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Research Article

Accuracy of School Screenings in the Identification of Minimal Sensorineural Hearing Loss

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Purpose: The goal of this study was to investigate how the use of a 25 dB HL referral criterion in school screenings affects the identification of hearing loss categorized as minimal sensorineural hearing loss (MSHL).
Method: A retrospective study applied screening levels of 20 and 25 dB HL at 1000, 2000, and 4000 Hz in each ear to previously obtained pure-tone thresholds for 1,475 school-age children. In a separate prospective study, 1,704 children were screened at school under typical conditions, and a subsample had complete audiological evaluations. Referral rates, sensitivity, and specificity were calculated for each screening level.
Results: Referral rates varied by grade and criterion level, with comparable results between the two data sets. In both studies, when the screening level increased, the sensitivity to MSHL declined markedly, whereas specificity increased in the prospective study.
Conclusions: Screening at 25 dB yields poor sensitivity to MSHL. Converging evidence from these diverse populations supports using the 20 dB level to help identify MSHL. Multistage screening is recommended to limit referral rates. Even at 20 dB HL, cases of MSHL may be missed. Audiologists should encourage parents, educators, and speech–language pathologists to refer children suspected of hearing difficulty for complete audiological evaluations even if they pass school screenings.

Identification audiometry is an important component of any comprehensive management strategy for school-age children with hearing loss. It is a well-accepted approach designed to separate in a simple, rapid, and inexpensive manner those children who have hearing loss from those who do not. Because children with minimal sensorineural hearing loss (MSHL), including children with slight/mild bilateral losses and unilateral losses, have been found to be at risk for a variety of psychoeducational problems (i.e., communication, social and emotional, academic; Bess, Dodd-Murphy, & Parker, 1998; Bess & Tharpe, 1984; Bess, Tharpe, & Gibler, 1986; Crandell, 1993; Most, 2004, 2006; Oyler & Matkin, 1988; Porter, Sladen, Ampah, Rothpletz, & Bess, 2013), it is important to identify and to monitor the progress of these children in the schools, even though they may not all qualify for individualized educational planning. Participants at the National Workshop on Mild and Unilateral Hearing Loss (2005) adapted criteria from Bess and colleagues (Bess et al., 1998) in their working definition of permanent mild or unilateral hearing loss: a bilateral hearing loss with pure-tone averages (500, 1000, 2000 Hz) between 20 and 40 dB HL in both ears, isolated high-frequency loss with air conduction thresholds greater than 25 dB HL at two or more frequencies above 2000 Hz in one or both ears, or unilateral hearing loss with a pure-tone average greater than or equal to 20 dB HL in the affected ear. Air–bone gaps of 10 dB or less were also required (hearing losses with air–bone gaps greater than 10 dB could also be included after ruling out medical intervention). In the present study, we use the National Workshop definition in categorizing MSHL.

Screenings of school-age children are of particular importance in detecting MSHL because of challenges that prevent its discovery at earlier ages. MSHL may be missed in infancy because neonatal screening methods are less sensitive to hearing loss below a moderate degree (Holstrum & Gaffney, 2005; Johnson et al., 2005; Joint Committee on Infant Hearing, 2007). Children with mild hearing impairment make up a large proportion of those who passed hearing screenings as newborns but who were identified in the preschool- or school-age period (Bamford et al., 2007; Beswick, Driscoll, Kei, & Glennon, 2012). In addition, the

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children lost to follow-up after failing newborn screenings are more likely to be those with milder loss (Liu, Farrell, MacNeil, Stone, & Barfield, 2008). Cone and coworkers indicated that evaluating risk factors may not be effective at identifying children with MSHL (Cone, Wake, Tobin, Poulakis, & Rickards, 2010). Additionally, acquired, progressive, and late-onset genetic hearing impairments are also targeted by school screening (Bamford et al., 2007; Cone et al., 2010; White & Muñoz, 2008).

Although pure-tone screening is the primary tool for identifying hearing losses in school-age children, the amount of variation in the methodology and referral criteria may render school-based screening less effective for identifying MSHL (American Academy of Audiology [AAA], 2011; Bamford et al., 2007). National guidelines (AAA, 2011; American Speech-Language-Hearing Association [ASHA], 1997) recommend screening at 20 dB HL for 1000, 2000, and 4000 Hz in each ear; children missing one or more tones in either ear would fail to pass the screening. Despite these evidence-based guidelines, state, regional, and/or school protocols vary widely; the most common referral criterion levels at the recommended frequencies are 20 and 25 dB HL (Bamford et al., 2007; Meinke & Dice, 2007; Penn, 1999). In addition, examiners often depart from standard protocols because of acoustic environment or concern about referral rates (AAA, 2011; Allen, Stuart, Everett, & Elangovan, 2004; Bamford et al., 2007).

The consequence of increasing the referral criterion level to decrease referral rates is a drop in sensitivity to hearing loss. There is a tradeoff between sensitivity and specificity of screening when the cutoff criterion is changed—a higher dB level cutoff that increases specificity (refers fewer children with normal hearing) will also decrease sensitivity. The common practice of using a 25 dB HL cutoff for pure-tone screening (rather than 20 dB) would be expected to decrease the sensitivity of the screening to MSHL. Meinke and Dice (2007) evaluated a variety of school screening protocols for the ability to detect noise-induced hearing loss, a commonly cited source of MSHL in adolescents. For the two most common protocols, screening bilaterally at 1000, 2000, and 4000 Hz at either 20 or 25 dB HL, they found poor sensitivity to noise-induced hearing loss for both levels; however, the 20 dB level detected a greater proportion of the noise-induced loss than did 25 dB (22.2% and 6.7%, respectively). The diversity of school hearing screening practices and the lack of studies on screening for MSHL both suggest that more research is needed in this area. Clearly, there is a need to develop a better understanding of the effectiveness of school screenings at identifying MSHL.

We analyzed two different databases to determine how increasing the cutoff criterion from 20 to 25 dB HL affects the sensitivity and specificity of pure-tone screening for detecting MSHL. First, the referral criteria were applied to known hearing thresholds of a large population of school-age children that included children with MSHL (Nashville study: Bess et al., 1998). The second data set was from a separate prospective study (Watauga County study) of follow-up hearing evaluations of children screened in typical school acoustic environments.

Method

Participants

Nashville Study

A complete description of the data collection procedures resulting in pure-tone audiograms for 1,475 children in grades 3, 6, 9, and 11 is detailed elsewhere (Bess et al., 1998). The children attended urban and suburban schools in the Nashville Metropolitan School District in Tennessee. Audiometry was conducted on site at each school in a sound-treated mobile unit. Pure-tone air conduction thresholds were obtained for each student at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in each ear. Bone conduction testing was performed when a student met the criteria for MSHL. Hearing loss was classified as sensorineural when air-to-bone conduction gaps equaled 10 dB or less. Tympanometry results were also considered in the classification of type of loss (conductive vs. sensorineural).

Watauga County Study

The initial hearing screenings were completed in the fall of the academic year, with the subsequent audiological evaluations scheduled in the spring of the same academic year. Following approval by the Appalachian State Institutional Review Board and the Watauga County School Research Committee, students in grades 1, 2, 3, 5, and 7 were invited to participate in the study. Of a total of 1,704 students screened in the fall, 108 children failed to pass the initial screening at 25 dB HL. All of these children were invited to participate in the study, along with 315 children who had passed the initial screening (at either 20 or 25 dB HL). Children invited from the "pass" group were chosen randomly from the screening records within the same grade and school of the children who were referred.

Teachers distributed letters describing the study, and those children whose parents returned the signed consent forms were scheduled for complete audiological evaluations at the Appalachian State Communication Disorders Clinic. A total of 82 children, with at least one participant from each of the eight county schools, received audiological evaluations, yielding a response rate of 19.3%. Forty of the participants were female; 42 were male. There were 25 in first grade, 23 in second grade, 19 in third grade, 11 in fifth grade, and four in seventh grade. The audiological evaluations were provided free of charge, and a cash payment of $10 was given to each child who participated.

Procedure

Nashville Study

To determine the effectiveness of the screening criteria, first, the audiograms from the Nashville database were categorized as MSHL, Normal Hearing, or Other. Audiograms that displayed normal hearing had no thresholds greater than 25 dB HL in either ear and pure-tone averages of less than 20 dB HL in both ears. The Other category was given to all audiograms showing hearing loss that did not meet the criteria for the MSHL or Normal Hearing categories, including conductive losses and bilateral sensorineural losses beyond the criteria for MSHL. A small number of participants demonstrated a hearing threshold outside normal limits (greater than 25 dB HL) at one frequency but did not meet the criteria for MSHL; their audiograms were also categorized as Other.

Each audiogram was then classified into one of three categories (pass, refer20, or refer25) depending on the pure-tone thresholds at 1000, 2000, and 4000 Hz in each ear. The assumption was that a child would respond to a frequency when the pure-tone screening level was equal to or greater than the child's threshold. For example, a child with thresholds of 20 dB HL at all three frequencies in each ear would pass the screening either at 20 or 25 dB HL. A child designated as "refer20" would have a threshold at 25 dB HL for at least one of the three frequencies in either ear but no thresholds greater than 25 dB at the screening frequencies. This child is assumed to pass a screening at 25 dB HL but to be referred when screened at 20 dB HL. The "refer25" category includes children with at least one threshold greater than 25 dB HL at one of the screening frequencies. These children would presumably fail the screening at either 20 or 25 dB.

On the basis of the categorical analysis, referral rates, sensitivity, and specificity were calculated for screening with a criterion of 20 and 25 dB HL. Hearing losses categorized as "Other" were omitted from the sensitivity/specificity analyses for MSHL.

Watauga County Study

Screening. All screenings were carried out in the eight elementary schools (K–8) of the Watauga County School District in the northwest corner of North Carolina. Two schools were in small cities; all others were in rural areas. All children present on the day of screening in grades 1, 2, 3, 5, and 7 were screened according to the current state guidelines. Additional students in other grades were screened because of teacher referrals for hearing-related concerns. Children with known hearing loss were not exempted from the screening to avoid singling out children as not participating in a whole-class activity. The screenings were conducted in a quiet classroom or office at each school. Noise levels varied; examiners were instructed to consider transient noise elevation in timing presentation of the tones, and ambient conditions were monitored throughout using periodic biological checks of the audiometers at 20 dB HL for listeners with known normal-hearing thresholds.

Pure-tone screenings were administered by master's-level students in speech–language pathology under the direct supervision of a North Carolina–licensed, ASHA-certified audiologist. The screenings were conducted using portable audiometers (Maico MA27, Beltone 119, or GSI 17) equipped with TDH-39 earphones. The audiometers were calibrated to meet ANSI S3.6-1996 standards (American National Standards Institute, 1996), and listening checks were conducted before and periodically throughout each screening session. All graduate clinicians were instructed by the supervising audiologist before the screening regarding procedure, criterion for referral, and data keeping. Children were screened at 1000, 2000, and 4000 Hz at 20 dB HL in each ear; they indicated that a tone was heard by raising a hand. If a child missed any one frequency in either ear after up to three presentations at 20 dB HL, the screening was repeated at 25 dB HL at all frequencies in each ear. Children who missed one or more frequencies in either ear at 25 dB HL were regarded as a categorical "refer." In cases where children did not pass the screening at 20 dB HL but passed at 25 dB HL, results for both screening levels were recorded, and the children were considered as passing. The speech–language pathologist(s) employed by each school later rescreened the children who failed to pass the initial screening at 25 dB HL. The authors did not have access to the rescreening records, so the pass/refer category of each child was based on the initial mass screening, using the same categories as in the Nashville study: pass, refer20 (those who passed at 25 dB HL but failed at 20), and refer25.

Audiologic evaluation. All audiologic evaluations were conducted by a licensed audiologist in a sound-treated booth in the university hearing clinic setting. The follow-up evaluation included a brief case history interview, including questions about parental concern regarding hearing, colds, sinus problems, ear infections, tubes, noise exposure, and family history of hearing loss. Children were asked about whether they had experienced hearing difficulties, tinnitus, or unexplained dizziness. Other assessments included otoscopic inspection and tympanometry (using the GSI-33). Pure-tone air conduction thresholds were determined at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in each ear. Bone conduction thresholds were obtained if air conduction thresholds were at 20 dB HL or greater at frequencies below 6000 Hz. Pure-tone audiometry was performed using a GSI 61 audiometer.

Data Analysis

Referral rates, sensitivity, and specificity were calculated based on the screening outcome of each child and the categorization of each audiogram as MSHL, Normal Hearing, or Other, using criteria stated earlier.

Results

Prevalence of Hearing Loss

Nashville Study

The prevalence of MSHL was 4.8% overall (48/1,000); the majority of MSHL was unilateral (49 of 71). The prevalence of minimal hearing loss ([MHL] including all types of loss) for the entire sample was 9.1% (91/1,000). Regardless of type of loss, 11 children had thresholds beyond the criteria of MHL, composing 0.075% (7.5/1,000) of the entire sample.

Watauga County Study

Of the 108 children who were referred at 25 dB HL, 19 had complete audiological evaluations for a return rate of 17.6%. Of the 315 children asked to participate who had passed at 25 dB HL, 20% (63) had audiological evaluations. Of these, 24 were among the 137 children who failed the screening at 20 dB HL but passed at 25 dB, representing 17.5% of the "refer20" group. Thirty-nine children who participated in the follow-up evaluations passed at 20 dB, representing 2.7% of children in the county who passed the school screening at 20 dB HL.

Of the 82 children who had follow-up audiological evaluations in the Watauga County study, 4 or 4.9% (49/1,000) met the criteria for MSHL; all had unilateral hearing loss according to the definition of MSHL. Two of the 4 children with MSHL had known hearing loss according to the parents during the case history interview; one was considered congenital, and the other was acquired after noise exposure. One additional child had conductive hearing loss that met the MHL criteria (with no previous hearing loss diagnosis), so the prevalence of all types of MHL was 6.1% (61/1,000). Another child had a previously diagnosed sensorineural loss in one ear at 4000 Hz only, which did not meet the criteria for MSHL. Three children had bilateral hearing loss beyond the criteria of MSHL, indicating a prevalence of 3.7% (37/1,000). One of these children, a third grader, had a bilateral conductive hearing loss and wore a hearing aid in the poorer ear. Another child, a second grader, was newly identified with a bilateral hearing loss—mild sensorineural loss in one ear and slight to moderate mixed loss in the other. Seventy-four children had normal hearing with pure-tone averages less than 20 dB HL in both ears and no thresholds greater than 25 dB HL at any frequency in either ear.

Referral Rates

Nashville Study

The estimated percentages of children who would have been referred based on the categorical database analysis are shown by grade in Table 1 for both referral criteria. Overall, the referral rate would have been 5.5% using 25 dB HL, with the referral rate nearly doubling when using the 20 dB criterion. Referral rates at 20 dB HL decreased with increasing grade. The trend is similar for referral rates based on 25 dB HL, with children in secondary education (ninth and 11th graders) having lower referral rates than children in primary grades (third and sixth). The sixth-grade referral rate of 10.3% for 20 dB HL is comparable to the fifth- and seventh-grade referral rates (11.3% and 9.3%, respectively) in the Watauga County study. The sixth-grade referral rate for 25 dB HL (6%) is slightly higher than the 4.7% and 4.2% for the Watauga County fifth and seventh graders.

Table 1. Percentage of students referred, by grade and by screening level.

	20 dB HL screening level		25 dB HL screening level	
Study	**%**	***n***	**%**	***n***
Nashville Grade 3	12.6	71/565	6.4	36/565
Nashville Grade 6	10.3	36/350	6.0	21/350
Nashville Grade 9	7.9	24/304	4.3	13/304
Nashville Grade 11	6.6	17/256	4.3	11/256
Total	10.0	148/1,475	5.5	81/1,475
Watauga County Grade 1	23.8	68/286	10.8	31/286
Watauga County Grade 2	17.8	56/315	7.6	24/315
Watauga County Grade 3	12.4	45/363	5.5	20/363
Watauga County Grade 5	11.3	41/363	4.7	17/363
Watauga County Grade 7	9.3	35/377	4.2	16/377
Total	14.3	245/1,704	6.3	108/1,704

Watauga County Study

The percentage of children referred from the initial school screening using a criterion of 25 dB HL is shown by grade in Table 1; also displayed is the percentage that would have been referred based on a 20 dB HL criterion by grade. The overall referral rate at 25 dB HL was 6.3%, slightly higher than that shown in the Nashville database analysis, increasing referrals for rescreen to 14.3% overall when using the lower screening criterion of 20 dB. Referral rates decreased with increasing grade level using either criterion level. Referral rates of 12.4% and 5.5% for the third graders were similar to the third-grade referral rates of 12.6% and 6.4% in the Nashville study.

The referral rates by grade at each criterion level are combined for the two studies and are shown in Figure 1. As mentioned earlier, referral rates showed a trend toward decreases as grade level increased. There was more variability in referral rates across grade at 20 dB HL than at 25 dB HL, with younger children showing larger differences in referral rates between the two different screening levels.

Sensitivity and Specificity

Nashville Study

The 20 dB criterion level yielded a sensitivity of 62% to MSHL, decreasing to 38% for the 25 dB level. Specificity was high for both criteria for retrospective application of the screening criteria to the database (see Table 2).

Figure 1. Referral rates for each screening level by grade for the Nashville (N) and Watauga County (W) studies. Nashville study data are shown with dashed lines, and Watauga County data are shown with solid lines. The number/letter combinations in the legend denote the grade and the study (e.g., "1W" indicates first graders in the Watauga County study).

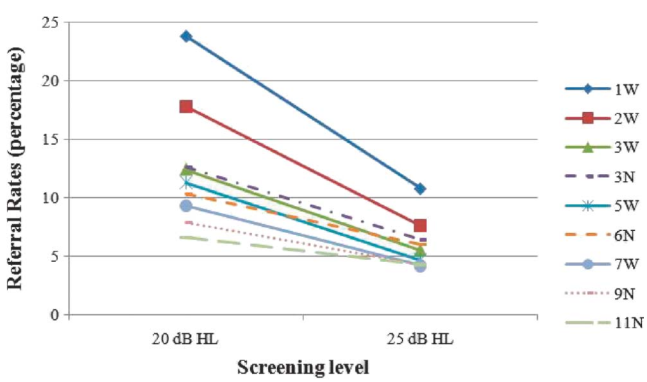

Table 2. Sensitivity and specificity percentage for minimal sensorineural hearing loss (MSHL), by screening level.

Study	Screening level	
	20 dB HL	25 dB HL
Nashville		
Sensitivity	62.0	38.0
Specificity	97.9	100.0
Watauga County		
Sensitivity	100.0	50.0
Specificity	52.0	80.0

Watauga County Study

Sensitivity to MSHL was 100% using the 20 dB screening level, which detected all cases of MSHL (and one case of conductive MHL) in the children who had follow-up evaluations. Use of the 25 dB level decreased the sensitivity to 50%, missing 2 of 4 children with MSHL (see Table 2). The high false-positive rate resulted in poor specificity (52%) at the 20 dB criterion and fair specificity (80%) using the 25 dB referral criterion.

A frequency distribution of the pure-tone screening patterns by grade is shown in Table 3 for the children who had false-positives: those who were referred by the initial pure-tone screening at 20 dB HL but were found to have normal hearing. One third grader had a hearing threshold of 50 dB HL at 4000 Hz in one ear, with all other thresholds less than 20 dB HL. This child did not meet the criteria for MSHL but was not included as a false-positive since one threshold for a screening frequency was outside of normal limits. The first and second graders accounted for 75% of the false-positives. Sixty percent of the false-positives were children who missed only one frequency in one ear, and about two thirds of the children who missed one frequency only in one or both ears failed to respond at 1000 Hz. One first grader referred for missing all three frequencies in one ear had a collapsible ear canal on that side, demonstrating normal hearing when tested with insert earphones.

Discussion

Prevalence

Despite the differences between the samples, the prevalence of hearing loss meeting the criteria for MSHL was similar for both investigations—4.8% (48/1,000) in the Nashville study and 4.9% (49/1,000) in the Watauga County study. Prevalence of MSHL in the Nashville study included sensorineural loss that was bilateral and slight to mild, unilateral, and unilateral or bilateral high-frequency loss. All cases of MSHL in the Watauga County study were unilateral sensorineural losses (two were high frequency only).

Table 3. Watauga County Study: Frequency of false-positives at 20 dB HL, by grade and by screening outcome.

Screening outcome for referrals	Grade					Total
	1	2	3	5	7	
Unilateral, one frequency	10	7	1	3	1	22
Bilateral, one frequency	2	0	1	0	0	3
Unilateral, multifrequency	3	2	1	2	0	8
Bilateral, multifrequency	1	2	0	0	0	3
Total	16	11	3	5	1	36

Note. Overall false-positive referral rate at 20 dB HL = 48% (36/75).

These estimates are higher than those reported by Australian researchers, who found a prevalence of 0.88% (8.8/1,000) of slight to mild bilateral sensorineural hearing loss in over 6,000 first and fifth graders (Cone et al., 2010). Inclusion of unilateral sensorineural hearing losses from their population would increase their MSHL prevalence rate to 2.4% (24/1,000). The prevalence of permanent bilateral slight/mild and unilateral hearing losses combined at school entry was even lower, 0.55% (5.5/1,000), in large-scale studies from the United Kingdom (Bamford et al., 2007; Fonseca, Forsyth, & Neary, 2005).

The higher prevalence rates may reflect some sample selection bias. In the Watauga County study, slightly less than 20% of children invited to participate had follow-up evaluations. Low return rates (10% to 32%) have been reported for follow-up evaluations following hearing screenings in primary care and preschool settings (Allen et al., 2004; Halloran, Hardin, & Wall, 2009; Serpanos & Jarmel, 2007). In particular, although participants who passed the screening at 20 dB HL made up almost half of the group who had diagnostic evaluations ($n = 39$), they represented only 2.7% of the total children in the district who passed the screening at that level. Prevalence of hearing loss in the study may be higher than in the general school population because parents who were most concerned about their child's hearing would be more likely to travel to the clinic for the follow-up evaluation. A significant proportion of parents of children categorized as "refer20" and "refer25" expressed concern about their child's hearing in the case history interview, whereas parents of only one of 39 children who passed at 20 dB expressed concern about hearing. The Nashville study also required written parental permission for participation, but the return rate was higher, possibly because all testing was conducted on site at the schools.

Referral Rates

The estimated referral rate based on a criterion of 20 dB HL for the Nashville study was 10% overall. For the 25 dB screening level, referral rates decreased by almost half, to 5.5%. These values could be viewed as the referral rates expected should all screening outcomes correspond perfectly to the threshold measurements. The overall referral rates for the Watauga County study were higher—14.3% at 20 dB and 6.3% at 25 dB. Higher referral rates were anticipated in the Watauga County study because actual screenings were conducted under typical school conditions (i.e., not in sound-treated environments). Furthermore, the Watauga County study also included first and second graders; referral rates for grades 3, 5, and 7 only (11% at

20 dB and 4.8% at 25 dB) were comparable to the referral rates from the Nashville database analysis, which included grades 3, 6, 9, and 11.

There was a tendency in both studies for referral rate to decrease as grade increased, particularly when using the 20 dB screening level (see Figure 1). Other researchers using a single-stage screening process and sharing similar referral criteria and age levels have reported relatively high referral rates (ranging from 21% to 29.1%) for younger children (Allen et al., 2004; Sabo, Winston, & Macias, 2000; Sideris & Glattke, 2006; Smiley, Shapley, Eckl, & Nicholson, 2012). The referral rate of 20.6% in the Watauga County study for first and second graders combined was consistent with the 21% referral rate reported by Smiley and colleagues (2012) for grades K–2 (both used the 20 dB criterion). Likewise, the referral rates using a 25 dB screening level (5.5% for the Nashville study and 6.3% for the Watauga County study) were comparable to previous findings; in a middle/high school population, Holmes et al. reported a 7% referral rate screening at 25 dB HL at 1000, 2000, and 4000 Hz (Holmes et al., 1997).

Sensitivity/Specificity

This research explored how increasing the pure-tone hearing screening criterion level from 20 to 25 dB HL would affect the detection of MSHL in a school-age population. Strikingly, applying the 25 dB criterion to the thresholds in the Nashville database demonstrated very poor sensitivity to MSHL (38%). In comparison, screening sensitivity to MSHL at 25 dB was slightly higher (50%), but still poor, in the Watauga County study. Analyses of both databases demonstrated that use of the 25 dB HL criterion resulted in missing half to over 60% of MSHL cases. Use of the 20 dB screening criterion resulted in identification of all children with MSHL who had follow-up audiological evaluations in the Watauga County study. The Nashville study showed relatively low sensitivity (62%) to MSHL even when using the 20 dB criterion.

The difference between the studies in sensitivity to MSHL is likely related to sample differences. Although the highest number of false-negatives was demonstrated by third graders in the Nashville study, the large number of older children may have elevated the false-negative rate for this sample overall by increasing the number of children with specifically high-frequency hearing loss other than at 4000 Hz. Forty-four percent of the false-negatives had thresholds greater than 25 dB HL at the high frequencies only, and the majority of these cases were in grades 6, 9, and 11. In addition, the screening criteria were applied to the hearing thresholds of the entire sample of children from the Nashville study (n = 1,475), whereas hearing thresholds were obtained on a small subset of children (n = 82) from the Watauga County screening, so the difference may be related at least partially to sampling error. There may have been children with MSHL among those who passed the initial screening but who did not receive follow-up evaluations in the Watauga County study.

Applying 20 and 25 dB screening levels to the Nashville data set does not provide clinically relevant specificity values, since no screenings actually took place and the criteria were applied to threshold values, the gold standard for pure-tone screening outcomes. The exclusion of the Other hearing loss group ensured 100% specificity for the 25 dB level, given the definition of normal hearing. The 97.9% specificity for the 20 dB level demonstrated that only a few children in the database who had audiograms designated as Normal had a threshold of 25 dB HL at one of the screening frequencies.

In the Watauga County study, actual screenings were conducted in representative school acoustic environments that typically hinder some children's consistent responses to tones presented at or near their thresholds. The specificity values for the Watauga County study (80% at 25 dB and 52% at 20 dB) were low, particularly at the 20 dB level. An analysis of the false-positive results showed that the first and second graders accounted for 75% of those who failed the initial screening but had normal hearing at follow-up. Screening outcomes for younger children are more likely to be influenced by factors like ambient noise levels, earphone placement, visual distractions, and examiner instructions and expertise. Schlauch and Carney (2012) describe aspects of pure-tone audiometry that contribute to the variability of hearing thresholds; many of these variables could also be expected to increase false-positives in pure-tone screening.

Table 3 specifies the number of false-positives by grade and screening pattern, using categories designated by Allen et al. (2004). The majority of the children with false-positive outcomes (61%) were referred due to missing one frequency unilaterally. Allen and coworkers also reported that "unilateral one-frequency refer" was the most common screening referral pattern for their entire sample of preschool children following an initial pure-tone screening. Almost 30% of their sample was referred after the first-stage screening, with a reduction to 20% overall referrals after rescreening. The Watauga County screening outcomes were based on an initial screening (first stage) rather than on the results of the rescreening because the audiologists who supervised the hearing screenings did not have access to the rescreen data. The relatively high false-positive rates reflect this; they would be expected to decrease for a two-stage screening process, increasing specificity.

Another factor that likely contributed to the low specificity was the delay between school screenings that took place in the fall and the follow-up study. The participant recruitment and complete audiological evaluations were conducted in the subsequent spring, months after the screenings. FitzZaland and Zink (1984) indicated a specificity of 98.8% for pure-tone screening for a large group of children in kindergarten and first grade. In their investigation, diagnostic and medical evaluation of all children who were screened took place within 2 days of the screening. Unfortunately, this is not typically feasible in clinical practice. Although a delay in diagnostic follow-up in the Watauga County study should not have affected assessment of the sensitivity of the two screening levels in detecting MSHL, some children who demonstrated normal hearing thresholds at follow-up may have failed the initial screening because of conductive hearing loss from transient middle-ear pathology no longer present at the later evaluation. The typically higher incidence of eustachian tube dysfunction and/or otitis media in younger children (Humes & Bess, 2014) may have contributed to elevated false-positive rates in that group.

Relatively few reports are available that provide the information necessary to calculate sensitivity and specificity of pure-tone hearing screening in the school-age population. FitzZaland and Zink (1984), Orlando and Frank (1987), Sabo et al. (2000), and Holtby, Forster, and Kumar (1997) seem to be suitable comparisons to the Watauga County study. All of these studies were prospective, provided hearing threshold evaluation for both “passes” and “refers,” and included children from preschool age up to grade 3 in the samples. However, comparing the results of these investigations to those of the present study in a meaningful way is complicated by variations in the screening frequencies and criterion levels, other procedures, and the nature of the diagnostic evaluations and definitions of hearing impairment. None of the four used the identical pure-tone screening protocol (frequencies and dB level[s]) that are considered in this research. One study conducted both the screening and the threshold measures in a sound-treated booth (Orlando & Frank, 1987); the high specificity reported is not expected to generalize to screenings occurring at schools under less ideal conditions. The procedures vary in whether one-stage or multistage screening is conducted and in whether Stage 2 screening occurs on the same day as Stage 1. Only Orlando and Frank (1987) provided a clear definition of the reference standard and what is defined as a positive result for hearing loss (threshold ≥30 dB HL at the screening frequencies). As noted in the Bamford et al. (2007) meta-analysis, variation or lack of information about case definition limits the ability to interpret sensitivity/specificity data.

Holtby et al. (1997) and Sabo et al. (2000) both used a 20 dB HL screening criterion at 1000, 2000, and 4000 Hz to assess almost 600 children. Holtby et al. also screened 250 and 500 Hz at 20 dB and Sabo et al. screened 500 Hz at 25 dB. The 100% sensitivity from the Watauga County study using 20 dB HL is higher than sensitivity values reported for these two studies—86% and 87%, respectively. The specificity at 20 dB HL for the Watauga County screening (approximately 50%) was lower than the 70% to 80% specificity reported by Holtby et al. and Sabo et al. Overall, the sensitivity/specificity results from the present study are not inconsistent with those reported previously in studies with larger samples. As noted previously, the low return rate for the Watauga County study may have introduced sample bias, limiting generalization of these findings.

Conclusion

Clinical Implications

Evidence from this research indicates that when screening is conducted at 1000, 2000, and 4000 Hz, a 25 dB screening criterion is inadequate to identify children with MSHL. Converging evidence from the two diverse populations across a wide range of grades supports the use of a 20 dB HL screening level to detect MSHL.

The higher referral rates that result from using a more sensitive criterion level present a notable challenge to audiologists and other professionals who coordinate mass school hearing screenings. Overreferrals add to the overall cost of screening, potentially straining resources of schools or other screening providers, as well as reducing credibility with parents and physicians. The false-positive rate from the Watauga County study was most likely elevated because of the delay between the initial screenings and the diagnostic evaluations and because the referrals were based on single-stage screening. Performing an immediate rescreen or combining pure-tone screening and tympanometry screening on the same day is recommended to reduce referrals and false-positives (AAA, 2011; FitzZaland & Zink, 1984; Flanary, Flanary, Colombo, & Kloss, 1999; Holtby et al., 1997; Mundy, 2001). Screening programs with multistage screening show lower referral rates than those with single-stage protocols; programs including participants in elementary grades have reported referral rates ranging from 2% to 6% (AAA, 2011; FitzZaland & Zink, 1984; Flanary et al., 1999; Holtby et al., 1997; Mundy, 2001). Note that a 6% referral rate is consistent with the referral rates from the Nashville and Watauga County studies using the 25 dB criterion. Conducting immediate or same-day rescreens for children who do not pass an initial screening at the 20 dB criterion should limit false-positives without sacrificing sensitivity to MSHL.

Working with school administrators, faculty, staff, and students to ensure a quieter environment for more accurate screening at 20 dB is also essential to improving screening outcomes over time, while raising the presentation level of the tones renders the screening process less valid. It is important to keep the purpose of the hearing screening in mind as well as the relative consequences of over- or under-referral. The European Consensus Statement on Hearing, Vision, and Speech Screening in Pre-School and School-Age Children states: “Pre-school and school screening will produce over-referrals. For the benefit of the children being screened for hearing, such false-positives are preferred over false negatives” (Skarżyński & Piotrowska, 2012, p. 121). The consensus statement asserts the importance of explaining the goals and limitations of hearing screening measures to the families of the children who are screened.

The retrospective analysis showed that, even within a best-case scenario, when the 20 dB criterion level is used and screening results match hearing thresholds exactly, pure-tone screenings may still miss almost 40% of MSHL cases. Clinicians, educators, and parents need to be aware that passing a pure-tone screening, even at 20 dB HL, does not guarantee the absence of educationally significant hearing impairment. MSHL potentially can contribute to learning vulnerabilities in children; therefore, it needs to be identified or ruled out. Any child with dysfunction at school that appears to be hearing related should receive a complete audiological evaluation regardless of his or her screening outcome.

Because not all children with MSHL experience academic and/or social problems, the use of functional measures is important to distinguish which children in this group would benefit from special support (Bess et al., 1998; Hornsby, Werfel, Camarata, & Bess, 2013; Johnson, 2010; Johnson & Seaton, 2012; Porter et al., 2013). Effective communication between the evaluating audiologist and school-associated professionals (e.g., school-based speech–language pathologists or special educators) is essential to exchange information about the need for intervention and about benefits and/or drawbacks of implementing audiological recommendations. Furthermore, diagnostic audiological evaluation may be valuable even for those children with MSHL without apparent functional difficulties or eligibility for special services; this time provides audiologists an opportunity to educate the family and child about hearing impairment and its potential effects, hearing loss prevention strategies, and the importance of follow-up for any suspected decrease of hearing. Depending on the etiology of the hearing loss, monitoring hearing sensitivity for changes may be integral. Children with presumed noise-induced hearing loss who continue to experience high-level sounds in the environment require relatively frequent monitoring to assess the effectiveness of hearing conservation strategies. Younger children, at higher risk for middle-ear pathology, may particularly benefit from audiological evaluation when a decrease in hearing is noticed. A conductive overlay on a MSHL could reduce audibility substantially and result in changes in behavior and communication ability. Should future progression of hearing loss occur in any child with MSHL, further evaluation and intervention would be expedited if the child were already under audiological management. Significant hearing loss progression over several years was noted in the Watauga County study for at least one participant with MSHL for whom subsequent audiological records were available.

Future Research

Prospective research with larger samples is needed to evaluate the sensitivity/specificity of two-stage school screening (immediate pure-tone rescreen and/or same-day follow-up with tympanometry) for detecting MSHL. Although otoacoustic emission screening was not evaluated in this research, further studies should compare the efficacy of pure-tone screening with that of otoacoustic emission screening. At this time, the most recent professional guidelines for childhood screening (AAA, 2011) state that the available evidence does not justify using otoacoustic emissions as an alternative to pure-tone hearing screening in the school-age population, although the use of otoacoustic emissions screening is suggested for those children who cannot be conditioned to respond to pure-tone testing. In screening sensitivity/specificity studies, the time interval between the screening and threshold determination should be controlled carefully to estimate screening performance more accurately. Screening for hearing impairment is only the first step; effective protocols are needed to assess educational and socioemotional risk for school-age children with MSHL and to assist clinicians and educators in decisions about individual needs for service.

In summary, pure-tone screening at 25 dB HL potentially misses up to 62% of school-age children with MSHL. Use of the 20 dB HL referral criterion is recommended for increased sensitivity to MSHL; strategies to reduce referral rates such as conducting follow-up tympanometry and immediate pure-tone rescreens are preferred over raising the cutoff level to 25 dB. Even when screening at 20 dB, up to 40% of MSHL could be missed. Children with suspected hearing problems should be referred for complete audiological evaluations even if they have passed a screening. Functional measures may play an important role in determining the need for audiological referral and intervention in such cases. Children with MSHL who fail to qualify for special education services are still likely to benefit from audiological monitoring and education.

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