ARTICLE

Three Tests of CNS Auditory Function

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Abstract
A battery of three difficult speech tests (competing message, filtered speech, and binaural fusion) were developed and standardized on a group of normal young adult subjects. This battery was designed for the purpose of identifying lesions at various levels of the central auditory system. The results showed equivalency between the two lists of each test except binaural fusion and generally confirmed the findings on normal adult subjects by other investigators. A review of the literature using this battery on neuropathologic adults supports the validity of the tests. The reliability of the binaural fusion subtest has been questioned in the literature. Therefore it would be appropriate to add a procedure such as the brainstem electric response (BSER) method for assessing the brainstem level of the auditory system in patients with suspected neuropathology. This battery with the addition of BSER should provide a uniform measure in the clinical setting which will allow the assessment of several levels and sidedness of the central auditory system.

Introduction

This article discusses the construction and normalization of three auditory tests in a battery for assessing central auditory function. These tests form the basis of the Colorado State central auditory processing test battery. Because this battery is widely used, a description of the concept, rationale, construction, and normalization of the test battery based on the original study would be useful (Ivey, 1969).

It was our position that there was a need to standardize a battery of tests which could be used with confidence by the clinician to identify and assess disorders of the central auditory pathways. This need may be emphasized by the fact that central nervous system (CNS) abnormalities affecting auditory processing may be of various types, including expanding neoplasms, degenerative lesions, developmental errors, metabolic errors, and blood supply disorders. Many of these abnormalities may not be evident using computerized tomography. Even expansive lesions may not be seen in the early stages prior to bone erosion or tissue displacement. It is important to identify the presence of expansive lesions early because, in general, the mortality rate for small tumors is less than for large tumors (Nager, 1969).

The usefulness of standard pure tone and speech audiometry, according to Bocca and Calearo (1963), Quist-Hanssen and Stromsnes (1960), and Willeford (1967) is limited to assessing peripheral auditory function. The cochlear portion of the VIIIth cranial nerve terminates at the cochlear nuclei. Whitfield (1967) states that "no primary afferents pass beyond the cochlear nuclei. . . ." For present purposes the peripheral auditory mechanism was considered to terminate with the synapse of sensory fibers at the cochlear nuclei.

Various levels of central auditory function have been studied by researchers. The procedures generally used were constructed by each investigator, and although similar results were found for each test between investigators, the tests themselves were not identical. Calearo and Antonelli (1963), Dirks (1964), Ohta, Hayashi and Morimoto (1967), Frager (1968), and Jerger (1969) agree that binaural separation (e.g., testing with competing sentences) is a function of the temporal lobes. Ohta et al. (1967) state that "the ability of binaural separation is a function of the highest levels of the central auditory pathway. . . ." Several investigators have found that persons with localized lesions of the temporal lobe show poorer scores for stimuli presented to the ear contralateral to the site of lesion (Calearo & Antonelli, 1963; Dirks, 1964; Ohta et al., 1967). Also, persons with diffuse cortical lesions show similar scores for both ears but had scores lower than those of normal listeners.

Filtered speech has been studied by Bocca, Calearo, Cassinari, and Migliavacca (1955), Jerger (1960), Quist-Hanssen and Stromsnes (1960), Billingslea (1963), Bocca and Calearo (1963), Calearo and Antonelli (1963), Gambino (1963), Linden (1964), Hodgson (1967), and Frager (1968). Bocca and Calearo indicated that filtered speech tests permit assessment of the function of the temporal lobe. Several investigators have shown that, in cases of unilateral lesions of the temporal lobe, the ear contralateral to the affected hemisphere gives the poorer discrimination score (Bocca et al., 1955; Jerger, 1960; Quist-Hanssen & Stromsnes, 1960; Hodgson, 1967). A diffuse cortical pathology, however, may be expected to show equally poor results in both ears.

In general, the work of Matzker (1962), Azzi (1964), Linden (1964), Hayashi (1966), and Ohta et al. (1967) shows that binaural fusion is a function of the brainstem. These investigators used items that had been electronically filtered into two different frequency segments for simultaneous presentation to opposite ears. The premise for this procedure was that for binaural fusion to occur, the fibers which decussate in the brainstem must be intact in order to combine the two segments into one perception. It should be noted that this process is more accurately termed binaural resynthesis, because the two segments do not actually fuse into a single image. The two segments contain complementary information that is apparently processed at the brainstem level, allowing the eventual recognition of a single item.

Most of these investigators had not adequately standardized their tests for more than experimental purposes. This lack of standardization permitted no reference to which an individual's results could be compared in clinical practice. Because of the evidence that different types of tests would challenge different levels of the central auditory nervous system, the next logical step would be to construct a battery of tests that would allow differential assessment within the central auditory nervous system.

Three types of difficult speech tests are discussed in this study: competing message (CM), filtered speech (FS), and binaural fusion (BF). The development of these tests was based on the research evidence cited above. That is, the three tasks would be useful in evaluating the efficiency of various levels of the central auditory system. Thus the purpose of the original study (Ivey, 1969) was to establish criterion boundaries for normal young adult behavior on the three tests of central auditory function so these tests might be applied as a standard test battery in clinical settings.

Experimental Design

Subjects

Twenty university students (between the ages of 19 and 33 years, with a mean age of 21.8) with negative otological and neurological histories served as subjects. They were screened by pure tone audiometry to assure that they had auditory thresholds no greater than 10 dB HL (ISO, 1964) bilaterally between 500 Hz and 4000 Hz. At the time of this study, the audiometers at Colorado State University were calibrated to the ISO 1964 standard. The reference threshold levels are identical to the ANSI 1969 standard for air-conducted pure tones. All subjects scored between 96% and 100% on a word discrimination test consisting of lists 6 and 7 of the revised CNC words as compiled by Peterson and Lehiste (1962). Subjects were then randomly divided into two equal groups. The two groups were used to counterbalance the presentation order of the lists for each test.

Tests

Competing Message (CM)

Material. Fifty sentences structured as 25 competing pairs were used for the CM test. The two different sentences of each pair were presented dichotically (separately but simultaneously to opposite ears). These sentences were carefully constructed and paired for similar length and related content. This test was developed by Willeford (1968) at Colorado State University.

Construction. The items used for the CM test were dubbed from an Ampex PR-10 recorder to an Ampex 354 recorder using master tapes which had been recorded previously. The sentences in list 1 and list 2 of the test were recorded on channel A and channel B, respectively, at levels which peaked at "0" on the VU meter of each channel (Appendix A).

Presentation levels. To challenge the higher auditory centres of normal young adult subjects, the sentences of the CM test were presented to the test ear at a message-to-competition ratio (MCR) of -15 dB. The test signal was presented at 30 dB SL (re: three frequency average). The levels were based on pilot study data on normal listeners who subjectively found this MCR to be slightly difficult. Kimura (1963) has pointed out that for dichotic verbal tasks, to reduce the effect of hemispheric dominance for language, the subject must be instructed to listen for the material presented in one ear and to ignore the material presented to the opposite ear. That instructional format was followed in this study.

Filtered Speech (FS)

Material. The material selected for the FS test was obtained from a study by Billingslea (1963) who investigated the intelligibility of CNC words that were passed through a 500 Hz low-pass filter. The FS words were selected from a group of 106 words that were correctly identified at least 95% of the time by normal listeners in Billingslea's study. Following the recording process, 99 of those words were determined to be suitable for use (the word *wash* was included in both lists; see Appendix B).

Construction. The original two unfiltered 50 word lists of the FS test were recorded on channel A only of an Ampex 354 tape recorder using the carrier phrase "You will say . . ." before each test item. The carrier phrases were monitored to peak at "0" on the VU meter. The recording process was accomplished in a two-room studio.

The unfiltered recorded words were then delivered from a PR-10 tape recorder through a Spencer-Kennedy, Model 302, 500 Hz low-pass filter (slope of 18 dB/octave), and then recorded on channel A of the Ampex 354 recorder. The gain on the Ampex 354 was adjusted so the carrier phrases peaked at "0" on the VU meter.

Presentation levels. The FS test was presented at 45 dB SL (re: the pure tone average), which was the level used by Billingslea (1963).

Binaural Fusion (BF)

Material. The BF test was composed of two lists containing 20 words each. These words were selected from a list of 114 spondaic words used in a pilot study. The criterion for selection was low intelligibility when passed through low band-pass or high band-pass filters monaurally, but relatively high intelligibility when combined binaurally (see Appendix C).

A pilot study was done on five young adults to select the final items for the BF test. Each of the five conformed to the same criteria as the subjects of the main study. Each subject was presented with all 114 spondees in three conditions: (1) low band-pass monaural; (2) high band-pass monaural; and (3) binaural dichotic. An error count was done for each condition to find which spondees met the selection criterion. None of the words had greater than 40% intelligibility when presented in either the low band-pass or high band-pass condition alone. The intelligibility of all of the words was 60% or greater in the binaural dichotic condition. Selected words were divided into two lists based on equal intelligibility in the three conditions. Table 1 shows the intelligibility of the spondees for each condition for the two lists. It appeared that the two lists were well matched and that the criterion of low intelligibility for the band-pass segments and high intelligibility for the binaural dichotic condition were met.

Table 1. Intelligiblity of the spondees for each filter and presentation condition for each list.

% Item Intelligibility	List 1			List 2		
	LBP	HBP	BIN	LBP	HBP	BIN
0	9	4	0	9	3	0
20	4	4	0	4	4	0
40	7	12	0	7	13	0
60	0	0	1	0	0	0
80	0	0	4	0	0	6
100	0	0	15	0	0	14
% Overall Intelligibility	18	28	94	18	30	94

(Percent intelligibility was determined for each item in each of three conditions: LBP = low band-pass monaural, HBP = high band-pass monaural, and BIN = binaural dichotic. The values in the table indicate the number of items found at a particular level of intelligibility. The percentage values reflect the overall intelligibility of each list. This was based on a pilot study using five subjects.)

Construction. The material for the BF test was prepared in several stages. The carrier word "Ready" was recorded on channel A of the PR-10 tape recorder. The carrier word was repeated every five seconds and was monitored to peak at "0" on the VU meter. Each test word was recorded on channel B following its carrier word (on channel A).

Filtering was done using the following procedure. The original tape was placed on the PR-10 tape recorder. Channel A was passed through a mixer (unfiltered) and recorded on channels A and B of the Ampex 354. Material on channel B was passed through a variable attenuator, to allow the presentation level of the words to be equalized. Then the unfiltered signal was routed in two ways: (1) through a 700 Hz low-pass filter, with a 36 dB/octave slope, and recorded on channel A, and (2) through a 1900 Hz high-pass filter, with a slope of 36 dB/octave, and recorded on channel B of the 354 recorder. These rejection rates were achieved by cascading the 18 dB slope components of two Spencer-Kennedy filters in the appropriate low- or high-pass condition.

To complete the filtering of the spondaic words on each channel without filtering the carrier word, the tape resulting from the foregoing process was then placed on the PR-10. Channel A stimuli were passed through a 500 Hz high-pass filter with a 36 dB/octave slope and then through a mixer to be recorded on channel A of the 354 recorder. Channel B stimuli were passed through a 2100 Hz low-pass filter with a slope of 36 dB/octave and also passed through a mixer before being recorded on channel B of the 354. To prevent the carrier word from being filtered, the mixer was used to combine the signals from channels A and B when the carrier word was being presented by the manipulation of two silent switches. The result was a series of unfiltered carrier words on both channels, followed by 500-700 Hz band-pass segments of the spondaic words on channel A, and 1900-2100 Hz band-pass segments of the spondaic words on channel B. The gain was set so that the low band-pass segment peaked at "0" on the VU meter and the high band-pass segment fell to its appropriate level relative to the low band-pass segment. The carrier word for both channels therefore peaked at about +4 dB on the VU meter.

Presentation levels. The band-pass components of the BF test were presented at the appropriate intensity with respect to each other by setting each hearing level dial to 25 dB SL (re: pure tone threshold values at 500 Hz for the low band-pass segment and 2000 Hz for the high band-pass segment). The presentation level was selected such that it was well above the level required for 100% intelligibility for unfiltered spondees and yet low enough to keep the intelligibility of the high band-pass segment from exceeding that of the low band-pass segment.

The Master Tape

For simplicity of administration, all of the speech tests were prerecorded on a single tape at a speed of 7 1/2 ips. Each test was recorded relative to a calibration tone at the beginning of the tape. In all instances the speech material was recorded by male talkers with general American dialect.

Electromagnetic Characteristics

The original master tape was analyzed using a graphic level recorder (Bruel & Kjaer model 2603) set to a writing speed of 250 mm/s with a lower limiting frequency of 20 Hz using the RMS setting for amplitude analysis. The analysis was similar to that described by Shea and Raffin (1983).

The level of the material was determined relative to the calibration tone recorded on the tape for each channel. For the CM test, the peaks for each item were measured and averaged together to determine the item level. The peak(s) of each monosyllable was measured for the FS test. The peaks for each syllable for both the high band-pass and low band-pass segments of the spondees of the BF test were measured (see Table 2).

Items of the CM test were found at an average level of +2.18 dB (*SD* 2.42) for list 1(A) and +2.20 dB (*SD* 1.98) for list

Table 2. Means and standard deviations of the recording level for the items of each test.

Test	CM	FS	BF–LP	BF–HP
List 1	+2.18 (±2.42)	+2.32 (±1.81)	+3.72 (±3.72)	−19.99 (±3.53)
List 2	+2.20 (±1.98)	+2.20 (±1.76)	+3.28 (±3.66)	−18.92 (±3.56)
Noise Floor	<-33	<-18	<-25	<-25

(The noise floor is included. All measurements are in dB relative to the calibration tone.)

2(B). The monosyllables of the FS test were found at an average level of +2.32 dB (*SD* 1.81) for list 1 and +2.20 dB (*SD* 1.76) for list 2. Both lists of the FS test were recorded on channel A. The low band-pass segments of the BF task were found at +3.72 dB (*SD* 3.72) for list 1 and +3.28 dB (*SD* 3.66) for list 2. Both of the low band-pass segments were recorded on channel A. The high band-pass segments of the BF task were found at -19.99 dB (*SD* 3.53) for list 1 and -18.92 dB (*SD* 3.56) for list 2. Both high band-pass segments were recorded on channel B.

The noise floor of the tape was found at different levels for each test. For the CM test the noise floor was better than -33 dB down. For the FS tests, the noise floor was better than -18 dB down. The increase of the noise in this case may result, in part, from the adjustment in level made (following the low-pass filtering) to bring the items up to peak at "0" on the VU meter. For the BF test, the noise floor was better than -25 dB down. The noise floor was found to consist primarily of frequencies below 300 Hz. Using a 300 Hz high-pass filter (Khron-Hite model 3202), the noise of the FS test was reduced by 10 dB and the noise of the BF test was reduced to better than -36 dB down. Although there was a recordable noise floor, the stimuli for which it would be most troublesome (the low-intensity high band-pass BF test items) were well displaced from its frequency content. No item was completely within the noise floor, but even at nearly equal intensity levels (in dB SPL) the human sensitivity curve of 24.5 dB SPL at 250 Hz and 8.5 dB SPL at 2000 Hz (ANSI, 1969) would cause an advantage of 16 dB for the high band-pass items. Therefore, when the BF test is presented at the recommended levels, the noise floor is not audible.

Procedures

Testing was conducted in a two room IAC 1400 suite, with the subject seated in the test room and the experimenter and equipment located in the control room. A pure tone test was administered initially and followed by the prerecorded word discrimination test.

Initially, the recorded speech tests were routed from a PR-10 tape recorder through the speech circuit of an Allison 22 audiometer. Stimuli were delivered to the subjects through

Table 3. Means, standard deviations, and ranges of scores for each list of each test, and *t*-test results between the two lists of each test.

		CM	FS	BF
List 1	Mean	98.2%	87.5%	93.8%
	SD	2.4	6.3	6.7
	Range	92–100%	74–98%	75–100%
List 2	Mean	96.6%	87.4%	86.0%
	SD	4.0	6.0	7.7
	Range	88–100%	74–98%	75–100%
t-test		1.54	0.05	3.4*

*significant difference at $p<0.05$ (critical value for t=2.09)

TDH-39 earphones mounted in MX-41/AR cushions. However, during the study, failure of a line amplifier in the Allison 22 necessitated substitution of a Grason-Stadler 162 speech audiometer with the PR-10 recorder. Four subjects in group 1 and five subjects in group 2 were evaluated with the Grason-Stadler 162.

The three tests were given to the two groups of subjects in a counterbalanced presentation order. Also, the three difficult speech tests were presented to different subjects in varying order following a pattern of CM-FS-BF, BF-CM-FS, and FS-BF-CM.

Results

Table 3 summarizes the results for each list of the three difficult speech tests. The CM test results were similar for both lists, showing a mean of 98.2% (range: 92-100) for list 1 and a mean of 96.6% (range: 88-100) for list 2, but there was a slight difference in the standard deviations. The results of the FS test lists also were found to be similar, with a mean of 87.5% for list 1 and 87.4% for list 2. However, the range (74-98% for both lists) was considerably wider than that found for the CM test. The results of the BF test list were dissimilar with means of 93.8% for list 1 and 86.0% for list 2.

Interestingly, the range (75-100%) for both BF lists was similar to the range of the FS test. The relatively wide range of scores for the FS and BF tests in normal adult listeners may have resulted from their inexperience with speech in which the redundancy had been sharply reduced. The CM test, on the other hand, presented undistorted material in which the subject was required to attend to a primary message in one ear while rejecting a competing stimulus in the opposite ear. The relatively narrow range of scores on the CM test is thought to indicate that the adult subjects in this study simply showed a mature function for that task. Willeford (1977) has shown that the ability to perform a binaural separation task develops over time, usually reaching adult levels by about the age of 9 or 10 years in normal children.

Test list differences were compared statistically. Using t-tests (Table 3) no significant differences were found between the two lists of the CM or FS tests at the 0.05 level of confidence. However, the lists of the BF were found to be significantly different at the 0.05 level of confidence. The standard deviations were relatively small for all three difficult speech measures, ranging from a low of ±2.4% for list 1 of the CM test to a high of ±7.7% for list 2 of the BF test.

Table 4 summarizes the results in terms of the presentation order of both lists of each difficult speech test. The FS test results were found to be similar for each presentation with means of 87.4% for the first presentation and 87.6% for the second. The range for both was 74-98%. There was minimal difference related to presentation order-ear difference found for the BF test. The means were 89.3% for the first presentation and 90.5% for the second. In both instances the range was 75-100%.

Table 4. Means, standard deviations, and ranges of scores for the presentation order of both lists of each test and t-test results between the two presentations of each test.

		CM	FS	BF
Ear 1 (RE)	Mean	98.8%	87.4%	89.3%
	SD	1.9	5.7	8.2
	Range	96–100%	74–98%	75–100%
Ear 2 (LE)	Mean	96.0%	87.6%	90.5%
	SD	3.9	6.3	8.3
	Range	88–100%	74–98%	75–100%
t-test		2.89*	0.11	0.48

*significant difference at p<0.05 (critical value for t=2.09)

(For binaural fusion [BF] right ear scores result from the right ear/low pass, left ear/high pass condition and the left ear scores result from the left ear/low pass, right ear/high pass condition.)

Three t-tests were performed on these results. No significant differences were found for the order of presentation for either the FS or BF tests. The CM test, however, did show a significant difference at the 0.05 level of confidence. The results of the second presentation is shown to be consistently poorer than those of the first presentation.

In summary, the data show that the lists of the CM and the FS tests are nearly identical in the results obtained from normal adult listeners. They also show that the presentation order had little or no effect on the results of the FS or BF tests. The only significant differences found in the study were between lists 1 and 2 of the BF test, and the first and second presentations of the CM test. There also was a slight difference for the standard deviations of the two lists of the CM test. The above differences warrant further comment.

Because of the apparent order effect found for the CM test and the differences of the standard deviation values between CM lists, an analysis was done on the errors made. This analysis showed that item number 10b (list 2, channel B) was repeated incorrectly more than any other single item. There were eight errors on this item while the competing item number 10a (list 1, channel A) had no errors associated with it when it was the target stimulus. All of the errors for this item occurred when the left ear was the listening ear. The next most commonly missed item was number 5b (list 2) with four errors. The competing item number 5a (list 1), however, was repeated incorrectly three times. Because of the experimental design, the order effect was confounded by a possible ear effect because the left ear was always the second listening ear. Therefore, the apparent order effect could be a combination of ear, order, and item (item 10b) effects.

Although the two lists of the BF test contained words of matched high and low band-pass intelligibility (as determined by the pilot study), the two lists were found to be significantly different. An explanation for this result might be word familiarity.

Each word was compared with Thorndike's (1932) list of 20,000 words. As two-syllable words the two lists were essentially equal in terms of frequency count. However, when the items were analyzed as two one-syllable words, "soybean" and "whizbang" had the lowest frequency count, and both were in list 2. Neither was included in the list of 20,000 as a two-syllable word. The word "soybean" was missed more than any other item and also was rated as the least frequently occurring item (as two one-syllable words) in either list. This may in part explain the differences between lists.

Three words were replaced by substitutes when these items were missed. These words were "stairway," "lifeboat," and "dovetail," and were replaced with "fairway," "lightbulb," and "dogtail," respectively. "Stairway" and "lifeboat" both appeared in list 2 and were missed eight times each. "Dovetail" was included in list 1 and was missed five times. Each of the correct and substitute items were found to be of nearly equal frequency when analyzed as two one-syllable words. This finding would suggest that these three words, particularly "stairway" and "lifeboat," have substitute words which are as available to a subject as the correct response. Two of the three items were found in list 2 and may provide another explanation the inequality of the two lists.

Discussion

It should be emphasized that the present tests were designed and standardized for use as a battery. The authors believe that in order to localize a deficiency in a given part of the central auditory system that the functioning of the adjacent areas of the system also must be known and compared.

To more fully analyze the results of the difficult speech tests, particularly the BF and FS tests, a baseline for word intelligibility should be ascertained with a standard word discrimination test. Most authors show that persons with central lesions will do well (within the range of normal) on undistorted word discrimination tests if there is no pathology of the peripheral mechanism. It may be expected that the presence of a peripheral hearing loss would affect the discrimination of filtered items as found in the FS and BF tests. Therefore, it is essential to perform standard pure tone and speech audiometry.

Miltenberger, Dawson, and Raica (1978) administered the CM, FS, and BF tests to 70 subjects with sensorineural hearing loss. Their results indicated that the performance on all of the tests was affected to some extent by peripheral hearing loss. Specifically, among their subjects, 17% failed CM, 77% failed FS, and 24% failed BF. Obviously, the FS test showed the greatest effect. The failures could not be consistently related either to word discrimination scores or to audiometric configurations alone. They note, however, that persons with high-frequency or low-frequency sloping sensorineural hearing losses should be expected to fail FS regardless of word discrimination ability. They concluded that it was possible to use these tests on persons with sensorineural hearing loss, with cautious interpretation including consideration of the peripheral audiologic evaluation. Similar cautions have been stated by Lynn and Gilroy (1977) and Rintelmann and Lynn (1983).

Competing Message (CM)

Studies on neuropathologic cases (Lynn, Benitez, Eisenbray, Gilroy & Wilner, 1972; Lynn & Gilroy, 1974; Lynn & Gilroy, 1977) have shown the CM test to be sensitive to temporal lobe and particularly corpus callosum lesions. Lynn and Gilroy (1977) present findings on a series of persons with surgically confirmed right or left temporal lobe tumors. These patients demonstrated poorer results for the ear contralateral to the tumor. On a group of patients with deep parietal lobe lesions (on either side) involving the corpus callosum, results of the CM were poorer for the ear which was contralateral to the nonlanguage dominant hemisphere.

The CM test showed a slight difference with respect to presentation order (Table 4) with a mean of 98.8% (range 96-100%) for the first and a mean of 96.0% (range 88-100%) for the second presentation. The reason for this difference may have been that during the first presentation, the list which was used as the primary signal was the same list used as the competing signal in the second presentation. Therefore, during the second presentation, the competing signal was familiar material and, as such, was more difficult to ignore. This reason would not have been a factor in the first presentation since both lists were essentially unfamiliar material.

The combination of the difficulty of item 10b and the left ear/order effect resulted in a significant difference for presentation order even though the two lists did not show a significant difference. It is likely that this difference is in part the result of the well known right ear superiority relating to hemispheric dominance seen in competing dichotic listening tasks (Kimura 1963).

This difference might be reduced by using two separate paired lists of sentences. One of the authors (Willeford) currently advocates using the test in a shortened version where ten paired sentences are presented as a test, and has standardized it in this fashion. This test could be useful as it is presently structured if this slight difference caused by the order of presentation is taken into account and if item 10b is used as competition rather than as the primary message. A remaining small right ear advantage may persist, reflecting cerebral dominance, but is not considered clinically significant.

Filtered Speech (FS)

Studies discussed previously on neuropathologic patients and more recent studies (Lynn et al., 1972; Lynn & Gilroy, 1974; Lynn & Gilroy, 1977; Miltenberger, Caruso, Correia, Love & Winkelmann, 1979) have shown that the FS test or similar tests using low-pass filtered words will, in general, show a deficit in the ear contralateral to a temporal lobe lesion. The FS test developed for this study has highly equivalent lists and good intelligibility for normal adult listeners. These attributes should allow reliable ear comparisons as well as a large enough range below normal to enable differentiation of various degrees of impairment.

Binaural Fusion (BF)

The BF test has been shown to be sensitive to brainstem lesions. Lynn et al. (1972) show a case of brainstem compression due to growth of a parietal lobe tumor. The patient scored 0% in the dichotic condition and scored 80-90% when the two narrow-band elements were combined and presented to one or both ears. Smith and Resnick (1972), like previously discussed researchers, have shown that similarly constructed tests can identify lesions of the brainstem.

There is, however, evidence that BF-type tests are not as reliable in detecting brainstem lesions as the brainstem electric response (BSER) method (Smith & Resnick, 1972; Musiek & Geurkink, 1982). Although BF and BSER are mediated in the brainstem, it is also possible to find deficits with BF without a BSER abnormality (Musiek & Geurkink, 1982). These findings are not surprising. There is no reason to believe that the on-effect type of processing reflected in the BSER is the only transmission device in the brainstem. Complex stimuli that exist over time depend also on temporal integration. In addition, BF depends on a mechanism in the brainstem above the superior olivary nuclei that allows for the resynthesis of different but complementary information. Because of the differences in neural processing that are challenged by BF and BSER, any evaluation for suspected neuropathology at the brainstem level of the auditory system should include BSER.

Order of presentation for the BF test had little or no effect on the results obtained. There is a list difference as shown in Table 2. Examination of word familiarity showed that some adjustments could be made to equalize the two lists of the BF test. A redistribution on the basis of binaural intelligibility and familiarity could be done from an item analysis of the normative data from this study.

Using White's (1977) error data on 49 children, the error rate for 10 of the most difficult items of the two lists might be equalized by exchanging items 11 through 15 of list 1 for items 8 through 12 of list 2. This would bring the error count from 75 to 123 for list 1 and from 175 to 127 for list 2. This could be done by redubbing, splicing, or by changing the ear channel condition during testing (with appropriate SL adjustments) for those items. Appropriate norms must be developed for any changes made, of course.

Willeford has suggested familiarizing the child with the items prior to testing and adding 10% to the score obtained on list 2. This may help to compensate for the known list differences when testing children using the original order.

Test Battery Findings

The test battery has been used on various populations. Lynn et al. (1972) and Lynn and Gilroy (1974, 1977) showed applicability in locating neoplasms. Miltenberger et al. (1979) showed applicability of use in identifying extent and level of central nervous system damage in decompression sickness. Others (Willeford, 1977; White, 1977; Willeford & Billger, 1978; Musiek, Geurkink & Kietel, 1982) have described the usefulness of a battery including CM, FS, and BF in identifying and describing difficulties that some children have in listening and learning in a complex auditory environment such as a classroom. Other tests that have been found to challenge the central auditory system to various degrees and levels are described well by Noffsinger and Kurdziel (1979) and Rintelmann and Lynn (1983).

The child norms were collected with tapes which were dubbed with the calibration tone 5 dB higher than the master tape such that the items were presented 5 dB lower relative to the calibration tone. To compensate, the recommended presentation levels were raised by 5 dB (Willeford, 1977).

The major goal of this report was the presentation of the concept, rationale, construction, and normalization of the test battery based on the original study (Ivey, 1969). The inclusion of the electromagnetic characteristics of the master tape was done in response to the article by Shea and Raffin (1983). Their data showed variations in the recording levels between taped copies of the original material. The master tape data presented the original recording levels of the items relative to the calibration tone. The differences found between various taped copies may have been the result of multigenerational dubbing or errors when dubbing from master or submaster tapes. The noise floor does not add distortion or interfere with intelligibility of the items on the master tape when the material is presented at the recommended levels.

The clinician should be careful not to add distortion to the tests. Tape recorders need to be cleaned, demagnetized, and aligned for proper operation. At no time should Dolby or output limiting be used with this battery. Because of the nature of the filtered material, further dubbing of the material, particularly from a cassette tape, may introduce distortion that negates the usefulness of the tests and the current normative data.

Summary

There was fairly good agreement between list and test scores for the normal subjects studied. Therefore, it appears that, as individual tests and as a battery of tests, the results represent a reasonable estimate of normal behavior in young adults. Until the central mechanisms for binaural resynthesis are better understood, the usefulness of BF-type tests may be questioned. For the present it appears that CM and FS are reliable tests, which, if coupled with BF and a more general brainstem test such as BSER, will allow the assessment of several levels and sidedness of the central auditory system.

For clinical purposes, it is recommended that interpretation of patient performance be based on the range of scores shown here rather than on mean values or standard deviations of each test. In other words, one would not interpret a result as indicating pathology unless it fell below the range of scores shown by normal subjects.

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References

ANSI S3.6 (1969). *American National Standards, Specification for Audiometers.* New York: American National Standards Institute, Inc.

Azzi, A. (1964). Clinical application of binaural audiometry. *Journal of International Audiology, 3*, 197-205.

Billingslea, B. (1963). *Intelligibility of distorted speech.* Unpublished master's thesis, Colorado State University, Fort Collins, CO.

Bocca, E., Calearo, C., Cassinari, V., & Migliavacca, F. (1955). Testing "cortical" hearing in temporal lobe tumors. *Acta Oto-laryngologica, 45*, 289-304.

Bocca, E., & Calearo, C. (1963). Central hearing processes. In J. Jerger (Ed.), *Modern developments in audiology* (pp.337-369). New York: Academic Press.

Calearo, C., & Antonelli, A. (1963). "Cortical" hearing test and cerebral dominance. *Acta Oto-laryngologica, 56*, 17-25.

Dirks, D. (1964). Perception of dichotic and monaural verbal material and cerebral dominance for speech. *Acta Oto-laryngologica, 58.*

Frager, C. (1968). Auditory integration in geriatrics. Unpublished master's thesis, Colorado State University, Fort Collins, CO.

Gambino, A. (1963). Filtered-speech articulation curves. Unpublished master's thesis, Colorado State University, Fort Collins, CO.

Hayashi, R. (1966). Binaural fusion test: A diagnostic approach to the central auditory disorders. *DSH Abstracts, 6.*

Hodgson, W. (1967). Audiological report of a patient with left hemispherectomy. *Journal of Speech Hearing Disorders, 32*, 39-45.

Ivey, R. G. (1969). Tests of CNS auditory function. Unpublished master's thesis, Colorado State University, Fort Collins, CO.

Jerger, J. (1960). Observation on auditory behavior in lesions of the central auditory pathways. *Archives of Otolaryngology, 71*, 797-806.

Jerger, J. (1969). *Audiologic correlates of brainstem disorders.* A paper presented at the University of Colorado medical audiology workshop, Vail, CO.

Kimura, D. (1963). Note on cerebral dominance in hearing. *Acta Oto-laryngologica, 56*, 617.

Linden, A. (1964). Distorted speech and binaural speech resynthesis tests. *Acta Oto-laryngologica, 58*, 32-48.

Lynn, G. E., Benitez, J. T., Eisenbray, A. B., Gilroy, J., & Wilner, H. I. (1972). Neuro-audiological correlates in cerebral hemisphere lesions. *Audiology, 11*, 115-134.

Lynn, G. E., & Gilroy, J. (1974). Effects of brain lesions on the perception of monotic and dichotic speech stimuli. In M. Sullivan (Ed.), *Central auditory processing disorders.* Proceedings of a conference. Omaha: University of Nebraska Medical Center, 47-83.

Lynn, G. E., & Gilroy, J. (1977). Evaluation of central auditory dysfunction in patients with neurological disorders. In R. W. Keith (Ed.), *Central auditory dysfunction* (pp. 177-222). New York: Grune and Stratton.

Matzker, J. (1962). The "binaural test." *Journal of International Audiology, 1.*

Miltenberger, G. E., Dawson, G. J., & Raica, A. N. (1978). Central auditory testing with peripheral hearing loss. *Archives of Otolaryngology, 104*, 11-15.

Miltenberger, G. E., Caruso, V. G., Correia, M. J., Love, J. T., & Winkelmann, P. (1979). Utilization of a central auditory processing test battery in evaluating residual effects of decompression sickness. *Journal of Speech Hearing Disorders, 44*, 111-120.

Musiek, F. E., & Geurkink, N. A. (1982). Auditory brain stem response and central auditory test findings for patients with brain stem lesions: A preliminary report. *Laryngoscope, 92*, 891-900.

Musiek, F. E., Geurkink, N. A., & Kietel, S. A. (1982). Test battery assessment of auditory perceptual dysfunction in children. *Laryngoscope, 92*, 251-257.

Nager, G. (1969). *Acoustic neurinomas, pathology, clinical aspects and differential diagnosis.* A paper presented at the University of Colorado medical audiology workshop, Vail, CO.

Noffsinger, P. D., & Kurdziel, S. A. (1979). Assessment of central auditory lesions. In W. F. Rintelmann (Ed.) *Hearing assessment* (pp. 351-377). Baltimore: University Park Press.

Ohta, F., Hayashi, R., & Morimoto, M. (1967). Differential diagnosis of retrocochlear deafness: Binaural fusion test and binaural separation test. *Journal of International Audiology, 6*, 58-62.

Peterson, G., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech Hearing Disorders, 27*, 62-71.

Quist-Hanssen, S., & Stromsnes, A. (1960). Speech audiometry in persons with brain damage. *Acta Oto-laryngologica*, (Suppl.), 158, 272-276.

Rintelmann, W. F., & Lynn, G. E. (1983). Speech stimuli for assessment of central auditory disorders. In D. F. Konkle and W. F. Rintelmann (Eds.) *Principles of speech audiometry* (pp. 231-283). Baltimore: University Park Press.

Shea, S. L., & Raffin, J. M. (1983). Assessment of electromagnetic characteristics of the Willeford central auditory processing test battery. *Journal of Speech Hearing Research, 26*, 18-21.

Smith, B. B., & Resnick, D. M. (1972). An auditory test for assessing brain-stem integrity: Preliminary report. *Laryngoscope, 82*, 414-424.

Stevens, S. D., & Thornton, A. R. (1976). Subjective and electrophysiologic tests in brainstem lesions. *Archives of Otolaryngology, 102*, 608-613.

Thorndike, E. (1932). *The teacher's book of 20,000 words.* New York: Teachers' College, Columbia University.

White, E. J. (1977). Children's performance on the SSW test and Willeford battery: Interim clinical data. In R. W. Keith (Ed.), *Central auditory dysfunction* (pp. 319-340). New York: Grune and Stratton.

Whitfield, I. (1967). *The auditory pathway.* London: Edward Arnold.

Willeford, J. A. (1967). Audiological evaluation of central auditory disorders. *Maico Audiological Library Series, 6*, Reports 1 & 2.

Willeford, J. A. (1968). *Competing messages for diagnostic purposes.* Unpublished manuscript, Colorado State University.

Willeford, J. A. (1977). Assessing central auditory behavior in children: A test battery approach. In R. W. Keith (Ed.), *Central auditory dysfunction* (pp. 43-68). New York: Grune and Stratton.

Willeford, J. A., & Billger, J. M. (1978). Auditory perception in children with learning disabilities. In J. Katz (Ed.), *Handbook of clinical audiology*, 2nd ed. (pp. 410-425) Baltimore: Williams and Wilkins.

Appendix A
Competing Messages

1. a. I think we'll have rain today.
   b. There was frost on the ground.
2. a. This watch keeps good time.
   b. I was late to work today.
3. a. I'm expecting a phone call.
   b. Please answer the doorbell.
4. a. The bus leaves in five minutes.
   b. It is four blocks to the library.
5. a. My mother is a good cook.
   b. Your brother is a tall boy.
6. a. Please pass the salt and pepper.
   b. The roast beef is very good.
7. a. There is a car behind us.
   b. This road is very slippery.
8. a. Leave the keys in the car.'
   b. Fill the tank with gas.
9. a. It's always hot on the fourth of July.
   b. Christmas will be here very soon.
10. a. We had to repair the car.
    b. You should really take a taxi.
11. a. The ice cream sundae is very good.
    b. We have chocolate and strawberry today.
12. a. Fasten your seat belt.
    b. Get ready for takeoff.
13. a. I think you need a band-aid.
    b. You should see a doctor.
14. a. This is the latest style.
    b. That fits you perfectly.
15. a. I will be back after lunch.
    b. You may take this Saturday off.
16. a. I have seen this movie before.
    b. This movie is not like the book.
17. a Air mail will get there faster.
    b. Please answer on a postcard.
18. a. I think we have met before.
    b. You probably don't remember me.
19. a.This train is going west.
    b. All the cars are air-conditioned.
20. a. The children are playing baseball.
    b. Football is an exciting game.
21. a. Let's sit down on this bench.
    b. Get me a chair so I can rest.
22. a. The office will be closed tomorrow.
    b. You should come to work on Monday.
23. a. I read that in the newspaper.
    b. The man on the radio said it.
24. a. I wonder what time it is.
    b. I think it is time to leave.
25. a. The traffic is getting worse.
    b. I hate the rush-hour traffic.

Appendix B
Filtered Speech

List 1

1. Home	14. War	27. Toad	40. Lash
2. Root	15. Have	28. Choose	41. Coin
3. Hide	16. Rain	29. Shock	42. Lag
4. More	17. Curve	30. Such	43. Tire
5. Lap	18. Patch	31. Bite	44. Cash
6. Phone	19. Moon	32. Lot	45. Luck
7. Pole	20. Car	33. Dime	46. Map
8. Mine	21. Head	34. Talk	47. Neck
9. Burn	22. Write	35. Coat	48. Watch
10. Ride	23. Hire	36. Shine	49. Fine
11. Jar	24. Gone	37. Bone	50. Wash
12. Much	25. Dumb	38. Hot	
13. Kid	26. Book	39. Search	

List 2

1. Wood	14. Jet	27. Hole	40. Nose
2. Hash	15. What	28. Wheat	41. Should
3. Dab	16. Chin	29. Shade	42. Loan
4. Work	17. Job	30. Neat	43. Light
5. Chum	18. Turn	31. Wish	44. Wire
6. Hush	19. Move	32. Pan	45. Sure
7. Hate	20. Word	33. Room	46. Wet
8. Which	21. Wash	34. Tone	47. Dish
9. Joke	22. Vine	35. Bug	48. Hair
10. Limb	23. Love	36. Tube	49. Well
11. Weak	24. Bar	37. Bun	50. Pull
12. Mire	25. Juice	38. White	
13. Loop	26. Dock	39. Pile	

Appendix C
Binaural Fusion

Test #1

1. Bagpipe	6. Daylight	11. Dovetail	16. Bluejay
2. Woodchuck	7. Rainbow	12. Shoelace	17. Birdnest
3. Baseball	8. Drugstore	13. Bedroom	18. Northwest
4. Bloodhound	9. Bonbon	14. Eyebrow	19. Although
5. Churchbell	10. Buckwheat	15. Meatball	20. Padlock

Test #2

1. Doormat	6. Lifeboat	11. Wigwam	16. Therefore
2. Footstool	7. Mishap	12. Dollhouse	17. Whizbang
3. Horseshoe	8. Nutmeg	13. Wildcat	18. Workshop
4. Stairway	9. Platform	14. Scarecrow	19. Yardstick
5. Housework	10. Watchword	15. Soybean	20. Bobwhite