American Academy of Audiology
Childhood Hearing Screening Guidelines

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The charge of the Subcommittee on Childhood Hearing Screening was to develop evidence-based recommendations for screening hearing of children age 6 months through high school.

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EXECUTIVE SUMMARY

The American Academy of Audiology endorses detection of hearing loss in early childhood and school-aged populations using evidence-based hearing screening methods. Hearing loss is the most common developmental disorder identifiable at birth and its prevalence increases throughout school-age due to the additions of late-onset, late identified and acquired hearing loss. Under identification and lack of appropriate management of hearing loss in children has broad economic effects as well as a potential impact on individual child educational, cognitive and social development. The goal of early detection of new hearing loss is to maximize perception of speech and the resulting attainment of linguistic-based skills. Identification of new or emerging hearing loss in one or both ears followed by appropriate referral for diagnosis and treatment are first steps to minimizing these effects. Informing educational staff, monitoring chronic or fluctuating hearing loss, and providing education toward the prevention of hearing loss are important steps that are needed to follow mass screening if the impact of hearing loss is to be minimized.

Summary of Hearing Screening Recommendations*

*Refer to the full Guidelines document for more detail on these recommendations. Note that the following guidelines are considered to be the minimum standard for educational settings. Programs are encouraged to follow a more intensive rescreening and referral protocol where staffing patterns permit.**

Pure tone screening

1. Perform biological check on pure tone screening equipment prior to daily screening.
2. Screen populations age 3 (chronologically and developmentally) and older using pure tone screening.
3. Perform a pure tone sweep at 1000, 2000, and 4000 Hz at 20 dB HL.
4. Present a tone more than once but no more than 4 times if a child fails to respond.
5. Only screen in an acoustically appropriate screening environment.
6. Lack of response at any frequency in either ear constitutes a failure.
7. Rescreen immediately.
8. Use tympanometry in conjunction with pure tone screening in young child populations (i.e., preschool, kindergarten, grade 1).
9. Screen for high frequency hearing loss where efforts to provide education on hearing loss prevention exist.
10. Minimum grades to be screened: preschool, kindergarten, and grades 1, 3, 5 and either 7 or 9.

Tympanometry screening

1. Calibrate tympanometry equipment daily.
2. Tympanometry should be used as a second-stage screening method following failure of pure tone or otoacoustic emissions screening.
3. Use defined tympanometry screening and referral criteria: a 250 daPa tympanometric width is the recommended criterion. If it is not possible to use tympanometric width then 0.2 mmhos static compliance can be used as the criterion. A final choice for failure criterion is negative pressure of >-200 daPa to -400 daPa however it is not appropriate for this criterion to stand alone to elicit a referral.
4. Young child populations should be targeted for tympanometry screening.
5. Use results of pure tone or OAE and tympanometry rescreening to inform next steps.

Rescreening

1. Rescreen with tympanometry after a defined period: after failing the immediate pure tone rescreening and in 8-10 weeks for children failing pure tone or OAE screening and tympanometry.
2. Do not wait to perform a second stage screening on children who fail pure tone screening only.

OAE

1. Use only for preschool and school age children for whom pure tone screening is **not** developmentally appropriate (ability levels < 3 years).
2. Calibrate OAE equipment daily.
3. Maintain primary DPOAE levels at 65/55 dB SPL.
4. Select DPOAE or TEOAE cut-off values carefully.
5. Default settings may not be appropriate.
6. Screening programs using OAE technology must involve an experienced audiologist.
7. Children failing OAE should be screened with tympanometry.

Acoustic reflex testing, reflectometry and hearing screening using speech materials are not recommended.

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INTRODUCTION

Background and Philosophy

Hearing loss is the most prevalent developmental abnormality present at birth (White, 1997). Identification of hearing loss by 6 months of age in combination with quality early intervention services is associated with language development at or near the typical rate of development (Yoshinaga-Itano, 1995; Yoshinaga-Itano, 1998; Yoshinaga-Itano, et al. 2000; Yoshinaga-Itano, et al. 2004). Age-appropriate language development and literacy outcomes require early and ongoing attention to skill development, and for the effects of hearing loss on skill development and socialization to be prevented, it first is necessary for childhood hearing loss to be identified. This document provides a review of the current "state of the art" in pediatric hearing screening and recommends evidenced-based protocols for the identification of hearing loss in the preschool and school-aged population.

Need for hearing screening guidelines

The presumption that hearing loss can be reliably identified based on a child's behavior in everyday situations has been shown to be faulty by several studies documenting outcomes from the use of parent questionnaires (Olusanya, 2001; Gomes and Lichtig 2005; Lo et al. 2006). The Joint Committee on Infant Hearing (2007) identified ten risk factors for delayed onset or progressive hearing loss in children. Evidence suggests that for 9-year-olds with educationally significant hearing loss, up to 50% will have passed newborn hearing screening (Fortnum et al. 2001). Finally, it is estimated that 9-10 per 1000 children will have identifiable permanent hearing loss in one or both ears by school-age (Sharagorodsky, Curhan, Curhan and Eavey, 2010; White, 2010).

The American Academy of Pediatrics (AAP) endorses hearing screening throughout infancy, early childhood, middle childhood and adolescence in its *Recommendations for Preventive Pediatric Health Care* (American Academy of Pediatrics 2007). All newborns are to be screened in accordance with the Joint Committee on Infant Hearing (JCIH) Year 2007 Position Statement with additional hearing screening to be performed during routine well child visits at ages 4, 5, 6, 8, and 10. Well-child care plays an important role in the provision of quality health care for children; however, many children have far fewer well-child visits than are recommended by the AAP (Selden 2006). Even when a child is seen for a well-child visit, pediatricians typically neither recheck hearing nor refer more than half of the ten percent of children who fail their hearing screening (Halloran et al. 2006).

It is the position of the American Academy of Audiology (AAA) that children with undetected hearing loss and/or persistent or recurrent middle ear disease be identified so that appropriate audiologic and medical management can be provided (AAA, 1997). The American Speech-Language-

Hearing Association (ASHA) *Guidelines for Audiologic Screening* endorses the identification of school children at risk for hearing impairment that may adversely affect education, health, development or communication as an expected outcome for hearing screening programs (ASHA, 1997).

Finally, the criteria for appraising the viability, necessity, effectiveness and appropriateness of screening programs are based on ten principles from the World Health Organization that serve as the basis for recommending or planning screening for early detection of significant health conditions. (Wilson & Jungner, 1968) (See Table 1). Hearing loss and its potential consequences unquestionably meet these criteria to qualify as a health condition that merits screening.

Table 1. Ten principles for appraising the appropriateness of screening programs

1.	The condition sought should be an important health problem.
2.	There should be an accepted treatment for patients with recognized disease.
3.	Facilities for diagnosis and treatment should be available.
4.	There should be a recognizable latent or early symptomatic stage.
5.	There should be a suitable test or examination.
6.	The test should be acceptable to the population.
7.	The natural history of the condition, including development from latent to declared disease, should be adequately understood.
8.	There should be an agreed policy on whom to treat as patients.
9.	The cost of case-finding (including diagnosis and treatment of patients diagnosed) should be economically balanced in relation to possible expenditure on medical care as a whole.
10.	Case findings should be a continuing process and not a "once and for all" project.

Table 1: World Health Organization Screening Principles (developed by Wilson & Jungner, 1968)

Prevalence of Hearing Loss in Children

The prevalence of congenital hearing loss in newborns has long been thought to range from 1 to over 3 infants per 1,000, or approximately 13,000 babies born in the United States each year with some degree of permanent hearing loss (Finitzo et al. 1998; Van Naarden et al. 1999).). Most recent information indicates that the current prevalence is 1.4 per 1,000 (US Centers for Disease Control and Prevention 2009). Early Hearing Detection and Intervention (EHDI) programs have become the standard of care in this country, and screening for hearing loss now occurs for more than 95% of infants born in the United States. Diagnostic findings for 43.3% of infants identified by hearing screening were reported as unknown due to lack of documentation at a state level, and more than one quarter (28.1%) of infants who were identified as having confirmed hearing loss could not be documented as receiving intervention services (US Centers for Disease Control and Prevention 2008). Not all cases of hearing loss

in early childhood are identified through EHDI programs due to the following factors: 1) universal newborn hearing screening (UNHS) programs utilize screening devices primarily designed to target hearing loss averaging 30 to 40 dB or more; 2) all infants not passing their newborn hearing screening do not receive needed diagnostic services; and 3) UNHS does not identify late onset, acquired, or many cases of progressive loss (Joint Committee on Infant Hearing, 2007).

Grote (2000) reported that neonatal hearing screening programs would not detect the 10 to 20 percent of cases of permanent childhood hearing loss that start later in life. Prevalence comparisons suggest a significantly higher prevalence of hearing loss in the school age population relative to the prevalence identified in the newborn period. Prevalence studies in the United Kingdom indicated that for every 10 children with permanent bilateral hearing impairment of greater than 40 dB HL detected by universal newborn hearing screening, another 5 to 9 children would manifest such a hearing impairment by the age of 9 years (Fortnum et al. 2001). Analysis of school hearing screening results from almost 100,000 students revealed that 2.9% required management such as advice to parents, referral to education services, watchful waiting, medical and surgical treatment, and amplification, and of the children screened, 2.2% were newly identified as hearing impaired (Fonseca et al. 2005).

The United States Centers for Disease Control and Prevention (CDC) has had the legislative authority to conduct the National Health and Nutrition Examination Survey since 1970 to provide current statistical data on the amount, distribution, and effects of illness and disability in the United States (CDC 2010). Three surveys have been conducted: NHANES I from 1971-1975; NHANES II from 1976-1980; and NHANES III from 1994-1998. NHANES data have been collected annually since 1999. Each of these surveys reported pure tone average air conduction results for (500, 1000, 2000, and 4000 Hz) of more than 5000 school-aged children. NHANES III data suggest 14.9% of school-aged children in the United States (more than 7 million children in the 6 to 19 year age range) have some degree of hearing loss (Niskar et al., 1998). It should be noted that NHANES findings do not separate temporary from permanent hearing loss. The success of EHDI programs is likely to reduce the number of new cases of permanent hearing loss identified in school-based hearing screening programs However, the importance of identifying late onset, acquired, and progressive hearing loss, as well as cases of congenital losses not identified through newborn hearing screening, underscores the need for identification practices beyond the newborn period to ensure the provision of timely intervention services and reduce or minimize educational and behavioral sequelae for all preschool and school-aged children and youth with hearing loss.

In summary, it has been estimated that the 3/1000 prevalence of permanent hearing loss in infants can be expected to increase to 9-10/1000 children in the school-age population (White, 2010) and permanent and/or transient hearing loss in one or both ears affects more than 14% (one in seven) of school-aged children. As a result, several students in every classroom potentially will have difficulties perceiving speech clearly in the educational environment. Hearing loss can contribute to difficulties with

attention, learning, and social function. The prevalence of hearing loss in children is great enough to affect individual and standardized school test scores if these students are not identified and provided the medical and/or educational assistance needed (Sarff, Ray, & Bagwell, 1981; Ray, 1992).

Economic Impact of Hearing Loss

One of the accepted principles of screening is that it should be economically balanced in relation to possible expenditures of resources. The costs of rehabilitation, special education, and under- and un-employment due to disorders of hearing, voice, speech, and language have been projected as $154-186 billion, approximately 3% of the gross national product of the USA in 1999 (Ruben, 2000). RTI International (Research Triangle Park, North Carolina) and the CDC analyzed data from multiple surveys and reported estimates for the direct and indirect economic costs associated with hearing loss, as well as other developmental disabilities in the United States (CDC, 2004-06.). Their estimated lifetime costs (in 2003 dollars) were $383,000 for each person with hearing loss, totaling a projected $1.9 billion for all persons with hearing loss. Total direct costs (i.e., direct medical plus direct nonmedical) amounted to approximately $601 million. Economic cost estimates clearly do not reflect the impact of hearing loss on intangibles that cannot be directly measured (e.g., quality of life).

The retention rate (repeating a grade) among students with unilateral hearing loss (UHL) has been estimated at 30% (Bess & Tharpe, 1986; Oyler, Oyler, & Matkin, 1986) and slightly higher, 37%, among their subjects with minimal sensorineural hearing loss (MSHL) (Bess, Dodd-Murphy, & Parker, 1998). The cost of retaining a student is an economic burden to the educational system. For 56 million school-aged children in the United States (United States Department of Education, 2006), slightly over 3 million (5.4%) will have MSHL, and 37% (approximately 1 million) can be projected to repeat a grade. With an average cost of $9,200 to educate a child for one year (United States Department of Education, 2006), the total expenditure for a repeated grade is in excess of 10 billion dollars.

The present calculated lifetime educational cost of hearing loss (greater than 40 dB permanent loss without other disabilities) is $115,600 per child and the identification, diagnosis and intervention for infants with permanent hearing loss resulting from newborn hearing screening reduces special education costs by an estimated 36% or a reduction of $44,200 per child (Grosse, 2007). This assumes that children who are deaf or hard of hearing receive 12 years of special education, that all children with hearing loss are diagnosed as a result of newborn screening and receive intervention services by 6 months of age, and that children who have multiple disabilities will have similar reductions in education costs as those with isolated hearing losses. These economic figures also suggest that school districts spend 2.4 times more on average for each student enrolled in a program for the deaf and hard of hearing than for a child who does not receive special education services.

Historically, unidentified childhood hearing loss has affected educational achievement, limited choices for higher education and ultimately decreased vocational options (Holden-Pitt & Diaz, 1998).

Holt, Traxler and Allen (1997) found that children who are deaf attained median reading scores at the 4.0 grade level by the age of 17 or 18 years. This information predates the impact of early identification of hearing loss secondary to universal newborn hearing screening. Of students who are deaf or hard of hearing who are accepted into higher education, 70% withdraw from college before earning a college degree (Stinson & Walter, 1992). Data from the 2000 U.S. census indicate the total unemployment rate for 16-64 years is 60% for persons with severe sensory disabilities, and less than one-third of adults who are deaf and under the age of 35 who want to work can find a job. Wages earned by males who are deaf are 77% of the national wage average, whereas the wages earned by females who are deaf are 88% of the national wage average within every occupational grouping (US Department of Labor, 1990).

In summary, even with a high school diploma, an individual with late-identified hearing loss is likely to have poorer language and reading achievement, be less competitive with other high school graduates for jobs, and is less likely to attain a college degree. Moreover, the jobs that are held by persons who are deaf often carry a reduced salary. Similar data do not exist for individuals who are hard of hearing and late identified; however, they are at high risk for delayed language, educational challenges and underemployment, although they typically would be affected to a lesser degree than individuals who are deaf. The greater costs to society due to late identified congenital hearing loss include expensive special education services, a less productive subgroup of the work force resulting in fewer dollars in lifetime tax contributions, and the individual costs that are both monetary and personal. If early identification of childhood hearing loss and provision of appropriate high quality early intervention services result in improved language abilities, lower educational and vocational costs, and increased lifetime productivity, then long-term cost savings can be predicted (Keren, Helfand, Homer, McPhillips, & Lieu, 2002).

Educational Impact of Hearing Loss

The typical classroom is an auditory verbal environment where accurate transmission and reception of speech between teachers and students, and from student to student, is critical for effective learning to occur (Smaldino & Flexer, 2008). Hearing loss, whether consistent or fluctuating, interferes with the accurate reception of speech, especially under noisy and reverberant classroom conditions and when speech is presented at a distance from the student (Blumsack & Anderson, 2004). The behavioral effects of hearing loss are often subtle and resemble effects similar to those of children who experience attention deficit disorders, learning disabilities, language processing problems or cognitive delays. Examples of commonly cited behaviors include the following (Johnson & Seaton, 2011):

1. Has difficulty attending to spoken or other auditory information.
2. Frequently requests repetition.
3. Fatigues easily when listening.

4. Gives inappropriate answers to simple questions.

5. Appears isolated from peers.

6. Has difficulty with reading skills.

7. Has difficulty with spoken and/or written language.

8. Is easily frustrated.

In a survey of parents of children with identified hearing loss, 3 out of 4 responding parents reported their children had experienced problems due to hearing loss (Kochkin et al. 2007). The most serious problems were noted to occur in the areas identified in Table 2.

Table 2. Percent of parents of children with hearing loss reporting problems related to the hearing loss.
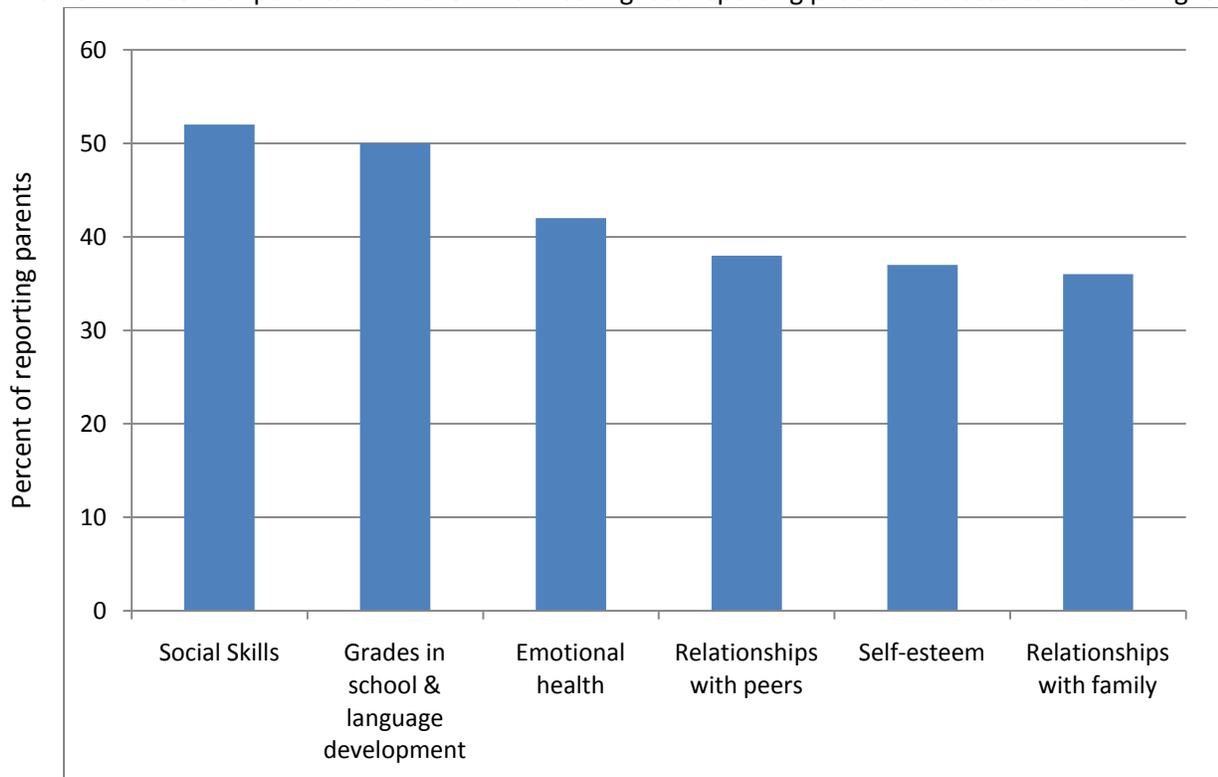
Definition of normal hearing

Because this document focuses on screening for educationally significant hearing loss, it is important to consider the criterion for "normal." The American Academy of Ophthalmology and Otolaryngology (AAOO, 1965) established 26 dB as an allowable limit of hearing damage with reference to worker's compensation regarding earning power. These guidelines were revised in 1973 and 1979 (Moller, 2006). In the context of vocational performance, 26 dB was set as an "acceptable hearing loss" because this was the hearing level at which an individual begins to experience difficulty understanding everyday speech in a quiet environment. The AAOO guidelines state the ability to understand normal

everyday speech at a distance of about 5 feet does not noticeably deteriorate as long as the hearing loss does not exceed an average value of 25 dB at 500, 1000 and 2000 Hz. This amount of hearing loss was regarded as a "just noticeable" handicap for which a worker in the United States was entitled to receive workmen's compensation for loss of earning power. The American Academy of Otolaryngology has not updated these early recommendations by the AAOO. Although the American Medical Association released the 6th edition of the Guides to the Evaluation of Permanent Impairment in 2007, they follow the AAO 1979 guidelines in their use of 26 dB as the demarcation for hearing loss.

Bavosi and Rupp (1984) described the use of 26 dB as a cut-off between normal and mild hearing loss as antiquated because this approach may cause individuals to conclude that no hearing problem exists below this cut-off intensity level. As reported earlier, more than 7 million children from 6 to 19 years of age (14.9% of school aged children in the United States) have some degree of hearing loss (Niskar et al., 1998). Even though the majority of hearing loss in this report was identified as unilateral and of minimal degree, evidence suggests these hearing deficits can adversely affect a child's development, overall well-being, or both (Ross et al., 2008). According to Frankenberg (1971), the outcomes of screening include identification as early as possible of those individuals who have a defined disorder, those who would otherwise have not been identified, and those for whom treatment will ameliorate the effects of the disorder. The foremost purpose in any hearing-screening program is to identify the children in the population who have hearing deficits that could adversely impact their education and who would not otherwise be identified. The linguistic and educational impact of minimal hearing loss is further described in the sections that follow.

Minimal Sensorineural Hearing Loss

Beginning in the mid-1980s research began to focus on milder degrees of hearing loss. The term minimal sensorineural hearing loss (MSHL) was used to include three different hearing loss categories: bilateral sensorineural hearing loss (average air conduction thresholds between 20 and 40 dB in both ears), high-frequency sensorineural hearing loss (mean air conduction thresholds >25 dB at two or more frequencies above 2 kHz in one or both ears), and unilateral sensorineural hearing loss (mean air conduction thresholds >20 dB in the impaired ear) (Bess, 1982; Bess & Tharpe, 1984; Bess & Tharpe, 1986; Culbertson & Gilbert, 1986; Klee & Davis-Dansky, 1986). A 5.4% prevalence of MSHL in a group of 3rd, 6th, and 9th grade children was reported by Bess, Dodd-Murphy, & Parker (1998), and they found lower educational test performance for 3rd grade children with MSHL compared with typical hearing peers and greater dysfunction in areas such as behavior, energy, stress, social support and self-esteem for sixth and ninth grade children with MSHL. Additional studies report children with this MSHL are at higher risk for academic struggles (37% repeating a grade), speech-language deficits (4.3 times more likely to experience trouble in communication) and social-emotional difficulties (poorer self esteem and less energy) (Tharpe & Bess, 1991; Bess et al., 1998; Bess, 1999; McKay, Gravel & Tharpe, 2008).

Unilateral Hearing Loss

Bess (1982) and his colleagues (Bess & Tharpe, 1984; Bess & Tharpe, 1986; Culbertson & Gilbert, 1986; Klee & Davis-Dansky, 1986) also highlighted the significance of unilateral hearing loss (UHL) and classroom challenges related to hearing loss of greater than 20 dB in one ear. Although differences in language skills and intelligence were not found between those with UHL and normal-hearing children, a slightly higher incidence of behavior problems was noted for the group with UHL. In addition, 37% of the children with UHL were found to have repeated a grade.

High Frequency Hearing Loss

Blair et al (1996) reported that 97% of 273 third graders surveyed had been exposed to hazardous sound levels, and Chermak and Peters-McCarthy (1991) found that 43% of elementary students routinely listen to a personal stereo or TV at a loud volume). Evidence of increased prevalence of hearing loss in students was obtained by Montgomery & Fujikawa (1992) who found that over a ten-year period, 2nd graders with hearing loss increased 2.8 times, and hearing loss in 8th graders had increased 4 times. Cone, Wake, Tobin, Poulakis, and Rickards (2010) reported the association between slight-mild sensorineural hearing loss and parent report of personal stereo use.

Using data from the third National Health and Nutrition Examination Survey (NHANES III), Niskar et al. (1998) reported a low frequency hearing loss (LFHL) prevalence of 7.6% for 6-11 year old students and 6.6% for the 12-19 year age group. High frequency hearing loss (HFHL) prevalence was 12.2% for 6-11 year olds and 13.0% for the older group. The degree of high frequency hearing loss reported in these studies is generally mild in nature and sometimes not even noticed by the children themselves. The prevalence of high frequency hearing loss was highest in the poorer ear at 6000 Hz (24.7%) and 8000 Hz (27.3%). NHANES III data also suggest that 14.9% of school-aged children in the United States have some degree of hearing loss (Niskar et al. 1998). Differences between the NHANES III and NHANES 2005-2006 data were recently analyzed, and the more recent data suggest an overall hearing loss prevalence increase from 14.9% to 19.5% (Shargorodsky, Curhan, Curhan, & Eavey, 2010),. More detailed analysis indicated 1 in 5 adolescents in the United States 12 to 19 years of age demonstrated hearing loss (most commonly unilateral (14%) and involving high frequencies (16.4%). Although the majority of the hearing loss was slight, the prevalence of any hearing loss 25 dB or greater increased significantly from 3.5% to 5.3%, or 1 in 20 children in this age group have mild or greater degrees of hearing loss.

Henderson, Testa, and Hartnick (2010) also investigated NHANES results for 1988-1994 and 2005-2006, and found no significant increase in noise-induced threshold shifts (3000 – 6000 Hz) between the survey periods and similar exposure to recreational noise between male and female youths. In this investigation females reported lower usage of hearing protection possibly resulting in an increase in high frequency hearing loss among females. Schlauch and Carney (2010) also investigated

NHANES results for 1988-1994 and 2005-2006, applying computer protocols for estimating false positive rates. They concluded that the NHANES III audiometric data had unacceptably high false positive rates and recommended eliminating calibration errors, repeating and averaging threshold measurements, and using earphones that yield lower variability at 6000 and 8000 Hz to reduce false positive responses when testing these high frequencies. Hood and Lamb (1974) noted response variability of 6000 Hz.

In summary, there is strong evidence that exposure to recreational noise has resulted in increases in high frequency hearing loss of adolescents. There is also evidence of potential errors in identification due to instability in testing the higher frequencies. This information lends support for screening students in their early adolescence with a focus on identifying previously unidentified high frequency hearing loss; however, care must be taken to prevent high false positive rates. The National Institutes of Health Consensus Development Conference (NIH, 1990) specified that strategies to prevent damage from sound exposure should include the use of individual hearing protection devices and education programs beginning with school-age children. Further support for consideration of screening for high frequency hearing loss in tandem with implementing interactive educational hearing loss prevention programs can be found in Chermak, Curtis and Seikel (1996), Bennett and English (1999), and Folmer (2003).

Hearing Loss due to Otitis Media with Effusion

Otitis media with effusion (OME) is defined as fluid in the middle ear without signs or symptoms of acute ear infection, whereas acute otitis media (AOM), usually lasting two to three weeks, is a middle ear infection of recent onset with symptoms and signs of infection such as fever, pain and irritability (AAP, 2004; Flexer, 1994). OME may occur spontaneously due to Eustachian tube dysfunction or as an inflammatory response to AOM. Middle ear effusion may account for more than 90% of all middle ear pathology in children (Brooks, 1978). Approximately 90% of children have OME at some time before entering school, most often between six months and four years of age (Tos, 1984). Fifty percent of children will experience OME in their first year of life, and more than 60% will have experienced the disease by two years of age (AAP, 2004). Casselbrandt, et al. (1985) examined preschool children at regular intervals for a year and found 50-60% of childcare center attendees experienced a middle ear effusion sometime during the year. Lous and Fiellau-Nikolajsen (1981) reported that 25% of school-age children had effusion some time during the year.

Otitis media with effusion is characterized by decreased mobility of the tympanic membrane that can serve as a barrier to sound conduction. The conductive hearing loss associated with OME is variable, fluctuating, and typically mild in degree (15-50 dB HL across the frequencies of 500-4000 Hz) (Daly, et al., 1999). The disease process alters the structure of the lining of the middle ear cavity, and spontaneous recovery occurs more slowly with each additional episode (Tos, Holm-Jensen, Sorensen, & Morgensen, 1982). Early identification of abnormal middle ear function allows initiation of appropriate

treatment, follow-up and possible prevention of the development of conductive hearing loss and other adverse sequelae such as recurrent acute suppurative otitis media, adhesive otitis media, cholesteatoma, tympanosclerosis, ossicular discontinuity, and cholesterol granuloma (McCurdy, et al., 1976).

The research on unilateral and minimal sensorineural hearing loss added a new perspective on the identification and management of children with other types of minimal/mild hearing loss, including OME and its impact on development and educational performance. In the 1990s, the literature reported a link between OME and speech and language delays (Klein, Teele, & Pelton, 1992), reading problems (Updike & Thornburg, 1992), and attention problems (Feagans, Kipp, & Boyd, 1994). Studies were criticized because they often focused on the number of episodes of OME and not the hearing loss associated with the disease--the variable hypothesized to affect development. Roberts et al. (2004) provided a review of the literature summarized in Table 3.

Table 3. Summary of OME and resulting educational effects as reviewed by Roberts: et. al (2004).

OME and Auditory Processing	"Difficult to conclude or refute a link between OME and central auditory processing". p. 113	Folsom, Weber, & Thompson, (1983); Anteby, Hafner, Pratt, & Uri, (1986); Gunnarson & Finitzo, (1991); Moore, Hutchings, & Meyer, (1991); Pillsbury, Grose, & Hall, (1991); Hall & Grose, (1993); Hall & Grose, (1994) Hall, Grose, & Pillsbury, (1995); Hogan, Meyer, & Moore, (1996); Hall, Grose, Dev, & Ghiassi, (1998); Hall, Grose, Dev, et al. (1998); Moore, Hine, Jiang, et al. (1999); King, Parsons, & Moore, (2000); Hogan & Moore, (2003); Knudsen, (2002);
OME and Speech	"Not an indication that OME represents a significant risk to speech production in otherwise healthy children". p. 114	Shriberg, & Smith, (1983); Eimas & Clarkson, (1986); Roberts, Burchinal, Koch, et al. (1988); Paden, Matthies & Novak, (1989); Nittrouer, (1996); Mody, Schwartz, Gravel, & Ruben, (1999); Paradise, Dollaghan, Campbell, et al. (2000); Shriberg, Friel-Patti, Flipsen, & Brown, (2000); Shriberg, Flipsen, Thielke, et al. (2000); Paradise, Feldman, Campbell, et al. (2001); Campbell, Dollagahan, Rockette, et al. (2003);Paradise, Dollaghan, Campbell, et al. (2003)
OME and Language	"OME-language linkage continues to be open to some debate". p. 115	Vernon-Feagans, Manlove, & Volling, (1996); Vernon-Feagans, Emanuel, & Flood, (1997); Feldman, Dollaghan, Campbell, e al. (1999); Maw, Wilks, Haarvey, et al. (1999); Rovers, Straaatman, Ingels, et al. (2000); Paradise, Dollaghan, Campbell, et al. (2000); Paradise, Feldman, Campbell, et al. (2001); Casby, (2001); AHRQ, (2002); Roberts, Burchinal, & Zeisel, (2002); Vernon-Feagans, Hurley, & Yont, (2002); Feldman, Dollaghan, Campbell, et al. (2003); Paradise, Feldman, Campbell, et al. (2003); Paradise, Dollaghan, Campbell, et al. (2003)

OME and Academics, Attention, and Behavior	"Data linking a history of OME to later academic skills, attention and behavior continue to be mixed". p. 116	Roberts, Sanyal, Burchinal, et al. (1986); Feagans, Sanyal, Henderson, et al. (1987); Roberts, Burchinal, Collier, et al. (1989); Teele, Klein, Chase, et al. (1990); Arcia & Roberts, (1993); Lous, (1993); Feagans, Kipp, & Blood, (1994);Gravel & Wallace, (1995); Paradise, Feldman, Colborn, et al. (1999) Roberts, Burchinal, Jackson, et al. (2000); Minter, Roberts, Hooper, et al. (2001); Roberts, Burchinal, & Zeisel, (2002);

Roberts, et al. (2002) and Zumach, et al. (2010) conducted prospective studies investigating the long-term effect of early OME on language and academic skills at age 7. Both studies found that the deficits identified at two and three years of age had resolved by second grade. Gravel & Ruben (1996) suggested that OME may be a form of auditory deprivation, and plasticity of developing auditory systems can facilitate recovery from early auditory deficits. Gravel, et al. (2006) examined the effect of conductive hearing loss secondary to OME in the first three years of life on peripheral and higher order auditory measures at school age. They reported that extended high frequency hearing (12.5, 14 and 16 kHz) and brainstem auditory pathway measures were associated with OME/hearing loss in early childhood. Yilmaz, Karasalihoglu, Tas, Yagiz and Tas (2006) found that significantly fewer otoacoustic emissions were detected in young adults with OME histories than in subjects without a history of OME, suggesting that OME in childhood may cause minor but irreversible damage to the middle ear or cochlea. At 4 years of age, children with positive histories of OME during their first year required a more advantageous signal-to-noise ratio than did otitis-negative peers to achieve the same level of speech perception accuracy (Gravel & Wallace, 1992). These authors speculated that the delays/disorders identified in the earlier studies of young children were related to inadequate or inconsistent access to auditory information during a period of rapid development. Roberts, et al. (2002), Zumach, et al. (2010), and Gravel, et al. (2006) further acknowledged that the home environment, irregular medical management, and low socioeconomic status were probably more influential on outcomes than OME or the associated fluctuating hearing loss, making it difficult to predict the impact of OME on future educational performance.

The diagnosis of OME is a medical rather than an audiological prerogative. The asymptomatic nature of the disease contributes to the difficulty in its diagnosis. Many children have far fewer well-child care visits than are recommended by the AAP (Seldon, 2006) and in 40-60% of cases of OME neither children nor their parents report significant complaints relative to the disease (Burkey et al., 1994; Rosenfeld, Goldsmith, Tetlus, & Balzano, 1997). Thus, parent report is highly inaccurate in identifying children experiencing non-acute OME, with or without substantial hearing loss (Burkey et al., 1994; Olusanya, 2001; Lo et al. 2006; Gomes & Lichtig 2005). Many episodes resolve spontaneously within 3 months, but approximately 30-40% of children have recurrent OME, and 5-10% of episodes last one year or longer (Stool, Berg, Berman, et. al, 1994; Tos, 1984; Williamson, Dunleavy, Baine, &

Robinson, 1994). Tos (1984) found that although 55% of children with OME improved by three months, one third had an OME relapse within the subsequent three months. These same studies reported that if middle ear effusion is present longer than three months, there will be little chance of recovery without medical treatment.

There is no clear consensus among educators, speech language pathologists, and audiologists regarding the impact of OME on development. Bluestone (1978) stated that the degree and duration of hearing loss associated with otitis media and the complications and sequelae required to produce impairment in the cognitive, linguistic, and emotional development of children were not defined. More than 30 years later this is still true. Although a short-term correlation between OME and development has been established, a causal relationship has not. It is difficult to document the duration and degree of hearing loss associated with OME, and ethical standards prevent control of this variable in order to provide the paradigm needed to study the phenomenon; thus, investigators must study OME in its natural course. It is reasonable to postulate that children with minimal conductive hearing loss might experience some of the same difficulties as Tharpe & Bess (1991) identified for students with minimal sensorineural hearing loss. One cannot draw the conclusion that outcomes for MSHL children are the same as those for children with mild/minimal hearing loss due to OME; however, MSHL research may help us better understand all students with minimal/mild hearing loss. In recognition of the noisy verbal environment in which children are educated, it is reasonable to assume that any degree of hearing loss, whether stable or fluctuating, can act as a barrier to complete perception of verbal communication within a school setting and ultimately may impact linguistic and academic performance.

POPULATION OF CHILDREN TO BE SCREENED FOR HEARING LOSS
Legislative Mandates

Although there is no single federal mandate for childhood hearing screening, the goal to identify children most likely to have a hearing loss that may interfere with communication and future school performance is supported by current federal legislation. The Individuals with Disabilities Education Act (IDEA) 2004 requires school districts to identify, locate, and evaluate all children with disabilities [20 U.S.C. §1412(a)(3)], and states that "each public agency must conduct a full and individual initial evaluation" to identify a disability and subsequent eligibility for special education services [34 CFR § 300.301(a)]. In addition, IDEA 2004, requires states to have a comprehensive child find system that ensures rigorous standards for appropriately identifying infants and toddlers with disabilities that will reduce the need for future services [20 U.S.C. §1435 (a)(5)]. Head Start Performance Standards specify that a hearing screening be conducted within the first 45 days of enrollment ([45 CFR 1304.20(b)(1)] Child health and developmental services). A requirement to offer annual hearing screening for children from birth to entry into kindergarten when needed is also included in the Head Start standards for training, qualifications and conduct of home visits (Public Law No: 110-134). Finally, the U.S. Department

of Health and Human Services (2005) suggested that there is a need to identify and reduce the proportion of adolescents who have elevated hearing thresholds in the high frequencies in both ears, signifying noise-induced hearing loss.

On a state and local level, procedures to identify hearing loss in children have existed in most public school systems in the United States for decades (Anderson, 1991).Over a decade ago Penn (1999) reported nearly 90% of the states had enacted hearing screening legislation or conducted some type of coordinated statewide screening activity for school-age children. Most educational jurisdictions have required hearing screening, but there are significant differences in the authority and specifications of the state laws governing these screening activities (National Association of State Boards of Education, 2010)*.*

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Early Childhood

Even mild alterations of auditory input during infancy may result in significant developmental speech delays, lending support for early identification of minimal degrees of hearing loss (Nozza, 1994). Children with mild hearing loss may pass newborn hearing screening, and many do not receive follow up rescreening or diagnostics when they do not pass. Mild hearing loss may be an early indicator for those with progressive or late onset hearing loss. The educational impact of minimal or mild hearing loss can be increased significantly when accompanied by other disabilities.

Early detection of permanent hearing loss has been greatly improved through newborn hearing screening, (Commission on Education of the Deaf, 1988; Harrison, Roush, & Wallace, 2003). However, children not screened at birth, those lost to follow-up after failing newborn screening, and children who present with later onset hearing loss may still be identified too late to prevent serious developmental problems associated with untreated hearing loss (Niskar, et. al, 2001). Data gathered on screening and follow-up of Early Head Start children (birth-3 years of age) suggest that approximately 2 of every 1000 children screened in early childhood settings are being identified with a permanent hearing loss, and an additional 18 children per 1,000 are being identified and treated for transient conductive hearing loss (Eiserman et al., 2008). It has been estimated that approximately 6-7 per 1000 children have permanent hearing loss in addition to the 3 per 1000 likely to be diagnosed shortly after birth (National Institute on Deafness and Other Communication Disorders, 2005; Bamford et al., 2007). An estimated 35% of pre-school children experience intermittent hearing loss secondary to repeated or untreated episodes of ear infections (American Speech-Language-Hearing Association (2007). The Joint Committee on Infant Hearing (2007) recommended regular surveillance of developmental milestones, auditory skills, parental concerns, and middle-ear status for all infants to be performed in the medical home, consistent with the American Academy of Pediatrics (AAP) pediatric periodicity schedule (Hagan, Shaw, & Duncan, 2008). For the early childhood population, a validated global screening tool is to be administered to all infants at 9, 18, and 24 to 30 months or at any time there is physician or parental concern about hearing or

language. JCIH further recommended that infants not passing the speech-language portion of a medical home global screening or for whom there is a concern regarding hearing or language be referred for speech-language evaluation and audiology assessment.

Preschool

Due to injury, illness, or genetics, children who pass hearing screening at birth can still be at risk for hearing loss that is progressive or acquired after newborn hearing screening occurs. It is estimated that by school age, approximately 6 to 7 percent per 1,000 children are expected to have a permanent hearing loss (Bamford et.al, 2007). One purpose of performing hearing screenings in the pre-school age population is to identify earlier screening failures that were lost to follow-up. Based on 2008 Centers for disease Control EHDI data, a total of 48 states reported that 62,246 infants did not pass the final screening before referral for diagnostics. Out of these infants, 46.6% were not documented to have a diagnosis (CDC 2009). Another purpose of hearing screening is to identify later on-set hearing loss that may interfere with language development and future success in school.

School-Age Children

The response to intervention (RtI) process was designed to increase supports under the No Child Left Behind (NCLB) Act (2001) for students with specific learning and behavior disabilities and to prevent academic failure for these school-age students through intervention within general education. RtI calls for a period of information and data gathering, evidence-based academic and behavioral strategies to be put into place, and ongoing monitoring of the effectiveness of those strategies. It is prudent to immediately rule out the presence of hearing loss in any student who is in the RtI referral process. With this in mind, the following three groups are typically targeted for school-aged hearing screening:

1. <u>All students in specific grades</u> (students in targeted grade levels selected by or mandated for school districts to screen annually). School districts that choose to identify students with hearing loss and/or OME typically target preschool and early elementary grade levels for mass screening due to the high prevalence of OME in young children and the desire to identify hearing loss as early as possible. One or more higher elementary grades (e.g. 4th or 5th grade) may be selected to identify late onset hearing loss. Because secondary students are more at risk for noise-induced hearing loss, one grade in middle/junior high school and/or one grade in high school are also targeted. Hearing screening in middle and high school grades also allows for noise protection counseling in order to prevent additional loss of hearing.

2. <u>Referral Students</u> (students not in grades with mass screening who are referred by a teacher or parent for concerns regarding hearing). This category would also include any student in the RtI

or special education eligibility process, especially those students who are being referred for a psycho-educational and/or speech/language evaluation. In these situations it is critical to rule out hearing loss as an underlying cause or contributing factor for educational difficulties.

3. New Students (any student enrolling for the first time in the school system). This category includes students who may be transferring from another system and students who have not been enrolled in school previously. It cannot be assumed that students transferring with IEP's have had their hearing adequately screened, and unfortunately, discovering a student being served in a special education program with unidentified significant hearing loss continues to occur. Students who transfer frequently may miss opportunities to participate in required mass screenings and should be included in a new student referral group as part of their enrollment process.

Targeted Grade Levels

As previously noted, it is important to perform hearing screening on young child populations in order to identify those with late onset or progressive hearing loss. In many states there also continues to be a significant proportion of infants who fail newborn hearing screening that are lost to follow up. Only by methodically screening in early childhood educational, childcare, and medical settings will previously undiagnosed children with educationally significant hearing loss be identified.

Although school hearing screening procedures have been in place in school districts for more than 50 years, there is minimal research specifying ages or grades when screening will most efficiently identify students with educationally significant hearing loss. The American Academy of Pediatrics and Bright Futures published Recommendations for Preventive Health Care (2008). These recommendations were developed to guide pediatricians for screenings and risk assessments of the well child and specify hearing screenings for school-aged children at 4, 5, 6, 8, and 10 years. Sarafraz & Ahmadi (2009) identified a significantly higher number of students with hearing loss in the second grade than in the first grade, data that supports hearing screening beyond school entrance. Information on high frequency hearing loss provides support for the need to screen for hearing loss beyond the elementary school years (Montgomery & Fujukawa, 1992; Niskar et al, 1998; Sargorodsky, et al, 2010).

Additional data to facilitate selection of targeted grades for hearing screening is provided in Appendices A, B, and C. Screening protocols and actual screening results over a three-year period for three school districts in Colorado and Florida were compiled and analyzed. Two districts in Colorado screened for high frequency hearing loss in secondary school, and all school districts used tympanometry when rescreening students who did not pass pure tone screening. Audiologists were integral in the screening program for all districts. The range of newly identified students per grade level, expressed in percent of the total, was combined in different grade combinations in Appendix C. Two of

the districts screened for hearing loss in grades 7 and 9 resulting in their total number of newly identified students being spread over a wider range than the third district that screened six instead of eight grades. The summary statements below are based on data from the three school districts included in Appendix A, B, C:

- School entry hearing screening at preschool and kindergarten will identify less than ¼ to less than ½ of students with newly identifiable hearing loss
- Screening per the AAP guidelines (aged 4, 5, 6, 8 and 10 years), specifically preschool, kindergarten, and grades 1, 3, and 5, results in identifying over ½ but less than ¾ of previously unidentified students (excluding one district's data for grade 6).
- Approximately 90% of new hearing losses will be identified if grades PS – 3 are screened; the remaining 10% that will be missed by not screening higher grades are likely to have a large proportion of emerging high frequency hearing loss, as evidenced in the two districts that did screen for high frequency hearing loss in grades 5 and higher.
- Screening at grades 5 or 6 and grade 7, OR screening at grades 7 and 9 yield very similar results.
- If screening only one secondary grade, 7th and 9th have similar yields, although identifying hearing loss earlier in combination with an educational prevention effort may be more effective prior to high school.
- To identify approximately 70% of previously unidentified hearing losses, preschool, kindergarten, and grades 1, 3, 5 and 7 or 9 should be screened at a minimum. Since these data reflect screening implemented over 2 or 3 years, students who may have had identifiable hearing loss in the grades that were not screened (e.g., grade 4) were identified one year later.
- The trend for identification of new hearing losses decreases in grades 1, 2 and 3 and increases in grade 5, suggesting a possible increased prevalence of high frequency hearing loss in upper elementary school.
- In addition to the minimum grades screened above, more students with previously unidentified hearing loss will be found if grade 2 is added rather than another secondary grade.

III. METHODOLOGY
Evidence-Based Review

There are a variety of ways in which the level of evidence is rated for individual studies. The US Preventative Services Task Force proposed the following 'levels of evidence' rating for quality when reviewing individual screening studies:

    Level I: randomized controlled trial
    Level II: non-randomized control trial
    Level III: cohort or case–control study

Level IV: ecological or descriptive studies (e.g. international pattern time series)

Level V: opinions of respected authorities based on clinical experience, descriptive studies or reports of expert committees (USPSTF 1996).

The British Health Technology Assessment concluded that there was only level III evidence for the effectiveness of preschool hearing screening (Bamford, Fortnum, Bristow et al. 2007). They provided the following summary related to hearing screening techniques using the pure tone average (PTA) criteria set from 15 to 30 dB depending on the study as the reference test:

- Studies comparing various screen protocols of pure tone sweep audiometry report high sensitivity and specificity for full PTA and therefore appear to be suitable tests for screening.
- Spoken word tests are reported to be a viable option because of their potential acceptable levels of specificity and sensitivity.
- Depending on referral criteria, transient evoked otoacoustic emissions (TEOAEs) have potentially high specificity, but somewhat lower sensitivity.
- Tympanometry and acoustic reflectometry have variable sensitivity and specificity.
- Parental questionnaire and otoscopy have poor sensitivity and specificity. Therefore, these tests are likely to be less suitable for screening.

It is a disadvantage to base practice guidelines on information that does not meet the highest evidence level. However, until higher quality evidence-based research becomes available, the current Guidelines for Childhood Hearing Screening are based on the following: (1) the sensitivity and specificity of the relevant studies identified by the British Health Technology Assessment, and (2) additional studies that provide evidence-based information on specific test measures or protocols.

Sensitivity and Specificity

The validity of a screening protocol is the degree to which results are consistent with the actual presence or absence of the disorder. Sensitivity and specificity are used to identify the validity of a screening test. The **sensitivity** of a test is its accuracy in correctly predicting individuals with the condition you are looking for (in this case, children who have potentially educationally significant hearing loss). The **specificity** of a test is its accuracy in correctly identifying individuals who do not have the condition, or for our purposes, children who do not have auditory acuity issues that are likely to interfere with educational performance. For a hearing screening protocol to be acceptable, it should correctly identify at least 90-95% of individuals with existing hearing loss (sensitivity) and fail no more than 5-10% of individuals who would be considered to have acceptable hearing (specificity) (Roeser & Downs, 1981). Over- or under-referral during the hearing screening process has liabilities or "costs" in time (staffing costs), effort, or cooperative good will of families. Medical and/or audiological follow-up costs associated with over-referral include time for retrieving every over-identified child for further

screening from their classroom setting, expenses associated with additional screening and/or diagnostic tests to confirm a hearing loss, and mental anguish of the parent and child (Frankenberg, 1971).

British National Institute for Health Research Assessment on School Hearing Screening

The British National Institute for Health Research published a detailed Health Technology Assessment on the current practice, accuracy, efficiency and cost-effectiveness of school hearing screening procedures that included performing a systematic review of the literature regarding the effectiveness of school hearing screening (Bamford, Fortnum, Bristow et al., 2007). An extensive search of the major relevant electronic databases from 1966 through May, 2005, sought to identify hearing screening test accuracy via sensitivity and specificity, specifically for studies that included 4-6 year old children. A total of 998 studies were identified via electronic searches, the majority from Medline (464), EMBASE (252), and ERIC (172). Of the total identified, 899 studies were excluded largely due to irrelevance for hearing screening. The remaining 99 articles were subjected to systematic quality review using the Quality Assessment of Studies of Diagnostic Accuracy (QUADAS) tool (Whiting, 2003) that consists of 14 questions. The quality of each article was scored by two experienced reviewers on the basis of the total number of 'yes' responses , ranging from zero (poorest possible quality score) to 14 (highest possible quality score). Based on QUADAS review, three systematic meta-analysis reviews and 25 primary research articles were considered to meet inclusion criteria specific to study design, comparator, screening test, population, and outcomes. Of these, 23 studies were identified from initial screening-based data searches and two from follow-up searches related to test accuracy. The assessment reported good agreement on the selection of this group of studies between the two reviewers (weighted kappa 0.67, 95% CI from 0.60 to 0.75). Refer to Table 7 for a summary of the specificity and sensitivity data for seven of these studies. Sensitivity/specificity information is calculated in terms of the total population whereas over and under referrals are calculated in terms of those having the condition. Roeser & Downs (1981) recommended that over-referrals should be between 5-10%. None of the protocols or combination of protocols evaluated by FitzZaland & Zink meets those criteria.

Table 7. Sensitivity and specificity of 7 studies per the British Assessment on School Hearing Screening (2007).

Test	Sensitivity	Specificity
[1]VASC screen (protocol 1) vs. pure tone	51%	96%
[1]VASC screen (protocol 2) vs. pure tone	59%	93%
[3]VASC vs. pure tone	87%	96%
[2]Pure tone vs. combined tests	93.4	98.8

[5]Bone conduction vs. impedance audiometry	26%	6.6%
[2]Tympanometry Type B or -150mm	92.7	91.1
[2]Tympanometry Type B or -175mm	92.7	94.6
[2]Tympanometry Type B or -200mm	91.2	97.8
[2]Pure tone + Type B or -200mm+	100	97
[5]Tympanometry vs. pure tone	85%	91%
[6]Tympanometry + stapedius reflex vs. pure tone	71%	65%
[7]Questionnaire vs. pure tone	34%	95%
[4]TEOAE vs. pure tone	87%	80%
[5]DPOAE (SNR ≥5dB at 1.9 kHz) vs. tympanometry + pure tone	97%	86%
[5]DPOAE (SNR ≥11dB at 3.8kHz) vs. tympanometry + pure tone	97%	83%
[5]DPOAE (SNR ≥5dB at 1.9 kHz AND SNR ≥11dB at 3.8kHz) vs. tympanometry + pure tone	98.5%	75%
[5]DPOAE (SNR ≥5dB at 1.9 kHz OR SNR ≥11dB at 3.8kHz) vs. tympanometry + pure tone	95.7%	95%

Ritchie & Merklein, 1972[1], FitzZaland & Zink, 1984[2], Hamill, 1988[3], Sabo, Winston, Macias, 2000[4], Lyons, Keri, & Driscoll, 2004[5], McCurdy, Goldstein, & Gorski, 1976[6], Olusanya, 2001[7].

Test Procedure and Protocol Review

Pure tone screening

Historically, the most widely preferred hearing screening procedure and the one that has been considered the gold standard is the pure tone audiometric sweep test that was first described in 1938 by Newhart (Krueger & Ferguson, 2002). Pure tone audiometric sweep can be conducted using an ANSI calibrated portable audiometer (American National Standards Institute, 2004) with TDH supra-aural earphones. Pure tone signals are presented across different frequencies, and responses to the signals typically include a hand raise or a conditioned response (e.g. dropping a block in a bucket). Meinke and Dice (2007) surveyed states regarding their hearing screening protocols, and their results for pure tone procedures are summarized in Table 8.

Table 8. Hearing screening protocols. From Meinke and Dice, 2007.

Screening frequencies and intensities	Referenced use of protocol
1000, 2000, 4000 Hz @ 20 dB HL	FL , IN, KY, LA, MD, MO, NY, OH, OK,

	RI, SC, TN, UT, WA, WY (ASHA, AAA)
1000, 2000, 4000 Hz @ 25 dB HL	CA, ME, NH, SD
1000 & 2000 Hz @ 20 dB HL & 4000 Hz @ 20 or 25 dB HL	AR, TX, WI
500, 1000, 2000, 4000 Hz @ 20 dB HL	NJ, OR, VA (AAP)
250, 500, 1000, 2000, 4000, & 8000 Hz @ 20 dB HL	NV, NM
500, 1000, 2000 Hz @ (a) 20 or (b) 25 dB HL	AL, DE
500, 1000, 2000, 4000 Hz @ (a) 20 or (b) 25 dB HL	AK, MA
500 Hz @ 25dB, 1000, 2000, 4000 Hz @ 20 dB HL	AZ, MN
500, 1000, 2000, 4000 Hz @ 25 dB HL	GA, IL, MS
1000, 2000 Hz @ 20 dB HL, 4000 Hz @ 25 dB HL	CT, MT
500, 1000, 2000, 4000, 6000 Hz @ 20 dB HL	KS
500 Hz @ 25 dB HL, 1000, 2000, 4000 Hz @ 20 dB HL, 6000 Hz @ 25 dB HL	CO
500, 1000, 2000, & 4000 Hz @ 15 or 20dB HL & 8000 Hz @15, 20, or 25 dB HL	IA
1000, 2000, & 4000 Hz @ 20, 25, or 30 dB HL	ID
1000, 2000, 4000 Hz @ (a) 20 or (b) 25 dB HL	MI
No information reported	HI, ND, WV, DC, NB, NC, PA, VT

Intensity

Pure tone screening presentation levels are reported to vary from 20 dB to 30 dB (ANSI, 1969). Niskar et al. (1998) and Sarafraz and Ahmadi (2009) identified students with hearing loss by using 15 dB HL criteria. The resulting prevalence data support the use of a 20 dB HL screening level as opposed to 25 dB HL. Meinke and Dice (2007) provided evidence of the greater sensitivity of a 20 dB HL screening level when compared to a 25 dB HL screening level in the identification of high frequency notches. Using a screening level of 20 dB HL has been shown to increase the sensitivity in identifying minimal hearing loss (MHL) (Dodd-Murphy & Murphy 2008).

Dodd-Murphy, Murphy, and Bess (2003) investigated the use of a 20 versus 25 dB HL screening level at 1000, 2000, and 4000 Hz for identifying educationally significant hearing loss (ESHL) in a group of 1219 students in grades 3, 6 and 9 for whom thresholds were known. Sensitivity/specificity rates were 100/92.2 for a 20 dB HL screening level and 97.5/97.4 for the 25 dB HL screening level. When these data were analyzed for identification of minimal hearing loss, sensitivity/specificity rates for a 20 dB HL screening level were 61.5/94.4 and 35.4/98.3 when 25dB HL was used.

In a later study Dodd-Murphy and Murphy (2006) screened 82 students at 20 and 25 dB HL for 1000, 2000, and 4000 Hz, and completed follow-up threshold testing for those who failed. Both screening protocols yielded a 2.4% prevalence of ESHL with 100% sensitivity. Specificity was poor (50%) for the 20 dB HL level, and only 78% for the 25 dB HL level. When the MHL criterion was applied, both screening levels found a 6.1 prevalence, sensitivity/specificity of 100/53 for the 20 dB HL level, and 60/81 for the 25 dB HL protocol. The authors concluded that pure tone screening at 25 dB HL had the best combined sensitivity/specificity rates for ESHL but unacceptable sensitivity when screening for MHL. They further acknowledged the small sample size and commented that reducing time between screening and diagnosis may improve specificity of a screening program.

The American-Speech-Language-Hearing Association *Guidelines for Audiological Screening for age 5-18 years* recommends a protocol that uses a 20 dB HL screening level and includes the frequencies 1000, 2000 and 4000 Hz (ASHA, 1997). As stated by Roeser and Northern (1981), "By decreasing the level at which the test is performed, the sensitivity of the test can be increased and children with even minimal hearing loss can be identified. Since audiologists feel that even slight hearing losses affect the development of speech and language the goal of many programs is to reduce the screening level to identify these children. However, we are forced into accepting screening levels of 20 to 25 dB HL because of the conditions under which most screening is performed" (pg 135).

Any discussion of intensity levels for hearing screening purposes must include recognition that the vast majority of school hearing screening does not occur in a sound-treated setting. FitzZaland and Zink (1984) screened 3510 students, and 123 were identified by audiological and medical examinations with conductive impairments. Of those identified, 115 failed pure tone screening even though 81 (70%) had clinically established thresholds better than the screening levels at all screening frequencies. The authors acknowledged that hearing screening is often conducted in less than ideal settings and suggested that the reason is primarily ineffective planning and negotiation with school administrators who can ensure adequate environments if they consider screening a high priority. These authors also found that frequent and thorough screener training, control of instrument calibration, and rigid ambient noise control reduced false-positive rates from a range of 40-90% down to a "more acceptable level" of 20-30%. As a part of an investigation of hearing health needs in developing countries by the World Health Organization Prevention of Blindness and Deafness (WHO) 2001, a study of 240 subjects was undertaken to measure the validity of testing in conditions with 40–45 dBA of ambient noise. Hearing screening results were compared with those on the same subjects in a soundproof room to give a "golden standard." When the 5 dB difference "normal" variation was acknowledged, the result was that 71.5% had the same thresholds but 28.5% had different thresholds.

Frequency

As previously stated, screening implies that a specific pass/fail criterion is applied to all results. It is preferable that a single failure at any frequency screened in either ear will constitute a failure of the

hearing screening in order to maximize the number of children with newly identified or emerging hearing losses. Requiring failure at more than one frequency in either or both ears will decrease the number of children who require hearing rescreen (i.e. increase the number who pass), but will also potentially increase false negatives (i.e. the number of children with hearing losses that are missed).

Most states perform screening between 1000 Hz through 4000 Hz, with the second highest number of states also performing hearing screening at 500 Hz (Meinke & Dice, 2007). There are limited data to support screening at just one or two frequencies (House & Glorig, 1957; Norton & Lux, 1961); however, the work of Siegenthaler and Sommer (1959) and Stevens and Davidson (1959) refuted limited frequency screening in favor of a pure tone sweep at three or four frequencies. The ASHA (1997) screening guidelines recommend a protocol that uses a 20 dB HL screening level and includes the frequencies 1000, 2000 and 4000 Hz. This is a change from previous ASHA guidelines that included 500 Hz at a 25 dB level as a means to improve identification of temporary hearing loss due to OME (ASHA, 1990). Screening at 500 Hz has since fallen into disfavor due to questionable validity as a means to identify OME, identifying only about half of children experiencing OME (Melnick, Eagles, & Levine, 1964; Brooks, 1971). The 500 Hz frequency is also more easily masked by room noise, thus reducing the specificity of screening results (ANSI S3.1 – 1999 (R2003); Minnesota, Department of Health, 2006).

FitzZaland & Zink (1984) investigated a pure tone screening protocol's ability to identify conductive hearing loss when using 25 dB HL at 500 and 4000 Hz and 20 dB HL at 1000 and 2000 Hz. They found that referred children who failed only the 500 Hz tone accounted for 15% of the children with confirmed conductive impairment, and that none of them had normal hearing. The authors acknowledged concern about the impact of ambient noise on screening at 500 Hz and stated that effective planning with school officials is critical to ensure an adequate screening environment.

Meinke & Dice (2007) evaluated a database of 641 9th and 12th graders with identified high frequency hearing loss using four different intensity and frequency combinations. Their findings are summarized in Table 9. The authors performed further analysis of 45 of the 641 audiograms and found that 48.8% of the diagnosed hearing losses involved the frequency of 4000 Hz, 46.1% involved 6000 Hz, and 5.1% involved 3000 Hz.

Table 9: Percent of students with known high frequency hearing loss who would have been identified by four hearing screening protocols (Meinke & Dice, 2007).

Screening Protocol	Percentage of Known HF Hearing loss Identified (Hit Rate)
20 dB HL at 1000 Hz, 2000 Hz and 4000 Hz	22.2

25 dB at 1000, 2000, and 4000 Hz	6.7
Protocols that include screening 6000 Hz at 20 dB	44.4
15 dB at 500, 1000, 2000, 4000, and 8000 Hz	44.4

Number of presentations

Screening implies that a specific pass/fail criterion is applied to all results. It is not unusual for children to fail to respond to a single pure tone presentation when hearing screening is performed in the presence of varying levels of ambient noise, when young children have limited attention spans, or when the intensity of the pure tone is close to threshold. Because of this, it is assumed that a pure tone will be presented more than once if a child fails to respond. Caution is warranted to prevent presenting so many repetitions of the tone that the eventual false positive responses from a child will be considered a pass. Therefore, it is reasonable that more than one, but no more than several (i.e. 4) pure tone presentations occur if a child does not respond to the first pure tone presentation. Other than for training purposes, it is important that the chosen decibel level screening criterion be adhered to throughout the hearing screening and that the level is not increased if a child fails to respond.

Screening environment

Based on a 20 dB HL screening level, the allowable ambient noise if an individual has 0 dB HL hearing thresholds is 50, 58, and 76 dB SPL respectively for 1000, 2000, and 4000 Hz (ANSI S3.1-1999 (R2003). Ambient noise sources from ventilation, adjacent hall or classroom noise, children moving about the room and screening personnel giving instructions all contribute to difficulty screening at levels less than 20 dB HL.   Most school systems do not have the equipment or expertise to take ambient noise measurements in the areas to be used for screening. An alternate approach is to use a biologic noise level check prior to the commencement of hearing screening. This has been defined as the ability to establish hearing thresholds at least 10 dB below the screening level (e.g.10 dB HL for screening conducted at 20 dB HL) at all frequencies for a person with known normal hearing. If these thresholds cannot be established, the area must not be used for screening (Minnesota, Department of Health, 2006).

School districts should be cautious when considering adding high frequency tones to the hearing screening protocol as sensitivity of the screening program may decrease due to response variability at 6000 Hz (Hood & Lamb, 1974). Schlauch and Carney (2010) recommended that precision of audiometric results could be improved by (1) eliminating systematic calibration errors, including a possible problem with reference levels for TDH-style earphones; (2) repeating and averaging threshold

measurements; and(3) using earphones that yield lower variability for 6000 and 8000 Hz (two frequencies critical for identifying noise notches).

Immittance Screening

Tympanometry

Since its development in the 1970's tympanometry has been used to assess middle ear function in the clinical setting (Margolis, Hunter & Goeboml, 1994). Tympanometry puts varied air pressure into the ear canal and then measures the acoustic energy that is transmitted through the middle ear system. The ear canal pressure in relation to the measured acoustic admittance is then plotted on a graph called a tympanogram. Tympanometry is not a test of hearing since it does not test auditory pathways beyond the middle ear. Krueger & Ferguson (2002) identified a high rate of false positives (6.4%) for students failing tympanometry screening as compared to pure tone screening at 35 dB HL. These authors found that two problems were apparent. First, pure tone screening and tympanometry assess different aspects of the auditory system. Because tympanometry is not a measure of acuity, comparing it to pure tone results that do measure acuity is flawed. Secondly, tympanometry is a more sensitive tool than the use of a 35 dB screening level to identify students with middle ear effusion.

In the 1970s, much research was focused on the use of immittance (then known as impedance audiometry) to identify poor middle ear function that is typically associated with otitis media with effusion. The question at that time was not *if* we should identify OME but rather how best to do so. Entire conferences were devoted to the topic, and impedance audiometry was established as a viable tool for screening children for the presence of middle ear fluid (Harford, Bess, Bluestone, & Klein, 1978; Task Force of the Symposium on Impedance Screening for Children, 1978). Tympanometry has been used clinically for decades, and it is an accepted clinical standard for identifying the likely presence of OME (Watters, Jones, & Freeland, 1997).

Middle ear pressure

When aeration of the middle ear space is interrupted by partial or complete obstruction of the Eustachian tube, the air in the middle ear space becomes static and is absorbed by the mucosal lining. Negative middle ear pressure (MEP) causes the tympanic membrane to become retracted and if this condition persists over a period of time, fluid may fill the middle ear space. The longer negative MEP exists, the greater degree of loss of the immuno-protective properties of the middle ear. This, in combination with an inflammatory process, creates a vicious cycle with recovery occurring more slowly with each episode especially at younger ages (Northern, Rock, & Frye, 1976; Tos, 1982). Because negative MEP is a precursor to the formation of middle ear effusion (MEE), it is often studied in young children where the prevalence of OME is greater.

Bluestone, Beery, & Andrus (1974) stated that tympanometry as a measure of MEP is an effective tool to identify Eustachian tube dysfunction but acknowledged that identifying the presence of an abnormal condition is not synonymous with identifying those that should be referred for medical evaluation. Other reports do not recommend the use of MEP in isolation for determining whether or not a medical referral should be made (Paradise & Smith, 1975; Hopkins, 1978). Roeser, Soh, Dunckel, & Adams (1978) found poor agreement between otoscopy and MEP in the identification of MEE. They reexamined their data to see if raising the cut-off for MEP would improve agreement and found that it did not. Findings by Lewis, Dugdale, Canty, and Jerger (1975) were similar.

The use of MEP has been criticized as a screening tool due to the over-referrals it generates (Bluestone, Fria, Arjona, Casselbrant, Schwartz, Ruben, Gateo, Downs, Northern, & Jerger, 1986; Page, Kramer, Novak, Williams, & Symen, 1995), and the ASHA *Guidelines for Audiologic Screening* (1997) recommend that tympanometric peak pressure (TPP) not be used to screen for middle ear disorders in children birth-age 18.   Although fluctuations in middle ear status can be reflected in other components of tympanometry, great variability exists in 'normal' MEP of young children. Liden & Renvall (1978) and Renvall & Liden (1978) found that 90% of 7-year-old subjects had negative MEP $\leq$-150. Margolis and Heller (1987), Nozza, Bluestone, Kardatzke, and Bachman (1992), Nozza, Sabo and Mandel, (1997), and Lyons, Kei, and Driscoll (2004), all found a similar large range for normal middle ear responses. To evaluate the use of tympanometric variables in the identification of MEE, Nozza, Bluestone, Kardatzke, and Bachman (1992) studied 61 subjects undergoing myringotomy and tube surgery. Those with MEE at the time of surgery had MEP ranging from -375 to -67 decaPascals (daPa), whereas those without fluid had a range of -458 to +18 daPa. Due to the large variability found in both groups, the use of MEP did not appear to be an effective tool to identify middle ear effusion.

 FitzZaland and Zink (1984) screened 3510 kindergarten and 1st grade students followed by audiological and medical exams within 2 days of screening. When combining pure tone screening with tympanometry screening using a flat (Type B) tympanogram or MEP in excess of -200 mmH$_2$O as refer criteria, sensitivity was 100% and specificity was 97%. Although the over referral rate was 42%, the under referral rate was 0%. Results of use of -150 and -175 mmH$_2$O are reported in Table 3.

Roeser, Jin Soh, Dunkel and Adams (1978), Schwartz, Schwartz, Rosenblatt, Berry, and Sweisthal (1978) and Konkle, Potsic, Rintelmann, Keane, Pasquaariello, and Baumgart (1978) studied tympanometric change over time and suggested that children whose MEP was between -100 and -200 daPa be retested in 6 weeks because it is the dynamic trend of MEP rather than a static state that is most important in determining if a medical referral should be made. As a means to more clearly identify children with negative MEP who should be referred from those who might benefit from further monitoring, Paradise and Smith (1975) suggested the additional use of gradient (sharp versus gradual) as a means to reduce false-positives.

Tympanometric width

An alternative classification system to the earlier ABC system devised by Jerger (1970) was offered by Paradise and Smith (1975) as a means to more clearly separate those who should be referred for medical management from those who might benefit from further audiological monitoring. They proposed the use of width and gradient (sharp vs. gradual) in this classification system and found that by using tympanometric shape (width, gradient) in conjunction with middle ear pressure, the number of false-positives could be reduced by 44%.

The term gradient has been used in several studies but is defined differently in each (Nozza et al, 1992; Roush, Bryant, Mundy, Zeisel, & Roberts, 1995; DeJonge, 1996). On the other hand, tympanometric width is always clearly defined as the distance in daPa between the sides of the tympanogram at one-half of the peak admittance. According to Nozza et al (1992), width is considered the best single variable for discriminating between ears with or without middle ear effusion, with a negative pressure cutoff of greater than -275 daPa being positive for middle ear effusion in children age 1 to 12 years. When including only children age 3 to 12 years, a cutoff greater than -250 daPa can be used. When considering tympanometric width in relation to children's ages, the younger the child, the greater the acceptable width to predict normal or effusion-free ears (Roush et. al, 1995). Larger tympanometric width has also been associated with ears having a recent history of middle ear effusion (Henderson & Roush, 1997). Thus, tympanometric width can be considered a better predictor of middle ear effusion than middle ear pressure, although medical practitioners receiving referrals from hearing screening may be more familiar with interpretation of MEP and static compliance than with the implications of tympanometric width.

Static admittance (compliance)

Static admittance is a measure of middle ear mobility that represents the transmission of energy through the middle ear space in its resting state. Once a tympanogram has been completed, the static or resting admittance of the middle ear is computed from two values: the compliance (C_2) obtained at +200 daPa in the ear canal and the compliance (C_1) at the tympanometric peak. Static compliance of the middle ear is then calculated by subtracting the first compliance from the second compliance [$(C) = C_2 - C_1$] (Zwislocki, 1963).

In a study of 280 subjects, Paradise, Smith and Bluestone (1976) found that low tympanic membrane compliance was highly correlated with otitis media with effusion. Nozza, et al. (1992), found that tympanometric peak height and tympanometric width, independently as well as in combination, strongly influenced the probability of middle ear effusion, whereas tympanometric peak pressure had only minor influence. In a study that was undertaken to acquire normative data for static admittance and tympanometric width in children under 3 years, Roush, et al. (1995) found that 90% of children in the study without middle ear effusion had static admittance within the range of 0.2 and 0.7 mmhos

(millimhos). It is common to find shallow tympanograms (i.e., 0.2 mmhos) that do not indicate a compromised middle ear system in the Asian American population (Wan & Wong, 2002). Because static admittance values can vary widely with age, ethnicity, and middle ear pathology, this measure should only be used in conjunction with other measures to assess middle ear functioning.

Acoustic Reflex and Reflectometry

Acoustic reflex testing measures the movement of the tympanic membrane as an indirect measurement of the contraction of the stapedius muscle in the middle ear in response to a loud sound. It is frequency specific, objective, and tests up to the level of the brainstem and can be used on students who are unable to perform a pure tone hearing screening. The main drawback of contralateral acoustic reflex is that it has an extremely high false- positive rate. A study performed by FitzZaland and Zink (1984) on 3,510 students found that 30.4% of the children with normal hearing and normal middle ear status had absent contralateral reflexes. Studies by Renvall and Liden (1980) and Brooks (1974) found similar results. Due to the unacceptable false-positive rate, contralateral acoustic reflex can be ruled out as an acceptable screening measure. A search of the literature regarding the use of ipsilateral acoustic reflex for screening preschool and school aged children was unsuccessful.

Acoustic reflectometry was introduced in 1984 as a method of improving the diagnosis of otitis media with effusion (OME), particularly in children. Early research as summarized by Holmes et al. (1989) suggested good specificity but widely varying sensitivity for this screening procedure. More recent studies (Babb et al. 2004; Chianese et al. 2007) report on use of newer technology that provides measures of reflectivity in terms of spectral gradient levels and angle data. Their results suggest again that this technique has good specificity but varying sensitivity that appears dependent on the pass/fail cut-off points used for interpretation. All studies reviewed concluded that acoustic reflectometry was not as efficient in identifying OME as either tympanometry or pneumatic otoscopy when screening the normal population.

Screening with Speech Stimuli Materials

Ritchie and Merklein (1972) studied the effectiveness of using the Verbal Auditory Screening for Children (VASC) with preschoolers as a means to identify hearing loss. The VASC uses a tape recording of spondaic words at progressively attenuated levels with a picture-pointing identification response (Mencher & McCulloch, 1970). In this study, 162 children were tested with pure tones and the VASC, and of the 41 students who failed the pure tone threshold tests, 48.8% were missed using the VASC. The authors concluded that the VASC is a much less efficient method of identifying hearing impairment when compared to using a pure tone test with preschool children.

Otoacoustic Emissions Screening (Early Childhood and School-Age)

Successful completion of pure tone screening can be challenging when screening young children or those with special needs. An analysis of pure tone hearing screening results from well-child visits at the pediatrician's office found that 3-year-olds are 33 times more likely than older children to be recorded as "could not test" for pure tone screening (Halloran et al., 2005). Forty five percent of 3-year-olds did not complete the screening, compared with 7% of the 4-year-olds, and this percentage decreased with increasing age. These challenges suggest the need for considering an alternative to pure tone screening for young children.

Measurement of Otoacoustic emissions

Otoacoustic emission (OAE) assessment is technically not a test of hearing, but rather a reflection of inner ear mechanics. OAEs are sounds detected in the external ear canal that are generated by the outer hair cells within the cochlea. OAEs recorded in the absence of stimulation are known as spontaneous OAEs. OAEs that are recorded in response to auditory signals are known as evoked otoacoustic emissions. When clicks or tone bursts are used to stimulate the ear, transient OAEs (TEOAEs) are elicited. Two pure tones, also known as primaries ($f1$=low frequency primary and $f2$=high frequency primary), are used to generate distortion-product OAEs (DPOAEs). Clicks stimulate a majority of the basilar membrane, while stimulation with tones is restricted to a discrete region. OAEs are measureable in ears with normal hearing sensitivity and in ears with abnormal hearing sensitivity of up to 30-40 dB HL (Gorga et al., 1997; Hussain et al., 1998). Both, TEOAEs and DPOAEs have been used to screen for hearing loss in infants and children. OAEs are also used to document outer hair cell function in persons with auditory neuropathy/auditory dys-synchrony (Starr et al., 1996; Berlin et al., 2005). When performing OAE screening, a small probe is placed in the ear canal and is used to present the stimuli and record the response. It is important that the status of the outer and middle ears is within the normal range as these structures form the pathway for stimuli to the inner ear and for reverse transmission of responses to the ear canal.

OAE screening considerations: environment and time

OAEs are low amplitude signals that travel from the inner ear back to the ear canal. An important variable in the validity of OAE screening results is the level of noise in the recording. Valid and reliable OAE results depend on the screening environment being as free from noise and vibration as possible. Proper selection and placement of the probe tip resulting in a good acoustic seal can mitigate the effects of background noise significantly. Disposable tips are preferred for optimal hygiene and infection control. If reusable tips are used, systematic procedures are needed to ensure disinfection of tips between uses. All studies on OAE screening reviewed here were completed in typical school screening settings or in homes, thus illustrating that it is possible to measure OAEs in screening environments in school facilities, without a sound-attenuating booth. Driscoll, Kei and Macpherson (2001) reported ambient noise levels between 34 dBA and 51 dBA, thus providing an acceptable range

to complete OAE screening. Test times reported for TEOAE screening range from 25 seconds to 330 seconds (Richardson et al., 1995; Driscoll, Kei & Macpherson, 2001; Sideras & Glattke, 2006). Eiserman et al (2008) reported an average of 4.8 minutes with a range between 1 minute and 30 minutes to complete visual inspection and DPOAE screening on preschool children. Assuming a quiet environment and a still child, the screening procedure takes less than a minute. Longer screening times were associated with technical difficulties, noisy environments, increased physiological noise (e.g., heavy breathing or swallowing), excessive child movement, non-compliance of subjects, and presence of hearing loss.

Transient-evoked otoacoustic emissions

Research exploring the potential role of TEOAEs in screening preschoolers and school-age children is summarized in Table 10. All studies reported utilizing clicks to obtain TEOAEs. The majority of measures of screening performance characteristics (i.e., sensitivity and specificity) were based on results of pure tone screening or pure tone screening and tympanometry. Only two studies used diagnostic audiologic results as the "gold standard" to calculate sensitivity and specificity. It is important to note that pure tone screening also has its limitations, and using these results as the "gold standard" is not as stringent as using diagnostic test results.

Most studies used the default setting on the TEOAE equipment for stimulus intensity (i.e. 85 dB pe SPL or 80 dB pe SPL). A range of variables was used to set pass/fail criteria for TEOAE screening results. Sensitivity ranged from 0.65 to 1.0. Lower sensitivity values were associated with the use of (1) a diagnostic test as the standard, (2) multiple variables for pass/fail criteria (e.g., OAE < 7 dB and OAE/N ≤ 0 dB), and (3) results of both pure tone screening and tympanometry. A reduction in sensitivity when compared with both pure tone screening and tympanometry indicates that TEOAEs are not sensitive to middle-ear pathologies identified using tympanometry. When criteria used for newborns (3 dB SNR across the frequency bands of 2000-3000 Hz and 3000-4000 Hz), was used on the school age population, sensitivity was 68% and specificity was 90% (Driscoll, Kei & Macpherson, 2001). Thus, 32% of children with identifiable hearing loss were missed by TEOAE screening using newborn screening criteria. This was attributed to the low sensitivity of TEOAEs to identify middle ear dysfunction in this population. Given the developmental changes seen with TEOAEs, use of newborn criteria for older children may not be appropriate, and consideration should be given to using different TEOAE pass/fail criteria for school-age children.

TEOAEs are reduced in amplitude (or potentially absent) in the presence of middle-ear conditions, especially in the low frequencies (Naeve et al., 1992; Trine, Hirsch & Margolis, 1993; Norton, 1994). Ho et al., (2002) found that the greatest correlation between TEOAE failure and tympanometry occurred when tympanometric width >300 daPa was used as the criterion for failure. They also found that 68% of the children between 2 weeks and 5 years failed the TEOAE screening due to an abnormal tympanogram. TEOAE failure has also been documented in the presence of negative middle ear pressure

(Ho et al., 2002) and increased admittance (Nozza et al., 1997). When TEOAE test performance was compared with pure tone screening and tympanometry, sensitivity and specificity were reduced (Nozza et al., 1997; Driscoll, Kei, & McPherson, 2001). Comparison of TEOAE and tympanometry results revealed sensitivity values of only 60% (Taylor & Brooks, 2000) and 69% (Georgalas et al., 2008). Nozza et al. (1997) revealed poor correlations between TEOAE variables and tympanometric variables in ears that were in the normal range on tympanometry. Reproducibility at 2000 Hz was affected by scarring on the tympanic membrane that was reflected on the admittance measure. Due to lack of a straightforward relationship between TEOAE variables and tympanometric values, TEOAEs cannot be used to predict middle-ear status. If TEOAEs are used to screen preschool and school-age children, it is prudent to use it along with tympanometry given the high incidence of middle-ear pathology in this population and the low sensitivity of TEOAEs to detect these conditions.

Referral rates with TEOAE screening range from 9% (Yin et al., 2009) to 13% (Sabo et al., 2000) in the normal population with age ranges between 2-6 years and 5-9 years. Referral rates are as high as 40% for special populations (Driscoll, Kei, Bates, & McPherson, 2002). Research conducted by Sideris and Glattke (2006) compared the results of conventional pure tone behavioral screening and transient otoacoustic emissions (TEOAEs) for 200 children ages 2 years 1 month to 5 years 10 months. The referral rates obtained with the two procedures were similar; 21.5% referred from pure tone screening and 21% referred from TEOAE screening. However, the majority of the referrals (>50%) from the pure tone screening were due to the inability to condition the children to respond, whereas only 10% of the referrals from TEOAEs were due to lack of cooperation. Nearly two-thirds (62%) of the children who were referred by TEOAE screening also failed immittance screening.

Table 10. Summary of screening studies using TEOAEs.

Study Authors	Protocol	Subjects	Protocol for TEOAEs	Pass/fail criteria	Test performance "gold standard" = pure tone screening or diagnostic test
• Richardson, Williamson, Lenton, Tarlow and	• Standard diagnostic audiometry • TEOAEs	• 52 children (104 ears) • 0.2-15	• 85 dB pe SPL clicks • Quickscreen on ILO	• Waveform correlation 50% • Weighted	• Sensitivity was 1.0 for all criteria used • Specificity ranged from

Rudd, 1995		years		response level 2dB • Corrected response level 0 dB • Rhode Island criteria (S/N ratio of 3 dB at any three frequencies between 1K Hz and 4 K Hz) • Bandwidth waveform reproducibility 60% • Bandwidth S/N ratio 3 dB	0.47 to 0.82 • Highest specificity for bandwidth S/N ratio of 3 dB
• Nozza, Sabo and Manel, 1997	• TEOAEs • Pure tone screening (20 dB HL at 1 KHz, 2 KHz, 4KHz and 25 dB at 0.5 KHz) • Pneumatic otoscopy	• 66 students • 5-10 years of age	• 83.5 dB pe SPL • Default mode on ILO 88	• Waveform reproducibility (50% and 40%)* • OAE amplitudes (6-8 dB SPL)	• Sensitivity ranged from 0.67 to 1.0 (by ears) • Highest sensitivity seen for * pass/ fail values • Specificity

	• Tympanometry			• OAE/N (0 dB and 1 dB*) • Reproducibility at 2 KHz (50%)* • OAE < 7 dB or OAE/N ≤ 0* • OAE < 7 and OAE/N ≤ 0 * see next column	ranged from 0.8 to 0.97 (by ears) • Highest specificity seen for OAE < 7 and OAE/N ≤ 0 • Sensitivity ranged from 0.6 to 1.0 (by children) Specificity ranged from 0.7 to 0.96 (by children)
• Sabo, Winston and Macias, 2000	• TEOAEs • Pure tone screening (25 dB HL at 0.5k Hz and 20 dB HL at 1, 2, 4 kHz) • Audiometric assessment	• 583 children • 5-9 years	• Default settings on Echoport ILO V5 system	• S/N ratio of 3 dB and reproducibility of 70% and stability of 90%	• Sensitivity of 65% • Specificity was 91% • Compared with results of audiometric assessment
• Taylor and Brooks 2000	• TEOAEs, • Tympanometry • Pure tone screening (20 dB HL at 1, 2,	• 152 children (297 ears) • 3-8 years	• 75 dB- 85 dB pe SPL • Otodynamic ILO88	• S/N ratio of 3 dB in at least 3 frequency bands	• Sensitivity of 81% • Specificity of 94 %

	4 kHz)				
• Driscoll, Kei and Macpherson (2001)	• Otoscopy, • TEOAEs • Pure tone screening (20 dB at 0.5, 1, 2, 4 KHz) • Tympanometry	• 940 children (1880 ears) • 6 years old	• 80 dB pe SPL Quickscreen on ILO 292	• S/N ratios of 1, 2, 3, 4, 7, 9, 15 dB at 2.4,3.2, 4 kHz	• Sensitivity ranged from 0.7 to 0.89 • Highest sensitivity was at S/N ratio of 15 dB • Specificity ranged from 0.84 to 0.96 • Highest specificity was at S/N ratio of 1 dB
• Yin, Bottrell, Clark, Shasks and Poulsen, 2009	• TEOAEs • Pure tone screening (25 dB HL at 1, 2, 4 KHz)	• 744 preschool children completed TEOAEs • 142 children completed both TEOAEs and pure tone screening • 2-6 years	• 80 dB pe SPL • Quickscreen on ILO288	• S/ N ratio of 5 dB for 3 of 5 frequency ranges (preset at factory)	• Sensitivity was 1.0 • Specificity was 0.94

Distortion-product Otoacoustic emissions

Use of DPOAEs as a screening measure was investigated in two major studies summarized in Table 12. Both of these studies used the same stimulus parameters to elicit the 2f1-f2 DPOAE (f2/f1 ratio of 1.22, L1/L2=65/55 dB SPL). Pass/ fail criteria were dependent on frequency of f2. Lyon, Driscoll and Kei (2004) used 3 different S/N ratios for pass/fail criteria. DPOAEs along with tympanometry and pure tone screening results were obtained, and the best hit rates were obtained with a SNR of 5 dB at 1.9 kHz and 11 dB at 3.8 kHz. At 1.1 kHz, hit rates were low and false alarm rates were high owing to increased ambient and physiological noise contaminating the response. In children who failed tympanometry, DPOAE amplitudes were reduced, leading to a reduction in the SNR as well. Hit rates reduced and false alarm rates increased when DPOAE results were compared with the battery of pure tone and tympanometry results. These two studies are in agreement that DPOAEs are not sensitive to those conditions detected using tympanometry. Others have also reported that DPOAEs are known to be affected (especially in the low frequencies) in the presence of middle-ear conditions (Owens et al., 1993; Akdogan & Ozkan, 2006)

Table 11. Summary of screening studies using DPOAEs.

Study Authors	Protocol	Subjects	Protocol for DPOAEs	Pass/fail criteria	Test performance
• Lyons, Kei & Driscoll, 2004	• Otoscopy • DPOAEs, • Tympanometry • Pure tone screening (20 dB HL at 0.5, 1, 2, 4 kHz)	• 1003 school children • 4.1-7.9 years	• F2 frequencies at 1.1, 1.9, 3.8 kHz • F1/f2=65/55 dB SPL • F2/f1 ratio of 1.21	• S/N ratios of 4, 5, and 11 dB at 1.1, 1.9 and 3.8 kHz, frequency specific analysis conducted	• Best hit rates obtained with 5 dB SNR at 1.9 kHz (0.89), and 11 dB SNR at 3.8 kHz (0.90). • High false-alarm rate.
• Eiserman et al., 2008	• DPOAEs (up to 3 OAE screenings in a 2-4 week period) • Otoscopy • Diagnostic	• 4519 children • ≤ 3 years old	• F2 frequencies at 2, 3, 4, 5 kHz, • F1/f2= 65/55 dB SPL,	• Frequency specific pass/fail criteria with minimum DP of -6 dB	• Sensitivity and Specificity could not be calculated.

assessments		• F2/f1 ratio of 1.22	at 5 kHz, -5 at 4 kHz, -8 at 3kHz, -7 at 2kHz with a S/N ratio of 6 dB.	

Eiserman et al (2008) described a multi-step strategy to screen migrant children enrolled in Head Start programs. The protocol included visual examination and up to three DPOAE screens over a 2-4 week period. The screenings took place in classroom play settings and homes. The referral rate for the first stage of DPOAE screening was 18%, and 6% of the children were classified as "can't test" due to excessive internal or external noise. After the three screenings, 5.7% of the children were referred, results comparable to those reported by Krueger and Ferguson (2002), who published a referral rate of 6.3% in their DPOAE screening study. The major drawback of a multi-step screening protocol is loss to follow-up. Fifteen percent of the children did not receive the second DPOAE screening, and 20% of the children did not receive the third step screening. Although the screenings were to occur in a 2-4 week period, this period was not strictly adhered to due to parent compliance issues and screener schedules.

Summary of Research on OAE and Childhood Screening
- TEOAE and DPOAE screening can be completed successfully in regular early childhood and school environments when extraneous noise is kept to a minimum.
- Pass/fail criteria for TEOAEs need to be chosen carefully to maximize sensitivity and specificity. Optimum SNRs for pass/fail criteria for DPOAEs are frequency dependent.
- Due to compromised sensitivity and specificity, TEOAEs or DPOAEs cannot replace the preferred battery of pure tone screening and tympanometry.
- Middle-ear status cannot be inferred by OAE measurements alone and should be verified if OAEs are absent to rule out transitory middle ear effusion as a cause of findings absent or reduced in amplitude.
- Referral rates for TEOAE screening range from 9% to 21% in pre-school and school-age children, and the rate may be higher when screening special populations. Referral rates for DPOAE screening are around 6%.
- Multistep screening protocols may be used to reduce referral rates; however, it is important to note that loss to follow-up is a concern when using this protocol.

- Although not mentioned in any of the screening studies reviewed earlier, it is useful to note that OAEs can be measured in ears with patent pressure-equalization tubes, although response amplitude may be reduced (Owens, McCoy, Lonsbury-Martin, & Martin, 1993).

Limitations of OAE screening

TEOAEs and DPOAEs are recordable from most ears with normal peripheral (outer hair cell) function. However, TEOAEs may be recorded in some ears with hearing sensitivity in the mild range (20-30 dB), and DPOAEs may be seen in some ears with hearing sensitivity in the mild to moderate range (20-50 dB HL). As TEOAEs and DPOAEs may be recorded in some ears with mild or mild to moderate hearing loss, these cases may be missed in a screening program that utilizes OAEs only.

It may not be possible to complete OAE screening on children in the low-frequency range (<1000 Hz) even in a sound-treated room due to contamination from physiological noise. If acoustic conditions are unfavorable in school environments, it may not be possible to screen below 2000 Hz. Although TEOAE and DPOAE protocols can be modified to not emphasize low frequency measurement (e.g., shortening the time window for TEOAEs or testing DPOAEs at 1000 Hz and above), appropriate pass/ fail criteria for the <1000 Hz frequency range have not been established. At this time, low-frequency hearing status can be screened only using pure-tones and cannot be inferred using OAEs.

Although OAEs can be an important tool in screening programs, it is significant to note that as many as 10% of children with normal OAEs may have an auditory synchrony problem (Berlin, Morlet & Hood, 2003). Auditory neuropathy/dys-synchrony (AN/AD) or "auditory neural hearing loss" is defined as a form of hearing impairment where outer hair cell function is normal but neural transmission in the auditory pathway is impaired (Rance, 2005). Most notably, individuals with AN/AD will typically have the following audiological profile:
- Normal tympanometry
- Abnormal acoustic reflexes
- Normal OAEs
- Absent or grossly abnormal auditory brainstem response (ABR) (a recordable measure of neural synchrony following an auditory click or tone burst stimuli)
- Variable pure tone audiometric results
- Significantly poorer speech perception abilities than expected

Although the above factors are typical, it must be noted that some children with AN/AD have absent OAEs with evidence of cochlear function based on the presence of cochlear microphonics (Deltenre et al, 1999; Rance et al, 1999; Starr et al, 2001).There have been some risk factors that are associated with AN/AD including children with a history of hyperbilirubinemia, prematurity, perinatal asphyxia and family history. However, many children identified with AN/AD, do not have any risk factors (Hood, 2002). It is beyond the scope of this paper, to discuss etiology, identification and management of

children with AN/AD, other than to note that this auditory disorder will be missed by screening programs using OAEs alone.

OAE Future Needs

More research is needed in order to establish test and equipment parameters if TEOAE or DPOAE screening is to be considered a replacement for pure tone screening in the typical school aged population. "Blinded" studies are needed to validate TEOAE and DPOAE test performance with the "gold standard" for diagnosis, currently a comprehensive evaluation for hearing loss. Also, OAE test performance cannot be compared directly with tympanometric results, as the "gold standard" for identifying middle-ear disease is pneumatic otoscopy and confirmation via myringotomy. Reflectance measures of middle-ear function and OAEs may help us develop more efficient protocols for screening for hearing loss and middle ear disease in the future. Additional data are needed regarding developmental norms and appropriate pass/ fail criteria using TEOAEs and DPOAEs. Before firm guidelines can appropriately be established for OAE as a mass screening tool for childhood populations, training on how to consistently attain accurate responses requires study and replication. More data are needed regarding the appropriate age at which screening can be accomplished for preschoolers and school-age children. Very little data are available on costs associated with OAE screening programs in preschool and school-age children. Technical challenges with OAEs include developing new strategies to reduce noise in recordings and possibly even developing strategies to screen with the outer ear pressure equal to tympanometric peak pressure to mitigate the effects of negative middle-ear pressure on OAEs (Nozza, 2001).

Rescreening

The term mass screening means that all individuals within a population or large sample of people will be examined in an identical manner to determine the probability of presence or absence of some trait, condition, or behavior. Effective mass screening programs will have optimal sensitivity and specificity rates. Due to variations in earphone placement, child behavior and hearing fluctuations from transient middle ear conditions, a 2-tiered hearing screening program is recommended to reduce false positive results. This protocol would include the initial screen and same-day rescreen for failures with a second tier rescreen completed a predetermined number of weeks after the date of initial screening for those who do not pass the same-day rescreen. Rescreening, preferably within the same session, has been found to reduce the number of failures by approximately one-half due to repositioning of earphones and reinstruction (Ayukawa, Lejeune, & Proulx, 2003). The data available from one Florida school district (see Table 5) revealed that immediate rescreen reduced the total number of failures by 25%.

Because of the transient characteristics of middle ear effusion and the need to minimize over-referral, screening protocols for middle ear disorders have recommended a rescreen in response to

abnormal tympanometric results before recommending a medical referral (ASHA, 1997; US Dept. of Health and Human Services, 1997). The rationale for the length of the period between initial mass hearing screening and rescreening is based on information known about spontaneous resolution of transient middle ear effusion. The prevalence of middle ear effusion in children within the preschool population is extremely high but often resolves spontaneously without treatment. Bluestone (2004) found that 80 percent of middle ear effusion resolved on its own in two months. Fiellau-Nikolajsen (1983) found that 36 percent of cases had resolved in four weeks, an additional 23 percent had resolved in eight weeks, and 9 percent more resolved after another four weeks. Tos (1980) found 50 percent of a population of 2 year olds resolved in three months without treatment.

In order to reduce the high over-referral rates, the ASHA (1997) guidelines revised the time between the initial screen and the rescreen to 6-8 weeks. The American Academy of Pediatrics (2004) recommended watchful waiting of the child with OME for 3 months from the date of effusion onset or diagnosis before providing treatment. Additional reports of time between the initial screen and the rescreen range from 2 weeks in Head Start programs (US Dept. of Health and Human Services, 1997), to 16 weeks in a New Zealand program (Claridge, Schluter, Wild, & Macleod, 1995). Serpano and Jarmel (2007) looked at 34,979 children through the Long Island Hearing Screening Program, and reported 18 percent of children were medically referred for middle ear dysfunction after the initial screen using ASHA (1997) criteria. No rescreens were performed. Of 1,462 preschoolers screened in a North Carolina Head Start, 29 percent of the children referred following the initial screen using ASHA criteria, and 8.5 percent of the children still had abnormal results on the rescreen which occurred two weeks later (a 71% reduction) (Allen et. al., 2004). Data available from one Colorado school district (see Table 5) revealed that rescreen after 8 -12 weeks reduced the total number of children requiring referral by almost 75%. The trend from the reported data is the longer the time between the initial screen and the rescreen, the lower the number of children failing rescreen and requiring referral.

The 2004 AAP guidelines recommend "three months of watchful waiting" for otherwise healthy children diagnosed with OME and further state that antimicrobials should not be used for routine management. The AAP guidelines were established for the medical community, but because school screening programs often refer hearing screening failures to the medical home, these guidelines are relevant to the establishment of school program goals and protocols for rescreening and referral. Vergison et al. (2010) discuss the difficulty discriminating between acute otitis media (AOM) and otitis media with effusion (OME), as well as the challenges in determining onset and duration. These authors speculate that lack of information regarding documentation of the disorder is related to the continued systematic use of antimicrobial drugs for the treatment of otitis media. When the duration of OME is unknown, physicians must use whatever evidence is available and make a reasonable estimate (AAP, 2004).

Hearing screening by school systems that includes identification of children with middle ear malfunction, together with subsequent rescreening or monitoring of hearing and tympanometry over a 2-3 month period can provide the medical community with important information on the duration of OME so that appropriate management options can be determined. Because of the large number of children routinely participating in school hearing screening programs, it is likely that the initial suspicion of OME will be the result of school hearing screening rather than from the medical home. For this reason a coordinated effort among school screening programs and the medical community will result in the optimum management for students with OME.

Because the primary purpose of hearing screening programs is to identify children with previously undiagnosed permanent hearing loss, it is important that the process attempts to minimize the time between hearing screening failure and diagnosis for these children. Therefore, it would be appropriate to immediately refer children who fail pure tone hearing screening and a same-day hearing rescreen but pass tympanometry. Hearing screening programs may also choose to rescreen children failing pure tone screening at a single frequency in one or both ears, with passing tympanometry results, rather than seek immediate referral depending upon local circumstances (interference of noise in screening environment, availability of screening staff, availability of in-district audiological evaluation, etc.).

DISCUSSION/RESULTS/RECOMMENDATIONS

As previously discussed, children with unilateral, minimal and fluctuating conductive hearing loss are all at higher risk for school problems than children with normal hearing. Therefore, identifying children with mild, high frequency, conductive or unilateral hearing loss using cost-effective, stringent screening protocols in early childhood, preschool or school settings are warranted, as is the identification of emerging high frequency hearing loss in early adolescence. Evidence-based hearing screening practices to identify all potentially educationally significant hearing loss can be justified; however, district level resources (e.g. screening program budget, personnel, educational audiology staff) and the willing involvement of medical and clinical audiology professionals in the community to accept and document outcomes for hearing screening referrals will ultimately shape the populations to be identified and the strength of the follow up practices.

Protocol Recommendations*
*Note that the following guidelines are considered to be the minimum standard for educational settings. Programs are encouraged to follow a more intensive rescreening and referral protocol where staffing patterns permit.

Pure tone screening

Table 12. Summary of pure tone screening recommendations for frequency and intensity

Pure tone screening	500 Hz*	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz**	8000 Hz**
Right ear	No	20 dB	20 dB	No	20 dB	No	No
Left ear	No	20 dB	20 dB	No	20 dB	No	No

1. **Perform biologic check on pure tone equipment prior to daily screening.**
2. **Screen using pure tones for populations age 3 (chronologically and developmentally) and older.**
3. **Perform a pure tone sweep at 1000, 2000, and 4000 Hz at 20 dB HL.**
4. **Present a tone at least twice but no more than 4 times if a child fails to respond.**
5. **Screen in an acoustically appropriate screening environment.** The screening environment should not exceed 50, 58, and 76 dB SPL respectively for 1000, 2000, and 4000 Hz as measured by a sound level meter. If no sound level meter is available, the screening environment should be quiet enough for a normal hearing adult to perceive 1000, 2000, and 4000 Hz tones presented at 10 dB HL. If this is not possible then the effectiveness of hearing screening will be compromised due to higher-than-acceptable failure rates.
6. **Lack of response at any frequency in either ear constitutes a failure** in order to maximize the number of newly identified or emerging hearing losses that will be identified.
7. **Rescreen immediately.** Any child that fails to respond at any frequency in either ear should be rescreened immediately, preferably by a different tester and with a different audiometer to include removing earphones from the child's head and carefully replacing them over the ears.
8. **Grades recommended for standard protocols** include preschool, kindergarten, and grades 1, 3, 5 and either 7 or 9 at a minimum to identify approximately 70% of cases of newly identifiable hearing loss (based on the data available). If identification of a great proportion of children with new hearing losses is desired, adding grade 2 will result in a greater yield than adding a higher grade level. Consideration should be given to screening for high frequency hearing loss starting in grade 5.
9. ***Use tympanometry in conjunction with pure tone screening in young child populations** in communities where medical professionals and school systems jointly target identifying children with otitis media with effusion in addition to those with permanent hearing loss. Screening at 500 Hz does not effectively identify this population.

10. ****Screen for high frequency hearing loss** in school districts that intend to implement noise induced hearing loss prevention educational efforts. Two protocols are recommended (a) including 6000 Hz at 20 dB HL, or (b) screening at 15 dB at 500, 1000, 2000, 4000 and 8000 Hz. Steps to prevent high false positive rates in the high frequencies should be implemented (per Schlauch and Carney, 2010).

Immittance

Tympanometry

Table 13. Summary of tympanometry recommendations.

	Perform	Cut-off Criteria Negative pressure
Initial screening	No	NA
As part of an immediate follow-up or second tier screening (rescreening) OR	Yes OR	Tympanometric Width250 daPa (preferred criteria upon which to base referral decisions) OR
As part of an immediate follow-up or second tier screening	Yes	Static Admittance Flat or <0.2 mmhos OR
As part of an immediate follow-up or second tier screening	Yes	Middle Ear Pressure > -200 daPa to -400 daPa or (do not refer based on this criteria alone)

1. **Calibrate daily.** Prior to use each day, tympanometry equipment should be calibrated per manufacturer instructions.
2. **Tympanometry should be used as a second-stage screening method.** Tympanometry should be used as an immediate next screening step, and/or second stage screening, following failure of pure tone hearing or otoacoustic emissions screening to help clarify the nature of the failure and most efficient referral protocol. With this step, the students with active middle ear effusion and hearing loss versus those with possible sensorineural hearing loss can be differentiated.
3. **Use defined tympanometry screening and referral criteria.** It is recommended that failure be identified as tympanogram tracings in excess of 250 daPa tympanometric width (-255 daPa to -400 daPa). A secondary choice of failure criteria if tympanometric equipment does not allow setting failure criteria to tympanometric width is static admittance less than 0.2 mmhos (flat tracing or 0 mmhos to 0.19 mmhos). A tertiary choice of failure criteria would be negative pressure >-200 daPa to -400 daPa, however failure of MEP criteria alone would

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not result in a medical referral. This criteria would be applied to all children with the exception of those with large ear canal volumes who are known to have pressure equalization tubes (the latter who would be considered to pass screening when a flat tympanogram and large ear canal volume is present). A second exception would be for children of Asian heritage with tympanometric peaks with static admittance less than than 0.2 mmhos.

4. **Young child populations should be targeted for tympanometry screening.** Younger children (preschool, kindergarten, grade 1) are at higher risk for hearing screening failure secondary to middle ear effusion. As this is also a period of rapid language and literacy development for which good audition is foundational, it is recommended that school districts consider including tympanometry at least for children in toddler, preschool, kindergarten and first grade populations. If the screening program has the support of the local medical community and the capacity for follow-up, initial screening using pure tone (or OAE for < 3 year olds) and tympanometry for these young child populations should be considered.

5. **Use results of pure tone and tympanometry rescreening to inform next steps.** The results of the second hearing screening in combination with tympanometry can help determine the need for periodic hearing monitoring of those children suspected of having recurrent middle ear effusion, referral to audiology and/or medical evaluations, and can be used as guidance for school staff (e.g., teacher inservice, deferring educational evaluations).

Acoustic reflex and reflectometry

Based on the current evidence, neither acoustic reflex screening nor acoustic reflectometry are recommended for use in mass hearing screening programs for preschool or school-aged children.

Speech Materials

Use of speech materials for mass screening of children for hearing loss is not recommended.

Otoacoustic Emissions

1. **Use only** for preschool and school age children for whom pure tone screening is **not** developmentally appropriate (ability levels < 3 years).

2. **Calibrate daily.** Prior to use each day, OAE equipment should be calibrated per manufacturer instructions.

3. **DPOAE levels at 65 dB SPL.** It is best to maintain primary levels for DPOAEs at or below 65 dB SPL (for example, 65/55 or 65/65) to maximize the response.

4. **TEOAE levels at 80 dB SPL**. Stimulus levels for TEOAEs should be maintained at 80 dB ±3 dB to avoid contamination of the ear canal response. At very high intensities, a stimulus artifacts are seen the ear canal response. False TEOAE responses may be seen with clicks presented at high intensities (e.g., 90 dB pe SPL).

5. **Select DPOAE or TEOAE cut-off values carefully.** Pass/ fail criteria should be chosen carefully to maximize sensitivity and specificity. Based on information summarized in Table 10, a combination of parameters (e.g. waveform reproducibility, TEOAE amplitude, and TEOAE signal-to-noise ratio) may be used as criteria. For DPOAEs, criteria may be based on minimum DPOAE amplitude and SNR. These cut-off values may be frequency specific (see Table 11). Clinicians are encouraged to collect normative data and establish cut-off criteria with their own equipment.

6. **Default settings may not be appropriate.** It is important to understand the "default settings" on equipment used for newborn screening for stimulus parameters and pass/fail criteria before these settings are used in non-infant screening programs. Performance specifications and functions to be provided by manufacturers are specified in the IEC standards for OAE screening equipment (IEC 60645, 2009).

7. **Screening programs using OAE technology must involve an experienced audiologist.** An audiologist familiar with OAE technology should be involved in decision making regarding screening technology and in tracking program outcomes.

8. **Children failing OAE testing should be screened with tympanometry.** Performing tympanometry in conjunction with OAE screening with subsequent referral for audiological evaluation for children failing OAE only and rescreening for children failing both OAE and tympanometry may reduce the need for multi-stage screening and improve loss to follow up.

Rescreening

Table 14. Summary of rescreening recommendations.

	Perform	
Following initial screening failure	Yes	Immediate or same day rescreen of pure tones. Conduct tympanometry screening if child fails the immediate pure tone rescreen or initial OAE screen.
Rescreening as a second tier screening	Yes	Minimum of 8 weeks, maximum of 10 weeks. Rescreen children failing pure tone and (or*) tympanometry screening OR Rescreen children failing only a single frequency in one or both

		ears and pass tympanometry screen
Rescreening as a second tier screening	No	Children who fail pure tone screening and pass tympanometry screening** OR Children who have more than a single frequency failure in one or both ears who pass tympanometry screening**

*refer to pure tone screening recommendations #6, tympanometry recommendations #3

**Refer for audiological evaluation

1. **Rescreen with tympanometry after a defined period.**
   a. Following initial pure tone screening failure and immediate rescreen, children still not passing should be screened with tympanometry.
   b. Following failure of pure tone and tympanometry screening on the day of mass screening, children who do not pass tympanometry* or children who do not pass both tympanometry and pure tone screening should be rescreened. The rescreening period will at a minimum be 8 weeks after the initial screening date and no later than 10 weeks after failing mass hearing screening.
2. **Do not wait to perform a second stage screening on children who fail pure tone screening only.**
   a. In order not to delay diagnosis of permanent hearing loss, is it strongly suggested that screening programs do not rescreen children who fail pure tone hearing screening and immediate rescreening and pass tympanometry. They should be referred for audiological evaluation after the mass screening date rather than wait for 8 to 10 weeks to rescreen.
   b. Hearing screening programs may choose to perform second stage screening on children failing a single frequency only in one or both ears. Children who fail two or more pure tone frequencies in one or both ears with passing tympanometry screening results should be immediately referred for audiological evaluation.
   c. School districts that employ audiologists to provide clinical evaluations may choose to immediately refer for audiologic evaluation those children failing tympanometry and two or more pure tone frequencies in order to assist in determining need for educational accommodations. In settings where no in-house audiological evaluation can be performed, referral by the primary physician for hearing evaluation may be required. Physician referrals to audiology may be more likely to occur following failure of hearing

and tympanometry rescreening 8-10 weeks after initial mass screening, with no access to hearing-related educational accommodations during this period.

REFERRAL AND FOLLOW-UP

When making responsible referrals to the medical community, it is important for audiologists to recognize how treatment for conditions with middle ear effusion has changed. Clinical practice guidelines on OME resulting from the joint efforts of the American Academy of Family Physicians (AAFP), the American Academy of Otolaryngology-Head and Neck Surgery (AAO/HNS) and the American Academy of Pediatrics (AAP) concluded that OME medical therapies should only be used if OME is persistent or provides significant benefit beyond the natural course of OME. It was further recommended that children with OME without risk factors should be monitored for three months from the date of onset or diagnosis. When a referral is made from the hearing screening program to the medical community the following information should be included if known: duration of OME, laterality of OME, results of prior hearing evaluations or tympanometry, evidence or concern of any speech/language difficulties, and any conditions that would exacerbate the impact of OME (AAP, 2004).

Mass screening is only effective if it results in the children identified receiving evaluations to determine if the condition of concern is truly present or absent. Accomplishing this for every child identified via school hearing screening is often challenging as it can require caregivers to devote time, health care resources and/or private funding to set up and transport their children to medical or audiological evaluation appointments. Flanary, Flanary, Colombo and Kloss (1999) evaluated the mass hearing screening program of a major metropolitan area and concluded that there was very poor follow-up by the families of those students needing referrals following the screening program. In the three school districts from which data were collected, information following referral was returned to the school in only 10-20% of cases. One Colorado school district documented that approximately 40% of the information returned following hearing screening was by families of preschool children, with return rates decreasing in number as children became older. Increasing family follow-up for medical evaluation following a child's hearing screening failure is challenging. It is important that screening results and referral information be presented to the family in their native language. Including a photo from video otoscopy, serial pure tone and tympanometry screening results, and a pamphlet describing potential effects of undiagnosed hearing loss are suggested considerations. It remains critical for the individual(s) coordinating the school hearing screening program to develop relationships with the local medical community, inform them of the screening protocols used and encourage their collaboration in returning results of medical or audiological evaluation following a hearing screening referral.

Some of the children identified by pure tone screening and tympanometry may have persistent or recurrent middle ear effusions that place them at higher risk for developmental, medical, and subsequent educational consequences. As has been illustrated, feedback on the result of the evaluation

following the referral from screening is relatively rare. Some school districts monitor the middle ear and hearing status of children with apparent middle ear effusion after mass hearing screening and referrals have been completed. One Florida school district referred 61% (Table 5) of children failing hearing screen and chose to follow 39% to the resolution of middle ear effusion or identification of students with effusion and episodic hearing loss for 3 months or more. The other two school districts routinely followed children referred with abnormal tympanometry screening results until the child was able to pass hearing and tympanometry screening three times consecutively. Monitoring hearing and middle ear status may also be justified for children with ventilation tubes, a family history of permanent hearing loss, syndromic populations at high risk for hearing loss and annual recheck of permanent hearing loss that does not meet criteria for hearing impairment under special education. Based on the small sample of data gathered, school districts with well-developed hearing screening programs and educational audiology services may routinely monitor 1% or more of the school district population annually or semiannually.

It is very important to recognize that the recommendations in this document represent minimum practice guidelines for mass hearing screening in school settings. If a school district employs educational audiologists who provide clinical hearing evaluations the number of students receiving referrals for both medical and audiological evaluation or audiological evaluations only, is likely to increase. In many cases children cannot be evaluated by an audiologist in a community clinic setting without referral from their primary physician, and these realities are likely to influence referral patterns.

HEARING SCREENING PROGRAM MANAGEMENT

Personnel and Staff Training

Richburg and Imhoff (2008) studied the training of hearing screening personnel in school systems. They reported that with no common source of training or supervision, the protocols used by persons performing the hearing screenings varied greatly. These authors also found that when a school system had an educational audiologist as a single supervisor the methods used for testing were much more consistent. Their results indicated that it was beneficial for identifying students with undiagnosed hearing loss (including minimal hearing loss) to have an educational audiologist train and supervise hearing screening personnel, and this was especially true when the audiologist was on site during the screening process. As a result of their survey, the authors concluded, "…supervision by an educational audiologist can lead to more uniform screening protocols that, in turn, should result in more accurate screening results, a better system for referrals, and proper diagnoses" (pg. 41).

The World Health Organization reported results of 240 subjects that received hearing screening by minimally trained "junior testers" that were compared with results for the same subjects when screened by specialist testers in ideal conditions in a soundproof room. Tests of inter- and intra-

observer variation revealed a variety of significant differences among results obtained by experienced and junior testers. It was recommended that screening programs have an experienced tester (at least one year experience in audiometry) for hearing testing in the field. Where newly trained testers are used, inter- intra- observer validation should be measured before mass hearing screening begins to determine the good and poor testers (WHO 2001).

Many states have licensure requirements for audiology assistants whose job description includes hearing screening. School personnel, including audiologists, who are responsible for hearing screening program management, should be familiar with their state's requirements. Additional information on the training, use, and supervision of audiology assistants can be found in guidelines developed by ASHA and AAA that were developed collaboratively as a Consensus Panel on Support Personnel in Audiology in 1997 (AAA 1997). In addition AAA has recently published an updated position statement that specifically addresses audiology assistants (AAA, 2010).

It is recognized that many of the thousands of school districts in the U.S. neither employ nor contract with an audiologist, and their hearing screening programs are managed by a non-audiologist who is typically a school health professional. Due to the importance of follow up within the medical community, it is very strongly recommended that the non-audiologist managers of school hearing screening programs utilize a single or small group of representative audiologists from their communities as an advisory body for hearing screening programs. This assistance is to ensure the appropriateness of the technical details of equipment, training, and protocols, as well as to facilitate buy-in by community audiologists that will ultimately improve collaborative referrals, recommendations, and follow-up.

Scheduling

Scheduling mass or school-wide hearing screenings must be a collaborative process between the audiologist or other program manager, persons completing the screenings, volunteer assistants, and relevant school personnel (e.g. principal, school nurse). Among the factors to consider are number of students and grades to be screened, grade-level or school-wide assessment time periods, scheduled vacation days, availability of support personnel and volunteers to assist onsite with the screening process, weather-related factors, and adequate time for follow-up screening and evaluations.

Consultation with the school principal is needed to provide a yearly schedule of grade-level academic assessments, as well as any other scheduled activities that might impact efficient implementation of school-wide hearing screening. Screening in the fall is most advantageous for follow-up of failures, but inservice time for training personnel to assist must be implemented prior to the actual screening. For these reasons, it might be more efficient to stagger grade levels screened throughout the school year especially for districts that have large numbers of students to be screened. Often school administrators will prefer to have the screening completed for all grades in one building on the same day, since that typically is less disruptive to the school routine and works efficiently for schools with

smaller student populations. If school volunteers are being used, a single designated screening day is also more practical. Weather-related issues and times of higher absenteeism may also need to be factored in for some schools or districts, and a higher screening failure rate can be expected during periods when children are more prone to have middle ear problems (i.e. winter or allergy seasons).

Equipment Selection

The types of equipment used for hearing screening will vary depending on the resources available to the program, the environment in which the screening will occur, the target population to be screened, and the expertise of the screening personnel. In addition to the actual screening instruments used, some equipment may require additional supplies, such as probe tips for otoacoustic emissions testing and immittance screening, insert earphones for pure tone screening, and specula for visual inspections using an otoscope. Probe tips, specula, and foam inserts may be disposable or reusable, but care must be taken to ensure they are properly sanitized before they are used again (see section that follows on infection control).

Pure tone screening equipment

Pure-tone screening requires the use of a pure-tone audiometer. Although screening audiometers with limited frequencies and intensity levels that may be pre-set are available, the cost-benefit of using a single-channel portable audiometer with two earphones (either circum-aural or insert style) that produces a minimum of octave frequencies between 250 and 8000 Hz at levels ranging from 0 to at least 90 dB HL should be considered. The money that will be saved when purchasing a limited frequency/intensity audiometer may not be worth the flexibility that is lost with this type of equipment. With a standard pure-tone audiometer, the screening level and the frequencies to be screened can be determined, rather than using the predetermined levels and frequencies set by a screening audiometer. Additionally, the standard pure-tone audiometer can be used for both screening and threshold procedures, whereas the screening audiometer can be used only for screening.

A pure-tone audiometer used for screening should be portable, lightweight, and durable. Most audiometers incorporate use of an electrical plug for power, but some audiometers are powered by a rechargeable battery. If battery-powered, a visual indicator for low battery charge should be included. Older school facilities may include screening environments with older electrical wiring where outlets are incompatible with three-pronged plugs found on many audiometers. The use of adapters typically does not meet electrical and/or fire code requirements, so screening audiometers with three-pronged plugs may be a safety hazard and thus have limited use in these school facilities. School safety directors should be consulted to determine any special electrical requirements before purchasing hearing screening equipment. Audiometers should be calibrated to the current standards developed and adopted by the American National Standards Institute (ANSI 3.6-2004). Specifications and appropriate corrections should be made when using insert earphones.

<u>Immittance screening equipment</u>

There are a number of automated acoustic immittance instruments that are useful for screening. The audiologist should be certain that the equipment can quickly and easily provide measurements of the components that will be considered in the screening, e.g., gradient, ear canal volume, and peak pressure, and that the instrument meets the ANSI S3.39 (1987) standards for instruments to measure acoustic immittance. Although some instruments are capable of multi-frequency measures, a 226 Hz probe tone is appropriate for screening preschool and school-aged children. As with pure-tone audiometers, an immittance screening instrument that is lightweight and durable is preferred. Instruments that contain both a pure tone audiometer and acoustic immittance reduce the number of pieces of equipment that must be transported and set-up, but a significant disadvantage is that when one component malfunctions, both are out of commission while repairs occur.

If immittance screening is included, a visual inspection of the ear canal and tympanic membrane using an otoscope must be completed prior to inserting the probe tip. The main requirement for an otoscope is that there be sufficient light to view the ear canal adequately. Halogen bulbs now available in many otoscopes provide the necessary brightness. Care must be taken to follow infection control strategies when using an otoscope, and selection should include considering purchase of disposable and/or latex-free specula.

<u>Otoacoustic emissions screening equipment</u>

Otoacoustic emissions screeners are automated and can incorporate several types of stimuli. Some screeners perform DPOAE, TEOAE or both types of tests. They come with an assortment of disposable or reusable probe tip inserts (again, care should be taken to include a visual inspection of the ear canal and tympanic membrane prior to inserting probe tips). Hand held screeners have easy to read screens, menu options and give a pass/refer test result requiring no interpretation. They will also give error messages such as when a poor seal is obtained or if the background noise level is too loud for the test to run. OAE screeners can run on battery power, AC or both. They can hold anywhere from 50 to 100 tests or run for 3 hours before needing to recharge if running on batteries. The cost of general maintenance, calibration, battery replacement, software upgrades, and replacement probes should be considered. Some screeners have portable printers that allow the test results to be printed at the test site. OAE screeners can also come with training manuals, quick reference guides and training videos. They come typically set with a default pass/refer criteria (e.g., 4 out of 4 frequencies, 3 out of 4 frequencies or 2 out of 4 frequencies). However, many units have options for changing the default pass/refer criteria.

Equipment Maintenance

Regardless of the type of equipment used in a screening program, it is critical that it be working properly on the day of the screening. Unless the equipment is performing as intended, the screening will not be accurate, resulting either in passing some children who have a hearing problem or in excessive failures. A back-up plan with loaner equipment should be developed for emergencies. All equipment should be calibrated to the required standards at least annually, and screeners should be trained to perform a daily listening and visual check prior to the use of the equipment. Screeners should be alert to excessive referrals during the screening process, and equipment should be checked any time it seems to be functioning improperly. Most manufacturers or their local representatives offer annual calibration and repair contracts. These contracts may prove to be cost-effective for larger districts or multi-system school cooperatives that are responsible for a large stock of hearing screening equipment, since many providers will negotiate cost based on numbers of instrument pieces that require recalibration. Back-up loaner units may also be available under a contractual repair agreement.

Infection Control

The purpose of infection control is to minimize the exposure of people and the environment to microorganisms that may make the testers or the students being tested, sick (Kemp & Roeser, 1998; Kemp & Bankaitis, 2000a; Kemp & Bankaitis, 2000b). The amount of risk from exposure to microorganisms can depend on the type of screening tests performed and the opportunities for transfer of microorganisms from person to person either directly or indirectly. Tympanometry or otoacoustic emissions screening provide opportunities for contact with and exposure to cerumen. Cerumen itself is not considered to be an infectious material, but it can contain substances that can be infectious (Kemp, Roeser, Pearson, & Ballachandra, 1996).   Because of cerumen's color and consistency it may be difficult to determine if there are contaminations from blood or other infectious substances, and, therefore, cerumen should always be treated as if it contains an infectious material (Kemp et al., 1996).

Probe tips used for tympanometry or otoacoustic emissions testing and insert earphones for pure tone testing should either be disposable or cleaned and sterilized after each use (Bankaitis, 2005; Clark, Kemp, & Bankitis, 2003). Surfaces such as supra-aural headphones and toys or objects used during screening should be cleaned and disinfected before each re-use by using a product such as a wipe or spray. Finally, it is always a good idea to check to see if there has been a lice outbreak in the population of students being screened. If so, a modification of the screening schedule is recommended. Although lice are unlikely to prefer the surface of the headphones to a scalp, the act of bending over to properly seat the headphones over the ears potentially places the adult performing the screening at-risk for lice transmission.

Each hearing screening program should include a section on strategies and techniques to be used to minimize the potential for spread of infection in the screening protocol, and persons responsible for this task should be identified (ASHA, 1991; Ballachanda, Roeser, & Kemp, 1996; Joint Commission on

Accreditation of Health Care Organizations, 1995; U.S. Department of Labor, Occupational Safety and Health Administration, 1991).

Accountability

Program management responsibilities for a hearing screening program must target the following three primary areas: accountability, risk management and program evaluation. The audiologist or designated non-audiology program manager is accountable for developing, supervising, and implementing any hearing screening program. Non-audiology personnel may perform the actual screening, but an audiologist typically is ultimately responsible for the training and supervision of the personnel administering the screening. As stated in the section above covering personnel and staff training, many states have licensure and/or certification requirements for supervising personnel in hearing screening programs, and the program manager should ensure that these requirements are met.

Program management responsibilities also include implementing a protocol that ensures patient confidentiality, parental notification and/or permission when required, appropriate referral, and counseling. It is strongly recommended that a single school-based staff member be designated for tracking referrals that arise from each school's hearing screening program to facilitate follow-up of individual student recommendations. However, it may be more efficient to develop and maintain a system-wide database for accountability and program evaluation purposes.

Management of risk factors, including the potential for infection, invalid screening results based on equipment malfunction or errors in calibration, and errors in patient referral and follow-up should also be under the surveillance of an audiologist. Quality assurance activities include on-site supervision, written documentation, and review on an annual basis at a minimum. Following this annual review, any revisions in protocols, to include recommendations for modifications in the referral system should be made.

Program managers must be knowledgeable about the requirements for parental consent under the law. The need for parental notification and/or permission for a child to participate in hearing screening when parents are not present may vary under local, state, and federal requirements for each population screened, and school districts are responsible for ensuring that their hearing screening protocols comply with current regulations. Typically, if the program is one of screening every child, parents must be given notice and allowed to refuse to have their child included. This notice can be completed easily and efficiently by the provision of written information during the school enrollment process. Follow-up testing where the child is singled out and given a rescreening or follow-up evaluation requires informed written parental consent unless rescreening is specifically included in the initial parental notice. Parents should always be provided with a copy of results and recommendations.

Evaluation

Program evaluation refers to the responsibility of the program manager to evaluate the effectiveness of the screening program. This involves developing mechanisms to (a) quantify the pass and refer rates, (b) estimate the false-positive and false-negative rates (i.e. sensitivity and specificity), and (c) assure the effectiveness of follow-up protocols for patients who need rescreening or are referred from the screening process. Program evaluation should occur on an ongoing basis to identify and adjust factors that hinder optimum screening program performance and patient care. Careful consideration of components such as professional liability, risk management and quality assurance as integral parts of program accountability and evaluation must be completed prior to implementation of any screening program. Appropriate development of these components assists the audiologist in ensuring overall program quality and effectiveness.

Types of information needed to determine the program's effectiveness include the following (adapted from Johnson and Seaton, 2011):

- Total number of children screened;
- Number and/or percentage of children who did not pass the initial screening
- Number and/or percentage of children who missed the initial screening due to absence, parental refusal or other reasons
- Number and/or percentage of children who did not pass a rescreening
- Number and/or percentage referred on for follow-up (audiological, medical, educational)
- Number and/or percentage seen for follow-up evaluations (audiological, medical, educational)
- Number and/or percentage with diagnosed hearing problems
- Number and/or percentage provided with medical treatment and/or educational services for hearing problems (including amplification or hearing assistive devices)

These data can help document need for the hearing screening program, identify over or under referrals that can target equipment or training needs, help track loss to follow-up, and clarify other issues that impact the efficiency and effectiveness of a hearing screening program In the schools.

Cost effectiveness is a critical aspect of hearing screening program evaluation. The total cost of personnel, equipment, equipment maintenance, and forms for each year can be compared to the number of children screened to determine the cost of screening each child. Additionally, the number of children identified as having a hearing problem (whether permanent or transient) can be compared to the total cost of the program to determine the cost of identifying each child with a hearing loss that may have educational impact.

SUMMARY

The evidence reviewed supports hearing screening in early childhood and school-aged populations to facilitate identification of late-onset or acquired permanent hearing loss and longstanding or frequently recurring conductive hearing loss that may impact linguistic development

and school performance. It is imperative that evidence-based practices be used by school hearing screening programs to the maximum extent possible. Annual hearing screening in early childhood, monitoring hearing of high risk populations and educational efforts targeting prevention of noise-induced hearing loss are critical strategies for achieving optimal academic and economic outcomes. These guidelines are based on current research and provide recommendations for education and public health agencies involved in implementing hearing health initiatives. Advocating for student needs and empowering parents with information about their children's ear/hearing status and related educational risks are necessary for family follow-up of hearing screening referrals. Equally important are collaborative relationships between the school hearing screening program, district student health program, educational audiology and the medical community to achieve the goal of optimal hearing health for every developing child.

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Appendix A: Summary of Screening Protocols of Three Large School District Hearing Screening Programs [i]

Hearing Screening Protocols	Orange Co (Orlando)	Cherry Creek (Denver suburb)	Douglas County (Denver area)
Frequencies screened	500, 1000, 2000, 4000 Hz	PS-K: 1k,2k, 4k + tympanogram; 1: 500,1k,2k,4k + tympanogram; Gr 2-5: .5, 1, 2, 4KHz Gr 6-12: 1, 2, 4, 6KHz	K-Gr 6: .5, 1, 2, 4KHz Gr 7-12: 1, 2, 4, 6KHz
Respective decibel levels for each frequency	30dB – 500 Hz 20dB – 1000, 2000, 4000 Hz	20dB- 500, 1000, 2000, 4000, 6000 Hz	25dB- 500, 6000 Hz 20dB- 1000,2000, 4000 Hz
Pure tone screen – initial screen of all students	YES	YES	YES
Tympanometry screen - initial screen of all students	NO	Preschool – Grade 1	K – 1 only Presch. when seen
Tympanometry used in immediate rescreen (same day of failed pure tone)	YES	YES	YES
Pure tone plus tympanometry for rescreen	If tymps were abnormal on immediate rescreen	Generally, unless high Hz hearing loss	YES
Pure tone, tympanometry only if PT not passed	YES		YES
Failure criteria for tympanometry: Flat plus?	> -150 daPa	>-200 daPa	>-275 daPa or <0.2
Screening protocol for secondary different	NO	YES	YES
Recheck protocol	3 months for medical referrals, 6 months for new permanent loss, annual for stable hearing losses	Annually for SN/HL; monitor tubes at least 2x/yr; monitor middle ear problems each visit to bldg.	Monitor until pass 3 consecutive tympanometry and threshold checks
Staff used in screening process	Volunteers,	Audiologist,	Volunteers for first

	audiologists, Techs for initial screen; Audiologist/Tech for immediate and rescreens	sometimes with assistance of Tech; Audiologist for rescreens	line screening; Techs/Audiologist for rescreen

Appendix B: Summary of Results of Three Large School District Hearing Screening Programs

Average mass hearing screening results for 3 years (2007/2008, 2008/2009, 2009/2010)	Orange Co (Orlando)	Cherry Creek (Denver suburb)	Douglas Co (Denver)
Total number students screened 2007 – 2010 (3 yrs)	187,987	37,503 (2 yrs)	101,931
Grades mass screened each year	PS, K, 1, 2, 3, 6	PS, K, 1, 2, 3, 5, 7, 9	K, 1, 2, 3, 5, 7, 9
% failing initial screen	8%	not available	not available
% failing immediate rescreen of total screened	6%	8.8%	3.7%
Rescreened after what period (weeks)?	8-10 weeks	8-12 weeks	8-12 weeks
% failing rescreen	not available	not available	25.9%
Percent of total # screened that were referred	6%	4%	3.16%
Referral to Medical – percent of total referred	25%	63%	33%
Referral to Audiology – percent of total referred	23%	37%	61.5%
Referral to both – percent of total referred	13%	0	5.5%
Percent of total referred for which evaluation results are reported back to school (verbal/written)	20% (medical refers)	20%	12.6%
% of total number of newly identified permanent hearing loss per grade Preschool (3 to 5)	12%	1%	9%
Kindergarten	28%	25%	10%
1	25%	21%	12%
2	16%	13%	7%
3	9%	9%	11%
*Denotes grade not included in mass screen 4	*	*	*
5	*	13%	15%
6	7%	*	*
7	*	13%	22%
8	*	*	*
9	*	5%	14%
10	*	*	*
11	*	*	*

	12	*	*	*
Pass rate for elementary (PS-5) initial screening	91%	89%	96.5%
Pass rate for secondary (6-12) initial screening	93%	91%	96.1%
Percent of newly diagnosed hearing loss due to unilateral/bilateral high frequency hearing loss	23%	not available	15%

Appendix C. Percent of total group of students with newly identified hearing loss in specified grade combinations for mass hearing screening based on results from 3 school districts.

Grade combinations	OCPS	CCSD	DCSD
PS, K	40%	26%	19%
PS, K, 1	65%	49%	31%
PS, K, 1, 2	81%	63%	38%
PS, K, 1, 3	74%	58%	42%
PS, K, 1, 5 or 6	72%	62%	53%
PS, K, 1, 3, 5 or 6	81%	71%	57%
PS, K, 1, 2, 3	90%	72%	49%
PS, K, 1, 2, 3, 5 or 6	97%	90%	72%
PS, K, 1, 5, 7	-	75%	68%
PS, K, 1, 5, 9	-	67%	60%
PS, K, 1, 3, 5, 7	-	71%	64%
PS, K, 1, 3, 5, 9	-	76%	71%
PS, K, 1, 2, 3, 5, 7	-	84%	71%
PS, K, 1, 2, 3, 5, 9	-	89%	78%

[i] Appendix A-C contain unpublished data provided by Orange County FL, Cherry Creek CO, and Douglas County CO school districts for the 2007-2008, 2008-2009, and 2009-2010 school years.