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Noise-Induced Hearing Loss in Pediatric Patients

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ABSTRACT

The purpose of this study is to examine the hearing tests that are done in the schools in the Philadelphia School District; it will examine the frequencies that are tested, the follow-up procedures for a poor performance in the exam, what barriers exist to follow-up, and educational methods used to prevent excessive noise-level. A previous literature review found that excessive noise was a major cause of hearing loss among school-aged children, and hearing impairment is increasing as a result of voluntary exposure to loud noise (Henderson, Testa, & Hartnick, 2011). Karper (2014) found that teenagers are not being tested at the right frequencies, and Abbasi (2014) found that the screening questions available do not identify which teenagers are at risk for hearing loss. A literature search was done using PubMed using keywords, such as "noise-induced hearing loss in pediatrics."

According to the Pennsylvania School Health Guidelines (2016), a student whose pure-tone threshold hearing test shows a level that is 30 dB or more for two or more tones in either one or both ears, or 35 dB or more for one tone in either ear, will be referred to the family's provider. If a student fails the hearing screen, a complete ear exam is recommended, and it is the family's responsibility to schedule this exam and follow up with the family's provider. This study looks into methods that will ensure proper testing and follow-up with the provider in the West Philadelphia area of the Philadelphia School District.

The expectation is that this study will evaluate the process of hearing screenings in schools in The City of Philadelphia, determine appropriate and effective methods of preventing noise-induced hearing loss, and find a way to ensure that all children get the follow-up care that they need. Collaboration between school officials, ENTs, pediatricians, and public health officials is necessary to properly address this problem.

BACKGROUND

Anatomy of the Ear

In order to understand how hearing tests are performed, it is important to understand how the ear works. There are three components to ear: the external ear, the middle ear, and the internal ear. The external ear can be examined using an otoscope, and includes the acoustic meatus and the tympanic membrane. The middle ear is the air-filled space in the temporal bone. It is located between the tympanic membrane laterally and the lateral wall of the internal ear medially. The middle ear includes the tympanic cavity and the epitympanic recess. The middle ear functions to transmit vibrations of the tympanic membrane across the cavity of the middle ear to the internal ear; it does so via three interconnected bones, the malleus, incus, and stapes. In the middle ear, the tensor tympani and stapedius contract in response to loud noises to reduce the force of vibrations and to prevent excessive oscillation, respectively. The internal ear consists of the bony labyrinth and the membranous labyrinth. The bony labyrinth contains the vestibule, semicircular canals, and the cochlea. The cochlea is involved in the process of hearing. The membranous labyrinth contains the semicircular ducts, the utricle, and the saccule, which are the organs of balance, as well as the cochlear duct, which is the organ of hearing (Drake, Vogl, & Mitchell, 2014)

The transmission of sound involves many steps, and includes all parts of the ear. Sound waves enter the external acoustic meatus and strike the tympanic membrane, moving it medially. Medial movement of the tympanic membrane causes movement of the malleus, incus, and stapes. Movement of the stapes moves the oval window medially. This completes the transfer of a large-amplitude, low-force, airborne wave that vibrates the tympanic membrane into a small-amplitude, high-force vibration of the oval window. This generates a wave in the fluid-filled scala vestibuli of the cochlea. This wave moves through the cochlea, causing an outward bulging of the secondary tympanic membrane that covers the round window at the lower end of the scala tympani. This causes the basilar membrane to vibrate, leading to stimulation of the receptor cells in the spiral organ. The receptor cells send impulses to the brain through the cochlear part of the vestibulocochlear nerve; this is where they are interpreted as sound. If the sounds are too loud and causes excessive movement of the tympanic membrane, the tensor tympanic muscle and/or the stapedius muscle contract to dampen the vibrations of the ossicles and decrease the force of the vibrations reaching the oval window.

Noise-Induced Hearing Loss

The traditional low pure-tone average for speech-affected frequencies calculated by averaging threshold in each ear at 0.5, 1, and 2 kHz and high pure-tone average by averaging the thresholds at 3, 4 and 6 kHz (Henderson, Testa, & Hartnick, 2011). Noise induced threshold shifts are defined by a distinct audiometric pattern. Initially, 3, 4 and 6 kHz are affected, but other frequencies become involved later. The criteria that describes the noise notch audiometric pattern include: (1) thresholds at 0.5 and 1 kHz of greater than or equal to 15 dB, (2) maximal threshold at 3, 4, or 6 kHz greater than or equal to 15 dB higher than the highest threshold for 0.5 and 1 kHz, and (3) threshold at 8 kHz greater than or equal to 10 dB lower than the maximal threshold for 3, 4, or 6 kHz (Henderson, Testa, & Hartnick, 2011).

Noise-induced hidden hearing loss refers to any functional impairment in subjects with noise exposing history but not permanent threshold shift (Shi, Chang, Li, Aiken, Liu, & Wang, 2016). Physiologically, the variations in auditory sensitivity after noise exposure are largely a result of the functional status of the outer hair cells in the cochlea. The outer hair cells provide the mechanical amplification of soft sounds. The synapse between the inner hair cells and the primary spiral ganglion neurons can also be damaged by noise. The disruption of these synapses can be permanent, which can result in degenerative death of spiral ganglion neurons (Shi et al., 2016). A permanent shift in hearing threshold does not always accompany this damage; therefore, it is likely to be missed in standard hearing assessments. This is why it is referred to as "noise induced hidden hearing loss." Noise induced hidden hearing loss manifests first as a reduced output of the auditory nerve at high sound levels, but it does not affect the hearing threshold.

Henderson, Testa, & Hartnick (2011) looked into the exposure to loud noise and music and the effect this has on noise induced threshold shifts in adolescents. It was found that the overall prevalence of exposure to loud noise or listening to music through headphones in the past 24 hours increased from 19.8% in 1988-1994 to 34.8% in 2005-2006. However, this increase was not associated with the prevalence of noise induced threshold shifts. There is a possibility that hearing damage from childhood noise exposure may not fully manifest by 19 years old. This delay may be due to the redundancy of the hair cells in the cochlea (Henderson, Testa, & Hartnick, 2011). Su and Chan (2017) found that, looking at the same surveys, the use of hearing protection declined. Hearing protection includes, but is not limited to, earplugs, semi-insert ear plus, and ear muffs (Canadian Centre for Occupational Health and Safety).

It is recommended that those using a standard personal music player and headphone combination should limit their listening to no more than 60% volume for 60 minutes or less for a CD player and 90 minutes or less at 80% volume for an MP3 player during any 24-hour period (Kenna, 2015). It is also recommended that sound-isolating ear phones be used in the presence of significant background noise. Most people are not aware of these recommendations and do not adhere to them, putting them at risk of damaging the inner ear structures. Hearing loss, even mild, can negatively impact both educational outcomes and social functioning (Su & Chan, 2017). Analysis of the National Health and Nutrition Examination Surveys (NHANES) III and 2005-2006 found that male sex, a history of 3 or more ear infections, and lower socioeconomic status are risk factors for hearing loss. NHANES 2009-2010 found that participants with the lowest poverty income ratio were more likely to have hearing loss than those participants with high poverty income ratio.

Objective

According to the 2010 Census, the population in West Philadelphia is 71.2% Black or African American, 17.4% white, 5.7% Asian, 3% Hispanic or Latino, and 2.2% mixed. Almost 75% of the population is of minority background, which is important as it was found that those of a minority backgrounds have a higher likelihood of hearing loss than non-Hispanic whites (Su & Chan, 2017). According to the 2019 US census, 24.3% of the population in Philadelphia is in poverty. Additionally, hearing loss can negatively impact children and adolescents. It is estimated that 30% of students with unilateral hearing loss and 37% of those with minimal sensorineural hearing loss will repeat a grade (Sekhar, Zalewski, Beiler, Czarnecki, Barr, King, Paul, 2016). Young students with mild hearing loss can also be misdiagnosed with attention deficit disorder, learning disabilities, and behavioral problems. The objective of this study was to analyze the methods of in-school hearing examinations and follow-up procedures. It is important to determine if the proper methods of testing are being utilized and what barriers may exist to follow-up. It is imperative to catch hearing loss early to prevent any adverse educational or social outcomes.

RESEARCH STRATEGIES

Literature Review

A literature review was done in order to determine the frequencies tested in schools and the accuracy of surveys given to patients and students. Additionally, current hearing tests policies in both Pennsylvania and Philadelphia specifically were evaluated, and were compared to the frequencies that are suggested for testing. The literature review will look for improvements that can be made to the hearing screen process. The researcher on several of the studies was contacted to consult on what methods would work in a lower income school district.

An IRB was prepared in order to send a questionnaire (Questionnaire 1) to Primary Care Physicians in the West Philadelphia Area. The questionnaire would be sent to the medical doctor and physicians at Children's Hospital of Philadelphia, Karabots location. The questionnaire included two questions: Do you get many referrals from school hearing screens, and what are the noise exposures in this area that you are the most worried about? This IRB has not yet been submitted however, a follow-up submission is planned for a later date and therefore, the questionnaire has not yet been sent out.

RESULTS AND DISCUSSION

Hearing Loss Prevalence and Long-Term Effects

According to the WHO, "Some 1.1 billion teenagers and young adults are at risk of hearing loss due to the unsafe use of personal audio devices, including smartphones, and exposure to damaging levels of sound at noisy entertainment venues such as nightclubs, bars and sporting," (Lobarinas, Spankovich, & Le Prell, 2016). This is not surprising, as the number of youths using these devices has increased in the last decade. A form of hidden hearing loss can occur, and has been shown in animal models. The hearing loss can occur without hair cell loss. These studies found that our standard method of care, which is based on audiometric thresholds, is not likely to capture the early markers of potential hearing loss (Lobarinas, Spankovich, & Le Prell, 2016). Current methods of testing were evaluated and improvements to these will be suggested.

Accuracy of Hearing Tests and Screenings

The American Academy of Pediatrics currently recommends that objective hearing assessments be done as a newborn, and at the 4, 5, 6, 8, and 10-year health maintenance visits. At all the other visits, a risk assessment (*Bright Futures*) should be performed. However, it was found that these screening questions are inadequate. *Bright Futures* (Table 1) is a set of theory-based strategies, principles, and tools intended to improve children's health maintenance. *Bright Futures* is used to determine adolescent with "risk factors" for hearing loss. An increased risk for hearing loss is indicated by a positive response to three or more screening questions (Sekhar, Zalewski, King, & Paul, 2014). However, these questions have not been validated as useful in adolescents. Therefore, the usefulness of these screening questions to determine which adolescents are at higher risk is unknown. Hearing screening questions that were significantly associated with referral on the high-frequency screen did not emerge as significantly associated with referral on gold-standard testing in a sound treated booth (Sekhar, et al., 2014). Therefore, the screening questions do not accurately predict which students would be referred following a regular hearing exam.

One problem that has been constantly noted is that noise-related hearing loss is not seen immediately after exposure. Noise-related high-frequency hearing loss may not be recognized until it affects the speech-related frequencies (Sekhar, et al., 2014). Hearing exams should test the levels that are initially impacted in order to find the hearing loss as early as possible. Even mild hearing loss increases the likelihood of repeating a grade ten-fold. The best way to prevent negative outcomes in adolescents with high-frequency hearing loss is to identify it early.

An additional study was done to compare the sensitivity of Pennsylvania's school pure-tone hearing screen with a pure tone threshold screening test (Sekhar, Zalewski, Ghossaini, King, Rhoades, Czarnecki, Grounds, Deese, Barr & Paul, 2014). The pure-tone threshold screening test included high-frequency tests points, which may detect adolescent hearing loss. The Pennsylvania screening tests frequencies 250, 500, 1000, 2000, and 4000 Hz; the high-frequency screen tests frequencies 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The study found that the current Pennsylvania hearing screens have low sensitivity for detection of adolescent hearing loss. Sensitivity refers to the percentage of true positives (Sekhar, et al., 2014). This means that the Pennsylvania hearing screen incorrectly labeled few students as positives for hearing loss. Adding the high-frequency test points to the current protocols, however, would most likely prove ineffective. Using threshold testing improved the sensitivity of the high-frequency screen, compared with the Pennsylvania screen. Additionally, screening at 20 dB of hearing level as opposed to 25 dB hearing level, along with the inclusion of 500 Hz in the screening protocol improved the sensitivity of adolescent hearing screenings (Sekhar, et al., 2014).

The high-frequency noise-induced hearing loss is often not noticed until it affects speech and communication. Progression of high-frequency noise-induced hearing loss is preventable, and the current test fails to identify the presence of it. The inclusion of new protocols will allow early detection of hearing loss in adolescents in exchange for a small additional time commitment. In order to avoid missing this morbidity, a new screening should have a high sensitivity (Sekhar, et al., 2014). The high-frequency used in the study fulfilled this criterion, with 100% sensitivity and 49% specificity. Specificity is the number of true negatives identified. Therefore, the screening incorrectly labeled more students as needing referral. Having a high number of false positives and a low number of true negatives will lead to more referrals. However, this is a small price to pay when compared with the positive impact that early detection could have on the adolescents' lives.

Hearing Test Policies in Pennsylvania

Each state, and subsequent school districts within the states, have different procedures for hearing screening exams. In Pennsylvania, the testing room should be selected based on its quietness: a tester should be able to hear frequencies 250, 500, 1000, 2000, 4000, and 8000 Hz at 20 dB in one ear with both headphones on (Pennsylvania School Health Guidelines, 2016). An audiometer should be used and calibration of the audiometer should be done annually. During the test, the tone should be held for about two to four seconds. In order to avoid the detection of a pattern to the tones, the tester should vary the intervals between and the lengths of the tones. In Pennsylvania, a Sweep Check Test Procedure should be performed, and a Pure-Tone Threshold

Hearing Testing Procedure may be done if required (Pennsylvania School Health Guidelines, 2016).

A Sweep Check Test, or Rapid Hearing Screening, is performed first. For this test, the frequency should be set to 1000 Hz and the decibels to 55 dB. The tone should be turned "on" briefly and then "off." After a response from the student, the decibels should be reduced to 40 dB; the tone should be tested once. Then, the decibels should be reduced to 25 dB, and this tone should be tested (Pennsylvania School Health Guidelines, 2016). For the rest of the test, set the decibels to 25 dB. The tester should change the frequency to 2000, 4000, then to 250 and 500 Hz, respectively, and test this tone. This should be repeated in the other ear as well. If a child does not hear two or more tones at 25 dB in one or both ears, he or she should be given a threshold test that day or within one month (Pennsylvania School Health Guidelines, 2016).

The Pure-Tone Threshold Hearing Testing Procedure will be done only if required based on the results of the Sweep Check Test. The frequency should be set to 1000 Hz and the decibels to 50 dB. The tone should be turned "on" briefly, then "off." If the student hears this tone, the decibels should be set at 40dB, and repeat this procedure, decreasing the decibels by 10 dB steps until the student no longer indicates that they hear the tone (Pennsylvania School Health Guidelines, 2016). Then, increase the decibels by 5 dB steps until the student does hear the tone again. Alternately, decrease and increase the tone in 5 dB steps for frequencies 1000, 2000, 4000, and 8000, then to 250, 500 Hz until the point or level below which they cannot hear is determined. Repeat this procedure in the other ear. If a student shows a hearing level of 30 dB or more for two or more tones in one or both eats, or 35 dB or more for one tone in either ear, shall be referred to the family's provider or usual source of care for a complete ear examination (Pennsylvania School Health Guidelines, 2016). A complete ear examination refers to otologic assessment and audiometric tests. It is the responsibility of the family to arrange this ear examination. The results of the screening should be recorded on the student's School Health Record and the Parent/Guardian Notification form.

School District of Philadelphia

The School District of Philadelphia follows the requirements of the Pennsylvania Public School Code. This requires that school nurses perform health screenings. These screenings include growth screening, vision screening, hearing screening, and scoliosis screening. The Hearing Screening is required specifically for Grades K, 1, 2, 3, 7, and 11 (*Mandated health screenings.* 2018).

Improvements

Preventive care services should include an objective hearing screen for all adolescents (Sekhar, et al., 2014). This could improve the screening process and better identify adolescents who are at higher risk of hearing loss. Pennsylvania school nurses are required to conduct threshold testing after the initial hearing screen referral; therefore, they should be familiar with the threshold testing procedure. Although the high-frequency screen is twice as long as the Pennsylvania hearing screen currently in place, time can be saved by removing the lower frequency test points for adolescent hearing screening (Sekhar, et al., 2014). Another option for schools is the portable testing centers that have been used in previous studies. Using the portable testing centers helps to control for outside noise during the hearing screening. This would make the hearing screening more accurate. However, the portable testing centers are expensive. In a low-income neighborhood, these expensive testing centers may not be available.

Additionally, there are audiometric technician certification programs that are available. School nurses and other school personnel could take these programs to improve the test quality and validity. It could also allow the school personnel to have a better understanding of the importance of the hearing screening. This will allow them to emphasize this to the students and the parents. Training more school personnel could also decrease the amount of time that nurses must devote to hearing screens in particular. The importance of the hearing screening should be emphasized to school personnel and to the students. It may be of use to give the students and parents information on the impact of hearing loss could have on academics.

Although there are ways to prevent noise-induced hearing loss, many of these options are too expensive for people of lower income. For example, the new AirPods are noise-cancelling; however, these cost $250. Over the ear noise-cancelling headphones of good quality usually cost over $50. For those of lower income, this is simply not a possibility. Additionally, a new analysis done by The Wirecutter found that half of 30 sets of children's headphones do not restrict volume to the promised limit (Saint Louis, 2016). Even more concerning, is that the worst headphones produced sound that was so loud that it could be hazardous to ears in a manner of minutes.

An editor at The Wirecutter was able to recommend a few headphones to parents that were would both limit volume and cancel outside noise (Saint Louis, 2016). Two Bluetooth models identified were JLab JBuddies Studio headphones and Puro BT2200. JLab JBuddies Studio headphones cost $29.99 and Puro BT2200 headphones cost $99.99. Of the headphones tested, only four of the thirty blocked sound similar to that in a car or on an airplane (Saint Louis, 2016). These include Eytmotic ETY Kids 3, Puro IEM200, Direct Sound YourTones, and Nabi . The prices of these vary: Eytmotic ETY Kids 3 headphones cost $49, Puro IEM200 headphones cost $29.99, Direct Sound YourTones headphones cost $119.95, and Nabi headphones cost $69.99 It is recommended that parents spend the money on the headphones that truly work.

RECOMMENDATIONS FOR FUTURE STUDIES

Future studies should look into the best quality noise-cancelling headphones that could be used and ways to make these more affordable. Additionally, creating an informative program that parents and students could attend during the school year. The program could include information on what the results of hearing screens actually means, the importance of these hearing screens, and how hearing loss can impact the student's performance and future. Often, with high frequency hearing loss, children do not notice that their hearing is impacted. As a result, they will continue to have exposure to the noise that is problematic until it impacts their speech and academics. Additionally, children of this age may not desire to wear a hearing aid. A program such as this one may be able to show students and parents how important it is to follow up and to protect themselves from excessive noise exposure.

Additionally, further follow-up should be done with the Pennsylvania Department of Health, as well as with school nurses. The Department of Health is aware of the importance of adding higher frequencies to the hearing screenings, but updates have been made to the guidelines yet. The American Academy of Pediatrics has updated their hearing screening recommendations. Providing additional information to the Department of Health may be able to push the changes to be made. This is especially important due to the impact that hearing loss may have on the education of students in Pennsylvania.

Finally, the questionnaire prepared for this study could be sent out with the approval of the IRB. The results of this questionnaire are expected to give a deeper understanding of the problem specific to West Philadelphia. For example, after speaking with a physician practicing in a rural area, they found that gunshots are a concern. The children in rural areas were going on hunting expeditions with families. Following the review of the risks for West Philadelphia children, it would be expected that more protocols and suggestions can be put into place that are specific to children in West Philadelphia.

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APPENDIX

Questionnaire 1

CHOP Karabots

4835 Market Street

Philadelphia, PA

19139

Attn: Medical Director and Physicians,

My name is Kimberly Townsend and I am a Master of Biomedical Sciences student at Philadelphia College of Osteopathic Medicine. For my capstone project I am examining noise-induced hearing loss in children and adolescents. I am looking at the West Philadelphia area specifically for two pieces of information.

1. Do you get many referrals from school hearing screens?
2. What are the noise exposures in this area that you are the most worried about?

Please let me know if you have this information.

Thank you,

Kimberly Townsend

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Table 1. Summary of Survery Components (Sekhar, et al., 2014)

Bright Futures hearing screening questions

1. Do you have a problem hearing over the phone?
2. Do you have trouble following the conversation when two or more people are talking at the same time?
3. Do people complain that you tur the TV volume up too high?
4. Do you have to strain to understand conversation?
5. Do you have trouble hearing in a noisy background?
6. Do you find yourself asking people to repeat themselves?
7. Do many people you talk to see to mumble (or not speak clearly)?
8. Do you misunderstand what others are saying and response inappropriately?
9. Do you have trouble understanding the speech of women and children?
10. Do people get annoyed because you misunderstand what they say?

Additional adolescent-specific questions

1. Can you hear if someone in the chair next to you whispers something to you during class?
2. If you sit at the back of the classroom, are you able to hear your teacher well?
3. Are you able to hear your own conversation in a noisy room?

Type and frequency [daily (>3 hours, 1-3 hours, <1 hour), not daily, never] of noise exposures

1. Digital audio player
2. Cell phone
3. Hands-free ear piece
4. Musical instrument
5. Concerts
6. Lawn mower/lawn tractor
7. Shop equipment
8. Hunting/gunfire
9. Motorcycle/motorbike/ATV

Digital audio player use

Questions focus on how teens listen (ear buds, headphones, stero connection/dockings ystem, plugged into car), where they listen (studying, driving, relaxing/sleeping, etc.) and volume at which they listen

History of hearing loss/use of hearing protection

Demographics (sex, race/ethnicity, age)