Comparison of school-based hearing screening protocols and the identification of noise induced hearing loss in adolescents

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INTRODUCTION

School-based hearing screening programs have been commonplace in the United States since the 1960's. Historically, the enrollment of children in the public school system afforded the first opportunity to have access to a large population of children in order to screen for hearing disorders. Such programs were primarily designed to identify hearing losses that necessitated medical referral and treatment and/or the students with educationally significant hearing loss. Typically, the screening approach focused on capturing children with congenital hearing loss and those with conductive hearing losses due to medical conditions such as otitis media. In the contemporary era, infants receive their initial hearing screening before hospital discharge, and the educational setting serves as a subsequent opportunity to identify hearing loss that has a later onset due to various genetic and environmental influences. Certainly, noise is one environmental hazard that may contribute to the later onset of hearing loss and tinnitus in children and adolescents.

The risk of NIHL has been demonstrated for youth engaged in farming (Broste et al. 1989), utilizing firearms (Clark 1991), playing with toys or fireworks (Axelsson & Jerson 1985; Gupta & Vishwakarma 1989; Weber et al. 1967) or listening to amplified music (Clark 1991; Meyer-Bisch 1996; West & Evans 1990). Even within the school environment itself, hazardous sound levels may be encountered during woodworking or band (Grayston & Alvord 1993; Lankford & West 1993; Plakke 1985; Roeser 1980; Woodford 1973). Occupational noise exposure may also begin during adolescence. Lankford et al. (1991) found that 12.4 % of high school students reported workplace noise exposure. The National Institute of Occupational Safety and Health (NIOSH) reports that 5.1 % of the U.S. workforce is comprised of teens aged 16-19 years (NIOSH 2004). It is estimated that 1.5 million youth aged 16-19 years are engaged in work with noise-hazardous exposures (Hager 2006).

Evidence of noise induced hearing loss (NIHL) in school-aged youth is offered by Niskar et al. (2001). These researchers evaluated audiometric threshold data from the U.S. National Health and Nutitrition Examination Survey III (NHANES III) and were interested in determining the prevalence of noise induced threshold shift (NITS) for children age 6 to 19 years (*n*=5,249). The criteria for a NITS or noise notch included all of the following (P1);

- Audiometric thresholds $\leq$ 15 dB HL at 500 and 1000 Hz.
- A notching configuration in the audiogram at 3000, 4000, or 6000 Hz at least 15 dB poorer than the poorest threshold at 500 or 1000 Hz.
- Recovery of at least 10 dB at 8000 Hz.

In their analysis, 12.5 % (n=597) or approximately 5.2 million children in the United States had a noise notch in one or both ears. Bilateral NITS was evident in 14.6 % of those exhibiting a noise notch. This implies that there are at least three children with a hearing loss suggestive of noise damage in every classroom (assuming an average class size of 24). These same authors also noted that as children advanced in age [or school grade], there was a corresponding increase in the prevalence of NITS. The older youth, aged 12-19 years had a NITS prevalence of 15.5 % versus the 8.5 % prevalence for the younger 6-11 year olds. Interestingly, the noise notches in these children were primarily limited to a single test frequency (3000, 4000 or 6000 Hz). The 6000 Hz NITS was most common (77.1 %) among those audiograms meeting the Niskar et al. (2001) notch criteria. These findings offer significant implications for school-based hearing screening program design if the intent is to identify noise-induced hearing loss.

The need for school-based hearing screening programs to identify high-frequency (≥ 3000 Hz) NIHL was first expressed by Cozad et al. (1974). These researchers studied 18,600 rural Kansas youth and found that high-frequency sensorineural hearing loss occurred at three times the rate as compared to conductive hearing losses. The audiometric configurations for these subjects with high-frequency hearing loss were suggestive of NIHL. These investigators also demonstrated that the occurrence of the high-frequency sensorineural hearing loss was more common in males and increased with age (between 6 to 18 years). Over thirty years ago, Cozad et al. (1974) advocated that schools implement medical referral, noise control, hearing protection, periodic audiological monitoring and formal educational interventions as preventive measures for children.

Currently, there are no federally mandated or nationally standardized school-based hearing screening programs in place in the United States. This is in contrast to the universal newborn hearing screening programs which look toward the Joint Committee on Infant Hearing (JCIH) position statements (JCIH 2007) to afford guidance, evidence-based outcomes and benchmarking. In the absence of federally or multi-disciplinary school-based hearing screening guidelines, state or local agencies are free to voluntarily implement and define the hearing screening program purpose and protocol.

School-based hearing screening protocols have typically been designed with one of two fundamental purposes; 1) an educational orientation to identify children with a hearing loss that might have negative academic consequences or 2) medically oriented programs designed for the early identification of existing health conditions that necessitate medical referral. The state level Department of Education (purpose #1) or Department of Health (purpose #2) is typically the authoritative agency for the majority of school-based hearing screening programs (Penn & Wilkerson 1999). A preventive approach for the purposes of identifying early signs of NIHL has not been a focus for school-based hearing screening programs.

Although pure-tone air-conduction screening is the most commonly used hearing screening method (Johnson 2002), there is considerable variability between different hearing screening guidelines. Penn and Wilkerson (1999) summarized 40 state protocols and found seven different frequency combinations and two different stimulus presentation levels (20 or 25 dB HL) were utilized. Additionally, they noted that states tended to focus hearing screening on the elementary school-level students, and 12 states did not include hearing screening at the high school level in their guidelines.

The present study was undertaken to compare hearing screening outcomes for currently implemented school-based screening protocols in terms of the ability to potentially detect NIHL in high school students by identifying students with a high-frequency notch (HFN) using the Niskar et al. (2001) noise notch criteria. The analysis was applied to an existing database of pure-tone threshold data from 9th and 12th-grade students in Colorado. For reporting this study, the terminology of HFN will be used rather than the Niskar et al. (2001) NITS terminology, since the underlying etiology of the hearing impairment is unknown, although the audiometric configuration is suggestive of noise damage.

METHODS

School hearing screening guidelines were gathered from each U.S. state using a variety of approaches, including Internet searches, e-mail correspondence, library reference search and phone inquiries to state agencies during the 2005 calendar year. The protocols were then summarized with respect to frequencies screened and decibel level(s) utilized. Each protocol was assigned a P# (protocol number) beginning with P2 (P1 referred to the Niskar et al.,2001 notch criteria). If a protocol afforded the opportunity for the screener to use more than one decibel level, then each protocol was further identified alphabetically for increasing decibel level. For instance, if protocol #2 had a screening level of either 20 or 25 dB HL, then the protocols were separately identified as P2a and P2b respectively.

An anonymous Colorado Department of Education high school audiometric database (HSAD) from 2004 was accessed with permission. The database included 641 students in the 9th (*n*=376) and 12th (*n*=265) grades from a suburban Colorado high school. Ethnicity was primarily Caucasian (*n*=399) and Hispanic (*n*=217). The database included valid air-conduction thresholds for 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz.

Audiometric threshold data was exported to Microsoft Excel 2003 for three separate groups, 9th grade only, 12th grade only and 9th and 12th grade combined. Audiograms were first reviewed and identified (counted) as having a HFN by applying the Niskar et al. (2001) NITS criteria described previously. For all other screening protocols, the number of student audiograms that would potentially be identified with a HFN were identified by meeting all of the following criteria;

- Thresholds $\leq$ 15 dB HL at 500 and/or 1000 Hz.
- Thresholds greater than the minimum screening level (dB HL) in either ear at 3000, 4000, or 6000 Hz (provided that the test frequency was included in the state protocol).
- Demonstrated recovery of 10 dB or more at 8000 Hz as compared to the poorest threshold at 3000, 4000, or 6000 Hz. (note: this criteria was applied regardless of the absence of 8000 Hz in the screening protocol to avoid identification of high-frequency hearing losses that were not suggestive of NIHL).

Significant differences were evaluated by comparing the number of student's identified with a HFN using the Niskar et al. (2001) notch criteria (P1) and the number of students identified with each state protocol. A non-parametric chi-square analysis was utilized. A significant difference was defined as a *p*-value $\leq$ .05. Yates's correction was applied for cell values < 5.

RESULTS

Screening protocols were obtained for 46 states and the District of Columbia as well as for the American Academy of Audiology (AAA 1997), the American Speech-Language Hearing Association (ASHA 1997) and the American Academy of Pediatrics (AAP; Cunningham & Cox 2003). Twenty-two unique combinations of test frequencies and presentation levels were identified. Six protocols have more than one screening level permitted. A complete review of the screening protocols and statistical analysis can be referenced in Meinke & Dice (2007).

Upon application of the Niskar et al. (2001) notch criteria to the combined 9th and 12th grade database, 45 students would be identified with NITS. This number serves as the expected outcome values for the chi-square analysis. Colorado, Kansas and Iowa protocols have the greatest potential to identify students with an HFN (n=20). In contrast, the Alabama and Delaware protocols did not identify any students with a HFN. The remaining protocols identify between 6 % and 33 % (n=3-15) of the students with a HFN. The HFN involved the frequencies of 4000 Hz (48.8 %) and 6000 Hz (46.1 %) rather than 3000 Hz (5.1 %). A unilateral HFN was more common for the left ear (61.8 %) than the right ear (38.2 %).

Chi-square statistical comparisons were not possible for those protocols that did not identify any HFN's. When combining grade levels, significantly fewer students were identified with a HFN when using any of the school screening protocols as compared to the Niskar et al. (2001) notch criteria regardless of decibel level utilized. During separate grade analysis, the Colorado (P13) protocol at the 9th grade level and the Iowa protocol (P14a) at the 12th-grade level were the only insignificant findings.

Hearing screening conducted at 1000, 2000 and 4000 Hz at either 20 or 25 dB HL is the most commonly used hearing screening protocol in the U.S. This screening approach will only identify 10 out of the 45 students (22 %) with a HFN. The second most commonly used hearing screening protocol (500, 1000, 2000 and 4000 Hz at 20 or 25 dB HL) also only identified 22 % of the students with a HFN. Therefore, only 22 % of the students with a HFN will be identified in by hearing screening programs conducted in 33 states. The two protocols that included 4000 and 6000 Hz (Kansas & Colorado) were most likely to identify a student with NIHL. Iowa's protocol includes screening at 15 dB HL and it also proved more likely to identify HFN's. The Kansas, Colorado and Iowa protocols each identified 20 students with a potential NIHL, or 44 % of the total number of students with a HFN.

DISCUSSION

Prevalence of HFNs

The present study suggests a HFN occurrence of 7 % for the combined 9th and 12th grades. This is a lower prevalence when compared to the 15.5 % reported by Niskar et al. (2001) for the same general age group (12-18 years). Perhaps this is attributed to study population differences including gender, race-ethnicity, socioeconomic status, urban status, or geographical region. It might also be attributable to methodological differences between the NHANES III testing protocol and the audiometric procedures used for the Colorado student testing. Lastly, such difference may relate to the actual noise exposures encountered by the students or alternative etiologies not investigated in the present study.

Unilateral HFN

The unilateral nature of HFN's is confirmed in this study. Niskar et al. (2001) reported 85.4 % unilateral NITS while 85.4 % were unilateral HFNs in the present data set. Acoustic trauma, progression of NIHL or asymmetrical vulnerability to NIHL may be considered in terms of possible explanations for unilateral noise notches. Gupta & Vishwakarma (1989) noted that toy weapons and fireworks were the primary explanations for NIHL in a pediatric study.

Importance of Audiometric Test Frequency

The importance of screening at 4000 and 6000 Hz is apparent in the present study as was also advocated by previous researchers (Axelsson et al. 1981; Katt & Sprague 1981; Holmes et al. 1997; Niskar et al. 2001). Historically, issues surrounding the inclusion of 6000 Hz have been debated on the basis of calibration issues, earphone coupling and potential normative reference errors (Luxon 1998). In the current study, if the HFN was attributable to calibration or standardization errors, especially at 6000 Hz, one would expect the HFNs to be found bilaterally and not predominately unilateral. Ultimately, the optimal test frequencies to include a school-based hearing screening protocol designed for the early detection of NIHL needs further study and investigation.

Pure-Tone Presentation Level

The higher the decibel screening level, the more likely NIHL remains undetected. It is necessary to screen at low 15 or 20 dB HL decibel levels in order to detect minimal or slight high-frequency hearing loss suggestive of NIHL. Twenty-one states recommend screening at 20 dB HL at all test frequencies. Seven states recommend screening at 25 dB HL. Other protocols have variable presentation levels between 15 and 30 dB HL. Nine states permit the screener to choose more than one screening level. Ambient noise levels in the test environment may drive the higher decibel levels used for screening and diminish the opportunity to provide early identification of NIHL in youth.

Failure to Detect HFNs

It appears that less than half of the students with potential NIHL would be detected during hearing screenings in the U.S. In this study, the 9th and 12th graders were given hearing tests and provided the opportunity to identify developing hearing losses. In most instances, school-based hearing screening is discontinued by the 9th grade. Consequently, if screening is not conducted, there exists no possibility of identifying NIHL.

If noise induced hearing loss goes undetected in the adolescent population, then opportunities to intervene and prevent further deterioration are missed. It is important for school administrators and professionals to recognize the limitations of existing hearing screening protocols with regard to NIHL. If noise notches are not identified, students and teachers may not recognize the risks from their daily activities and school systems may encounter medicolegal challenges in the future if a false sense of security was perceived due to “passing” the hearing screening. Medical referral, education and follow-up would not be provided to the affected individual(s). Certainly, the burden of expanding the screening program to a larger student contingent is more costly. There may not be adequate resources or personnel available to design and implement a screening program for the early detection of NIHL.

Future Directions

Innovative approaches are necessary to identify students at risk of NIHL. Perhaps noise risk surveys or student/parent/teacher interviews would determine the potential risk of NIHL for an individual and targeted audiometric monitoring would then be provided. Periodic monitoring may be more beneficial in terms of early identification of NIHL or monitoring existing NIHL. Pure-tone threshold monitoring also affords an opportunity for ongoing evaluation regarding the effectiveness of interventions applied, such as the use of hearing protection in sound hazardous classrooms. Audiometric monitoring in the schools may be enhanced by applying the industrial model of hearing testing to at risk students and teachers (Meinke et al. 2008). The use of insert earphones may help address the high ambient noise levels encountered during school-based hearing testing and promote screening at more sensitive decibel levels. It might also be worthwhile to consider the use of otoacoustic emissions as a screening tool for NIHL. Lastly, educational outreach and prevention can be integrated into existing hearing screening programs to create realistic expectations regarding the existing programs and the need for individuals at risk of NIHL to monitor their hearing thresholds closely. Currently, teachers, parents and students should not rely on the school hearing screening outcomes with regard to the detection of NIHL.

Future research is necessary, especially with regard to sensitivity and specificity for NIHL obtained by school-based hearing screening programs. There is a longstanding need for longitudinal research regarding the detection and progression of NIHL in children. Schools may afford an optimal public health environment for such a study. In the short-term, cross-sectional studies may be beneficial. Certainly, this study highlights the need for a public health-focused research initiative to address the lack of standardization and consensus regarding school-based hearing screening, especially in the era of widespread universal newborn hearing screening.

CONCLUSION

School-based hearing screening protocols vary greatly from state to state within the U.S. The currently implemented protocols are non-standardized and inadequate for the detection of NIHL in adolescents. Early detection and intervention for NIHL is denied and incipient NIHL will go undetected. Ultimately, such losses may progress toward a more debilitating hearing loss in the future. There is a critical need to standardize and implement effective and efficient hearing screening and monitoring programs in U.S. schools, especially with regard to the prevention of NIHL.

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