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Assessment of the Efficacy of a Hearing Screening Program for College Students

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Abstract

Background: The Towson University (TU) Speech-Language-Hearing Center (SLHC) conducts annual hearing screenings for college students entering education or health-care professions. Hearing is screened in therapy rooms, and students who fail the screening are rescreened in a sound-treated booth. Students who fail the rescreening are referred for a comprehensive audiological assessment, which is offered at no cost to students at the SLHC.

Purpose: The purpose of this study was to examine the efficacy of the hearing screening program, to report trends in hearing screening statistics for the college student population, and to make recommendations regarding ways universities can optimize hearing screening programs.

Research Design: The study included retrospective and prospective portions. Hearing screening records were reviewed from 1999 to 2011. The prospective study involved recruiting students to participate in diagnostic testing following the hearing screening and measuring background noise levels in the therapy rooms.

Study Sample: Hearing screening records from 1999 to 2011 were reviewed. In addition, during the three-day fall 2011 hearing screenings, 80 students were selected to participate in diagnostic testing.

Data Collection and Analysis: Data from the retrospective review were used to determine positive predictive value (PPV) between screening and rescreening. Return rates were also examined. For the prospective study, pure tone threshold results were compared to screening results to determine sensitivity, specificity, and PPV.

Results: The retrospective file review indicated that the hearing screening in the therapy room had poor PPV compared with the rescreening in the sound booth. Specifically, if a student failed the screening, they had only a 49% chance of failing the rescreening. This may have been due to background noise, as the prospective study found noise levels were higher than allowed by American National Standards Institute (ANSI) standard. Only a third of students referred for diagnostic testing from 1999 to 2010 returned for recommended diagnostic testing. For the prospective study, specificity and sensitivity were good when considering hearing loss present at the same frequencies as those screened (1000, 2000, 4000 Hz) but poor in comparison to hearing loss overall. The screening missed many students with a high frequency notch, which was most prevalent at 6000 Hz. The prevalence of a high frequency notch was 21 and 51%, using two different criteria for establishing the presence of a notch.

Conclusions: If college hearing screenings are conducted in rooms that are not sound treated, poor PPV should be expected; thus, an immediate second stage rescreening for failures should be conducted in a sound booth. Hearing screenings limited to 1000, 2000, and 4000 Hz will miss many cases of hearing loss in the college-age population. College hearing screening program directors should carefully consider the purpose of the screening and adjust screening protocol, such as adding 6000 Hz and a question about noise exposure, in order to identify early signs of noise-induced hearing loss in college students. Programs should focus on ways to promote high return for follow-up rates. Estimates of prevalence of a high-frequency audiometric notch are highly dependent on the criteria used to define a notch.

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Key Words: Efficacy, hearing loss, hearing screening, high frequency notch, noise-induced hearing loss

Abbreviations: ANSI = American National Standards Institute; ASHA = American Speech-Language-Hearing Association; BT = best threshold; MPANLS = Maximum Permissible Ambient Noise Levels; ND = notch depth; NIHL = noise-induced hearing loss; ORR = over-referral rate; PPV = positive predictive value; PT = poorest threshold; SLHC = Speech-Language-Hearing Center; TU = Towson University

State law generally mandates hearing screenings for infants and children through high school age but not beyond (American Speech-Language-Hearing Association [ASHA], 2012). However, universities may choose to offer or require hearing screenings for all or some of their students. For example, students applying for admission to the Teacher Education program at the University of Tennessee, Knoxville are required to complete a hearing screening (University of Tennessee, Knoxville, 2013). The same is true of communication sciences and disorders students at the University of Alabama (University of Alabama, 2013) and Marywood University (Marywood University, 2013). Towson University (TU) requires a hearing screening for all students enrolled in disciplines that include off-campus teaching or health-care internship. For these students, professional development relies heavily on their ability to communicate well with others, particularly in interactions with students and patients. Although the TU hearing screening program has existed for many years, the efficacy had not been examined prior to this study. Therefore, the purpose of this study was to examine the accuracy of the screening results and the return rate for follow-up services.

INTRODUCTION

Accuracy of a Screening Program

An effective screening program should, as accurately as possible, separate individuals into two categories: pass (negative) and refer/fail (positive). Screening accuracy is examined using a 2 × 2 contingency table (Table 1), which compares the result of the screening to the result of diagnostic testing. This contingency table contains four possible outcomes: hit (true positive), false alarm (false positive), miss (false negative), and correct rejection (true negative). Measures of efficacy (Table 2) are based on values extracted from the 2 × 2 table. Frequent indicators of efficacy are sensitivity and specificity; however, these values cannot be calculated based on a retrospective records review because miss and correct rejection values are unknown. Furthermore, hit and false alarm rates can only be estimated based upon data from individuals who fail the screening and elect to return for follow-up testing. For example, Martin and Church (1991) reported the efficacy of a hearing screening program at Central Michigan University involving over 18,000 students. Their study described trends in hearing screening for the college population and estimated prevalence of hearing loss; however, sensitivity and specificity could not be calculated, because miss and correct rejection rates were not available. Hit and false alarm rates could be estimated based on the 65% of students who returned for follow-up testing after failing the screening. When only hit and false alarm rates are available, accuracy calculations are limited to positive predictive value (PPV) and over-referral rate (ORR). PPV and ORR probability values sum to one, so if one is known the other can be calculated; therefore, they provide, in essence, only one piece of information, that is, if an individual has a specific screening result (positive or negative), will it be accurate? Although a retrospective records review can provide some valuable data on the efficacy of a hearing screening program, prospective studies of accuracy are also required.

Hearing Screening Protocols

The protocol used at TU follows ASHA (1997) guidelines for school-age children (5–18 yr), including the use of 1000, 2000, and 4000 Hz pure tones presented at 20 dB HL. Lower frequencies are omitted due to the false positive rate associated with ambient noise (Alvord, 1993). In the ASHA protocol, screening frequencies are limited to 1000 to 4000 Hz, likely because this is the "frequency

Table 1. Screening Result Compared to Presence of Disorder

		Disorder	
		Present (+)	Absent (−)
Screening Result	Positive (+) (Fail/Refer)	Hit (True positive) A	False alarm (False positive) B
	Negative (−) (Pass)	Miss (False negative) C	Correct rejection (True negative) D

Table 2. Formulas to Calculate Accuracy of Screening Tests

Column Data (in reference to the disorder)		
Measure of Accuracy	Formula	Probability that …
Sensitivity	A/(A + C)	someone with the disorder has a positive screening result
Specificity	D/(B + D)	someone without the disorder will have a negative screening result
False negative rate	C/(A + C)	someone with the disorder will have a negative screening result
False positive rate	B/(B + D)	someone without the disorder will have a positive screening result
Row Data (in reference to screening result)		
Measure of Accuracy	Formula	Probability that …
Positive predictive value	A/(A + B)	someone who has a positive screening result has the disorder
Negative predictive value	D/(C + D)	someone who has a negative screening result does not have the disorder
Under-referral rate	C/(C + D)	someone who has a negative screening result has the disorder
Over-referral rate	B/(A + B)	someone who has a positive screening result does not have the disorder

region most important for speech recognition" (ASHA, 1997, p. 41). The procedure used for college students is consistent with procedures used by our outreach screening programs for younger children. Although there is overlap between the highest age range for the ASHA guidelines and the age of college students, most college students are over 18; therefore, this population is not completely represented by the screening guidelines. A review of studies involving college students and "young adults" indicated many variations in screening technique compared with the procedures used at our facility, including the use of different frequencies (500 Hz, 6000 Hz), test environments (quiet rooms, sound-treated rooms), screening levels (15 dB HL, 20 dB HL), and techniques (Lipscomb, 1972; Rabinowitz et al, 2006; Agrawal et al, 2008; Widén et al, 2009; Le Prell et al, 2011). The diversity of screening protocols in the literature is most likely due to the lack of a standardized screening protocol for this population.

The omission of high frequencies in the ASHA protocol is a concern in the college-age population due to the increased risk of noise-induced hearing loss (NIHL) attributed to recreational noise exposure, including personal listening devices (Lipscomb, 1972; Tharpe and Sladen, 2008; Vogel et al, 2009, 2010; Levey et al, 2011). A review of hearing loss prevalence literature by Phillips et al (2010) indicated the prevalence of a high-frequency notch, most often at 6000 Hz, increased steadily from childhood to adolescence across multiple studies. Other studies have indicated high-frequency hearing loss is more prevalent than low-frequency hearing loss in the 20–30 yr group (Rabinowitz et al, 2006; Agrawal et al, 2008; Le Prell et al, 2011) and that significant increases in high-frequency pure-tone average (3000–6000 Hz) occur within this population (Agrawal et al, 2008).

The omission of high-frequency tones may result in a missed opportunity to identify early indicators of NIHL. A classic indicator of NIHL is a high-frequency notch in the audiogram, characterized by a pure-tone threshold between 3000 and 6000 Hz that is poorer than both adjacent thresholds. Niskar et al (2001) examined 5000 people from 6 to 19 yr of age and found a 6000 Hz notch commonly occurred. This discovery was similar to the outcomes of a number of other studies involving adolescents and young adults (Cozad et al, 1974; Holmes et al, 1997; Meinke and Dice, 2007; Phillips et al, 2010; Sekhar et al, 2011). Sekhar et al (2011) tested 296 high school students and found that only 15 failed a hearing screening, but 78 had hearing loss, and most of the audiograms (86%) had a high-frequency notch. Meinke and Dice (2007) reported that the ASHA protocol is the most frequently used screening method in the United States, but their results indicated this protocol correctly identified only 22% of students with a high-frequency notch.

A potential negative consequence of including 6000 Hz in a screening protocol is an increase in the false positive rate. Schlauch and Carney (2011) found this to be the case for young children (6–11 yr), but clear data are not available for the college-age population. Lipscomb (1972) found a much higher failure rate in a college hearing screening that included 6000 Hz compared with a study by Martin and Church (1991) that did not; however, their methodologies were so different as to make a direct comparison impossible, so it is unknown if there would be an increase in the false positive rate for the college-age population.

Follow-Up Testing

Low return rates have been observed in studies conducted on hearing screenings for all age ranges (e.g., Martin and Church, 1991; Allen et al, 2004; Fonseca et al, 2005). Although some universities require education and communication sciences and disorders majors to have their hearing screened, requirements for follow-up testing vary (Marywood University, 2013; University of Alabama, 2013; University of Tennessee, 2013). At Towson University, it is the student's responsibility to seek follow-up assessment, and documentation of follow-up is not required. At the University of Tennessee, Knoxville, students must pass a hearing screening or provide documentation of hearing loss to the Teacher Education Admissions Board. Return rates for university hearing screening programs are rarely available; however, it is possible that the follow-up rate is better for universities that require follow-up than it is for universities with optional follow-up. At Marywood University, hearing screening and follow-up (if applicable) are required, but it is the students' responsibility to make follow-up appointments and provide documentation to the program. From 2009 to 2012, 16 students failed the screening and 63% of these returned to the university clinic for follow up (Andrea Novak, pers. comm., October 4, 2012). To date, Martin and Church (1991) were the only researchers to publish return rates for a large-scale study of a university-based hearing screening program (at Central Michigan University [CMU]). It is unknown if their return rate of 65% is characteristic of college-age students in general or specific to their program. At CMU, participation in the screening (but not follow-up testing) was a graduation requirement at the time of their study; however, a booth in the CMU clinic was reserved to immediately conduct follow-up testing after the screening, if time permitted, and this may have resulted in an inflated follow-up rate compared with a clinic that cannot conduct immediate follow-up testing (Gerald Church, pers. comm., September 18, 2012).

College-age students are at risk for high-frequency hearing loss, but there is limited published research regarding the efficacy of hearing screening programs targeted to this population. Therefore, this study was conducted to (a) examine the efficacy of a hearing screening program for college students using both a retrospective records review of follow-up rate and PPV and a prospective study to examine sensitivity and specificity, (b) report trends in hearing screening statistics for college students, and (c) as needed, make recommendations regarding ways that university hearing screening programs can optimize their efficiency.

METHODOLOGY

This study was reviewed and approved by the Towson University Institutional Review Board for the Protection of Human Subjects.

Retrospective Study

Results for the TU Speech-Language-Hearing Center (SLHC) hearing screenings are kept in a storage facility for a minimum of 10 yr. Screening, rescreening, and return for follow-up results were available from 1999 to 2011. All available data were examined to determine PPV, ORR, and follow-up rates.

Prospective Study

Subjects

During the fall (September) 2011 hearing screening at the TU SLHC, 669 undergraduate students were screened. The examiner waited in the hallway and asked all students leaving the screening room if they would participate in a follow-up study. Thus, students were asked to participate in the study regardless of the result of the screening, and the examiner did not know the result of the screening when she asked the student to participate. A total of 80 students participated in this study, for a participation rate of 12%. Of the 80 participants, 22 were male and 58 were female. The average age of the participants was 23 yr with a range from 18 to 49 yr old. The vast majority of participants were of typical college age (83% were under 24 yr).

Procedure

Screening

All hearing screenings were held in a small speech-language therapy room and were conducted by speech-language pathology graduate clinicians with training in hearing screening, under the supervision of state licensed and nationally certified speech-language pathology faculty. Using a portable audiometer (GSI-17 or Maico MA-40) and supra-aural earphones, students were screened at 20 dB HL at 1000, 2000, and 4000 Hz in both ears (ASHA, 1997). If the student responded to all six tones, no further testing was recommended, and "pass" was indicated on the screening form. The usual and customary procedure was that of ASHA (1997). As the purpose of the study was to examine the effectiveness of existing protocols, we did not change the testing for the purposes of this study to include 6000 Hz in the screening.

Rescreening

If the student failed to respond to any of the three tones presented to either ear, "rescreen" was indicated, and the student was sent to the audiology suite to be rescreened in a double-walled, sound-treated booth with a diagnostic audiometer (GSI-61 or Madsen Astera). The sound booth met American National Standards Institute (ANSI) standards for background noise (ANSI, 2008). The audiometers were professionally calibrated within 1 mo prior to the screening and met ANSI standards (ANSI, 2004). Biologic listening checks were also conducted every day of the screening. The rescreening was conducted by an audiology doctoral student under the supervision of a licensed and certified audiologist. If the student correctly responded to the tones at 20 dB HL, "pass" was recorded. If a tone was missed during the rescreening in the booth, the student was referred for a full audiological evaluation.

Research Protocol

For the purpose of this research study, all participants were directed to the audiology suite from the initial screening room. If the student had failed the screening, the standard rescreening was conducted first, as previously described. All participants were administered an audiological assessment that included otoscopic exam, tympanometry, and pure-tone air conduction threshold testing including 250, 500, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. Pure tone thresholds at or below 20 dB HL at all test frequencies in both ears were considered to indicate normal hearing. All audiograms were examined for the presence of a high-frequency notch. Although a high-frequency notch may be caused by noise and is commonly referred to as a noise notch, this pattern can occur for other reasons. There are also indications in the literature that NIHL is overestimated in younger populations (McBride and Williams, 2001; Green, 2002), so we have referred to this phenomenon as a high-frequency notch for the purposes of this article. There are varying definitions of *noise notch, audiometric notch,* and *high-frequency notch*; therefore, we selected two criteria to determine if a high-frequency notch was present and conducted two sets of analyses. Notch 1 criterion was based on the definition of a *noise notch* from Phillips et al (2010). Specifically, a notch was present if the notch depth (ND) was ≥15 dB with a recovery of 5 dB or greater at a higher frequency. ND is equal to the difference between the best threshold (BT) at 4000, 3000, 2000, or 1000 Hz and the poorest threshold (PT) at 3000, 4000, or 6000 Hz (i.e., ND = PT – BT). Based on this definition, a student with audiometric thresholds within the normal range could have a notch. For the Notch 2 criterion, a notch was present if the audiometric threshold of the notch was above the normal range (>20 dB HL) and the recovery above the notch was >5 dB. Notch depth criteria are not consistent in the literature, but we felt these two captured both a liberal and a more conservative estimate of the prevalence of a high-frequency notch pattern.

Ambient Noise Levels

To identify possible issues with ambient noise level in the screening rooms, a B&K Type 2130 digital frequency analyzer with octave band filters was used to measure the background noise inside the initial screening room with the door closed during screening hours. Octave band measurements were taken with center frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. A screener and participant were in the room sitting quietly during the noise measurement. The microphone was placed in the center of the room, between the screener and the participant.

Analysis

Data from both the retrospective and prospective portions of the study were transferred from paper records to an Excel spreadsheet and then uploaded into SPSS for analysis. Analyses were primarily descriptive. Additional analyses were conducted on nominal data using the χ^2 test via Excel and SPSS analysis tools.

RESULTS

Retrospective Study

Table 3 lists the total number of students who participated in hearing screenings from 1999 to 2011, a summary of the test results, and the return rate. Over this 13 yr period, 10,162 students were screened and 274 students (2.7%) were referred for follow-up testing. The referral rate was generally consistent and varied from 1.5 to 3.4%, with an average of 2.7%. Overall, only 33% of these students returned to the SLHC for follow-up, but this number varied from year to year with a low of 5% to a high of 100%. Within the past 5 yr, the rate

Table 3. Summary of Hearing Screening Results for 1999–2011

Year	Total Students Screened	Failed Screening (therapy room)	Failed Rescreening (sound booth)	Referral Rate	PPV	ORR	Return Rate to SLHC
2011	1023	64	24	2.3%	0.38	0.63	N/A
2010	1111	68	34	3.1%	0.50	0.50	21%
2009	965	42	24	2.5%	0.57	0.43	50%
2008	938	55	30	3.2%	0.55	0.45	23%
2007	943	51	23	2.4%	0.45	0.55	50%
2006	639	25	15	2.3%	0.60	0.40	47%
2005	746	56	20	2.7%	0.36	0.64	5%
2004*	609	12	9	1.5%	0.75	0.25	67%
2003	807	46	26	3.2%	0.57	0.43	60%
2002	803	60	27	3.4%	0.45	0.55	30%
2001*	428	27	13	3.0%	0.48	0.52	38%
2000	561	30	18	3.2%	0.60	0.40	63%
1999	589	27	11	1.9%	0.41	0.59	100%
Total	**10,162**	**563**	**274**	**2.7%**	**0.49**	**0.51**	**33%**

Note: PPV = positive predictive value; ORR = over-referral rate.
*Data were compiled for one screening (fall or spring) and not both for that year.

has varied from 21 to 50%. The number of students who sought follow-up care at other facilities is unknown; however, it is suspected that this number is close to zero. The SLHC was conveniently located close to most academic buildings and services are free for students. In addition, students were directed to the front desk following the screening and encouraged to make an appointment for follow-up services.

A comparison of the screening in the therapy room with the rescreening in the sound-treated booth indicated the PPV varied considerably with an overall value of 0.49. This means if a student failed the hearing screening in the therapy room, there was only a 49% chance that he or she would fail the rescreening in the sound booth, so about half of the initial screenings were not accurate once students were rescreened in a sound booth.

Prospective Study

Of the 80 total participants in the prospective study, 60 passed the screening in the therapy room and 20 were rescreened; 8 of these students failed the rescreening (5 male, 3 female; mean age = 23.6 yr). The referral rate for this group was 10%, which is significantly higher than the overall referral rate of 2.7% found in the retrospective review ($\chi 2$ = 15.81; df = 1; N = 10242; $p < .01$). This suggests an ascertainment bias in that students who failed the initial screening were more likely to agree to participate in the study when asked by the examiner, compared with students who passed. Although this is a methodological weakness, it is not assured that a similar outcome would not be seen if students were asked to participate prior to the first screening, with students who perceive they have a hearing loss possibly more likely to agree to diagnostic testing compared to students without this perception.

Octave band levels for ambient noise measured inside the screening room exceeded Maximum Permissible Ambient Noise Levels (MPANLS) by 14 dB at 500 Hz and by 10 dB at 1000 Hz, but the levels were within the ANSI standard at all other frequencies between 125 and 8000 Hz. This is somewhat surprising as the 12 students who failed the initial screening but passed the rescreening were most likely to have failed to respond to a tone at 4000 Hz (n = 6), compared with 1000 Hz (n = 3), 2000 Hz (n = 2) or multiple frequencies (n = 1). A possible explanation is that the intermittent nature of speech noise in a clinic hallway resulted in some time periods in which the noise was higher than indicated by our noise measurements since a steady-state noise exceeding the MPANLS in the lower frequencies would have affected the low-frequency screening results to a greater degree.

Diagnostic testing indicated 29% of the participants had hearing thresholds >20 dB HL at one or more frequencies (n = 23 out of 80; 6 male, 17 female; 12 bilateral, 5 right, 6 left). Tympanometry was abnormal for two participants with hearing loss (one shallow, one hypermobile) and four participants with normal hearing (all hypermobile). All other tympanometric and otoscopic results were normal. None of the participants had thresholds ≥20 dB HL at the lowest two frequencies tested (250 and 500 Hz).

According to the Notch 1 criteria (Phillips et al, 2010; notch may be present within normal range), 51% (n = 41) of the entire sample of 80 participants had a high-frequency notch (10 male, 31 female; 13 bilateral, 18 right, 10 left). For the subset of 23 participants with hearing loss, 83% (n = 19) had a notch. Notch depth ranged from 15 to 60 dB HL with a mean of 22 dB HL. Ear-specific data from the 41 participants with a notch indicated 54 ears with a notch, with the notch centered at 6000, 4000, and 3000 Hz for 74, 11, and 9% of ears, respectively. Additionally, 9% of notches spanned 4000–6000 Hz, which was more of a plateau than a single pointed notch.

According to Notch 2 criteria (>20 dB HL for at least one threshold; >5 dB recovery), 21% (n = 17) of the entire sample of 80 participants had a high-frequency notch (4 male, 13 female; 4 bilateral, 7 right, 6 left). Notch depth ranged from 25 to 60 dB HL with a mean of 30 dB HL. Ear-specific data from the 17 participants with a notch indicated 21 ears with a notch, with the notch centered at 6000, 4000, and 3000 Hz for 76, 10, and 10% of ears, respectively, with 5% spanning 4000–6000 Hz.

Table 4 shows the results of the screening compared with the presence of hearing loss as determined by (a) pure-tone thresholds ≥20 dB HL across all frequencies (bolded text) and (b) pure-tone thresholds ≥20 dB HL only at screening frequencies (text in parentheses). Specificity is excellent (100%), for both comparisons, because all participants with normal hearing passed the screening. Sensitivity is poor, 0.35, when screening results are compared to all frequencies from the diagnostic results but good, 0.89, compared to only screening frequency results. PPV was 1.0, meaning all students who failed the screening had a hearing loss. PPV may have been slightly inflated due to the higher than expected prevalence in this sample. All but 3 of the 15 false negatives had thresholds >20 dB HL at 6000 Hz in one or both ears,

Table 4. Results of the Screening (pass/fail) Compared to the Results of the Audiological Assessment (AC threshold ≤20 dB HL) Considering All Frequencies (bold) and Only Frequencies Screened (parentheses)

		Hearing Loss		
		Present (+)	Absent (−)	Total
Screening Result	Fail	**8**	**0**	**8**
		(8)	(0)	(8)
	Pass	**15**	**57**	**72**
		(1)	(71)	(72)
	Total	**23**	**57**	80
		(9)	(71)	

meaning that if the screening had included 6000 Hz, the process should have identified most of the students with hearing loss, and the sensitivity would improve to approximately .87 for identification of hearing loss overall. The remaining three students had hearing loss only at 8000 Hz and would not have been identified even with the inclusion of 6000 Hz in the screening.

DISCUSSION

Follow-Up Rate

Ideally, a hearing screening protocol should be accurate and have an impact on the long-term outcome of individuals with hearing loss. Even a highly accurate screening program will be ineffective if students identified as at risk do not return for follow-up care. In a review of clinical records from 1999 to 2010, we found, overall, only a third of students returned for diagnostic testing after a failed screening. This figure is half that reported by Martin and Church (1991) in an earlier study of college-age student screening, in a program with immediate follow-up testing for many of the failed screenings. Low follow-up return rates for mass screening programs for younger children are not uncommon. For example, Allen et al (2004) found that only 10% of preschoolers referred for full hearing evaluations were actually brought back to the clinic for the evaluation. However, limited data are available regarding follow-up rates in the college population. TU is located in a large metropolitan area, which is not the case in the Martin and Church study, which is located in a more rural college town; however, the ease with which students could return to the TU SLHC and the free cost suggests that students were not just lost to the center but from follow-up services in general. This speaks to the need to emphasize the importance of healthy hearing, including the need for proper diagnosis, treatment, and prevention of further hearing loss. It is possible that the student screeners did not appropriately emphasize the importance of follow-up care. At the TU SLHC, considerations for changes based on the results of this study include (a) requiring all screeners to escort students to the front office window for a follow-up appointment, (b) making available a sound booth for follow-up diagnostic testing for failed screenings, and (c) developing handouts specifically targeted to education and health majors, emphasizing the importance of optimal communication for future career opportunities.

Accuracy

A records review indicated the initial hearing screening in the therapy rooms resulted in a poor PPV, on average 0.49, compared with rescreening in the sound booth. In other words, only half of students who failed the initial screening had an accurate rescreening result. We attributed this to high ambient noise levels in the therapy rooms because (a) noise levels exceeded ANSI standards, (b) students who failed the initial hearing screening often complained noise was distracting, and (c) previous studies have demonstrated the impact of noise on hearing screenings (e.g., Sekhar et al, 2011). The TU SLHC from 2001 to 2012 was too small to contain, quietly, hundreds of students assembled for the purposes of screening; the same may be true of other small university clinics. However, the TU SLHC moved in 2012 to a new and larger center as part of the TU Institute for Well Being. Future studies will be conducted to examine if this change has an impact on the accuracy of the initial screening. The use of a two-stage screening was not considered to be an entirely negative aspect of the screening protocol. The two-stage screening protocol allowed screeners to learn about issues associated with background noise and false positive results, with minimal impact on the time required for an accurate final screening result. However, if other programs are using a one-step process conducted in rooms that are not sound treated, the accuracy of the screening is unacceptable without continuous noise level monitoring and carefully orchestrated human traffic control.

The sensitivity of the overall screening processes was excellent when the presence of hearing loss was determined solely based on the same frequencies used for screening (.89) and much poorer when hearing loss was determined by the overall audiogram (.35), as would be expected. If 6000 Hz were included in the screening process, it is estimated the sensitivity would increase to .87 as 80% of the students who fell into the false negative category had thresholds poorer than 20 dB HL at 6000 Hz. These data suggest that the false negative response rate for college-aged students should improve with the addition of 6000 Hz in the screening process. Any possible negative effect on the false positive rate remains to be investigated, as this was not examined at this time.

Because of the prevalence of high-frequency hearing loss in the college-aged population, program directors should be aware that they need to make a purposeful choice regarding screening protocol. If the purpose of the hearing screening is to determine a specific minimum "functional" hearing ability for students to teach and do clinical work, it may be adequate to limit screening to 4000 Hz. If, however, the intent is to identify possible early signs of NIHL, higher frequencies should be considered for inclusion in the screening. This study showed that some students with a high-frequency notch were missed with the commonly used ASHA (1997) screening protocol. NIHL, though irreversible, can be limited through increased awareness and education (Meinke and Dice, 2007). If a student is identified with a high-frequency notch, individual susceptibility and noise exposure habits could be discussed to see if early

NIHL is evident. Students can then be informed about their susceptibility to NIHL and the possibility of preventing further damage with time/intensity limits in occupational and recreational environments and the use of hearing protection, when applicable. This might be an opportunity also to dispense free hearing protection to students, if possible, and for screeners to learn to do hearing conservation counseling. At a minimum, follow-up intervention should include careful consideration of case history and tests beyond the audiogram, to avoid assuming all high frequency notches are caused by noise exposure, as some researchers have found that attribution of the high-frequency notch to noise damage can be erroneous (McBride and Williams, 2001; Green, 2002).

In the current sample, using the "noise notch" criteria described by Phillips et al (2010) resulted in the identification of a high-frequency notch in almost half of the participants, usually centered at 6000 Hz. This is similar to the findings of Phillips et al (2010) for college musicians (78%) and Sekhar et al (2011) for 11th grade students (97%). Using more conservative criteria for the presence of a noise notch, which requires greater recovery (<5dB) and a notch threshold outside of the normal range, the prevalence in the current study dropped to 21%. This highlights the difficulty of comparing prevalence figures across studies, which has been pointed out by previous researchers (e.g., Phillips et al, 2010).

The PPV was found to be excellent in this study (100%); however, the PPV is affected not only by the accuracy of a screening but also by the prevalence of a disorder in a given population. In the current prospective study, 11% of the participants had some degree of hearing loss, which appears to be affected to some degree by ascertainment bias (discussed previously), as this rate is greater than the referral rate of 1.2% reported by Martin and Church (1991) and the referral rate from our retrospective review of 2.7%. PPV estimated from the follow-up data of 139 college students in the Martin and Church study was .82, which may be more realistic than our 100% figure, but only 65% of the students who failed their screening completed diagnostic testing, so an ascertainment bias cannot be completely ruled out for their study either.

Limitations and Future Research

One limitation of this study was the sample size. Over 600 students attended the screenings, and only 80 participated in the prospective trial. This was due to time constraints of the examiner and space limitations for testing. In future studies of college hearing screening efficacy, more participants should be included in a prospective study, 6000 Hz should be included in the screening, students should be asked to participate prior to any screening procedures, and a history of noise exposure should be examined via case history question(s).

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