Audition assessment using the NIH Toolbox

Steven G. Zecker, PhD
Howard J. Hoffman, MA
Robert Frisina, PhD
Judy R. Dubno, PhD
Sumitrajit Dhar, PhD
Margaret Wallhagen, PhD, GNP-BC, AGSF, FAAN
Nina Kraus, PhD
James W. Griffith, PhD
Joseph P. Walton, PhD
David A. Eddins, PhD
Craig Newman, PhD
David Victorson, PhD
Catherine M. Warrier, PhD
Richard H. Wilson, PhD

Correspondence to
Dr. Zecker:
zecker@northwestern.edu

ABSTRACT

The NIH Toolbox project has assembled measurement tools to assess a wide range of human perception and ability across the lifespan. As part of this initiative, a small but comprehensive battery of auditory tests has been assembled. The main tool of this battery, pure-tone thresholds, measures the ability of people to hear at specific frequencies. Pure-tone thresholds have long been considered the "gold standard" of auditory testing, and are normally obtained in a clinical setting by highly trained audiologists. For the purposes of the Toolbox project, an automated procedure (NIH Toolbox Threshold Hearing Test) was developed that allows nonspecialists to administer the test reliably. Three supplemental auditory tests are also included in the Toolbox auditory test battery: assessment of middle-ear function (tympanometry), speech perception in noise (the NIH Toolbox Words-in-Noise Test), and self-assessment of hearing impairment (the NIH Toolbox Hearing Handicap Inventory Ages 18–64 and the NIH Toolbox Hearing Handicap Inventory Ages 64+). Tympanometry can help differentiate conductive from sensorineural pathology. The NIH Toolbox Words-in-Noise Test measures a listener's ability to perceive words in noisy situations. This ability is not necessarily predicted by a person's pure-tone thresholds; some people with normal hearing have difficulty extracting meaning from speech sounds heard in a noisy context. The NIH Toolbox Hearing Handicap Inventory focuses on how a person's perceived hearing status affects daily life. The test was constructed to include emotional and social/situational subscales, with specific questions about how hearing impairment may affect one's emotional state or limit participation in specific activities. The 4 auditory tests included in the Toolbox auditory test battery cover a range of auditory abilities and provide a snapshot of a participant's auditory capacity. ***Neurology*® 2013;80 (Suppl 3):S45–S48**

GLOSSARY

HHIA = Hearing Handicap Inventory for Adults; **HHIE** = Hearing Handicap Inventory for the Elderly.

The human auditory system has the capacity to detect sounds, recognize and discriminate among sounds, comprehend the meaning of acoustic events, localize sound sources, and determine the direction and presence of sound movement. Hearing involves both the physical processing of acoustic signals (e.g., intensity and frequency) and their psychological percepts (e.g., loudness and pitch). Humans can detect, discriminate, and localize a wide variety of auditory stimuli, including linguistic sounds (e.g., speech syllables, words, sentences), and nonlinguistic sounds (e.g., clicks, tones, music). Audition research, traditionally concerned primarily with functions supported by mechanisms in the auditory periphery, has recently begun to examine more central aspects of processing auditory information and the role of hearing as it relates more broadly to human communication.[1]

Audition occurs when acoustic energy enters the outer ear and stimulates the eardrum (tympanic membrane), which transduces acoustic energy into mechanical energy. This mechanical energy is transmitted via the ossicles (malleus, incus, stapes) to the inner ear (cochlea), which transduces hydro-mechanical energy into electrochemical energy to activate the eighth cranial (auditory)

From the Northwestern University (S.G.Z., S.D., N.K., C.M.W.), Evanston, IL; National Institute on Deafness and Other Communication Disorders (H.J.H.), NIH, Bethesda, MD; University of South Florida (R.F., J.P.W., D.A.E.), Tampa, FL; Medical University of South Carolina (J.R.D.), Charleston, SC; Northwestern University (J.W.G., D.V.), Feinberg School of Medicine, Chicago, IL; University of California (M.W.), San Francisco, CA; Cleveland Clinic (C.N.), Cleveland, OH; VA Medical Center (R.H.W.), Mountain Home, TN; and East Tennessee State University (R.H.W.), Johnson City, TN.

Go to Neurology.org for full disclosures. Funding information and disclosures deemed relevant by the authors, if any, are provided at the end of the article.

nerve. The neural signals are then transmitted through the brainstem to the midbrain, thalamus, and cortex.[2] The auditory system has high sensitivity, sharp frequency tuning, fast temporal resolution, and a wide dynamic range, allowing for multifaceted perceptions of the auditory environment.

The evaluation of auditory function is a critical component in health assessment because of its importance to daily living and quality of life, and because many factors and conditions can adversely affect an individual's ability to hear and communicate. Similarly, an impaired ability to hear and communicate can adversely affect treatment adherence and health outcomes. Hearing may be impaired or lost as a result of genetic influences, trauma, disease, long-term exposure to occupational or recreational noise, ototoxic drugs, and/or the aging process. Hearing loss may be present at birth, increase gradually over the course of a lifetime, or occur rapidly because of trauma or pathology. Hearing impairment is associated with numerous communicative, social, cognitive, and emotional consequences.

The physical processing of sound and the psychological correlates of acoustic information can be assessed using a variety of techniques, including behavioral, physiologic, and electrophysiologic measures, and by self-assessment.[3] Performance on these varied measures of auditory function provides the basis for a range of interventions. Measures of hearing can be conducted under earphones to evaluate each ear individually or by testing both ears simultaneously. The presentation of auditory signals can also be delivered via sound field (free field). Hearing can be measured in optimal conditions (e.g., in quiet) and in challenging conditions (e.g., with competing signals such as noise, or by using brief sounds or rapid sequences of sounds).

In reviewing the extensive literature on the assessment of auditory function, it became apparent that few brief and inexpensive measures were available that could be used by nonspecialists to assess auditory function of participants of all ages. Auditory function is typically assessed by graduate-level professionals, namely, audiologists, using standardized procedures and specialized equipment requiring frequent adjustment and calibration. Many assessment tools also require substantial preparation and/or data collection times. Given these constraints, 4 assessments of auditory function (1 primary and 3 supplemental) were identified that were consistent with the goals of the NIH Toolbox: thresholds for pure tones (primary), assessment of middle-ear function (tympanometry), speech perception in noise, and self-assessment of hearing impairment. Within these areas, specific tools for evaluating auditory function were selected.

THRESHOLDS FOR PURE TONES Thresholds for pure tones have long been considered the "gold standard" for the assessment of auditory function. Accordingly, measurement of pure-tone thresholds was considered a priority, and significant work was undertaken to identify and develop a suitable measurement for the NIH Toolbox. Typical commercial devices to assess pure-tone thresholds are costly and require considerable expertise to administer. Thus, our goal was to develop for the NIH Toolbox a nearly automated procedure for obtaining pure-tone thresholds that uses low-cost, widely available computer and audio equipment and can be administered to participants of a wide age range by nonspecialists. A novel system, the NIH Toolbox Hearing Threshold Test, was developed that presents tones of varying levels (a range up to 80 dB sensation level) at one of several frequencies (0.5, 1, 2, 4, 6, and 8 kHz) to each ear individually to establish a threshold as the participant indicates whether the tone is heard. The selected procedure incorporates logic of existing psychophysical paradigms used to assess pure-tone thresholds (e.g., the modified Hughson-Westlake procedure[4]) in a quick, reliable, and precise manner. The system developed for the NIH Toolbox is an air conduction test, and does not include bone conduction testing. Based on the thresholds obtained at each frequency, the system allows any audiometric configuration desired to be produced by a layperson examiner using inexpensive and widely available equipment. Catch trials were included and additional quality assurance features were developed for the purpose of data integrity and analysis. A pilot study is underway whereby experienced audiologists compare the results of the NIH Toolbox Hearing Threshold Test with standard clinical procedures, in terms of threshold levels indicative of hearing sensitivity and speed of administration. Further refinements of the system will be made as it is tested across a wide range of participants, including young children and older adults.

Three additional aspects of auditory function (assessment of middle-ear function, speech perception in noise, self-assessment of hearing impairment) will be represented by supplemental tools and are described below.

ASSESSMENT OF MIDDLE-EAR FUNCTION (TYMPANOMETRY) Tympanometry measures the effect of variations in air pressure in the outer ear canal to assess tympanic membrane mobility. It can be used to assess middle-ear function and to help infer whether elevated thresholds for pure tones are due to conductive pathology (outer or middle ear) or sensorineural pathology (inner ear, auditory nerve, or more central locations). The brief test uses a small pump to vary the air pressure (positive to negative) within the sealed ear canal (1 ear at a time) and a miniature speaker to deliver a probe sound to the sealed ear canal. Using a miniature microphone, the system indirectly measures the response of the eardrum to the change in air pressure by monitoring the sound pressure level generated in the sealed ear canal. Tympanometers have a well-established history of use with participants across the lifespan. Many commercial tympanometers were considered for the NIH Toolbox with the goal of identifying a device that 1) was relatively inexpensive; 2) required relatively minimal expertise to administer; 3) would remain available for purchase for the foreseeable future; and 4) provided data in desired formats. Additionally, regarding technical characteristics, only tympanometers that provided stable performance and maintained calibration well were reviewed. After considering several devices, Otowave, a handheld device requiring annual recalibration available from Maico Diagnostics in Eden Prairie, MN, was selected.

SPEECH PERCEPTION IN NOISE Assessment of the ability to understand spoken words in a noisy background yields an ecologically valid measure of hearing because a substantial portion of communication in the real world occurs in less than ideal environments. Moreover, speech perception in noise is often difficult to predict from pure-tone thresholds or from speech perception in quiet, and therefore must be measured independently (e.g., Ferman et al.,[5] 1993). Among several measures evaluated, the NIH Toolbox Words-in-Noise Test[6–8] best met the NIH Toolbox objectives. The NIH Toolbox Words-in-Noise Test is brief, reliable, and valid, as well as easily administered. The task requires listeners to identify a series of words presented to each ear individually in a background of increasingly loud noise, thereby reducing the signal-to-noise ratio. The test can distinguish between individuals with and without hearing loss[9] and its task simplicity minimizes confounding factors such as memory and attention. The NIH Toolbox Words-in-Noise Test has been normed on individuals between 6 and 84 years of age.[7,10] A Spanish version of the test (Spanish Words-in-Noise: SWIN) is also available.[11]

SELF-ASSESSMENT OF HEARING IMPAIRMENT Self-assessment measures of hearing are positively correlated with other measures of auditory function (e.g., thresholds for pure tones and speech perception). Nevertheless, correlations are often only moderate, suggesting that global self-assessment measures account for aspects of hearing handicap beyond those explained by behavioral measures of hearing. After considering several available measures varying in content and length, 2 versions of the Hearing Handicap Inventory were selected as the self-assessment metrics of hearing impairment. The Hearing Handicap Inventory for the Elderly (HHIE),[12] designed for use in adults aged 65 years and older, consists of 25 questions (each answered on a 3-point scale: Yes, Sometimes, No) relating to an individual's assessment of hearing-related activity limitation and participation restriction. This test was subsequently modified for use with individuals aged 18 to 65 years (the Hearing Handicap Inventory for Adults [HHIA]).[13] Both tests have been translated into many languages, including Spanish. These instruments are not considered appropriate for use with young children; the use of proxy is not considered valid a) because of the likely lack of awareness by the proxy about the state of the child's hearing and communicative abilities, and b) because several questions relate to situations in which young children have little or no experience (e.g., vocational settings). Research has consistently demonstrated that the HHIA and HHIE have high degrees of internal consistency, test-retest reliability, and construct validity.[12–15] Both tests have 10-item short-form screening versions (HHIA-S and HHIE-S) with technical characteristics comparable to the longer versions.[15] Given their brevity combined with strong technical characteristics, these screening versions are recommended as part of the NIH Toolbox: the NIH Toolbox Hearing Handicap Inventory Ages 18 to 64 and the NIH Toolbox Hearing Handicap Inventory Ages 65+.

CONCLUSIONS Tests selected for measurement of audition for the NIH Toolbox assess multiple aspects of auditory function, include behavioral, physiologic, and self-assessment tools, use a variety of auditory signals, include assessment of multiple sites along the auditory pathway and a subjective measure, and meet the NIH Toolbox initiative requirements of brevity, ease of use, and low cost. A hearing threshold test needed to be developed anew for the NIH Toolbox, but well-validated tests existed for self-assessment of hearing-related impairment, as well as a test for hearing difficulties in noisy environments. For most of the assessments, normative data already exist for the age range covered by the NIH Toolbox. In future research beyond the NIH Toolbox, expansion of the age range for both older and younger participants for the measurement of pure-tone thresholds will increase the ability to assess hearing across the lifespan. At present, additional research on the NIH Toolbox Hearing Threshold Test is ongoing.

AUTHOR CONTRIBUTIONS

Dr. Zecker, Mr. Hoffman, Dr. Frisina, and Dr. Dubno were involved in design and conceptualization of the study, interpretation of the data, and drafting and revising the manuscript. Dr. Dhar was involved in design and conceptualization of the study and interpretation of the data. Dr. Wallhagen was involved in design and conceptualization of the study, interpretation of the data, and drafting and revising the manuscript. Dr. Kraus was involved in design and conceptualization of the study and interpretation of the data. Dr. Griffith, Dr. Walton, and Dr. Eddins were involved in design and conceptualization of the study, interpretation of the data, and drafting and revising the manuscript. Dr. Newman was involved in design and conceptualization of the study and interpretation of the data. Dr. Victorson was involved in design and conceptualization of the study. Dr. Warrier and Dr. Wilson were involved in design and conceptualization of the study, interpretation of the data, and drafting and revising the manuscript.

STUDY FUNDING

This study is funded in whole or in part with Federal funds from the Blueprint for Neuroscience Research, NIH, under contract no. HHS-N-260-2006-00007-C.

DISCLOSURE

S. Zecker and H.J. Hoffman report no disclosures. R. Frisina has received funding from the National Institute on Aging, the National Institute on Deafness and Other Communication Disorders (NIDCD), the NIH Toolbox, and the NIH Toolbox project. J. Dubno's research is funded by NIH grants R01 DC000184, P50 DC000422, RC3 DC010986, and R21 DC011174. S. Dhar reports no disclosures. M. Wallhagen serves on the board of HLAA without compensation. N. Kraus reports no disclosures. J. Griffith has received financial support from NorthShore University HealthSystem, the Cleveland Clinic Foundation/Teva Neurosciences, Inc., Ironwood Pharmaceuticals, Inc., and Forest Laboratories, Inc., the NIH, the Department of Defense (DOD)–United States Army, and the FWO, Belgium. In addition to NIH Toolbox funding, he receives funding from the NIH for other research (grant U01 DK082342). He has also been a paid consultant to Dr. Kathryn Grant of DePaul University, and maintains a clinical psychology practice for which he bills for his services. J. Walton receives funding from the National Institute on Aging, and the NIH Toolbox project. D. Eddins receives funding from the NIH, National Institute on Aging, National Institute on Deafness and Other Communication Disorders, the National Science Foundation, and the NIH Toolbox project. C. Newman reports no disclosures. D. Victorson holds stock options in Eli Lilly and Company, received an honoraria for serving on the Steering Committee of the Reeve Neuro-Recovery Network, was funded by NIH contracts HHSN265200423601C and HHS-N-260-2006-00007-C and grants R01HD054569-02NIDRR, 1U01NS056975-01, R01 CA104883, received support from the American Cancer Society (national and Illinois Division) for research in prostate cancer, received institutional support from NorthShore University HealthCare System for research in prostate cancer, received institutional support from the Medical University of South Carolina for sarcoidosis research, and received institutional support from the Northwestern Medical Faculty Foundation for urology research. C. Warrier received NIH Toolbox funding for scientific support to the NIH Toolbox audition team from 2009 to 2011. R. Wilson is the developer of the Words-in-Noise Test (WIN), which is distributed on audio compact disc free of charge to US Government agencies and to researchers. Nongovernment audiologists can obtain the test materials through the East Tennessee State University Foundation for a suggested donation of $50. The money in the Foundation is used to support the Auditory Research Laboratories at East Tennessee State University and at the VA Medical Center, Mountain Home, Tennessee. Go to Neurology.org for full disclosures.

EDITOR'S NOTE

The NIH Toolbox Words-in-Noise Test is in the core Sensation Battery. The Hearing Threshold Test remains under development.

Received June 6, 2012. Accepted in final form November 2, 2012.

REFERENCES

1. Roeser RJ, Valente M, Hosford-Dunn H. Audiology Diagnosis. New York: Thieme Medical Publishers; 2007.
2. Pickles JO. An Introduction to the Physiology of Hearing. New York: Academic Press; 2008.
3. Katz J. Handbook of Clinical Audiology. Philadelphia: Wolters Kluwer/Lippincott William & Wilkins; 2009.
4. Carhart R, Jerger JF. Preferred method for clinical determination of pure-tone thresholds. J Speech Hear Disord 1959;24:330–345.
5. Ferman L, Verschuure J, Van Zanten B. Impaired speech perception in noise in patients with a normal audiogram. Audiology 1993;32:49–54.
6. Wilson RH. Development of a speech-in-multitalker-babble paradigm to assess word-recognition performance. J Am Acad Audiol 2003;14:453–470.
7. Wilson RH, Burks CA. Use of 35 words for evaluation of hearing loss in signal-to-babble ratio: a clinic protocol. J Rehabil Res Dev 2005;42:839–852.
8. Wilson RH, McArdle RA, Smith SL. An Evaluation of the BKB-SIN, HINT, QuickSIN, and WIN materials on listeners with normal hearing and listeners with hearing loss. J Speech Lang Hear Res 2007;50:844–856.
9. Wilson RH, McArdle R. Intra- and inter-session test, retest reliability of the Words-in-Noise (WIN) test. J Am Acad Audiol 2007;18:813–825.
10. Wilson RH, Farmer NM, Gandhi A, Shelburne E, Weaver J. Normative data for the Words-in-Noise Test for 6- to 12-year-old children. J Speech Lang Hear Res 2010;53:1111–1121.
11. McArdle R, Carlo M, Wilson R. Words-in-Noise-Test: English and Spanish. Presented at the American Speech-Language-Hearing Association 2009 convention; New Orleans.
12. Ventry IM, Weinstein BE. The hearing handicap inventory for the elderly: a new tool. Ear Hear 1982;3:128–134.
13. Newman CW, Weinstein BE, Jacobson GP, Hug GA. The Hearing Handicap Inventory for Adults: psychometric adequacy and audiometric correlates. Ear Hear 1990;11:430–433.
14. Newman CW, Weinstein BE. The Hearing Handicap Inventory for the Elderly as a measure of hearing aid benefit. Ear Hear 1988;9:81–85.
15. Newman CW, Weinstein BE, Jacobson GP, Hug GA. Test-retest reliability of the hearing handicap inventory for adults. Ear Hear 1991;12:355–357.