Spring 2024

Considering Extended High-Frequency Audiometry as a Screening Tool for Auditory Processing Disorder

Maylee Martin
mm581@uakron.edu

The University of Akron

School of Speech-Language Pathology and Audiology

Considering Extended High-Frequency Audiometry as a Screening Tool for Auditory Processing Disorder

Maylee Martin

Williams Honors College, Honors Research Project

Sponsor: Erin L. Miller, Au.D.

Table of Contents

Abstract

The purpose of this research project is to describe Auditory Processing Disorder (APD) and its background and etiology, signs and symptoms, and treatment options. APD is an auditory disorder that affects the central nervous system. Individuals with auditory processing disorders are able to detect sounds at normal hearing levels and pass a standard hearing test, but struggle with higher order auditory skills such as auditory discrimination, binaural processing, including understanding in the presence of background noise, and temporal processing (ASHA, 2005). A full auditory processing test battery is time consuming, and many audiologists are not skilled in administering typical APD screening procedures, however, there is growing evidence that extended high-frequency audiometry can be an effective screening tool. Specifically, the report highlights this screening option for APD and determines whether extended high-frequency audiometry could be added to normal testing procedures for children in a clinical setting. To perform extended high-frequency audiometry, tones of high frequency between 8,000 and 20,000 Hz are presented to determine if they are detected by the patient. If the tones are not detected, or elevated, it may suggest the child needs to be evaluated for APD. The research project examines the possibility of implementing this comprehensive pure tone testing broadly in audiologic settings but recognize cost, accessibility of equipment and time may impact the viability of this screening option. APD being directly correlated with extended high-frequency audiometry testing could lead to greater accessibility for screenings, more appropriate referrals, and earlier diagnosis of APD in children.

Auditory Processing Disorder: An Overview

Auditory Processing Disorder (APD) is a disorder that affects the central auditory nervous system. It is challenging for individuals with APD to understand auditory information even though their peripheral hearing is normal. In individuals with normal hearing and processing ability, the auditory signal is transmitted from the cochlea to the auditory nerve and then to the primary auditory cortices where the information is interpreted (ASHA, 2024). Heschl's gyrus, also known as the transverse temporal gyrus, is the area of the brain that houses the primary auditory cortex in humans and is where auditory information is processed and comprehended. Specifically, Heschl's gyri are responsible for language comprehension, speech production, phonological retrieval, and semantic processing.

This perceptual processing of auditory information that occurs in Heschl's gyrus, as well as other biologic activity that happens within the auditory cortices, is what underlies auditory processing and is how the disorder has been defined by organizations representing the professionals that manage the disorder (AAA, 2010). Simply put, for individuals with APD, something prevents the brain from processing or interpreting the signals received. When this occurs, the brain misinterprets the signal, and the individual has difficulty understanding what was said.

Signs and Symptoms

The characteristics of this complex disorder can include struggling with sound discrimination, verbal instructions, and processing sounds, especially those that are accompanied by background noise (ASHA, 2024). Sound discrimination is when the brain is trying to distinguish multiple sounds at once and determining which sounds to focus on and which sounds to block out. Verbal instructions and sound processing challenges are due to the miscommunicated signal received at the level of the brain. Additionally, people with APD might have a shorter attention span as well as associated reading, learning, and/or spelling problems (ASHA, 2024). All these components can affect a child's performance in the classroom, home life, and social environments.

In children, APD can present as a learning disorder, attention, or behavioral disorder. Because of the inability to focus on specific sounds, follow directions, or hear sounds in the presence of background noise, these two disorders are similar and challenging to differentiate. The comorbidity of APD and Attention Deficit Disorder/Attention Deficit Hyperactivity Disorder (ADD/ADHD) in the pediatric population has been suggested to be between 50-80% of those diagnosed with ADD/ADHD (Rawool, 2015). These behavioral complaints can lead to misdiagnosis and inadequate treatment, as APD and ADD are treated very differently.

Etiology and Current Treatment Options

The etiology of APD remains under debate, but potential causes of APD include age-related changes to the central auditory nervous system, genetics, and otologic disorders, including chronic history of middle ear infections, injury, prenatal or neonatal factors, or neurological disorders. Prenatal factors may include low birth weight, prematurity, or drug exposure during pregnancy. Specific neurological disorders that could cause APD include brain injury (i.e. head trauma, meningitis), cerebrovascular disorder (i.e. stroke), degenerative diseases (i.e. multiple sclerosis), exposure to neurotoxins (i.e. heavy metals, organic solvents), lesions of the central nervous systems, or seizure disorders (ASHA, 2024). Treatment options for APD focus primarily on improving the signal-to-noise ratio (SNR) to support communication in different environmental situations. Counseling on effective communication strategies is also promoted with patients who have APD. Some of these strategies include facing the person while talking, sitting in the front of the classroom, moving to quiet spaces for one-on-one communication, supplementing sound with text, low-gain amplification, aural rehabilitation, and more (Cancel et. al., 2023).

Screening for APD

APD screening involves both speech and non-speech tasks that ultimately assess potential areas of deficit within the central auditory nervous system. The patient's case history, their perception of listening difficulties, as well as results from their language and cognitive assessments, help support the need for a complete evaluation. The goal of screening is to be more proactive in detecting APD and seeking treatment options and compensatory strategies sooner. Two types of tasks are typically used for APD screening: binaural integration tasks and speech-in-noise tests. Binaural tests include testing a patient's dichotic listening, lateralization, and sound localization in different simulated situations. Testing speech-in-noise involves examining the effects of adverse listening conditions on speech recognition and recall.

A study performed by Cancel et. al. (2023) at the University of Pittsburgh Medical Center (UPMC) determined which APD screenings would provide the most useful information needed to refer for further APD assessment. The test battery consisted of three domains with two tests per domain. The tests in the study included the Random Dichotic Digits Test (RDDT), Dichotic Words, QuickSIN, Words-in-Noise (WIN) Test, Gaps In Noise, and Frequency Patterns tests. After testing, the Hearing Handicap Inventory for Adults (HHIA-S) was administered where patients responded to a subjective questionnaire about their perceived hearing difficulties. A diagnosis of APD was made if a patient scored outside the normal limits on any two tests within any domain of this screening. This protocol aligned with the American Speech-Language Hearing Association (ASHA) and American Academy of Audiology (AAA) practice guidelines. If the individual scored outside the normal limits on two tests in different domains, they would be flagged for auditory concerns, but a diagnosis of APD could not be made until a full evaluation was performed (Cancel et. al., 2023).

According to the Cancel et. al. (2023) UPMC study, "Of the 47 patients who underwent assessment for APD, 24 scored two standard deviations outside normal limits on two tests within a single testing domain, resulting in an APD diagnosis. This was equivalent to a positive test rate of 51%".

From this study, Cancel and colleagues (2023) determined that the WIN, RDDT, and QuickSIN screenings identified most patients with APD. For the WIN test, the patient is presented with lists of five words masked by varying degrees of multi-talker babble that have an increasingly more difficult Signal-to-Noise Ratio (SNR). Scores are based on the number of words that were repeated correctly. A score of 4 dB or lower is considered to be within normal limits. The RDDT test presented either one, two, or three pairs of numbers in both ears. The patient is then asked to repeat the digits they heard in a free recall format (in any order) and the number of correctly recalled digits were scored per ear. Being able to recall more than 90% of the numbers was considered a normal score. For QuickSIN, there are six sentences spoken by a female voice in the presence of four-talker babble at signal-to-noise ratio levels of +25, +20, +15, +10, +5, and 0 dB. Each sentence has five keywords, and patients are asked to repeat the sentence to the best of their ability. One point is given for each correctly recalled keyword. Adults with normal hearing needed an average +2 dB S/N ratio level to repeat words with 50% accuracy (Cancel et. al., 2023).

The tests utilized in Cancel's study were considered to be useful screener tools to motivate referrals for more in-depth APD evaluation. Although there are no universally accepted procedures for APD screening, the study suggests that there are methods that could be used.

APD Assessment

Currently, clinical APD assessments are in-depth and may take between 60-120 minutes, while standard audiologic testing takes 15-30 minutes (Cancel et. al., 2023). For an APD assessment, candidates must also be at least 7 years old and have normal hearing and normal intelligence. Failed APD screenings, individuals with normal hearing who have a history of listening complaints, along with a referral from an audiologist will deem the individual eligible to be assessed (AAA, 2010). Evaluation for APD is much longer in duration and more in-depth than a screening, and only following an APD evaluation can the diagnosis of APD be made.

Audiometric Test Battery

Prior to completing an auditory processing evaluation, standard audiologic testing is necessary to ensure peripheral hearing is normal. The standard audiometric test battery includes case history, ear examination, otoscopy, tympanometry, pure tone air conduction, pure tone bone conduction, and speech testing including Speech Recognition Tests (SRT) and Word Recognition Scores

(WRS). Case history is completed before any audiometric tests to identify otologic conditions that could impact testing including prior surgeries, family history, or noise exposure. Audiologists perform a visual inspection of the pinna and ear canal before audiometric testing to view the anatomical structures and rule out any pathological concerns. Tympanometry tests are often completed to determine how well the patient's tympanic membrane moves in response to pressure changes (National Research Council (US) Committee on Disability Determination for Individuals with Hearing Impairments, 2005).

Pure-tone threshold audiometry measures an individual's hearing sensitivity using calibrated pure tones. Diagnostic standard pure-tone threshold audiometry is most often used in clinical settings and includes air-conduction measurements at frequencies of 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. Insert earphones or supra-aural headphones are used to measure air conduction thresholds and a bone oscillator is used to measure bone conduction thresholds. Bone conduction measurements are completed at the octave intervals from 250 Hz to 4000 Hz (ASHA, 2005).

The patient's SRT threshold is determined by their lowest threshold of ascending runs where they correctly repeated two spondee words. This test is done to check the reliability of their pure tone test results. The second speech test, the WRS, is a suprathreshold test. WRS consists of a list of monosyllabic words that are presented at a loud, but comfortable, intensity. This is typically at least 30 dB above the patient's SRT. There is no familiarization of words, and the purpose of this test is to measure the patient's ability to understand words at a comfortable listening level (National Research Council (US) Committee on Disability Determination for Individuals with Hearing Impairments, 2005).

Extended High-Frequency Audiometry

Extended High-Frequency Audiometry (EHFA) tests the frequencies above 8,000 Hz, commonly completed during the standard audiometric test battery. The frequencies tested range from 9,000 Hz to 20,000 Hz. Because healthy children and young adults can perceive pure tones up to 20,000 Hz, and frequencies above 8,000 Hz may reveal additional information that could impact hearing disorders, testing these frequencies would provide more information regarding the auditory system, and may lead to earlier diagnosis of hearing disorders, including APD (Hunter et. al., 2020). Therefore, it is predicted that the inability of children to detect EHFs could potentially be a clinical indicator of APD.

According to Lough, Plack (2022) and Škerková et. al. (2022) research that examined EHFA in clinical practices, EHF testing may have unreliable results due to calibration issues or misplaced earphone inserts. Special circum-aural headphones, as well as an adapted audiometer, are needed to generate the tones up to 20,000 Hz that are used for EHFA (Lough & Plack, 2022, Škerková et. al., 2022). Additionally, a tight seal over the ear is required to decrease the likelihood of the sound leaking out around the headphones which could compromise results. To ensure accurate and reliable thresholds, all of these criteria must be met. Obtaining hearing thresholds in healthy children and young adults in the extended high frequencies, up to and including 20,000 Hz, could reveal additional information about hearing disorders not able to be detected with standard audiometry.

Background Noise

People who have APD often present difficulties in differentiating sounds originating from the front compared to those from the back. They struggle with selectively hearing the important auditory information and blocking out the background noise. Because of the relationship between struggles with background noise and the loss of high-frequency sounds, this suggests that testing the EHFs could provide information about a person's ability to discriminate sounds, especially in difficult signal-to-noise ratio environments. If someone presents with hearing loss in the EHFs, they will likely have difficulty in complex listening situations which could be a sign of APD. Therefore, this strengthens the argument that testing in the EHFs could be considered as a possible screening tool for APD.

Speech Perception

Difficulties with speech perception affect a person's productivity, personal relationships, and overall well-being. The normal hearing thresholds recorded on the audiogram fail to adequately assess the processes that contribute to speech comprehension under challenging conditions. Specifically, with EHFA, additional information regarding speech perception can be assessed because the production of voiceless fricatives such as /s/ and /f/ have bursts of EHF energy spreading into the extended frequencies (Lough & Plack, 2022). Therefore, even though speech sounds typically range from 250 Hz to 8,000 Hz, EHFs from 8,000 Hz to 10,000 Hz provide some additional phonological information. Additionally, Walker (2023) in her recent review article illustrated the value of providing high-frequency information to children with hearing loss. For adult female and child talkers, the spectral peak for important speech phonemes, such as

/s/ extends to 9,000 Hz. If a child with hearing difficulties, such as APD, had an identified hearing loss above the standard audiometric thresholds, it could impact their ability to pick up important information that would allow them to detect these important phonemes and would impact their understanding of words and spoken language (Walker, 2023). However, other sources suggest that although some phonemic sounds spread into the EHFs, they ultimately have little to no role in being able to perceive speech. This is because most speech perception for reproducing intelligible speech occurs in frequencies below 7,000 Hz (Hunter et. al., 2020).

Possible Causes of EHF Hearing Loss

For young and healthy individuals, normal hearing sensitivity reaches frequencies of 20,000 Hz on average. Testing in the frequencies above 8,000 Hz is known as testing in the extended high-frequency (EHF) region. However, it is also evident that these EHF areas of the cochlea are sensitive to disease, drugs (including chemotherapeutic agents), aging, and noise exposure. Therefore, changes in these frequencies could be the beginnings of indicating further complications and could be useful for diagnosis (Lough & Plack, 2022). Mishra et. al. (2021) research on EHFA's relation to early aging, speech-in-noise perception, and cochlear function indicated that impairments in the EHFs were directly correlated with early auditory aging and even other clinical implications. This study strongly emphasized the importance of using EHFA in clinics for early identification, monitoring, and prevention of hearing impairment (Mishra et. al., 2021).

Adding APD Screening to the Audiometric Test Battery

Hearing in the EHFs is early to mature and early to decline, implying that it could be useful information in the early detection of hearing disorders in children (Mirshra et. al., 2022). Adding EHFA to the audiometric test battery in pediatric patients would provide additional information about the patient's hearing capabilities, based on their established thresholds. Children with thresholds in the EHFs greater than 20 dB are categorized as being outside of the normal range, therefore, this could indicate underlying hearing disorders that could include APD. Furthermore, adding EHFA to the audiometric test battery could be a screening measure for APD.

A screener of APD needs to be quick to administer during routine audiological visits, can be completed by professionals with minimal training and no expertise in APD, and should require minimal equipment (Cancel et. al., 2023). Because EHFA audiometry requires specialized equipment, it may be a drawback in attempting to implement it in the standard audiological test battery. However, most audiologic equipment being manufactured today allows for an EHFA option to be added to the equipment at a relatively low cost.

Accessibility and Relevance

A key component that impedes the direct implementation of EHFA is the lack of necessary equipment in many audiologic practices. Reasons for the lack of equipment may be because of financial constraints, as previously mentioned, or the unperceived need for the equipment (Lough & Plack, 2022). Thus, evaluating the evidence for establishing a new screening protocol for APD or considering alterations to the current standard test battery could allow EHFA to be a great resource in the clinical setting for detecting hearing disorders. Additionally, educating, researching, and providing hearing professionals with information may promote the benefits of EHFA, making the test more relevant and creating gateways for accessibility.

Lack of Guidelines

Although EHFA has great potential to be used as a screening measure for APD, another limitation to implementing it includes the lack of clinical guidelines and standards supporting its use. Since this testing is still being newly introduced to audiologists, additional evidence and data will be needed to change standard practice. The lack of gold-standard APD referral guidelines makes diagnosis and treatment plans challenging (Cancel et. al., 2023) and there is a need for increased education surrounding clinical indicators of APD. With more education and information, audiologists would be better able to identify through patient history, self-assessments, standard audiometric testing, and subjective questionnaires patients who should be screened for APD using EHFA.

Cost and Insurance Coverage

To implement EHFA into clinical practices, the cost of the technology must be considered. To administer EHFA, the components include the high-frequency headphones, an audiometer that is capable of producing extended-high frequencies, an installation fee (software must be installed into existing audiometer), shipping, and other miscellaneous costs. According to a quote received from an audiologic equipment vendor (email communication with E3 Diagnostics vendor), the expense to add EHF audiometry, including the appropriate headphone transducers, would be approximately $1,725, excluding taxes. Dedicating budgets towards EHFA technology may be challenging for some clinical settings, considering this test would have limited application.

Investing in EHFA testing could be viewed as less necessary compared to funding other technology or supplies.

Finally, insurance companies require that evidence exists to support the use of diagnostic tests to identify a health disorder. The lack of strong evidence, standards for EHFA, and professional guidelines documents suggests this would not be a covered benefit and would require patients to pay for this testing out of pocket. This is consistent with other emerging technology or services in healthcare and may not impede individuals with the potential disorder from seeking services.

Outcomes

Good hearing across all frequencies builds a stable foundation for language learning skills. Being able to detect the EHFs could rule out auditory disorders not otherwise detected with standard audiometry, including APD. Speech sound energy from 3,000 Hz to 10,000 Hz includes the phonemes /ʧ, f, dʒ, s, ʃ, ð, v, and ʒ/, therefore, substantial spectral energy is present in frequencies higher than 8,000 Hz for linguistically important speech sounds. Losing or having deficits in these frequencies would negatively affect language acquisition for young children (Hunter et. al., 2020). A key factor of implementing EHFA testing is the notion of early intervention. Noticing these patterns and advocating for early intervention provides children with the opportunity to have auditory processing disorders identified and diagnosed, resulting in a better prognosis for the patient. EHFA is a useful test in detecting hearing loss in frequencies that could impact the understanding of speech and that may highly impact hearing capabilities (Škerková et. al., 2022). It is essential to identify these types of disorders during early childhood because it will set the child up for success with language acquisition and cognitive development as they progress through school and can determine if the child needs additional support. With children who have APD, this could include compensatory strategies at home or in the classroom, environmental modifications, direct therapy, or other services. Delayed diagnosis and intervention could result in the development of language delays, issues with pragmatic skills, social and emotional delays, behavioral issues, and poor academic success.

Conclusion

The goal of implementing EHFA is to promote earlier diagnosis of children with APD by utilizing a screening tool that can be easily implemented by audiologists in all clinical settings. Efforts to improve access to EHFA require an analysis of systems and policies to implement change across clinical settings. Given the current evidence, EHFA could detect early signs of hearing disorders not otherwise detected with standard audiometry and may be a viable method for screening for APD.

References

American Academy of Audiology. (2010). *Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder*. American Academy of Audiology Clinical Practice Guidelines.

American Speech Language Hearing Association. (2005). Guidelines for Manual Pure-Tone Threshold Audiometry.

American Speech-Language-Hearing Association. (n.d.). *Central Auditory Processing Disorder*. American Speech-Language-Hearing Association. https://www.asha.org/practice-portal/clinical-topics/central-auditory-processing-disorder/#collapse_9

Cancel, V. E., McHaney, J. R., Milne, V., Palmer, C., & Parthasarathy, A. (2023, August 21). A data-driven approach to identify a rapid screener for auditory processing disorder testing referrals in adults. https://www.nature.com/articles/s41598-023-40645-0

Hunter, L. L., Monson, B. B., Moore, D. R., Dhar, S., Wright, B. A., Munro, K. J., Zadeh, L. M., Blankenship, C. M., Stiepan, S. M., & Siegel, J. H. (2020, November 17). Extended high frequency hearing and speech perception implications in adults and children.

Lough, M., & Plack, C. J. (2022, March 22). *Extended high-frequency audiometry in research and clinical practice*. The Journal of the Acoustical Society of America. https://doi.org/10.1121/10.0009766

Mirshra, S. (2022). 20Q: Extended High Frequency Hearing Loss - Translating Science into Clinical Practice. https://www.audiologyonline.com/articles/20q-extended-high-frequency-hearing-loss-28181

Mishra, S., Saxena, U., & Rodrigo, H. (2021). *Extended High-Frequency Hearing Impairment Despite a Normal Audiogram: Relation to Early Aging, Speech-in-noise Perception, Cochlear Function, and Routine Earphone Use*. Ear & Hearing .

Mishra, S., Saxena, U., & Rodrigo, H. (2022). *Hearing Impairment in the Extended High Frequencies in Children Despite Clinically Normal Hearing*. Ear & Hearing.

National Research Council (US) Committee on Disability Determination for Individuals with Hearing Impairments. (2005, January 1). *Assessment of the Auditory System and Its Functions*. Hearing Loss: Determining Eligibility for Social Security Benefits. https://www.ncbi.nlm.nih.gov/books/NBK207835/#:~:text=The%20basic%20audiometric%20test%20battery,noise%2C%20and%20acoustic%20immittance%20measures.

Rawool, V. (2015). Attention Deficit Hyperactivity and Auditory Processing Deficits . In *Auditory Processing Deficits: Assessment and Intervention* (1st ed.). essay.

Walker, E. A. (2023, January 3). The Importance of High-Frequency Bandwidth on Speech and Language Development in Children: A Review of Patricia Stelmachowicz's Contributions to Pediatric Audiology.

Škerková, M., Kovalová, M., Rychlý, T., Šlachtová, H., & Tomášková1, H. (2022, June 28). *Extended high-frequency audiometry: Hearing thresholds in adults*. SpringerLink. https://link.springer.com/article/10.1007/s00405-022-07498-1