92 Cochlear Implants International
Cochlear Implants Int. **7**(2), 92–106, 2006
Published online in Wiley InterScience
(www.interscience.wiley.com) **DOI**: 10.1002/cii.302

Auditory speech sounds evaluation (A§E®): a new test to assess detection, discrimination and identification in hearing impairment

PJ GOVAERTS, K DAEMERS, M YPERMAN, C DE BEUKELAER, G DE SAEGHER, G DE CEULAER, The Eargroup, Antwerp-Deurne, Belgium

ABSTRACT *This paper describes a set of suprathreshold tests, available as a software package (A§E®), for the auditory evaluation of the hearing impaired. It uses isolated speech sounds as test material for a discrimination, identification and detection test, and is specifically suited to test preverbal children. All tests allow strict analytical interpretation. The test material and procedures are described. Their clinical use is illustrated. The authors claim that suprathreshold tests are feasible in the preverbal child, allowing analytical evaluation of the auditory capacities. These tests are complementary to the routinely used detection tests and add significantly to the hearing evaluation in preverbal children. The authors recommend the phoneme discrimination test for selection of cochlear implant candidates and for the evaluation and fitting of cochlear implants.*

Keywords: hearing loss, hearing aid, cochlear implant, supraliminal audiological test, suprathreshold, speech sounds, phoneme discrimination, phoneme identification

Introduction

This paper describes the Auditory Speech Sounds Evaluation (A§E®, ©PJ Govaerts, Antwerp, Belgium), which is an audiological evaluation tool that uses strictly defined phonemes or speech sounds as stimulus material for detection, discrimination and identification tests. The A§E® was designed as a language-independent test yielding suprathreshold information on the auditory function with as little cognitive bias as possible. The main purpose of the test is to evaluate the discriminatory power of the cochlea of very young, preverbal hearing-impaired children with hearing aids. It was hoped that the results of such a test could be used in the selection and the evaluation of cochlear implant candidates. Hence, the reasons to choose speech sounds were the following: (1) speech sounds can be presented at suprathreshold intensities; (2) speech sounds are basically language independent (although not entirely, as discussed further); (3) speech sounds can be constructed with exact duration and intensity, thus limiting the potential cues; (4) speech sounds can be used for discrimination, thus eliminating the cognitive abilities that are required for speech audiometry for example; (5) speech sounds are more attractive to infants and children than either pure tones or synthetic material; and (6) the frequency spectrum of speech sounds can be measured and this can be used for analytical evaluation of the test results. The construction of the test material, the test procedure and the clinical applications are described. It is not within the scope of the present paper to provide normative data. With the present description of the test material and now that it is available in several centres worldwide, normative data can be obtained in many different age groups and they will be reported in separate publications.

Construction of the A§E®

The A§E® is an audiological evaluation tool based on speech sounds as stimuli. In a first stage, the isolated speech sounds were recorded on CD, and the response and tester forms were on paper. In a second stage, the whole test procedure was converted in a software package (contact the authors (www.eargroup.net) for details, deposited at InterDeposit Digital Number, Geneva IDDN. BE.010.0101010.000.R.P.2003.035.31230). All speech sounds were recorded by one female speaker of the Flemish dialect. The selection of the speech sounds will be discussed for each test (detection, discrimination and identification) separately.

Loudness balancing

All speech sounds were digitally trimmed to the same length of 625 μs, rms-balanced and recorded as *.wav-files on CD (16 bit stereo 48k sample rate). Then, each speech sound was loudness-balanced with reference to the /a/ in six normally hearing adults to eliminate loudness differences as cues for the discrimination (all phonetic symbols will be according to the IPA, i.e. International Phonetic Alphabet, see www2.arts.gla.ac.uk/IPA/sounds.html). For this purpose, each speech sound was presented in free field at random intensities (between an upper and a lower fence, see below) and alternated with the /a/ which was presented at 70 dB SPL. The test subject was asked whether the test phoneme sounded louder, softer or equally as loud as the /a/. If a given intensity was scored 'louder than /a/' for three consecutive presentations, this intensity was considered to be too loud and defined the upper fence for the time being. The same was true for intensities that were

Cochlear Implants Int. **7**(2), 92–106, 2006

DOI: 10.1002/cii

scored ‘softer than /a/’ for three consecutive presentations and that defined the temporary lower fence. The step size decreased from 3 dB in the beginning to 0.8 dB at the end of the test. In this way, the intensity range between upper and lower fence was narrowed until all remaining intensities resulted in ambiguous comparisons with the /a/. This was typically the case for three or four remaining intensities of the test speech sound. Then the test speech sound was presented seven times at each of these remaining intensities, again in random order and alternating with the same /a/ at 70 dB SPL. For each presentation the score was recorded, and at the end the intensity with the most frequent score ‘sounds equally loud as /a/’ was saved as the loudness-balanced intensity of that particular speech sound. The intensity of all speech sounds was modified according to this algorithm. Thus all speech sounds were loudness balanced with reference to /a/ at 70 dB SPL and with a precision of 0.8 dB. Finally, the /a/ was loudness balanced according to the same algorithm with reference to a 1 kHz narrow-band noise at 70 dB HL, and all speech sounds were adjusted accordingly. In consequence, the intensity of the speech sounds can be expressed in ‘dB HL (re 1 kHz narrow band noise)’.

Intensity roving

The precision of this loudness balancing was 0.8 dB, since this was the minimum step size used in the test procedure. In addition, the temporal profile of the speech sounds may still contain intensity cues that would help discrimination between two speech sounds. In order to eliminate these possible intensity cues, the A§E® is designed in such a way that a gain is added to the intensity of all speech sounds. This gain varies randomly between an upper and a lower limit, which can be defined by the tester. Limits of +3 dB and −3 dB respectively are recommended and set as default values. This introduces a random variability in the intensity of the speech sounds that overrules any possible intensity differences between two speech sounds. In consequence the test subject is ‘deconditioned’ to take notice of any possible intensity cues.

A§E® discrimination test

The speech sound discrimination test is an oddity test in which two speech sounds are presented and the infant is conditioned to react to the odd speech sound. The details of the procedure are described below.

The speech sounds for the A§E® were selected to be ‘linguistically representative’. This means that for the vowels, the three cardinal vowels /a/, /i/ and /u/ were selected as well as /ɛ/, /y/ and /o/, which are lying in between the three cardinal vowels in the vowel triangle and the centrally positioned /ə/ (Peterson and Barney, 1952). For the consonants, speech sounds were selected that differ only in one feature (like voicing (/z/–/s/), articulation place (/v/–/z/ and /s/–/ʃ/)) or in several features (like articulation place and mode and nasality (/m/–/z/), articulation place and mode and nasality and voicing (/m/–/f/ and /m/–/r/)). This selection also

DOI: 10.1002/cii

includes the Ling-sounds (/a/–/i/–/u/–/s/–/ʃ/). From the many possible combinations that can be constructed, a 'basic set' of 22 speech sound pairs was selected (Table 1) in such a way that most contrasts are represented.

Test procedure

Since the A§E® discrimination test can be used for both adults and children, the test procedure is given in general terms. It is basically an oddity procedure (Figure 1). For each pair of speech sounds (Table 1), the first serves as background and the second as odd speech sound. Sounds are routinely presented at 70 dB HL (re 1 kHz narrow band noise). In case of doubt whether this exceeds the audible level of the aided patient, this is checked and the presentation level may be increased. All test sessions begin with a training or conditioning phase in which the test subjects are trained (adults) or conditioned (children) to react to the odd speech sound. The training or conditioning procedure is the same as the actual test procedure; only the odd speech sound is much longer (between 1941 and 3261 ms). The background speech sound is repeated at regular intervals (typically 850 ms, although this can be varied from 500 to 3000 ms). After a random number (between three and eight) of presentations of the background speech sound, the next background speech sound is replaced by the odd speech sound, and if the test subject responds to this in a consistent way, it is concluded that the contrast between the background and the odd speech sound is well discriminated. In adults, consistent

Table 1: 'Basic set' of speech sound pairs that were tested for discrimination

a–r	i–ɛ
u–ʃ	ə–ɛ
u–i	ə–i
i–a	y–i
u–a	u–y
o–a	z–s
u–o	m–f
ə–a	m–z
ə–u	m–r
ə–o	s–ʃ
ɛ–a	v–z

The first speech sound of a pair is presented as the background speech sound and the second as the odd speech sound. The black fields represent the speech sound pairs of the 'minimal set', see text.

Cochlear Implants Int. **7**(2), 92–106, 2006

DOI: 10.1002/cii

Conditioning track

O	O	O	O	O	O	XXXX	O	O…
O	O	O	O	XXXX	O	O	O	O…
O	O	O	O	O	XXXX	O	O	O…
O	O	O	O	XXXX	O	O	O	O….

Test track

O	O	O	O	O	X	O	O	O…
O	O	O	O	X	O	O	O	O…
O	O	O	O	O	O	X	O	O…
O	O	O	O	X	O	O	O	O….
O	O	O	O	O	O	X	O	O…
O	O	O	O	O	X	O	O	O…
O	O	O	O	X	O	O	O	O…

Figure 1: Example of the conditioning and test tracks of the A§E® to test the discrimination of a stimulus speech sound in a background of a repeated other speech sound. Each line represents a track consisting of a series of the background speech sounds (O), which is replaced by the stimulus speech sound (X) at random positions. The duration of the background speech sounds and of the stimulus speech sounds marked as X is 625 ms. The duration of the stimulus speech sounds marked as XXXX varies from 1941 to 3261 ms.

responses are obvious, but in the young child the expert judgement of paediatric audiologists is needed.

All 14 speech sounds can be used as background speech sound and 11 as odd speech sound (Figure 2).

Use in our clinical audiology

The discrimination test of the A§E® is used routinely to evaluate the cochlear function in hearing-impaired children and adults. As a measure of the frequency-resolving capacity of the aided cochlea (with hearing aids), it has become an essential tool in the selection of cochlear implant candidates. If the patient fails to discriminate on several speech sound pairs, it is anticipated that their discrimination will be better with an implant. Obviously, the speech sound discrimination is not the only selection criterion for cochlear implantation and the results should be combined with audiological and other results before a final decision is made.

The discrimination test of the A§E® is also used routinely for the evaluation of cochlear implants. This information adds to other outcome measures and is essential as feedback for the selection of new candidates. Figure 3 shows a typical cochlear implant patient file.

DOI: 10.1002/cii

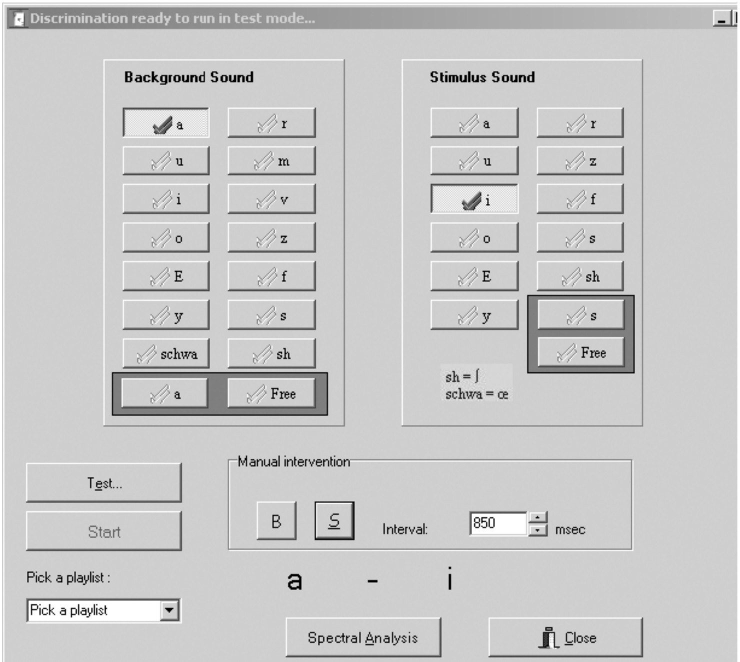

Figure 2: Test screen of the A§E® speech sound discrimination test. The 14 background speech sounds and 11 odd speech sounds are represented by buttons. The tester selects one of each (in this case /a/ and /i/ respectively), switches to conditioning or test mode (in this case test mode) and defines the interval between the speech sounds (in this case 850 ms). IPA (International Phonetic Alphabet) symbols are used, except for E, which stands for /ɛ/; schwa, which stands for /ə/; and sh, which stands for /ʃ/.

A§E® identification test

The A§E identification test is a two or more forced-choice speech sound identification test with a picture-pointing response. The details of the procedure are described below.

The same speech sounds as for the discrimination test were selected, with the exception of /y/ and /ə/. Both speech sounds are situated either intermediately or centrally in the vowel triangle (Peterson and Barney, 1952), and it is not easy to find pictures (onomatopoeia or mouth images, see below) that clearly represent these speech sounds. For all 12 remaining speech sounds, pictures were made that unambiguously represent the speech sound. Two types of pictural representations were made, the first type based on onomatopoeia (Figure 4) and the second type based on the mouth image of the speech sound (Figure 5). Onomatopoeia are commonly used by speech therapists and teachers of the deaf to elicit phonation and auditory attention in hearing-impaired children. The speech sounds or syllables have to refer to a known object or situation. A set of such Flemish onomato-

Cochlear Implants Int. 7(2), 92–106, 2006

DOI: 10.1002/cii

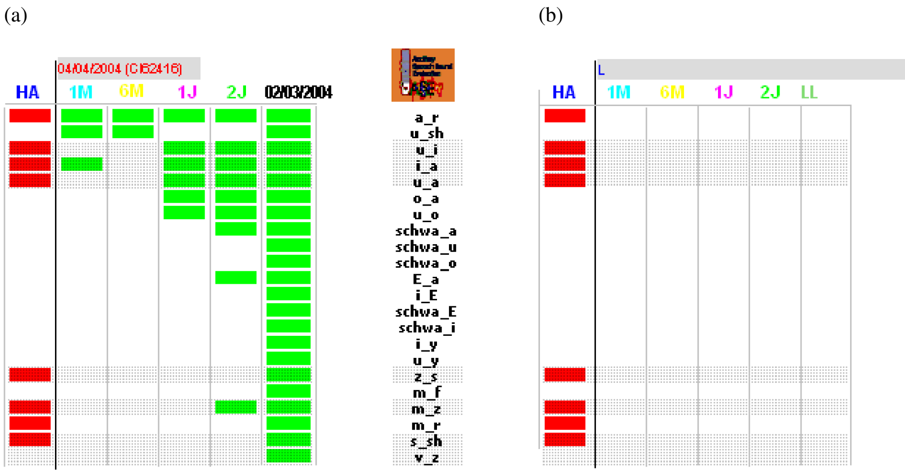

Figure 3: Typical A§E® discrimination report as routinely used in the Eargroup. This represents the right ear (a) and the left ear (b) of a boy with congenital deafness due to connexine-26 mutations, who received a cochlear implant on his right ear at the age of 14 months. The thick vertical line in the middle of each pane represents the moment of implantation. The column to the left of this line (marked HA) contains the A§E® results with hearing aids prior to the implantation. The fields are red (black on B&W) in case no discrimination was found on the given speech sound pair and green (grey on B&W) in case discrimination was found. The columns to the right of the vertical line are the results at different moments after implantation, as marked on top of the column. IPA (International Phonetic Alphabet) symbols are used, except for E, which stands for /ɛ/; schwa, which stands for /ə/; and sh, which stands for /ʃ/. (The colour version of this figure can be found via www.interscience.wiley.com/journal/cii)

poeia had earlier been developed by the Royal Institute for the Hearing and Speech Impaired in Hasselt, Belgium (Koninklijk Instituut voor Doven en Spraakgestoorden) and was adapted and recorded for the A§E®. Mouth images are also familiar to hearing-impaired children, since they start reading lips from birth and continue to use this spontaneous faculty. From the many speech sound combinations that can be possibly constructed, a limited number of multiple choice sets were selected in such a way that the number of test speech sounds ranged from two to six (Figure 6).

Test procedure

Since the speech sound identification test can be used for both adults and children, the test procedure is given in general terms. It is basically a forced-choice procedure (Figure 6). Speech sounds are combined in sets of two, three, five or six. The tester can choose how often each speech sound has to be presented (range three to six times). The order of presentations is randomized. Sounds are routinely presented at 70 dB HL (re 1 kHz narrow band noise). In case of doubt whether this exceeds

DOI: 10.1002/cii

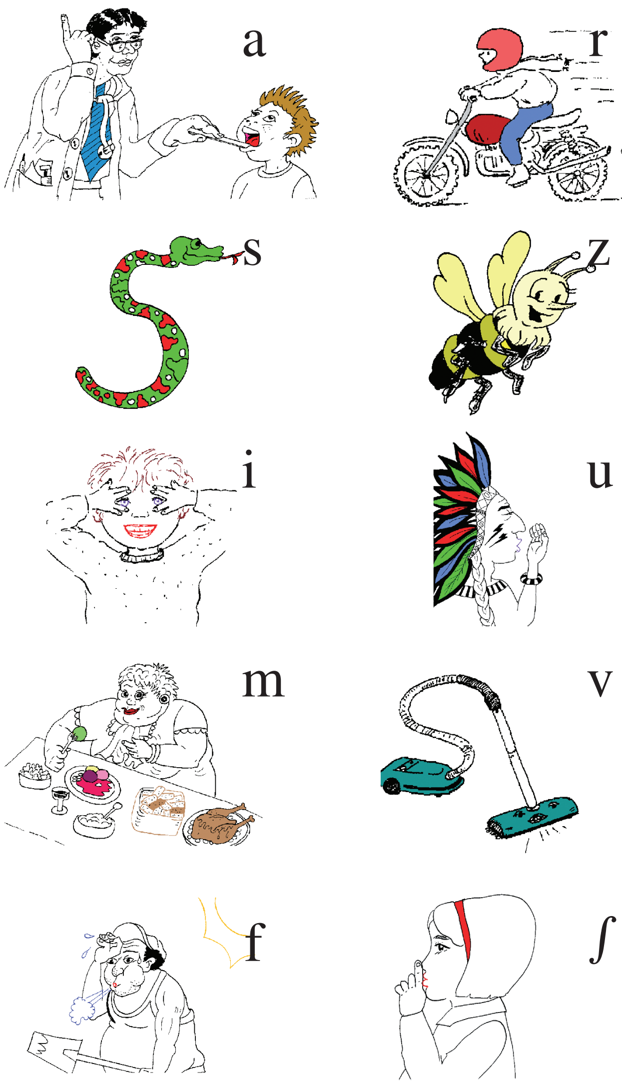

Figure 4: Pictures of the Flemish onomatopoeia of the speech sounds for identification (pictures by Marijke Duffhaus). IPA (International Phonetic Alphabet) symbols are used.

the audible level of the aided patient, this is checked and the presentation level may be increased. After a speech sound is presented, the test subject has to identify it, either by just repeating it (adults), or by pointing to the correct picture (children). This choice is registered and the next speech sound is given. The test stops when all speech sounds in the set have been given the predefined number of times. The number of correct responses and the confusion matrix of all errors are given in the report, as well as the overall score. The overall score is a yes or no score,

DOI: 10.1002/cii

Figure 5: Pictures of the mouth images of the speech sounds for identification. Note that hearing-impaired children are used to read lips, which may facilitate the test. IPA (International Phonetic Alphabet) symbols are used.

meaning that the given set of speech sounds is correctly identified or not. This is based on binomial statistics with a significance level of 0.05.

Use in our clinical audiology

The identification test of the A§E® is not used routinely in clinical practice. The reason for this is that it requires not only good discrimination of the speech sounds, but also good cognitive processing, and this is not the primary scope of the audiological evaluation. A discrimination test assesses the cochlear frequency-resolving function in a purer way. On the other hand, an identification test is less boring than a discrimination test and this may be interesting for some patients. In addition, an identification test can be helpful in case the discrimination of speech sounds is difficult but not impossible. In such a case, it may be interesting to know whether this hardly discriminated speech sounds result in distinct identifications

DOI: 10.1002/cii

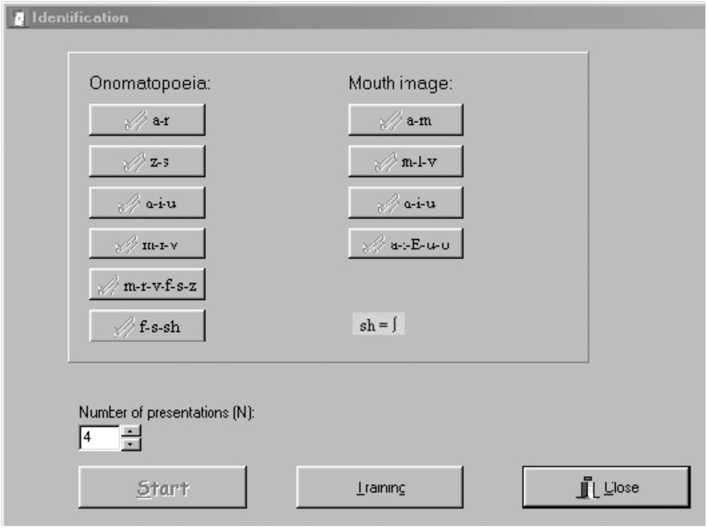

Figure 6: Test screen of the A§E® identification test. The six multiple-choice tests with onomatopoeia and the four multiple-choice tests with mouth images are represented by buttons. The tester can choose how often each speech sound has to be presented (in this case four times). The report form will say whether the test subject has identified the speech sounds correctly with a statistical significance based on real-time binomial statistical calculations. IPA (International Phonetic Alphabet) symbols are used, except for E, which stands for /ɛ/, and sh, which stands for /ʃ/.

or not. This knowledge adds nuances to the audiologist's interpretation of a person's audiological performance, e.g. for the selection of cochlear implant candidates.

The identification test of the A§E® can also be used for the evaluation of cochlear implants. This information adds to other outcome measures, although its quantitative information is limited.

Finally, the identification test is sometimes used to adjust the fitting of the cochlear implant. The results contain a confusion matrix indicating which speech sounds are easily confused with which other speech sounds. Spectral analysis of two such speech sounds can help the audiologist in finding out which channels need readjustment.

In combination with the speech sound discrimination test, the results can help the rehabilitative therapist to focus and train on specific speech sounds that are discriminated but not identified as distinct speech sounds.

A§E® detection test

The speech sound detection has been added to the A§E® on the request of several users. As said before, the primary purpose of the A§E® was to have a suprathreshold test. Detection of sound can be tested by routine audiometry using pure tones,

DOI: 10.1002/cii

warble tones, narrow band noise, etc. These are well calibrated, validated and are part of every basic audiological test equipment. Assessing the detection thresholds for the speech sounds of the A§E® can be useful as an internal control to check the response thresholds of the child, and to check the equipment and hearing aid used.

All consonants of the basic set (Table 1) were selected, together with the vowels /a/, /o/ and /i/. The other vowels have been left out since the /a/, /o/ and /i/ sufficiently cover the whole frequency range of human hearing. In addition, the stop consonants /t/, /p/, /k/, /d/ and /b/ have been added as experimental tools on the request of several audiologists and to be used at their own discretion.

Since the speech sounds of the basic set had been loudness balanced at a level of approximately 70 dB HL, a rebalancing was carried out at threshold levels for the detection test. For this purpose, thresholds were determined for all speech sounds in six normally hearing adults. The threshold of a 1 kHz narrow band noise was used as reference. This yielded the correction factors that were used to modify the intensity of each speech sound. The speech sounds have been loudness balanced in such a way that the normal thresholds are 25 dB HL on a calibrated audiometer (hence, this is 0 dB HL re 1 kHz narrow band noise).

Test procedure

Since the speech sound detection test can be used for adults and children, the test procedure is given in general terms. It is basically the same as any detection test aiming at defining the hearing threshold. The same strategies can be used as for audiometry and a 5-up, 10-down procedure may be preferred by most audiologists. Speech sounds are presented three times after the proper button has been pushed.

The test subject is asked to give a response when the speech sound is heard. Depending on the subject's age this can be an oral response, a conditioned instrumentation response or an orientation reflex. The tester records whether the test subject has detected the speech sound or not and proceeds to the next speech sound. In adults, consistent responses are obvious, but in the young child the expert judgement of paediatric audiologists is needed.

Use in our clinical audiology

As mentioned before, the speech sound detection test does not constitute the primary goal of the A§E®. It is not routinely used in clinical practice, since detection thresholds are better assessed by means of classical audiometry. On the other hand, speech sounds may have specific advantages. Like for the other speech sound tests, speech sounds are more attractive to many infants and children than pure tones and it may be easier and time saving to work with speech sounds. Speech sounds also cover all frequencies, and in the case of hearing aids or implants, it is

DOI: 10.1002/cii

not always obvious how the electronic device modifies these frequencies. Hence, it may be interesting to know the detection threshold for a given speech sound rather than for a specific tone.

Discussion

One of the challenges in handling the paediatric hearing-impaired population is the assessment of hearing. Pure tone audiometry, otoacoustic emissions, automated brainstem audiometry, etc., only assess hearing at its detection (or 'liminal') level. This may be sufficient to know whether a hearing problem exists or not, but it hardly reflects the capacity of the hearing-impaired child to discriminate or identify language. So far, too little attention has been given to the fact that a sensorineural hearing impairment not only means an increase in detection threshold but also a loss of the frequency resolving power of the cochlea (e.g. Khanna and Leonard, 1982; Sellick et al., 1982; Moore 1986, 1996; Ruggero 1992). The recent evolution of early identification of hearing loss and early intervention have forced us to look for suprathreshold evaluation techniques that are suitable for very young children. Such tests are needed in the evaluation of hearing aids and in the selection of cochlear implant candidates and the evaluation of cochlear implantees.

Suprathreshold features of hearing are discrimination and identification of sounds. Discrimination of sounds means that two different sounds are perceived as different by the subject, without the necessity to identify them. Identifying refers to the cognitive ability to label two different sounds with their correct meaning. Detection and discrimination are basic cochlear features. The necessary capacities hardly require cognitive skills, and they already exist in neonates (Eimas et al., 1971). They can be assessed by looking for reflexive or orientation responses. Identification, in contrast, requires detection, discrimination and cognitive processing and it can only be tested by means of behavioural responses (such as in play audiometry).

Infants of 2 months old have been shown to be able to discriminate consonants with different places of articulation (Morse 1972; Jusczyk 1977), stop/glide distinctions (Eimas and Miller, 1980a) and distinctions between different glides (Jusczyk and Thompson, 1978) or different nasals (Eimas and Miller, 1980b). Distinctions between different fricative consonants can be made after 6 months of age. Similar findings have been reported for discrimination of vowel contrasts (Trehub 1973; Swoboda et al., 1976; Kuhl 1983) and prosodic features (Spring and Dale, 1977; Jusczyk and Thompson, 1978). This discriminative capacity is not only present for the native language, but also for contrasts that do not occur in the native language (Trehub 1976; Werker and Tees, 1984). Infants appear to be born with the capacity to discriminate contrasts that could potentially appear in any of the world's languages (Eimas et al., 1987).

Tests for discrimination or identification of spoken language (words and sentences) exist, but especially in the preverbal child the results are strongly biased

DOI: 10.1002/cii

by the language level and cognitive skills. A 'preverbal' child is a child with no or very limited functional speech, both comprehensive and productive. Hearing children usually become verbal by the age of 1 year (Barrett 1994; Gillis and Schaerlaekens 2000). In hearing-impaired children this age is very variable. It depends on the level of hearing loss and the type and intensity of stimulation. Their preverbal stage may typically last until the age of 4–5 years.

A common way to investigate auditory performance is the identification test. Identification tasks presuppose knowledge of both stimulus and distracting words as well as the complex abilities to remember the stimulus, to match it with the auditory image of the distracting words, to take a decision, etc. (Boothroyd 1995; Dillon and Ching 1995). This degree of linguistic knowledge and higher functions is not always present in the hearing-impaired child. In consequence, these children tend to score too low on this type of test when compared to their real auditory capacities. Thus most of the existing identification tests are only fit for verbal children. In hearing children they are feasible from the age of 2–3 years onwards but in deaf children or children with additional problems in language development they cannot be done at this young age.

Another, and possibly more correct, way to test preverbal children with minimal bias related to the level of linguistic development is testing discrimination instead of identification. No knowledge of the stimulus is required. The child has to discriminate between two or more successive stimuli and has to show a behavioural response (Bochner et al. 1992; Dillon and Ching 1995). A disadvantage of conventional discrimination tests may be the lack of behavioural response to small perceptive differences, and it has been reported that these tests are not feasible below the age of 3 years or even later in hearing-impaired children (Daemers K et al., oral communication, 3rd European Conference on Audiology, Prague, 1997; De Sloovere M et al., oral communication, 4th European Symposium on Paediatric Cochlear Implantation, 's-Hertogenbosch, 1998). Furthermore, these tests are boring and cognitively demanding (Boothroyd 1997). On the other hand, when conventional discrimination tests were modified for the younger children to visually reinforce discrimination audiometry, some proved to be feasible (Eilers et al. 1977; Moore 1995; Dawson et al. 1998). An additional advantage of discrimination tests as part of a test battery is that they allow for the assessment of the cause of systematic confusions when these occur in identification tests. Indeed, if a child fails to identify a given stimulus while it can be shown that the discrimination of the same stimulus is present, it can be concluded that the identification problem is not due to auditory perceptive deficiencies (Dillon and Ching 1995). Identification in such a case cannot be improved by changing the fitting or programming parameters of the hearing aid or implant. In contrast, an identification problem of a given stimulus that can be shown not to be discriminated properly is obviously due to bad discrimination and thus to an auditory perceptive deficiency. In the latter case better identification may be achieved by optimizing the fitting or programming parameters of the device.

DOI: 10.1002/cii

By using calibrated speech sounds that only differ from one another in their spectral content, the A§E® attempts to overcome many of the disadvantages related to conventional identification and discrimination tests.

In conclusion, the A§E® is a new test to assess the suprathreshold auditory performance. It is lexicon and language independent, feasible in the preverbal child and complementary to existing audiological tests.

References

Barrett M (1994) Early lexical development. In: Fletcher P, MacWhinney B (eds) The handbook of child language, pp. 362–392. Oxford: Blackwell.

Bochner J, Garrison W, Palmer L (1992) Simple discrimination isn't really simple. Scandinavian Audiology 21: 37–49.

Boothroyd A (1995) Speech perception tests and hearing-impaired children. In: Plant G, Spens KE (eds) Profound deafness and speech communication, pp. 345–371. San Diego, CA: Singular Publishing Group.

Boothroyd A (1997) Auditory capacity of hearing-impaired children using hearing aids and cochlear implants: issues of efficacy and assessment. Scandinavian Audiology 26(suppl 46): 17–25.

Dawson PW, Nott PE, Clark GM, Cowan RS (1998) A modification of play audiometry to assess speech discrimination ability in severe-profoundly deaf 2- to 4-year-old children. Ear and Hearing 19: 371–384.

Dillon H, Ching T (1995) What makes a good speech test? In: Plant G, Spens KE (eds) Profound deafness and speech communication, pp. 305–344. San Diego, CA: Singular Publishing Group.

Eilers RE, Wilson WR, Moore JM (1977) Developmental changes in speech discrimination in infants. Journal of Speech and Hearing Research 20: 766–780.

Eimas PD, Miller JL (1980a) Contextual effects in infant speech perception. Science 209: 1140–1141.

Eimas PD, Miller JL (1980b) Discrimination of the information for manner of articulation. Infant Behavior and Development 3: 367–375.

Eimas PD, Siqueland ER, Jusczyk PW, Vigorito J (1971) Speech perception in infants. Science 171: 303–306.

Eimas PD, Miller JL, Jusczyk PW (1987) On infant speech perception and the acquisition of language. In: Harnad S (ed.) Categorical perception. New York: Cambridge University Press.

Gillis S, Schaerlaekens A (2000) Kindertaalverwerving: een handboek voor het Nederlands. Groningen, Netherlands: Martinus Nijhoff.

Jusczyk PW (1977) Perception of syllable-final stops by two-month-old infants. Perception and Psychophysics 21: 450–454.

Jusczyk PW, Thompson EJ (1978) Perception of a phonetic contrast in multisyllabic utterances by two-month-old infants. Perception and Psychophysics 23: 105–109.

Khanna SM, Leonard DGB (1982) Basilar membrane tuning in the cat cochlea. Science 215: 305–306.

Kuhl PK (1983) Perception of auditory equivalence classes for speech in early infancy. Infant Behavior and Development 6: 263–285.

Moore BCJ (1986) Parallels between frequency selectivity measured psychophysically and in cochlear mechanics. Scandinavian Audiology Suppl 25: 139–152.

Moore JM (1995) Behavioural assessment procedures based on conditioned head-turn responses for auditory detection and discrimination with low functioning children. Scandinavian Audiology 24(suppl 41): 36–42.

DOI: 10.1002/cii

Moore BC (1996) Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. Ear and Hearing 17(2): 133–161.

Morse PA (1972) The discrimination of speech and nonspeech stimuli in early infancy. Journal of Experimental Child Psychology 14(3): 477–492.

Peterson GE, Barney HL (1952) Control methods used in a study of the vowels. Journal of the Acoustical Society of America 24: 175–184.

Ruggero MA (1992) Responses to sound of the basilar membrane of the mammalian cochlea. Current Opinions in Neurobiology 2: 449–456.

Sellick PM, Patuzzi R, Johnstone BM (1982) Measurements of basilar membrane motion in the guinea pig using the Mössbauer technique. Journal of the Acoustical Society of America 72: 131–141.

Spring DR, Dale PS (1977) Discrimination of linguistic stress in early infancy. Journal of Speech and Hearing Research 20: 224–232.

Swoboda P, Morse PA, Leavitt LA (1976) Continuous vowel discriminiation innormal and at-risk infants. Child Development 47: 459–465.

Trehub SE (1973) Infant's sensitivity to vowal and tonal contrasts. Developmental Psychology 9: 91–96.

Trehub SE (1976) The discrimination of foreign speech contrasts by infants and adults. Child Development 47: 466–472.

Werker JF, Tees RC (1984) Cross-language speech perception: evidence for perceptual reorganization during the first year of life. Infant Behavior and Development 7: 49–63.

Address correspondence to: Paul J Govaerts MD, MSc, PhD, The Eargroup, Herentalsebaan 75, B-2100 Antwerp-Deurne, Belgium. Email: dr.govaerts@eargroup.net

Accepted 8 November 2005

DOI: 10.1002/cii