochlea in the inner ear or to damage in the pathways to the brain [6, 9]. This may have a number of causes, including aging, toxic drugs, head trauma, and malformation of the inner ear. However, the most common cause of sensorineural hearing loss is from noise (i.e. noise-induced hearing loss). Due to the nature of this damage, sensorineural hearing loss cannot be medically or surgically corrected, meaning that it cannot be "fixed" by a hearing aid. Mixed hearing loss is a combination of conductive and sensorineural [6, 7, 9].

Additionally, hearing losses can be described in relation to the rate at which the loss occurs. Progressive hearing loss refers to one that becomes worse over time, while a sudden hearing loss occurs quickly, sometimes after a single incident [9]. The focus of this paper is sensorineural hearing loss, which is often progressive in nature. However, it is important to note that it can also occur suddenly [9, 10], such as from a single loud arc flash event!

III. WHAT DOES HEARING LOSS MEAN?

Although the anatomical and physiological properties of hearing loss can be discussed in intricate detail, this information is useless unless people understand how it applies to them. Common environmental sounds, such as a baby crying, music playing, a lawn mower running, a music concert, and an airplane take-off, are all visually represented in Figure 2 in relation to their average pitch (frequency) and loudness (intensity). They are also depicted in relation to English speech sounds, degrees of hearing loss, and minimum level for hearing protection.

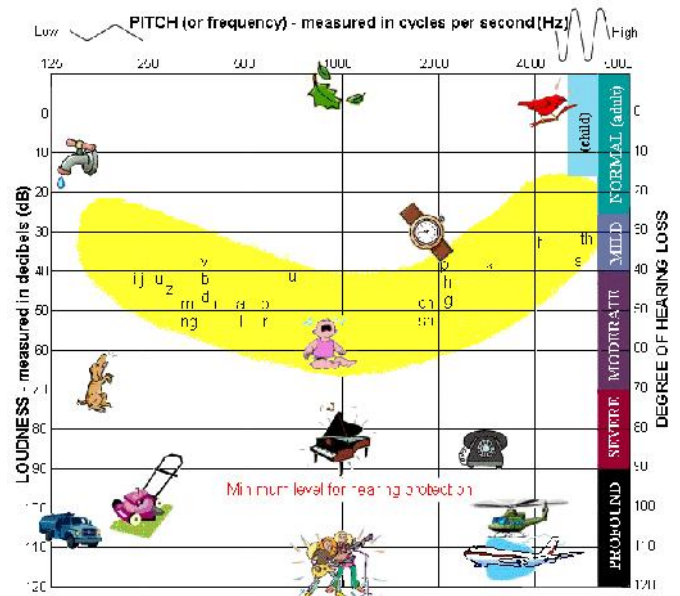


Figure 2 – Common Environmental Sounds [11]

OSHA [12] has extensive information concerning sound exposure levels, durations and protection required, including an 8-hour limit of an average 85 dB level. For every increase of 3 dB in noise level, the safe exposure time is decreased by approximately half. A Portuguese survey [4] was conducted of workers from different industrial companies whose 8-hour noise exposures exceeded this 85 dB limit. 45% of the workers responded that they never use hearing protection devices (such as ear buds, headphones, etc.), even though they are mandatory in these work places. 27% of the workers reported wearing hearing protection devices all of the time. The study further revealed that the worker's perception of the potential risk was the most significant factor in determining whether they would wear their hearing protection devices. However, it also revealed that workers are generally poor judges of the risk

factor. One of the objectives of this paper is intended to change that perception.

Many people do not realize that hearing loss results in more than turning up the volume for the six o'clock news. It makes many aspects of everyday life very challenging, including the basic perception of speech. Because sensorineural hearing loss typically damages the cochlea, higher frequencies are more difficult to hear, especially the common consonants "s," "f," "sh," and "h." Since consonants are the primary components for understanding speech, the inability to hear them can make conversations incredibly difficult [13].

Balance can become an issue with sensorineural hearing loss because it involves damage to the inner ear. The inner ear structure of hearing, the cochlea, is closely connected to the vestibular system, the area that controls the aspect of balance [5, 6, 7]. A lack of balance can lead to uncoordinated movements and increased risk of falling or dropping items, drastically increasing the risk of injury both at home and in the work place [14].

Sensorineural hearing loss often greatly affects one's personal life. This impacts some simple events in everyday life, such as hearing the telephone or doorbell ringing, watching a movie or television show, and listening to music. However, this hearing loss can have an even greater impact on important life moments. Because children's voices have higher frequencies, the ability to hear and understand them is often greatly impaired with sensorineural hearing loss. Therefore, parents and grandparents often have difficulty hearing and understanding their children and/or grandchildren, which can lead to depression or increased social withdrawal.

Social withdrawal is also a prevalent result of hearing loss. With hearing loss, it's common to miss portions of jokes or stories, and the person laughs along with others simply to avoid appearing "out of the loop." Additionally, family and friends may believe that individuals with hearing loss are having memory troubles, while they are struggling because they simply aren't hearing all of the information. Many individuals with hearing loss report the need to "listen harder" and ask for frequent repetition during conversations, which can be mentally exhausting and embarrassing [13].

IV. ELECTRICAL WORKER APPLICABILITY

Requirements for mandatory hearing protection have been around for a very long time. As previously stated, OSHA [12] has extensive information concerning sound exposure levels, durations and protection required. While the OSHA information is general in nature and not specific to electrical situations, it is certainly applicable. Most closely associated with arc flash is the requirement that exposure to impulsive or impact noise should not exceed 140 dB peak sound levels. Electrical safety requirements from [15] include hearing protection. While [15] contains many more specifics related to the thermal aspect of arc flash hazards, the PPE Tables of Hazard/Risk Categories 0-4 have contained a requirement for hearing protection (ear canal inserts) for several editions. The 2012 edition has added a separate statement to require hearing protection whenever working within the arc flash boundary.

Although many, many papers have been published about arc flash hazards, their main focus has typically been the thermal hazard. [16] is titled as a "Guide for Performing Arc-Flash Hazard Calculations" and is recognized worldwide as a calculation model. Even so, this document specifically states

that "This guide is based upon testing and analysis of the burn hazard presented by incident energy. Other potentially hazardous effects...have not been considered in these methods." Until more definitive hazards are addressed, future revisions to this Guide should consider renaming it to "Performing Incident Energy Calculations," as this more accurately reflects its content. In contrast to thermal hazards, the amount of published information specific to the hazardous sounds produced by arc flash incidents is very limited. While no arc flash testing was conducted specifically for this paper, we will cite the work of others who have previously taken sound measurements and recorded their levels.

Early work [17] of arc flash advocate pioneers Richard Doughty and Dr. Thomas Neal documented sound level measurements for 3 phase, Low Voltage, open air and in-a-box testing (See Figure 3). The electrical circuit parameters were: 600V, 36kA (prospective), duration of 6 electrical cycles (0.1 s). Using [16], and depending upon the specific configurations, the corresponding incident energy for these circuit parameters calculates within the range of 5-12 cal/cm². While the focus of their paper was the testing of protective clothing, their work included a portion addressing sound level hazards. A few important conclusions resulting from this work include:

- 1) Peak sound levels generally increased with average arc current
- 2) All recorded sound levels greatly exceeded the OSHA exposure limit (140 dB impact). Sounds at this level have no safe exposure time. Damage will occur immediately.

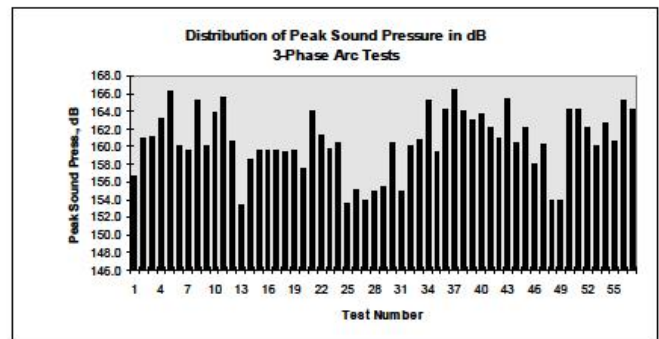


Figure 3 — Measured Sound Levels
(Originally presented as Figure 14 of [17])

The IEEE/NFPA Arc Flash Phenomena Collaborative Research Project has been conducting extensive testing. In their update [18] published January 2011, they also included a portion addressing sound level hazards. Figure 4 shows the results from their medium voltage arc flash testing. The electrical circuit parameters were: 4160V, 20-63 kA (prospective), duration of 6 and 12 electrical cycles (0.1 and 0.2 s). Using [16], and depending upon the specific configurations, the corresponding incident energy for these circuit parameters calculates within the range of 3-20 cal/cm². Important conclusions resulting from this work include:

- 1) Sound levels are affected by the magnitude of short circuit current
- 2) There is little correlation between sound level and arc duration

- 3) All recorded sound levels also exceeded the OSHA exposure limit (140 dB impact).

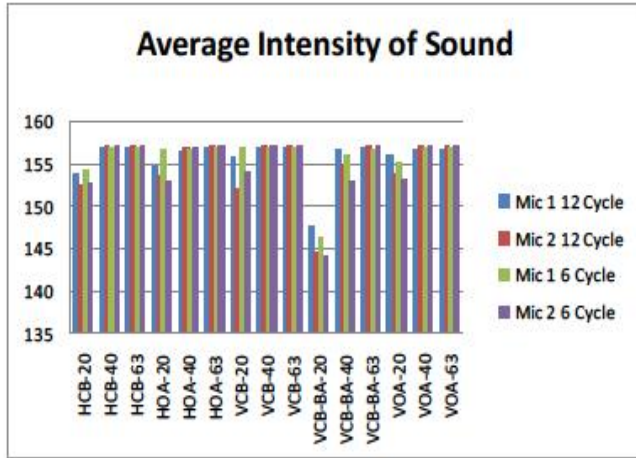


Figure 4 — Measured Sound Levels (Reprinted with permission from [17])

Review of these results clarifies that sound hazards are indeed associated with arc flash incidents. The ranges of the test parameters included in both sets of results are certainly applicable to today's real-world low voltage and medium voltage electrical installations. Awareness should increase our desire to want to identify, educate, and address the sound hazards associated with arc flash incidents.

V. POTENTIAL METHODS FOR REDUCING THE HAZARD

Industry has made great progress in addressing the thermal hazards associated with arc flash hazards. A vast majority of people are now aware of the hazard, and are using widely available tools to quantify this aspect. Numerous methods for reducing thermal hazards are becoming mainstream. "Safety by Design" incorporates features which will lessen the arc flash energy (current/time limitations); redirect and/or contain the energy; and remove the worker from the immediate thermal exposure area. Vendors continue to develop innovative products and services to meet these needs of industry. Some of these same solutions can be used to address the sound hazards also associated with arc flash. As previously noted, arc flash sound levels typically increase with the associated arc current. Methods used to provide current-limitation to address the arc flash thermal aspect, will also serve to reduce the risk of higher sound-level hazards of the arc flash event. While short distance is not itself an effective means to reduce the sound hazard, remote operation from completely different rooms/locations is. Hearing protection devices are considered the last option to control exposures to noise. External hearing protection can be used to mitigate the sound level hazard, but one must recognize that due to thermal considerations these may need to be arc-tested, or used in conjunction with a properly arc-rated external covering (i.e. hood).

Hearing protection devices are widely available in several different styles. Ear muffs are constructed of materials which attenuate the sound and use soft ear cushions that cover the outer exposed portion of the ear. They are typically held firmly

in place by some type of head band. Another type is the semi-insert ear plugs. These are constructed from two ear plugs which are also held over the ends of the ear canal by a rigid headband. The other type is the ear plug. Ear plugs are inserted to block the ear canal. They are available as pre-molded (preformed) or moldable (foam ear plugs) and as disposable or reusable plugs. Custom molded ear plugs are also available. These are probably the simplest hearing protection available today and have become a preferred method of sound protection when considering arc flash hazards.

When selecting hearing protectors, users should verify that they have been tested to American National Standards (ANSI) to establish their Noise Reduction Rating (NRR). The NRR is a unit of measurement used to determine the effectiveness of hearing protection devices to decrease sound exposures. The higher the NRR number assigned to a hearing protector, the greater the sound reduction. Consult the manufacturers to determine how to apply the NRR number as the National Institute for Occupational Safety & Health (NIOSH) notes that there are various methods for calculating real world sound attenuation.

The National Library of Medicine (NLM) provides simple guidelines for maintaining better hearing health habits in everyday life. It is important to become aware of the noises around you, including the length of exposure to noise/music and the level of noise. For example, when listening to music, experts caution to never turn up the volume on music devices to block out noise from the environment. The volume is most likely causing damage. Also, headphones are recommended over ear buds for listening to music, because ear buds do not block out noise from the environment. Another simple fix is to limit the volume on music devices to lower than level 5 to prevent excessive volume use [19].

VI. CONCLUSIONS

This paper has described in detail how the human sense of hearing is a complex set of intricate, and delicate, functioning items which are seldom considered during the events of a normal working day. This sense is often taken for granted, exposing people to dangerous sound levels. While many exposures are not immediately debilitating, long term damage can greatly reduce hearing capabilities and impact vital social interaction. Results of arc flash testing confirm that readily available electrical systems potentially expose individuals to sound levels greatly exceeding OSHA requirements for immediate impact exposure. Multiple methods are available to protect from the excessive sound hazards from electrical arc flash incidents. As with the thermal aspect, the sound hazard should also always be identified, with methods taken to eliminate it when possible. Alternatively, methods should be taken to minimize the risk (likelihood and severity) of excessive sound hazards. As a last resort, proper hearing protection should be utilized.

It's important to remember that safe practices begin at the home. Routinely integrating safety practices into the home life causes them to become second nature in the workplace. As related to hearing protection, basic, common-sense rules should begin to be utilized at home: 1) Recognize the damaging sound levels that may be present (e.g., at nightclubs and concerts; using a lawn mower/weed trimmer/chain saw; helicopter or airplane take-off); 2) Lower the sound levels of

music players, televisions and other audio devices; 3) Make it a habit to routinely use hearing protection for the potentially damaging situations.

The sense of hearing is just as important as the sense of sight. Individuals should give attention to protecting their hearing in the same manner as done for sight. Failure to do so creates a hearing impairment which impacts not only the individuals, but their families too. How sad would it be, if due to sheer negligence from protecting against something fully preventable, anyone were to miss a soft voice from a spouse, child or grandchild, saying "I Love You".

VII. REFERENCES

- [1] American Speech- Language- Hearing Association (ASHA), 2011, *Hearing Loss*, ASHA.
- [2] M. C. McReynolds, 2005, "Noise-Induced Hearing Loss", *Air Medical Journal*, vol. 24, no. 2, pp. 73-78, Mar/Apr 2005.
- [3] Bureau of Labor Statistics, U.S. Department of Labor, "Distribution of Occupational Injury and Illness Cases," October, 2011.
- [4] P. M. Arezes, A. S. Miguel, "Individual Perception of Noise Exposure and Hearing Protection in Industry," *Human Factors*, vol 47(4), pp 683-692.
- [5] P. W. Alberti, "The Anatomy and Physiology of the Ear and Hearing," *Occupational Exposure to Noise: Evaluation, Prevention, and Control*, pp 53-62, 2001.
- [6] J. A. Seikel, D. G. Drumright, and D. W. King, "Anatomy of Hearing," in *Anatomy & Physiology for Speech, Language, and Hearing- 4th ed.*, 2009, pp 449-520.
- [7] Better Hearing Institute, *How We Hear*, 2014, Washington, DC: Better Hearing Institute.
- [8] L. Chittka, A. Brockmann, "Anatomy of the Human Ear," *Perception Space – The Final Frontier*.
- [9] American Speech- Language- Hearing Association (ASHA), 2011, *Type, Degree, and Configuration of Hearing Loss*, *Audiological Information Series*: ASHA.
- [10] F. E. Thurston, "The Worker's Ear: A History of Noise-Induced Hearing Loss," *American Journal of Industrial Medicine*, vol 56(3), pp 367-377, 2013.
- [11] Alexander Graham Bell Association for the Deaf and Hard of Hearing: Listening and Spoken Language Knowledge Center, <http://listeningandspokenlanguage.org/SpeechBanana>.
- [12] Occupational Safety & Health Administration, (OSHA) Code of Federal Regulation (CFR) 29, Labor, Part 1910.95, "Occupational noise exposure".
- [13] A. W. Smith, "Noise Can Damage Your Hearing," *World Health*, vol 51 (5), pp 10-11, Sept/Oct 1998.
- [14] K. H. Kilburn, B. Hanscom, R. H. Warshaw, "Are Hearing Loss and Balance Dysfunction Linked in Construction Iron Workers?," *Brisish Journal of Industrial Medicine*, vol 49, pp 138-141, 1992.

- [15] NFPA 70E, *Standard for Electrical Safety in the Workplace*, National Fire Protection Association, Quincy, MA: NFPA.
- [16] IEEE 1584, "Guide for Performing Arc-Flash Hazard Calculations", New York, NY: IEEE.
- [17] R. L. Doughty, Dr. T. Neal, T.A. Dear, and A. H. Bingham, "Testing Update on Protective Clothing & Equipment for Electric Arc Exposure", IEEE Petroleum and Chemical Industry Conference, Sept., 1997.
- [18] IEEE/NFPA Arc Flash Phenomena Collaborative Research Project, Update January 11, 2011, Wei-Jen Lee, Ph.D., P.E. Tammy Gammon, Ph.D. <http://standards.ieee.org/about/arcflash/>.
- [19] L. J. Vorvick, "Hearing Loss and Music," *Medline Plus, a Service of the U.S. National Library of Medicine and the National Institutes of Health*, May 2012.

VIII. VITA

Kevin J. Lippert is the Manager, Codes & Standards for Eaton Corporation in Moon Township, PA, responsible for their Electrical Sector's overall codes & standards domestic and international strategic direction. He has over 28 years of industry experience: Heavily involved with NEMA, a member/past-member of several UL Standards Technical Panels; a US Representative to several groups of the IEC and 2010 recipient of the IEC 1906 Award; The US National Committee (USNC) Vice-President for Membership Development & Recruitment and a member of the USNC Council to the IEC; an alternate member of the NFPA NEC, Code Making Panel 10, an alternate member of NFPA 70E - Electrical Safety in the Workplace; and Board of Trustee member for the NFPA Research Foundation. He is a senior member of the Institute of Electrical and Electronic Engineers (IEEE), a former Chair of the IEEE PCIC Safety Subcommittee, an active member of several IEEE committees and has published industry articles and IEEE White Papers. He has been Registration Chair of the IEEE Electrical Safety Workshop for several years.

Amanda M. Lippert obtained her B.S. in Communication and Science Disorders with a Minor in Special Education from the Pennsylvania State University (2012). She is presently continuing her studies there towards her M.S. in Speech Language Pathology with a focus in Augmentative and Alternative Communication (2015). Amanda has also been actively advancing her skills in this area through clinical applications, notably in the pediatric population focusing on auditory processing and auditory-visual therapy.