AUDITORY HYPERSENSITIVITY AND AUTISM SPECTRUM DISORDERS: AN EMOTIONAL RESPONSE

BY JAY R. LUCKER, EDD, CCC-A/SLP, FAAA, AND ALEX DOMAN

Abstract

Many children diagnosed with an autism spectrum disorder are described as having auditory hypersensitivities. This paper describes auditory hypersensitivities, the systems involved in hypersensitive hearing, methods for evaluating auditory hypersensitivity in children, and possible treatments. Auditory hypersensitivity involves the non-classical auditory system and is an emotional response to sound rather than an auditory response. Children described as being hypersensitive to sound have negative emotional reactions to sounds and situations in which the sounds are present. It is possible to desensitize these negative emotional reactions and reprogram the emotional memory system so that children are no longer frightened by sounds.

AUDITORY HYPERSENSITIVITY AND AUTISM SPECTRUM DISORDERS

One concern parents and professionals may have with children who have been diagnosed with an autism spectrum disorder (ASD) is that some of these children cannot tolerate listening to certain sounds. Often, parents observe that the children put their hands over their ears, run away from sounds, or sometimes lose control of their behaviors in the presence of certain sounds. These children are often identified as having *auditory hypersensitivity* or *hypersensitive hearing*.[1-10] Although concern about auditory hypersensitivity has been especially focused on children on the autism spectrum, many non-autistic children also present with behaviors labeled as auditory hypersensitivity.[2-4,6-9]

For many years, experts focusing on auditory hypersensitivity and treatment for problems of hypersensitive hearing looked at this phenomenon as an auditory-system-based problem involving abnormal hearing but not hearing loss. Some defined auditory hypersensitivity as an overreaction to sounds that should (over time) no longer warrant such responses. However, recent research has led us to a better understanding of what may be going on in children who have hypersensitive hearing. An understanding of possible mechanisms can assist us in providing more appropriate interventions to help children overcome auditory sensitivity problems. This article discusses auditory hypersensitivity with a focus on the current state of our understanding of the problem and treatment for such problems.

HEARING VERSUS PERCEPTION AND AUDITORY PROCESSING

Generically, auditory hypersensitivity usually refers to a person who is considered overly sensitive to sounds, especially loud sounds. There are many who might think that children with auditory hypersensitivities, therefore, have hearing-related problems. However, the following three definitions clarify that auditory hypersensitivity has to do with our *perception* of sound rather than our *hearing* of sound:

1. One definition of auditory hypersensitivity is "abnormally sensitive hearing in which normally tolerable sounds are perceived as excessively loud."[11]

2. Another definition is "an increased sensitivity to sound perception, subjective in nature."[12]

3. In discussing auditory hypersensitivity, Gomes and colleagues[5] cite Kanner,[13] who discusses children on the autism spectrum as having *aversions* to certain loud sounds rather than having problems hearing or listening to loud sounds.

ALEX DOMAN is founder and CEO of Advanced Brain Technologies. He is also a bestselling author, producer, and speaker. He has focused his career on sound, music, and technology and their capacity to improve brain health and performance. His credits include being co-producer of *Music for Healing at the Speed of Sound™* and *Music for Babies™* as well as executive producer, creator, or collaborator on more than 50 other music albums and products including *Sound Health®, Music for the Mind™, BrainBuilder®,* and *The Listening Program®.* Doman is coauthor of the bestselling book *Healing at the Speed of Sound®.* See also **www.advancedbrain.com**.

JAY R. LUCKER, EDD, CCC-A/SLP, FAAA, is an associate professor in the Department of Communication Sciences & Disorders at Howard University in Washington, DC. He is also a certified/licensed audiologist and speech-language pathologist specializing in auditory information processing disorders (APD). Dr. Lucker is president, cofounder, and chair of the board of the National Coalition on Auditory Processing Disorders (NCAPD). See also **www.ncapd.org.**

Hearing is the recognition of the presence of a sound. This recognition does not mean we understand the meaning of the sound nor does it indicate that we have any perception of the sound. *Perception* is our cognitive ability to give *meaning* to a sound. In contrast to hearing, which is just the awareness of the presence of sound, when we perceive a sound, we make a cognitive decision as to what that sound means.

All of these descriptions and definitions look at auditory hypersensitivity as a problem with behavior (perception) and not with hearing. As these definitions indicate, the phenomenon we refer to as auditory hypersensitivity is not a problem with the auditory system being hypersensitive but with the person being hypersensitive to sounds. We will take up the topic of why a person becomes overly sensitive to sound though the hearing or auditory system is functioning perfectly normally as we proceed.

Hearing can be described as sensitivity to sounds. Better stated, it is our ability to recognize that a sound has entered our ears and traveled to our brains where the sound is "heard" or registered as present. Thus, hearing is the recognition of the presence of a sound. This recognition does not mean we understand the meaning of the sound nor does it indicate that we have any perception of the sound.

Perception is our cognitive ability to give *meaning* to a sound. In contrast to hearing, which is just the awareness of the presence of sound, when we perceive a sound, we make a cognitive decision as to what that sound means. Consider the following example. You are sitting at home and you suddenly hear a rapping sound. It comes as "tap, tap, tap," with three taps or bangs that are of the same exact pitch or frequency, of the same loudness or intensity, each lasting the same length of time with the same short gap of quiet between each of the taps. Your auditory system merely hears these sounds and notes the pattern of sounds. However, when you react to the sounds, get up, go to the door, ask who is there, and open the door, your cognitive decision making system has taken that auditory pattern and made sense out of it. Recognizing that the "tap, tap, tap" is a unique pattern that you have heard before, you perceive that you have a memory trace for this pattern. That memory trace leads you to know what the pattern means. You even have a name for it, calling it "knocking on the door," and you have a mental image that when this pattern occurs, you should respond by seeing who is at the door. This perception occurs through a series of processes we refer to as *auditory processing*.

PROCESSING IN AUDITORY HYPERSENSITIVITY

Consider that you are a little child, and you hear certain sounds. Your *processing systems* make the decision that the sounds are frightening, annoying, and very loud. What do you do? You may cry, run away, hide, or merely tremble in fear. This may be a normal response in a very young child. The frightening sound strikes your cognitive system, and you react in a negative emotional way. What happens next could be that the memory of this frightening sound is stored so that the pattern of sound, when heard, is again perceived as a frightening sound. You may react with fear not only toward the sound but also toward the situation in which the sound occurs and the thing making the sound. Over time, just as Pavlov's dogs began to salivate at the sound of the bell without food being present, the frightening sound itself may no longer be needed to elicit the negative emotional memory associated with the sound. The situation or thing that made the sound also can set off your fear responses. Eventually, something called generalization occurs so that similar situations or objects similar to the ones that made the original frightening sound also will elicit the negative emotional reactions. This is how an initial auditory-based hypersensitivity becomes a more general hypersensitivity to sound and the situations in which the sound occurs.

Auditory processing involves at least six integrated systems.[6,14] These systems include:

- The auditory system itself
- The cognitive decision making system
- Memory (including emotional memory)
- The emotional system
- Language systems
- Sensory regulation systems

Over time, the auditory system itself may not be that important in the processing of loud sounds, and we may instead draw on the other systems. That is, we may *think* that a sound will be loud and frightening (cognitive decision making system); we may *remember* the way the original sound scared us (memory); we may want to avoid sounds and the situations in which these frightening sounds occurred (emotional system); or we may have an autonomic nervous system reaction, which typically involves what are called *fight or flight* responses. For example, in anticipation of the frightening sound, we may lose control of our behavior and try to run away (flight); we may put up a strong, negative emotional fight to avoid the sounds (fight); or we may retreat into ourselves seeking to calm ourselves through behaviors such as rocking or running around in a circle (another type of flight response).

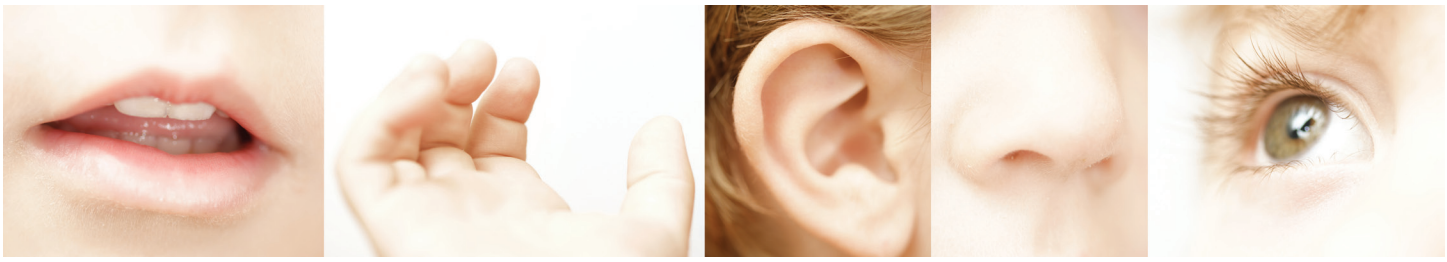
Thus, a hypersensitive reaction can occur in anticipation of a sound, even if the sound itself is absent. These reactions can also occur when we hear a soft, nonthreatening sound if our processing system persuades us that the situation or sound is or will be the same as a previously heard sound. In this way, we can enter into automatic, negative, and emotionally reactive behaviors and maladaptive responses. These maladaptive responses are behavioral reactions that result from our fear of a sound and our fear that the sound may occur without warning. Behaviors are considered maladaptive and inappropriate when they perpetuate or even strengthen the child's fear. For example, some children demand to be removed from or avoid participating in certain situations. Other children go from wearing earplugs (or earmuffs or headphones) in a few situations to wearing earplugs all the time or wearing earplugs and avoiding certain situations. This type of maladaptive response not only can limit a child's experiences but also does not take care of the problem because it focuses on treating the auditory/hearing system rather than the real underlying systems involved.

CLASSICAL AND NON-CLASSICAL AUDITORY PATHWAYS

Let us review the basic auditory system, which is also known as the *classical auditory system*. This system starts with the ear. The ear has three parts before entering the central auditory pathways, which are also called the central auditory nervous system (CANS). The three parts of the ear include:

1. The outer ear: The outer ear includes what we see and call "the ear," which is really the pinna or auricle. The outer ear collects sound and brings it to the ear drum or tympanic membrane.

2. The middle ear: The tympanic membrane begins the middle ear, which also involves the three bones of the middle ear: malleus or hammer, incus or anvil, and stapes or stirrup. The basic function of the middle ear is to deliver the sound signal to the inner ear or cochlea.



3 The inner ear or cochlea: The inner ear or cochlea is a fluid-filled structure that also houses the sensory cells of hearing called the hair cells. When the hair cells are appropriately stimulated, they release neurochemicals to the auditory nerve or eighth nerve.

The eighth nerve transmits the neural signal to the low brainstem where nerve stations pick up the signal, do some processing of their own, and transmit the processed signal to the upper brainstem, where it then travels to a region of the thalamus (just below the cortex of the brain). After some processing in the thalamic area, the neural signal is transmitted to the auditory centers of the cortex on the right and left sides, which connect with each other via a structure called the corpus callosum. Once the neural signal is in the auditory centers of the brain, it can be relayed to various other centers of the brain such as the language center (for linguistic understanding), the memory centers (to remember the auditory patterns we hear), and the cognitive decision making centers (so that we can make decisions about the sound patterns we hear). (There are many good websites and basic anatomy books that provide more in-depth descriptions of the classical auditory pathway. See, for example, the basic audiology textbook by Martin and Clark, 2011.[15])

It was not until the early 2000s that Moller and associates described what they called the *non-classical auditory pathways.*[16,17] Essentially, these non-classical pathways begin with the eighth nerve as do the classical auditory neural pathways. Where the classical pathways eventually connect with the auditory centers of the cortex, however, the non-classical pathways make connections within the region of the brain called the limbic system and the cerebellum. The limbic system is an old neural system hidden deep inside the cortex of the brain. It houses a number of structures, two of which are likely involved in auditory hypersensitivity. One structure involves our emotional reactions and leads to behaviors associated with the fight or flight response. Another is the amygdala, which is the center of emotional memories.

Moller and Rollins[16] demonstrate that the non-classical auditory pathways are highly active in young children and become suppressed as we get older. It is not surprising to see a young toddler frightened by a loud, unexpected sound. Often, the toddler will cry and demonstrate other negative emotional reactions to such a sound. Over time, toddlers learn to inhibit or suppress the non-classical pathways so that they may initially react to a loud sound but then gain control and show only annoyance at the sound. As children learn that they are able to control their reactions to annoying sounds, they come to understand the sounds, the things producing the sounds, and the situations in which the sounds occur. They learn that they have no need to avoid or be afraid of such sounds and situations.

What if a child is not able to suppress the non-classical auditory system? What if the non-classical system remains highly active long after it is no longer needed for normal functioning? These questions and the recent interest in non-classical pathways have led to descriptions of how the non-classical pathways may contribute to the behaviors and reactions we see in children with auditory hypersensitivity.[6,18] Investigators hypothesize that children with sensory processing problems, including children on the autism spectrum, maintain activity of the non-classical auditory system.[6,17,19] From this perspective, the negative emotional memories and reactions to sounds (and situations in which such sounds have occurred in the past) become strongly conditioned into these children's limbic systems. Generalization has occurred, so that the children are frightened by things that might make loud and annoying sounds as well as situations in which such sounds might occur, even if the sounds are highly unlikely to actually occur. This leads to the phenomenon we call auditory hypersensitivity.

EVALUATION OF AUDITORY HYPERSENSITIVITY

Typically, a person is identified as being hypersensitive to sound through checklists or descriptions of behaviors.[5,20,21] However, these diagnostic tools are highly subjective. A less subjective method for assessing auditory hypersensitivity needs to be developed. One of us (JRL) described an approach (using earphones) that used three methods normally employed by audiologists to fit the maximum loudness of hearing aids and cochlear implants for children: standard audiological tolerance, uncomfortable loudness (UCL), and threshold of discomfort (TD).[6] In this study, only 32% of children diagnosed with an ASD could *not* tolerate extremely loud sounds. When Gomes and colleagues[5] used a similar approach (with sounds presented through loudspeakers rather than earphones), they found that only around 24% of their subjects could not tolerate the loud sounds used. Thus, both studies indicated that children identified with ASD overwhelmingly are able to tolerate loud sounds when the sounds are presented in controlled, standard, audiological (i.e., hearing test) conditions. This suggests that the 68% to 76% of children in the two studies who *could* tolerate loud sounds are likely to have emotional memory reactions to loud sounds rather than continued auditory-based reactions. For these children, who represent the overwhelming majority of ASD children with auditory hypersensitivities, the treatments that we recommend below are likely to bring about positive outcomes much more quickly than for children who react strongly to the presence of loud sounds. The latter group of children can also be helped, but it may take a longer period of training.

The basis of desensitization training, as the name suggests, is to desensitize the emotional and non-classical auditory systems so that they no longer react negatively to loud and annoying sounds, the things that make the sounds, and the situations in which such sounds may occur.

What we previously believed was an auditory or hearing-based problem can instead be understood as a problem of negative emotional reactivity and programming of negative memories to specific sounds and the situations in which the sounds occur.

TREATMENTS FOR AUDITORY HYPERSENSITIVITIES

Two types of treatments have been tried to help children with auditory hypersensitivity. The first group of treatments focuses on the problem as an emotional-behavioral problem based on learned behaviors, which we suggest is due to conditioning via the non-classical auditory pathways. This set of treatments focuses on what is called a *desensitization* approach.

The second group of treatments focuses on *listening* without formal desensitization training. In the past, this second treatment approach was thought to work by changing the auditory system. More recent interpretations suggest that it, too, works through the non-classical auditory pathways, using specially modified sound to reprogram limbic system reactions and thereby reteach the brain.

DESENSITIZATION TRAINING

The basis of desensitization training, as the name suggests, is to desensitize the emotional and non-classical auditory systems so that they no longer react negatively to loud and annoying sounds, the things that make the sounds, and the situations in which such sounds may occur. A better term for desensitization training might be *systematic desensitization* because the approach uses a systematic, organized method to get the child to stop reacting negatively to loud and annoying sounds. Descriptions of specific desensitization training programs for auditory hypersensitivity in children with ASD indicate that a program of systematic desensitization can succeed in helping children not to fear loud and annoying sounds.[22,23] Koegel and colleagues[22] also demonstrated that children were able to tolerate annoying sounds up to one year after completing desensitization training, and (according to parents) their tolerance generalized to other sounds previously described as frightening but not desensitized during training.

Systematic desensitization involves placing the child in a comfortable, stress-free situation and slowly and carefully introducing the sounds to which the child is hypersensitive. In this type of training, the sounds are usually presented at low levels, and the loudness of the sound is brought up to a normal level over time. The child is then presented with the sound for increasingly longer periods of time. Over the course of such training, the child is brought closer and closer to the sound and situation in which the sound is used, until, in the end, the child is able to engage in the situation in the presence of the previously frightening sound. The sound may still be annoying, but the child no longer loses control of his or her behavior and no longer presents with negative emotional reactions to the sounds.

Desensitization methods seem to be worth trying for many children who have auditory hypersensitivities. However, this approach requires that children be willing to listen to the initial presentations of the sound. This is where listening methods may be helpful. We recommend that listening methods be considered as the first level of intervention for all children identified with auditory hypersensitivities. Once listening and loud sounds are no longer frightening, desensitization training can be tried, if necessary.

LISTENING METHODS

This type of training involves a more passive method to desensitize the limbic system and reprogram the emotional memory system, with the aim of making sounds something one desires to listen to rather than avoid. The listening method described here uses specially chosen sounds and music, typically classical music. The sounds or music are acoustically modified to lead the child to react less negatively to sounds and, thus, reduce the child's hypersensitivity. Although a number of listening methods have been developed, we focus on one specific method called The Listening Program® (TLP). A trained provider, usually a professional such as an occupational therapist or speech-language pathologist, conducts the TLP training. The provider typically establishes the actual program and protocol based on the individual child's needs and carries out the training in the home or at school.

When listening using TLP, it is thought that the sound signal travels along both the classical and non-classical auditory pathways. Likely confirming this assumption, one of the first outcomes that parents, educators, and professionals often see in children undergoing TLP training is that the children are calmer. This is a good indicator that the listening has tapped into the emotional areas of the limbic system via the non-classical auditory pathways. Over the course of training, children often are also reported to be more attentive to sounds, better able to detect sounds they hear, and more communicative when communication is verbal, likely because they are more open to listening. As the training proceeds, the child continues to relax and become calmer when listening. We hypothesize that this is because a reprogramming of emotional memory in the amygdala is occurring. The training reprograms listening and sounds as positive experiences. When the child then finds himself or herself in a real-world situation and hears sounds that may have been frightening or annoying in the past, the training allows the child to process the sounds in more neutral manner.

For many children, the use of a program such as TLP is sufficient to reprogram their systems so that sound is no longer frightening. This does not mean that loud and annoying sounds may not still be irritating. The child may still react verbally saying that he or she does not like such sounds or the situations in which the sounds occur. After TLP training, however, the child will not lose control of his or her behavior. In addition, the child may be more willing to listen to parents or teachers, who can model desensitization by saying, "Well, the sound is annoying, so let's move over here," or "If we walk more quickly toward (our goal), we can get away from having to hear that sound." These two statements model appropriate behaviors that one can use when in an annoying listening situation.

CONCLUSION

As we have shown, what we previously believed was an auditory or hearing-based problem can instead be understood as a problem of negative emotional reactivity and programming of negative memories to specific sounds and the situations in which the sounds occur. This negative programming occurs via the non-classical auditory pathways, which may remain more active in some children, especially those on the autism spectrum. Once we better understand what auditory hypersensitivity is, we can look at what can be done to retrain the non-classical auditory system so that children will no longer be hypersensitive to sounds. We can differentiate children who have an overly active non-classical auditory system from those who have learned to suppress the non-classical auditory pathways. Furthermore, there are treatments to help reprogram the emotional and non-classical auditory systems so that a child can become more able to tolerate previously frightening sounds. After treatment, the sounds merely become annoying to the same degree that they might annoy many people without auditory hypersensitivities. Of the two therapy approaches discussed, we recommend that listening training be used as the initial approach. This can allow the child to be more successful with subsequent desensitization training. Desensitization may then become something that the child routinely practices in everyday situations rather than a special therapeutic approach.

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