Journal of Educational Psychology
1980, Vol. 72, No. 1, 21–44

Human Abilities Revealed Through Auditory Tests

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Established findings from studies of visual, musical, and speech perception abilities were used to guide the construction of auditory ability tests. Forty-four measures based on these tests were obtained from a sample of 241 adult males. Correlation and factorial analyses were used to indicate structural interrelationships and relationships with education, musical experience, general intelligence, and age. The results indicated separate capacities for Auditory Verbal Comprehension, Auditory Immediate Memory, Temporal Tracking, Auditory Cognition of Relationships, Discrimination Among Sound Patterns, Speech Perception Under Distraction/Distortion, and Maintaining and Judging Rhythm.

Theory, Rationale, and Purpose

The principal purpose of this study is to provide indications of the ways in which elementary auditory abilities are organized. The study derives from a substantive theory of fluid (Gf) and crystallized intelligence (Gc; as propounded mainly by Cattell, 1971; and Horn, 1970, 1976, 1978a, 1978b), and from the design/analytic metatheory of a simple structure factor analysis (originating with Thurstone, 1947). Variables and subjects were selected and analyses were conducted, in accordance with these two theoretical stances, the major objective being one of indicating simple structure factors among auditory performances.

Gf/Gc theory derives from a number of considerations of evidence pertaining to physiological/neurological functioning, achievement in relation to social class and related determinants, age differences in intellectual performances, and structural interrelationships among abilities, as well as several other bits of evidence and plausibility argument. Fairly complete statements of the current shape of the theory can be found in several easily accessible sources (Horn, 1978a, 1978b, 1979; Horn & Donaldson, in press), so only the general features of the theory and the details that are most pointedly related to the rationale for the present study need be reviewed here.

As noted, one of the major features of the theory pertains to the structural interrelationships among the abilities of intelligence. This feature is relevant to the present study. It involves the notion that the major processes involved in intellectual abilities are organized at different levels. There are two ways in which the idea of levels is used in the theory.

Level enters in one way from consideration of results from studies of the intercorrelational, principally factor-analytic, studies of intellectual performances. Although there are many problems in arriving at a definitive summary of the results from this work (cf. Horn, 1976), the evidence is fairly consistent in indicating (a) a rather large number of primary-level patterns of organization among performances on diverse tests and (b) organization among the primary-level abilities in terms of a relatively small number of second-level principles (Cattell, 1971; Guilford & Hoepfner, 1971; Hakstian & Cattell, 1974; Horn, 1968, 1970,

The major financial support for this study was provided by the Army Research Institute, Grant DAHC 19-74-G-0013, and the National Science Foundation, Grant GB-41452. Some of the write-up of the work was done under support from National Institute of Aging Grant 1 R01 AG00583-01.

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 0022-0663/80/7201-0021$00.75

1972, 1976, 1978a, 1978b, 1979, in press; Horn & Donaldson, in press; Ekstrom, Note 1; French, Ekstrom, & Price, Note 2).

The results from more than 100 factor-analytic studies provide replication support for some 30, or somewhat more, reliably and independently measured primary-level abilities.[1] There are different ways to represent this regularity, as by different rotational solutions, but each representation, and therefore the evidence as a whole, provides a fairly comprehensive starting point for developing a sound, evidence-based theory about cognitive functioning. The evidence for second-level organizations is based on this foundation.

The concepts of Gf/Gc theory derive primarily from evidence pertaining to second-level structure. The most notable of this evidence comes from factor-analytic studies of variables representing primary-level abilities. Results from these studies have indicated some six broad, second-level dimensions. These dimensions indicate superordinate organizations relative to the primary-level factors and thus are at a different, namely a more general, level in this sense. However, the different dimensions, as such, appear to represent different levels of the functions that enter into performances on intellectual tasks. In particular, they appear to represent levels in the sense of distinguishing between sensory, perceptual, associational, and comprehensional awarenesses (see Horn, 1979, in press; Horn & Donaldson, in press).

All intellectual performances reflect functioning at each of these levels, which is to say that individual differences in test performances are due in part (and to a different extent in different individuals) to variations in functioning at the different levels. But some tests (in a given kind of sample of subjects) provide a more reliable and valid measure at one level than at another. For example, performances on a matrices test reflect individual differences in (a) simply seeing the lines of the stimulus materials; (b) perceiving the differences in shapes formed by these lines; (c) associating meanings with these shapes; and (d) understanding relationships, and possible relationships, among these meanings. However, if the matrices are easily seen and perceived but a major source of difficulty in the problems is introduced by making the relationships among the shapes complex, then a matrices test should mainly indicate functioning at the comprehensional level of awareness. Even though all levels of functioning enter into intelligence, abilities that represent the comprehensional level are usually regarded as most characteristic of the highest forms of intelligence.

Two of the broad dimensions indicated in studies of structure involve comprehensional abilities that are central in most concepts of intelligence. Both indicate capacities for forming concepts, solving problems, abstracting, drawing valid conclusions, and, in general, behaving intelligently. The two differ primarily in the extent to which they reflect acculturational influences.

The Gc dimension involves a complex of abilities in which individual differences are associated with systematic influences of acculturation. The abilities thus affected are much valued in a culture and are believed to be essential for maintenance of the culture. For these reasons considerable effort is marshalled to transmit these abilities from one generation to the next. Although these efforts are directed at all individuals of a culture, they are both more and less effective with some as compared to other individuals. The result is that notable individual differences in Gc emerge as development proceeds.

The abilities that determine the Gf dimension are imparted by influences other than those of acculturation. Many features of learning are not systematized in acculturation, but instead they represent idiosyn-

[1] Full discussion of what is meant by "reliably and independently measured" would take us rather far afield in the present report. Such discussion is provided in Horn (1978a, particularly Footnote 3), Horn (1978b, particularly Section 3.1), Horn and Cattell (1965), and Horn and Knapp (1973, 1974, particularly the latter). The basic notions are that an ability should (a) be indicated by several different kinds of performances, (b) be objectively overdetermined in factor-analytic work, and (c) have internal consistency among its indicants that is substantially larger than the squared multiple correlation of the ability measure with measures of other abilities.

cratic, or what is referred to as incidental, learning. Also many influences that affect the neurological underpinnings for the development of intellectual abilities operate largely independently of acculturational influences. Together these incidental learning and neurological influences produce a complex of abilities that are central to intelligence. These are the abilities of Gf.

A broad speediness dimension (Gs) and two dimensions involving associational learning and retrieval processes have also been indicated in second-level analyses. One of the associational dimensions is characterized by fluency in the recall of material learned days, months, and years earlier. The measures that define this dimension are largely verbal. For this reason it was interpreted as indicating verbal productive thinking in early studies. Recent work, however, has suggested that it is best regarded as an indication of organization among processes of long-term storage and retrieval (TSR). The second associational dimension involves a wide variety of measures of short-term acquisition and retrieval (SAR).

A broad visual-perceptual (Gv) dimension was given particular attention in developing the rationale for the present study. As described by Horn and Cattell (1967), the Gv dimension represents a considerable variety of

> processes of imagining the way objects may change as they move in space, maintaining orientation with respect to objects in space, keeping configurations in mind, finding the gestalt among disparate parts in a visual field, and maintaining flexibility concerning other possible structurings of elements in space. (p. 268)

The dimension accounts for a substantial proportion of the variance in intellectual performances.

This finding of a pervasive visualization function in intellectual performances led to speculation that broad perceptual organization processes associated with each sensory input modality might produce some variance in measures of intelligence (Horn, 1968). In particular, such a process might be associated with auditory functioning. Horn also noted that existing measures of intelligence may be deficient in part because they do not involve subtests to measure abilities that are primarily dependent on auditory functions. The present study was launched to provide a basis for exploring hypotheses of this kind. In accordance with this objective, two basic ideas guided the development of the set of variables to be analyzed.

One idea was to obtain auditory tests that are similar in major respects to the visual tests markers for primary-level factors. In particular, it was thought that it would be interesting to study auditory tests that seemed to involve the same thinking processes as are involved in visual tests but depend on audition rather than vision. This idea had been tried out before by White (1954) and Fleishman, Roberts, and Freidman (1958), but only on a very limited basis, not in respect to a goodly sample of primary-level abilities. (See Horn, 1973b for a review of this work.)

It was necessary to construct most of the tests based on this rationale. For example, the induction primary-level factor can be defined by tests in which the subject must comprehend relationships among a series of dots, but existing auditory tests do not involve series relationships similar to those of the induction markers. A corresponding auditory test can be constructed, however, in which the same kind of basic relationships are involved, but are set among pure tones or chords or voices. In a similar way sounds can be used to construct intellectual problems that parallel those of visual test markers of other primary mental abilities. The thought was that by shaping subjects' behavior with tests of this kind, it might be possible to determine a factor structure for auditory tasks that would represent intellectual functioning at about the same level as is represented by the primary-level factors that have been defined on the basis of visual tests.

The second major idea that guided the selection of variables for this study was to represent highly regarded measures of musical abilities and speech perception, particularly the former. Detailed accounts of the various matters that were given consideration in this regard are provided in Stankov (1972) and Horn (1973b). For present purposes it is probably sufficient to note that theories associated with tests of musical abilities and speech perception often are similar in major respects to hierarchical theories of the kind that provided the principal orientation for this study.

Other features of the theory and rationale for this study might be mentioned, but this discussion should indicate the general orientation. The main objective of the study was to lay out a basis for describing something similar to a primary mental ability structure, but in a realm of behavior based on input through the auditory modality.

Method

Construction and Selection of Variables

As indicated in the previous section, the rationale for this study dictated that auditory variables be obtained to represent processes similar to, or analogous to, those represented in primary mental abilities. Since there are many of the latter and subjects will give only very limited amounts of time to psychological research, it was necessary to select a relatively small number of primary-level marker tests to serve as models for the construction and selection of auditory tests. This selection was dictated in part by the feasibility of translating a visual test into auditory form. In part it was dictated by a desire to obtain ability measurements that could, in future studies, help to clarify the nature of the principal concepts of Gf/Gc theory. Also, of course, it was dictated by arbitrary factors relating to investigators' interests, tests available, concern for subjects' morale, and so forth. The visual tests finally developed as models and the corresponding auditory tests constructed and selected on the basis of these models are indicated in Table 1.

In selecting variables from other sources to include in this study, major attention was given to whether the variable had been used in a previous study of interrelationships among a variety of auditory tasks. The work of Drake (1939); Karlin (1941); Seashore, Lewis, and Saetveit (1960); McLeish (1950); Shuter (1968); and Wing (1948) provided the principal source for such variables in the realm of musical abilities. Studies by Fleishman et al. (1958); Hanley (1956); Harris (1964); Karlin (1942); Solomon, Webster, and Curtis (1960); Spearritt (1962); Sticht (1972); and White (1954) provided evidence for selection of tests pertaining to perception of speech sounds and listening comprehension. Discussion of the structure among the tests of these various studies is provided in Stankov (1972) and Horn (1973b).

The battery of tests finally put together for this study is described in Table 2. (Also see Figure 1 for some examples of test.) The basic psychometric properties of the measures are suggested by the summary statistics of this table.

Subjects

A total of 241 male inmates of the Colorado State Penitentiary System provided the basic data for this study.[2] These men were located at two different institutions. The major portion of the sample (n = 156) was obtained at a Canon City branch of the system; a similar group (n = 85) was obtained at a Buena Vista branch.

The men were paid $2 each for completing the tests in a conscientious manner. They were also offered, at their request, feedback about their own performances.

An inmate sample was selected for this study for several reasons. Availability was no doubt a major factor, but also important was the fact that such samples have been used in other studies on which Gf/Gc theory is based and the fact of substantial variance in this kind of group. Contrary to what some people believe, there is considerable variability in a prison population with respect to influences associated with the development and expression of abilities.

In the sampled group, the standard deviation for age was 7.75 years and the mean was 25.64. The mean Otis IQ for the group was 100.42 (SD = 11.51). The average hearing acuity in the sample was in the normal range, as has been found in other studies of convict samples (Melnick, 1970). Other descriptive statistics of use in characterizing the sample are provided in the right-most sections of Table 3.

Testing Procedures

Subjects were tested in groups ranging in size from 8 to 55 men. The tests were administered by tape recorder, which was run by a test administrator (Horn), who, between tests, provided small talk and information in the manner of a disk jockey. The recording and administration was done with Wollensak 3M and SONY 350 tape recorders at a tape speed of 7.5 inches per sec (to ensure good fidelity). The same male voice provided instructions and similar spoken information for all but two tests. A female speech therapist provided the stimuli of Sound Blending and Incomplete Words. For most tests involving tones, a piano was used to provide the stimuli. In pilot work it was found that subjects liked piano tones better than pure tones. Only the Seashore tests, and those of loudness, are based on pure tones.

Tape-recording reels were designed to provide 1 hour of testing. Each reel contained about 50 minutes of actual testing, the remaining 10 minutes of the hour being set aside for a rest period. Administration time for the entire battery (including rest periods) was approximately 9 hours. This was scheduled over three sessions, one each day, usually on consecutive days, but in some cases a weekend intervened, and thus a session

[2] We thank George Levy and his staff (particularly L. C. Hurd and John Martinez) for help in securing this sample.

was separated from another by 2 days. Individual audiometer tests, requiring about 10 minutes, were obtained between testing sessions. At the end of the testing, subjects filled out a biographical questionnaire.

The tests were given in the same order, by the same test administrator, to all subjects. Three different testing rooms were used. These appeared to have similar accoustical properties, but no refined tests were carried out to check this observation. The men were deployed at different distances and angles with respect to the stimulus source, but again no refined analyses were done to check whether these factors produced systematic variance in the measures. It seems likely that such influences would have nontrivial effects (as would a host of other uncontrolled factors that inevitably operate in any study of people). Thus some anomalous results were anticipated. Offsetting this

(text continues on page 31)

Table 1
Plan for Construction of Auditory Tests

Visual primary factor	Visual test model	Auditory test constructed or selected[a]
1. Verbal Comprehension	Speed of reading	1. Intelligibility
	Speed of reading	13. Wepman word discrimination
	Rapid spelling	2. Rapid spelling
	Disarranged sentences	3. Disarranged sentences
	Cloze	4. Cloze
	Synonym vocabulary	5. Spoken synonyms vocabulary
6. Flexibility of Closure	Gottschaldt figures	6. White noise masking
	Designs	39. Talk masking
	Designs	40. Cafeteria noise masking
	Designs	36. Rhythm
	Designs	41. Tempo A
	Designs	42. Tempo B
	Gestalt completion	37. Compressed speech
	Gestalt completion	38. Expanded speech
7. Speed of Closure	Gestalt completion	7. Low pass filter
	Gestalt completion	8. High pass filter
	Truncated words	43. Incomplete words
	Truncated words	44. Sound blending
	Truncated words	27. Chord parts decomposition
3. Immediate Span	Number span backward	9. Number span backward
	Letter span forward	10. Letter span forward
	Memory for landmarks	11. Memory for emphasis
4. Induction	Letter groups	34. Chord matching
	Letter groups	35. Tonal classification
	Number and letter series	20. Loudness series
	Number and letter series	22. Tonal series
	Number and letter series	23. Chord series
8. Visualization	Form board	14. Nonsense syllables reordering
	Form board	15. Tonal reordering
	Form board	16. Voices reordering
	Form board	17. Loudness reordering
	Punched holes	25. Chord decomposition
	Punched holes	26. Notes per chord
2. Cognition of Semantic Relations	Verbal analogies	24. Tonal analogies
9. Spatial Scanning	Map planning	18. Detection of repeated voices
	Map planning	19. Detection of repeated tones
10. Spatial Orientation	Figures	12. Tonal figures
5. Visual Memory	Map memory	30. Musical memory
	Map memory	31. Tonal memory
	Map memory	32. Memory for pitch
	Map memory	28. Pitch change in chords
11. Length Estimation	Estimation of length	21. Time
	Estimation of length	29. Pitch differences
	Estimation of length	33. Timbre

Note. Only those tests that were used in the main analysis (Tests 1–44) are listed here.
[a] See Table 2 for a description.

Table 2
Test Descriptions

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
1.	*Intelligibility:* Three words are spoken. They are also presented in printed form among a set of many words, some of which are phonetically similar. The task is to mark the words that were heard. Example: Auditory Presentation: Border Shot Insist. Words from which to select: order mortar border water shook shout shut shot enlist insist assist resist	This study	27	280	62.04	11.39	.93
2.	*Rapid spelling:* Write familiar words that are spelled, auditorily, very rapidly.	This study	20	280	7.30	4.63	.86
3.	*Disarranged sentences:* Words were spoken in haphazard order. The subject's task was to arrange the words in writing so the resulting order "made sense" (i.e., syntactically).	This study	10	320	3.90	2.75	.70
4.	*Cloze:* Write 2 words that are missing in 8-word sentences (missing words being replaced by clicks).	Modified Taylor (1957)	18	280	8.07	3.52	.79
5.	*Spoken synonyms vocabulary:* Choose a synonym for a spoken word from among four alternatives printed on paper.	This study	25	165	16.84	4.44	.80
6.	*White noise masking:* From among 4 phonetically similar words printed on paper, find a word that has been spoken against a loud white noise background.	This study	24	220	13.43	2.90	.62
7.	*Low pass filter:* From among 4 printed words, select one that had been spoken via tape recording in which frequencies below 1,600 cps have been filtered out.	This study	24	140	16.85	3.24	.61
8.	*High pass filter:* The same as test 7 except frequencies above 2,000 cps are filtered out.	This study	24	140	19.40	2.71	.64
9.	*Number span backward:* Several numbers (from 3 to 9) are spoken at fixed rate. After hearing all, the task is to write them in the reverse of the order in which they were spoken.	French, et al. (Note 2)	12	430	2.51	2.21	.82

Table 2 *(continued)*

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
10.	*Letter span forward:* The same as test 9 except the task is to write the words in the same order as they were spoken.	French, et al. (Note 2)	12	210	3.46	2.18	.62
11.	*Memory for emphasis:* After listening to a spoken discourse in which particular words were markedly emphasized, the subject must identify the emphasized words in a printed script.	This study	15 + 15	180	8.29	3.99	.62
12.	*Tonal figures:* Subjects heard a set of 4 notes presented in ascending or descending order of pitch. Four choices of 4 notes in opposite order of pitch were then presented. One of these choices involved the same 4 notes that were given in the first set. The subject's task was to identify this choice by marking a number identifying it on a piece of paper. An illustrative example is given in Figure 1.	This study	18	150	7.56	5.13	.67
13.	*Wepman word discrimination:* Subjects made "same–different" judgments in respect to pairs of spoken words for which either a vowel or a consonant was different. Example: pot–pat.	After Karlin (1942)	40	225	33.84	3.89	.77
14.	*Nonsense syllables reordering:* Three nonsense syllables were spoken. Subjects were asked to "label" these words with numbers corresponding to the order in which they were presented. After a short pause, the same three syllables were spoken in a different order. The task was to write the number "labels" in an order corresponding to the order of presentation on this second hearing. Example: dos vup pif: 1st presentation 1 2 3: Numbers attached vup dos pif: 2nd presentation 2 1 3: Numbers to represent answer	This study	15	250	9.68	3.42	.82
15.	*Tonal reordering:* The same as test 14 except stimuli were piano tones rather than nonsense syllables.	This study	20	140	6.99	3.82	.74

(table continued)

Table 2 (*continued*)

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
16.	*Voices reordering:* The same as Tests 14 and 15 except stimuli were three different persons saying the same syllable word (such as "Hi").	This study	10	160	4.07	2.30	.68
17.	*Loudness reordering:* The same as tests 14, 15, and 16, except stimuli were the same 1,000 cps pure tone played 3 times with supraliminal intensities differing by 10 dB.	This study	10	160	7.20	2.36	.73
18.	*Detection of repeated voices:* The same as test 19 except sounds were voices of 4 different people.	This study	20	430	5.81	3.75	.70
19.	*Detection of repeated tones:* An 8-tone melody was presented. Among the 8 tones, only 4 were different with respect to pitch. The task was to identify each of these 4 tones the first time it appears and not thereafter. An illustrative example is given in Figure 1.	This study	20	240	5.93	4.79	.89
20.	*Loudness series:* A series was introduced by varying the intensity of a 1,000 cps pure tone. For example, tones of 40, 50, 60, and 70 dB were presented. These were followed by 3 answer choices, 50, 80, and 70 dB. The task was to indicate which of these 3 continued the loudness series by marking a number corresponding to the order of the answer choice.	This study	13	600	6.68	2.58	.54
21.	*Time:* Pairs of tones varying in duration between .05 and .30 seconds were presented. The task was to indicate whether the second tone lasted for a longer or lesser time than the first.	Seashore, Lewis, & Saetveit (1960)	40	290	28.55	6.11	.84
22.	*Tonal series:* Four notes were played in series (ascending, descending, or other), followed by 3 answer choices. The task was to indicate the tone that continued the series by marking a number corresponding to the order of the answer choices. An illustrative example is given in Figure 1.	This study	20	400	8.67	3.41	.69
23.	*Chord series:* The same as test 22 except series were comprised of chords.	This study	20	400	8.83	3.35	.61
24.	*Tonal analogies:* Three notes	This study	20	240	9.33	3.81	.77

Table 2 (*continued*)

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
	were played followed by 3 answer choice notes. The task was to select an answer choice that was the same tonal interval away from the third note as the second note was away from the first one. An illustrative example is given in Figure 1.						
25.	*Chord decomposition:* A 3-note chord was followed by 4 answer choices in which 3 notes were played separately. The task was to indicate which answer choice involved the same 3 notes as were in the original chord. An illustrative example is given in Figure 1.	This study	20	460	9.02	4.15	.78
26.	*Notes per chord:* A chord was played. The task was to indicate how many notes it involved.	Wing (1962) chord analysis	20	215	7.98	2.78	.58
27.	*Chord parts decomposition:* A 3-note chord was followed by 3 answer choices in which 2-note chords were played. The task was to indicate which answer choice involved two notes that were part of the original chord. An illustrative example is given in Figure 1.	This study	20	200	10.11	3.54	.67
28.	*Pitch change in chords:* Two chords are presented. The task is to indicate whether the 2 are the same or whether a note had gone up or down in the 2nd presentation.	Wing (1962)	30	250	16.31	5.01	.71
29.	*Pitch differences:* Pairs of tones differing in frequency by between 2 and 17 cps are presented. The task is to indicate whether the second tone is higher or lower than the first.	Seashore et al. (1960)	50	285	31.10	8.63	.90
30.	*Musical memory:* A short melody is played. This is followed by the playing of from 2 to 7 answer-choice melodies. The task is to indicate whether an answer choice is the same as the first melody or differs with respect to either key or time or notes.	Drake (1954)	27	620	19.54	11.66	.92
31.	*Tonal memory:* Pairs of tonal sequences are presented. Each sequence consists of 3, 4, or 5 tones. The task is to indicate which note makes the second sequence different from the first.	Seashore et al. (1960)	30	400	19.39	7.32	.91

(*table continued*)

Table 2 (*continued*)

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
32.	*Memory for pitch:* Pairs of tunes involving from 3 to 10 notes are presented. The task is to identify the note that makes the second tune different from the first.	Wing (1962)	30	240	14.38	5.12	.81
33.	*Timbre:* Pairs of tones are presented. Each tone is made up of fundamental and the first five harmonics, the intensities of the third and fourth being varied in some pairs. The task is to indicate whether the tones are the same or different.	Seashore et al. (1960)	30	250	20.04	4.36	.80
34.	*Tonal classification:* A series of 5 chords was presented. The task was to identify the chord that does not belong to the series. An illustrative example is given in Figure 1.	This study	18	150	9.93	2.89	.67
35.	*Chord matching:* Two chords were played one after the other. One was in major, the other was in minor. A third chord was either in major or in minor. The task was to indicate whether the 3rd chord was most similar to the first or the 2nd chord. An illustrative example is given in Figure 1.	This study	20	120	11.83	3.26	.60
36.	*Rhythm:* Pairs of rhythmic patterns of varying lengths were presented. The task was to indicate whether the pairs were the same or different.	Seashore et al. (1960)	30	280	23.90	3.63	.82
37.	*Compressed Speech:* Short sentences were played at a faster tape recording speed than that used in recording. The task was to write the sentence.	This study	10	180	6.52	5.96	.67
38.	*Expanded Speech:* Sentences were played at a slower speed than that used in recording. Again, the task was to write the sentence.	This study	10	280	4.18	3.59	.69
39.	*Talk Masking:* The task was to write isolated words spoken by one voice in the midst of increasingly loud continuous talking by another voice.	This study	24	160	14.30	5.91	.90
40.	*Cafeteria Noise Masking:* The same as test 39 except the background "noise" was that of a cafeteria.	This study	24	210	14.93	4.82	.84

Table 2 *(continued)*

Variable	Name and description	Source	No. items	Total time in sec	*M*	*SD*	Split-half reliability
41.	*Tempo A:* The task is to continue to count a beat established by a metronome and after varying lengths of time write the number to which the beat has been carried.	Drake (1954)	28	520	176.01	22.14	.93
42.	*Temp B:* The same as Test 41 except that an interference beat is introduced after the established beat ceases.	Drake (1954)	28	560	171.95	25.19	.95
43.	*Incomplete Words:* Subjects listened to words in which sounds had been eliminated. The task was to write the word. Example: Identify the sound "table" when the vowel sound, as "t__ble" is omitted.	After White (1954)	20	120	17.30	1.96	.88
44.	*Sound blending:* The task was to identify spoken words in which there was pause between the phonemes. Example: "p-oo-t" instead of "put."	This study	15	170	3.53	2.96	.80

Note. All tests except those numbered 41 and 42 were scored by counting number of correct responses. Also, all auditory tasks were presented via tape recording. All split-half correlations are in fact odd-even correlations, except for test 11 where it is based on "parallel forms." "Same" in this context means "of the same general form" not that the items are the "same" except for the indicated difference. cps = cycles per second.

concern is the fact that the sample of subjects and the sample of variables were reasonably large, and some of the factors that could not be controlled were expected to produce only random effects. Major lawful effects should be sufficiently overdetermined to ensure their emergence.

Scoring and Data Reduction

Programs were written to identify correct responses for every item and to provide scores (usually as simple linear composites; cf. Horn, 1963) for analyses of reliability; 50 auditory variables were obtained initially.

In most cases, odd–even split-half scores were correlated to indicate reliability. If a correlation was .5 or less, the test was regarded as suspect. The test's correlations with other variables were then examined. If these were generally below .20, it was concluded that the test measurements, as obtained, were unreliable. The full matrix of intercorrelations among all items of the test was then generated and inspected. If pockets of nonrandom intercorrelations appeared in the matrix (and the first eigenvector was in some cases consulted to provide a clue to this), the items having generally low correlations were omitted, scores were recalculated on the remaining items, and reliability was again checked. If the reliability was still below .5 and the correlations with other variables were still below .2, the variable was eliminated from further consideration. In fact, only six variables were put through these examinations, and only one test (Sound Breakdown was not included in Table 2) failed to pass muster up to this point. However, tests were eliminated for other reasons, described next.

To further identify sources of unreliability and specificity, a preliminary factoring was done with the 49 auditory variables that survived the analyses indicated earlier. The variables were intercorrelated, and the resulting correlation matrix (with unities in the main diagonal) was factored using the vector approximation principal components procedure described by Horst (1965, pp. 160–169). The Kaiser-Guttman-Dickman (KGD) criterion (as described in Horn, 1965) was used as a basis for rotating 13 components in accordance with the criteria of normal varimax (Kaiser, 1959). The varimax solution then became the target for a promax (Hendrickson & White, 1964) rotation (oblique) with power set at 5. The resulting approximations to a simple structure were examined to see if factors were overdetermined to the extent that the studies of Horn (1967); Horn and Knapp (1973); and Humphreys, Ilgen, McGrath, and Montanelli (1969) suggest they should be if results are to be believed. These inspections, along with consideration of the scree test (Cattell, 1966) and Horn's (1965) modification of

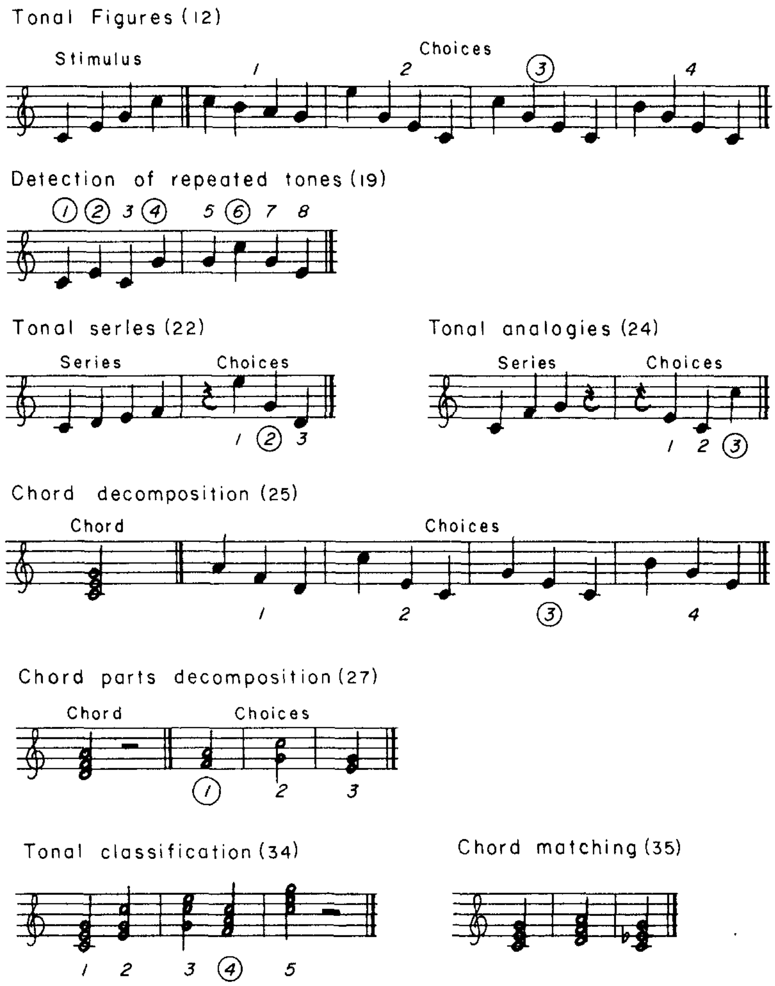

Figure 1. Examples for some tests used in this study. (A more detailed description is given in Table 2; numbers in parentheses indicate test number.)

the root-one criterion, suggested that seven factors were sufficiently overdetermined to justify belief that they could be replicated. These analyses also suggested that the low reliabilities estimated for five variables were not spurious and that these variables were in fact producing mainly only noise to the system. Accordingly, these variables were not used in the main factor analyses to be described next.[3]

Item analyses to improve variables of low reliability were thus of little use. The 44 variables used in the main analyses were the same 44 variables that passed the initial test of having a split-half correlation larger than .5 or correlations larger than .2 with other variables. These variables involve no capitalization on chance in item analyses to select items that maximize reliability. Also, since the two half-tests (of the split-half correlation) were added to provide the variable measures, the reliabilities for the variables are, in accordance with the Spearman-Brown principle, larger than the split-half correlations. These reliabilities are indicated in Table 2.

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[3] Four of the five tests excluded on the basis of these analyses involved loudness discriminations. This exclusion thus greatly reduced the possibility of identifying a factor, or factors, of loudness. This prospect was clearly recognized at the time. However, it was reasoned that the evidence in support of a loudness factor was already at hand (French, 1951), that other evidence indicated that loudness tests do indeed tend to be unreliable and factorially complex (Harris, 1964; Karlin, 1942), and thus further analyses of the unreliable loudness tests of this study were likely to generate confusion. Finally, too, since extension analyses were planned, it seemed most sensible to recover such information as these tests might yield in the extension analyses rather than in further factoring.

Table 3
Means and Standard Deviations for Extension Variables and Correlations With Factor Scores

Variable	Va	Msa	Tc	ACoR	DASP	SPUD	MaJR	*M*	*SD*
	Factors								
1. Grade before 18th birthday	.31	.24	.29	.32	.24	.13	.17	9.90	1.59
2. Graduated from high school	.32	.24	.33	.29	.20	−.10	.12	.27	.44
3. Grade after 18th birthday	.40	.28	.38	.41	.21	.04	.17	10.78	1.90
4. General intelligence (Otis score)	.39	.36	.46	.40	.24	.00	.10	100.42	11.51
Musical experience:									
5. Classes	.25	.19	.16	.37	.36	.13	.10	.19	.39
6. Playing	.16	.20	.14	.27	.29	.15	.08	.32	.47
7. Singing	.12	.18	.15	.19	.28	.11	.13	.37	.48
8. Age	.02	.02	.07	.07	−.13	−.42	.04	25.64	7.75
9. Age corrected for subsample difference	.08	.02	.15	.11	−.14	−.65	.11		
Hearing Acuity:									
10. Left 500 cps	−.01	−.03	.00	.04	.16	.31	−.02	65.71	9.00
11. Left 1,000 cps	.03	.03	.02	.05	.08	.24	−.02	73.04	4.39
12. Left 2,000 cps	−.03	.03	−.02	.07	.06	.10	−.03	74.44	2.38
13. Left 4,000 cps	−.03	−.01	−.05	−.10	−.04	.20	−.02	68.85	11.05
14. Right 500 cps	.04	−.02	.03	.07	.11	.21	.04	65.04	8.40
15. Right 1,000 cps	.00	.04	−.05	.06	.05	.30	−.05	73.23	4.31
16. Right 2,000 cps	−.06	.02	−.06	.00	−.04	−.02	−.03	74.40	1.11
17. Right 4,000 cps	−.03	−.03	−.09	−.05	−.02	.15	−.03	70.56	10.26

Note. The method of limits was employed in obtaining the basic data for the hearing acuity measures. For each frequency, the threshold value (in decibels) was obtained. This value was then subtracted from 100 to yield the values reported in the table. Thus the larger the values in the table, the less the decibel level at which the subject reported the tone was "heard." cps = cycles per second; Va = Listening Verbal Comprehension; Msa = Auditory Immediate Memory; Tc = Temporal Tracking; ACoR = Auditory Cognition of Relationships; DASP = Discrimination Among Sound Patterns; SPUD = Speech Perception Under Distraction/Distortion; MaJR = Maintaining and Judging Rhythm.

Factoring and Extension Analyses[4]

The factoring of these intercorrelations proceeded in the manner described in the previous section. That is, the Horst (1965) vector approximation procedure was used to obtain the roots and vectors (components). Application of the KGD criterion in these analyses would permit as many as 11 factors, but for the reasons indicated in the description of the preliminary analyses (including consideration of the scree and modified-KGD criteria), 7 factors were retained for rotation. The latent roots for these factors were 11.42, 2.95, 2.48, 2.13, 2.03, 1.31, and 1.30. The percentages of common variance represented by these principal components are 48, 12, 10, 9, 9, 6, and 6, respectively. Thus the first principal component among auditory ability variables represents roughly 50% of the common variance. Such a finding is consistent with results from studies of visual abilities (e.g., Horn, 1972).

Varimax followed by promax (with power at 5) was used to achieve rotation to an approximation to simple structure. The reference vector structure obtained from the promax (i.e., oblique) solution is given in Table 4. These results provide the principal basis for discussion in subsequent sections of this report.[5] The intercorrelations among the factors, as determined from the transformation matrix of the oblique rotation, are shown in the below-diagonal part of Table 5.

The intercorrelations above the diagonal in Table 5 were obtained from estimated factor scores computed as unweighted linear combinations of salient variables. The salient variables of a factor are identified with the asterisks above the coefficients in Table 4. The coefficients for the first factor for the first eight variables in Table 4, for example, indicate that these variables were used to measure Factor 1.[6] The variables thus identified in a given factor were converted to stan-

[4] The intercorrelations among the 44 auditory variables of the main analysis are available from the authors.

[5] In subsequent discussion, terms such as *factor* and *factor coefficient* are used to represent elements of the reference vector structure, not elements of the factor pattern, perhaps the more common referent. A simple proportionality exists between the structure and pattern, however, so there is little cause for concern if the two are confused. The structure coefficients are correlations, bounded by −1.0 and 1.0, whereas the pattern coefficients are as beta coefficients in multiple regression analyses, the boundaries of which are difficult to discern, even when variables are in standard score form. For these reasons, primarily, the reference vector structure "factor" coefficients provide the preferred basis for interpretation.

[6] In accordance with common practice, factor coefficients larger than .30 were regarded as salient. A

Table 4
Reference Vector Structure for 44 Auditory Variables

Variable	Factor 1	2	3	4	5	6	7	h^2	G
1. Intelligibility	**66***	−06	−05	−03	00	00	11	72	56
2. Rapid spelling	**54***	10	−03	11	−07	−07	−01	55	51
3. Disarranged sentences	**45***	11	05	18	−11	00	05	62	60
4. Cloze	**44***	−06	22	01	12	00	−04	66	65
5. Spoken synonyms vocabulary	**30***	04	26	10	00	−04	−06	55	59
6. White noise masking	**46***	−02	−14	06	18	04	00	45	47
7. Low pass filter	**58***	21	−18	−05	21	03	−23	57	39
8. High pass filter	**38***	**−47**	17	−15	12	14	−05	56	33
9. Number span backward	14	**63***	05	−03	00	10	−09	50	24
10. Letter span forward	21	**53***	21	−18	−01	00	−05	50	27
11. Memory for emphasis	08	**49***	21	−09	03	−03	12	45	34
12. Tonal figures	−12	**71***	−04	24	17	00	00	71	32
13. Wepman word discrimination	19	**−59**	23	13	−09	14	00	58	35
14. Nonsense syllables reordering	11	00	**45***	−03	00	02	10	51	52
15. Tonal reordering	10	23	**36***	22	21	−22	07	63	61
16. Voices reordering	−20	−03	**31***	26	02	12	−07	34	35
17. Loudness reordering	−10	14	**40***	01	14	−02	19	43	47
18. Detection of repeated voices	−06	06	**56***	−15	**32**	03	−02	54	50
19. Detection of repeated tones	−15	06	**48***	−01	**46**	−13	−13	62	51
20. Loudness series	−09	−04	**34***	19	05	08	**−46**	47	50
21. Time (Seashore, Lewis, & Saetveit, 1960)	04	−08	27*	02	18	06	19	36	49
22. Tonal series	−04	06	−01	**57***	−13	17	00	52	47
23. Chord series	00	11	04	**53***	−03	09	−22	59	46
24. Tonal analogies	−02	−03	07	**36***	18	−02	01	41	49
25. Chord decomposition	03	−02	−17	**54***	08	03	08	49	47
26. Notes per chord (Wing, 1962)	17	−01	−22	**40***	12	01	−11	36	37
27. Chord parts decomposition	00	−17	00	**40***	20	−14	13	52	52
28. Pitch change in chords (Wing, 1962)	−01	10	09	**30**	**33***	04	−02	55	58
29. Pitch differences (Seashore et al., 1960)	04	03	−05	**36***	17	08	29	55	59
30. Musical memory (Drake, 1954)	21	−07	05	29*	14	**−39**	−19	56	44
31. Tonal memory (Seashore et al., 1960)	03	06	17	03	**58***	03	05	66	60
32. Memory for pitch (Wing, 1962)	08	08	15	04	**52***	02	02	59	59
33. Timbre (Seashore et al., 1960)	−13	06	−04	13	**36***	27	25	46	36
34. Tonal classification	04	03	04	07	**43***	−12	15	41	46
35. Chord matching	−04	09	03	06	**35***	−05	−03	20	46
36. Rhythm (Seashore et al., 1960)	13	−12	16	−15	**44**	−06	**32***	56	49
37. Compressed speech	19	−04	−06	−20	**39**	**37***	−14	50	34
38. Expanded speech	−15	09	07	−08	**38**	**52***	−10	53	56
39. Talk masking	02	−03	00	03	02	**81***	−04	74	70
40. Cafeteria noise masking	00	04	−02	25	−17	**79***	10	73	60
41. Tempo A (Drake, 1954)	00	−02	05	−03	11	00	**73***	59	30
42. Tempo B (Drake, 1954)	−04	−02	−06	02	10	00	**71***	67	38
43. Incomplete words	28	03	04	−14	−08	00	**49***	49	32
44. Sound blending	25	22	03	26	−22	28*	07	53	49

Note. Decimal points omitted. Factor coefficients .30 or larger (absolute value) are in boldface. Asterisks indicate variables used in calculating factor scores. (See also Footnote 6.) G represents the general factor loadings, h^2 stands for communalities.

(*Footnote 6 continued*)
variable might be salient by this criterion in more than one factor, however. If such a variable were used to measure both factors, a spurious contribution to correlation between the factors would result because precisely the same behavior would be counted in both factors. To avoid such spurious contributions to correlations, it is desirable to use a variable to measure only one factor. This practice was followed here.

dard-score form and were added to provide the factor measurements (estimated). It is the intercorrelations among the factors measured in this manner that are provided in the above-diagonal section of Table 5.

Results from the studies of Wackwitz and Horn (1971) and Horn, Wanberg, and Adams (1974) indicate that for moderate-to-small sample sizes, factors measured in the manner described earlier provide results that are more stable than results obtained by other,

Table 5
Factor Intercorrelations Obtained Directly From Rotation (Below the Diagonal) and From Factor Score Estimates (Above the Diagonal)

Factor	1	2	3	4	5	6	7
1. Listening Verbal Comprehension		.36	.55	.56	.57	.22	.35
2. Auditory Immediate Memory	.17		.43	.36	.32	.07	.18
3. Temporal Tracking	.54	.19		.65	.62	.10	.24
4. Auditory Cognition of Relationships	.47	.19	.58		.65	.19	.21
5. Discrimination Among Sound Patterns	.31	.01	.13	.39		.34	.38
6. Speech Perception Under Distraction/Distortion	.14	−.06	−.06	.23	.23		.11
7. Maintaining and Judging Rhythm	.34	−.01	.26	.19	.19	.07	

seemingly more elegant, procedures. These factor measurements were used, therefore, to estimate the relationships between factors and variables, called extension variables, that were not included in the factor analysis. Determination of these relationships is called extension analyses (major features of which are described in Horn, 1973a). The left part of Table 3 contains correlations between extension variables and factors measured as unweighted linear combinations of salient variables.

Results

Some General Features

Visual ability measurements (if they are reliable) are almost always positively intercorrelated, even in samples of subjects for which there has been selection in respect to ability (Horn, 1970; Horn & Donaldson, in press). This is one of the most frequently established findings in psychology. It is not surprising, therefore, to find in the present data that all of the intercorrelations were either positive or zero; none were significantly negative.

As Thurstone (1947) pointed out many years ago, a finding of positive test intercorrelations does not necessitate a theory of positively intercorrelated simple structure factors, nor does it require a theory that all variable-factor correlations be positive or zero. His analyses also showed, however, that although these conditions are not necessary, they are highly plausible and much to be expected.

In the present results, the first of these conditions does hold, as can be seen in Table 5. The factor intercorrelations, estimated in two different ways, were generally positive, often significantly so. None were significantly negative. Since the rotation procedure was completely objective and not constrained to produce positively correlated factors, these results can be accepted as a feature of the data, that is, not, as in some studies, only an indication that the data can be made to conform with a hypothesis of positive (or zero) factor intercorrelations.

Some of the variable-factor correlations were negative, however, and large enough (absolute value) to suggest that the outcomes are not simply random variations on a true correlation of zero. Such findings can raise interesting questions about opposing influences represented by a factor—the idea that development of an ability works against good performance of a particular kind. Consideration of such questions should be tempered by realization that the findings are likely to reflect nonchance features of samplings of subjects and complex interactions associated with selection of the particular variables under study. These possibilities should be taken seriously in studies such as this one in which many of the tests are newly constructed and the subject sample is heterogenous with respect to several variables. Negative factor coefficients in ability data should be regarded in much the same way as suppressor influences in multiple regression analyses. They can represent nonchance findings that are not likely to be replicated. For these various reasons, then, the few negative factor-variable correlations indicated in these results are considered only cursorily.

Factors

In the discussion to follow, each factor is considered in some detail. Factor coefficients of less than .30 will be regarded as not significant (i.e., not likely to indicate a replicable salient feature of a factor). Coefficients of less than .15 are regarded as in the hyperplane. In gaining a correct perspective on what a factor represents, it is often as important to attend to hyperplane loadings as it is to attend to salients.

Factor 1: Listening Verbal Comprehension (Va)

Two different kinds of variables define this factor. First, there are tests that measure knowledge of the elements and form of the English language. The Vocabulary test, measuring understanding of the meanings of words, perhaps best exemplifies this category, but also prominent in the factor are Intelligibility (distinguishing between words having similar sounds but different meanings), Rapid Spelling (identifying words that have been rapidly spelled), Disarranged Sentences (rearranging words to make a sensible statement), and Cloze (furnishing words that will complete incomplete sentences). Considered in terms of these marker variables, the factor is similar to the Verbal Comprehension (V) primary ability that has been identified in many studies based on visual tests. A second set of variables in the factor adds an interesting twist to this observation. These are variables that seem to involve only elementary perception of spoken language, as in the measures of detection of clipped speech (High and Low Pass Filter), and identification of words spoken in an unusual manner (Interrupted Words and Sound Blending). Thus understanding of language is closely linked to merely recognizing words under conditions that interfere with clear perception. Although it is not surprising to find a verbal comprehension factor among auditory tests, and it is not counterintuitive to find that this is implicated in language perception, it is by no means obvious that the link between comprehension and perception should be close enough to produce this factor. Some findings from other studies may help to put this result in proper perspective.

It should be noted first that the present result is not entirely without precedence. Solomon et al. (1960) found a similar link between verbal comprehension and perception of speech variables. It is noteworthy, also, that a factor involving this link between verbal comprehension and verbal perception could not be expected in some studies because no, or few, markers for verbal comprehension were present (cf. Hanley, 1956). The suggestion is that variables or factors that seemingly involve only elementary perception of speech may in fact involve substantial comprehension of language, as represented in V, but this is not detected unless studies have good markers for the verbal comprehension primary ability.

The present findings do not rule out the possibility that it is useful to distinguish between an auditory verbal comprehension/perception factor (i.e., Va) and the V factor that has been well established among visual tests. The findings of Sticht (1972) suggest that this distinction might be made, at least in samples of young people or people of low general ability. It is possible, too, that the findings of Spearritt (1962) represent this distinction, although it seems more likely that they are indicative of the distinction found in the present study between Factor 1 and Factor 6, representing resistance to distraction in listening to spoken discourse. In any case, until there is further empirical evidence of the relation between the present Va factor and the V factor of previous studies, it is desirable to retain the hypothesis that they represent somewhat independent dimensions of comprehension of the dominant language of a culture.

Factor 2: Auditory Immediate Memory (Msa)

There is a close resemblance between this factor and a Memory Span (Ms) factor that has been identified in several studies of primary-level structure. It is appropriate to identify the present factor with Ms because in previous research auditory memory span tests have behaved in much the same way as comparable visual memory span tests (Kelley, 1964).

The Tonal Figures and Memory Span Backward tests are most highly correlated with Factor 2 and thus provide good indications of the processes involved. In both of these tests, one must become aware of discrete items of information and retain this awareness while making use of it in a particular way. In Tonal Figures a perception of four notes must be held in awareness while one listens to four sets of four notes in order to choose the one set that is the same as (most similar to) the set retained. The time over which the perception must be retained is upwards from 10 sec but no more than about 30 sec. Thus the time span is a bit on the long side to represent primary memory and a bit on the short side to represent secondary memory (see Kintsch, 1970). In Memory Span Backward, on the other hand, the perceived items need to be held in awareness only long enough to write them down in the reverse of the order of presentation (i.e., about 10 sec). Thus the factor appears to encompass the processes of both primary and secondary memory.

Factor 3: Temporal Tracking (Tc)

On the face of it, at least, this factor is not similar to any of the established primary-level factors of the visual domain. Yet the processes it represents are rather similar to some that have been considered in a number of theories about intellectual functioning. Let us first consider the tasks that provide the measurements that characterize the factor and then consider some hypotheses related to such performances.

Nonsense Syllables Reordering is one of the "cleaner" (least involved with other factors) markers for the factor. In this task one must first affix number "labels" corresponding to the order in which syllables are spoken; for example, dos, vup, and pif would be labeled first, second, and third, respectively. One must retain these labels for 5–10 sec while the syllables are spoken again, this time in a different order, as vup, dos, pif. Finally, one must write the labels for the syllables in an order that represents the order of this last presentation, as 2, 1, 3.

Detection of Repeated Tones also has a prominent correlation with the factor. The task in this test is to identify a note the first time it is heard but not thereafter. For example, if the notes were C, E, C, F, F, E, F, G, the task would be to identify them in the way indicated by the underlining of the letters.

In the Loudness Series test, which also loads fairly "cleanly" on the factor, the task is to select one of four loudnesses that best continues a series of loudnesses.

In each task that is prominent in the factor, there is need to attend to a series of successive events for which there is an ordered pattern. This process seems to be similar to one of two components of what Pollack (1969) discussed as temporal integration (the other component being an immediate memory process similar to that identified here in Factor 2). Prior to Pollack, Hearnshaw (1956) had referred to temporal integration (TI) as "the formation of contemporaneous patterns of action and meaning when the units from which these patterns are constituted are serially ordered and in temporal succession" (p. 5). The suggestion is that the phenomena discussed in theories of temporal integration are adumbrated by this factor.

Massaro (1975) has described a process similar to the one represented here in the context of theory about short-term memory. The QRST task he used to identify this process is almost identical to the Detection of Repeated Sounds tests of this study. He refers to the process as "working memory." It is not clear just how this memory might differ from primary and secondary memory as these concepts have come to be used by cognitive psychologists who attend particularly to temporal aspects of cognitive processing (cf. Horn, 1978a; Hunt, Lunneborg, & Lewis, 1975; Kintsch, 1970).

In sum, then, Factor 3 represents an aspect of thinking with sequential information presented in a paced stream across time. The label *temporal tracking* seems to capture the idea of the factor. It seems likely that the factor will relate to some visual tasks—for example, tasks based on tachistoscopic presentations—but as of now the factor has been identified only in auditory stimuli.

Factor 4: Auditory Cognition of Relationships (ACoR)

Three of the tasks that define this factor were designed to parallel visual tasks in which cognition of relationships was a major feature. In Tonal Series and Chord Series, the model tests were those of the Inductive

Reasoning primary factor. In Tonal Analogies the model was Cognition of Figural Relations. Chord Decomposition and Chord Parts Decomposition can be seen to involve processes of comprehending the relationships among notes. Thus the factor appears to be one involving eduction of relations in reasoning.

Some of the other markers for the factor might at first seem to pertain to only rather elementary aspects of perception, not the cognitive processes of reasoning. For example, the Notes Per Chord test requires one to merely indicate how many notes are in a chord. This may seem to be a simple perceptual task, but when people attempt it, they typically find that it involves considerable thinking (i.e., reasoning). The Musical Memory task is similar in this respect. One must comprehend a melody before trying to determine whether it is this or another melody that is heard in subsequent playings.

It is noteworthy that four of the markers for this factor are subtests of published musical ability tests. It is noteworthy, also, that these four tests have come together to define a factor in several previous studies. (See French, 1951; Shuter, 1968.) In interpretations of these previously determined factors, it has been suggested that tonal memory depends on pitch discrimination. In the context of the present factor, however, these tasks are seen to involve cognition of relationships. Thus, what has been regarded as primarily a musical factor can be seen to involve reasoning processes similar to those that characterize the intelligence dimensions identified among visual tasks.

It is possible, of course, that the cognition of relations involved in this factor is exclusive to the auditory domain. It seems likely, however, that a substantial proportion of the variance of the factor will be common to some of the reasoning primary abilities that are prominent in defining fluid and/or crystallized intelligence.

Factor 5: Discrimination Among Sound Patterns (DASP)

The essential feature of this factor appears to be one of detecting various simple as well as complex patterns in sounds of several kinds. The two tests that are most prominent in the factor require the subject to identify changes in a pattern of pitch (melody). In Wing's (1962) Memory for Pitch test, for example, the subject is first presented with a rather pleasant little tune of 3–10 notes. The tune is then played once again, but on this playing a note is changed. The subject's task is to indicate which note was changed. Seashore's Tonal Memory is similar, but pure tones are used, and the tones do not form what most would be inclined to call a melody. In Seashore's Rhythm test the patterns appear in beats; the task is to indicate whether two rhythmic patterns are the same or different. The Tonal Classification test requires one to identify which one of five chords does not belong with the others. In the Compressed and Expanded Speech tests, the subject must comprehend the pattern of a short spoken message when this is sent at a slower or faster speed than it was recorded. The patterns of the Timbre test are among the fundamental and first five harmonics of tones.

In all, then, throughout a variety of markers for this factor, there is consistent indication that it represents an ability for discriminating between patterns of sounds. A recent study by Dewar, Cuddy, and Mewhort (1977) suggests that the ability involves a sensitivity to relational cues. It remains to be seen whether the ability can be measured in nonauditory tests.

Factor 6: Speech Perception Under Distraction/Distortion (SPUD)

This factor clearly involves some aspect of speech perception under conditions when the speech is not entirely clear. The two variables having the highest correlations with the factor (as well as small correlations with other factors) are Intellective Masking and Cafeteria Noise Masking. These tests require the subject to identify isolated words spoken against a background of noise, in the first case the "noise" of someone talking constantly and in the second case the noise of a cafeteria. The Expanded Speech and Compressed Speech tests require one to determine the meaning of short messages that are played at a different (slower or faster) speed than used in the recording. In Sound Blending the subject must gain the meaning of a word spoken in a different way, at a different rate, than is customary, as "p . . . oo . . . t" for the word "put."

Thus the factor can be seen to involve an ability to recognize words and sentences either when these words or sentences have been distorted in particular ways or when they have been spoken against a background of similar sounds. It is noteworthy that White Noise Masking, High Pass Filter, and Low Pass Filter do *not* have substantial correlations with the factor; it does not involve all of the variance in detection of distorted speech and listening under auditorily distracting conditions. Perhaps the important element of distraction in this factor is the presence of speech sounds similar to those one is asked to detect. This element is lacking in White Noise Masking, and this may account for the absence of this variable among the markers for the factor.

Hanley (1956), Karlin (1942), Solomon et al. (1960), and Spearritt (1962) each found a factor (or possibly two factors) rather similar to the one identified here. In the first two and fourth of these studies, the factor in question was interpreted as representing a quality of resistance, as in resisting background distraction or the distortions of words. Solomon et al. described the factor as involving a tolerance for unpleasantness. In each of these interpretations, there is discussion to suggest that the essential processes of the factor might pertain to sensory/perceptual functions of the kind that filter out noises, enhance signals, and in similar ways "prepare" information for central processing mechanisms.

The negative correlations in the factor may provide some support for the idea that the factor in some sense involves tolerance for unpleasantness. The Drake test of Musical Memory has the principal negative loading on the factor. This provides rather pleasant auditory stimulation, whereas the principal markers for the factor involve notably unpleasant sounds. Hence, it may be that some people perform rather well on auditory tasks when the stimuli are rather pleasant but perform particularly poorly when the stimulation is unpleasant. This could very well be a nonchance influence associated with this particular sample of subjects and thus not a finding that is likely to be replicated.

Factor 7: Maintaining and Judging Rhythm (MaJR)

All of the tests designed to measure an ability to identify and maintain rhythm are involved in this factor. The principal markers require the subject to continue a beat that has been established with a metronome. In the B form of Drake's test, the beat must be maintained under conditions in which a distracting faster or slower beat intervenes. As noted in the discussion of Factor 5, the Seashore rhythm test requires the subject to indicate whether two beats are the same or different. A major portion of the variance in this task seems to involve processes of discriminating among sound patterns generally (i.e., Factor 5), but the remaining reliable variance is in the present rhythm-qua-rhythm factor.

The factor is defined by incomplete words as well as by the above-mentioned rhythm tests. It is difficult to postulate a priori that incomplete words clearly involves rhythm (more so than other tests), but after the fact of finding its correlation with the factor, it can be seen to involve processes of discerning rhythm in spoken words. The task is one of identifying a spoken word when certain sounds have been left out, as in the speech of young children or retarded individuals. For example, the word *mattress* might be spoken as *mattes.* To detect that the latter is intended to represent the former may require sensitivity to the rhythm of the word. Actually, some recent results by Robinson (1977) suggest that this is in fact the case.

It might be argued that the rhythm factor of the present analysis is really only a swollen specific brought about by including two subtests from the Drake battery. Opposing this argument is the fact that the two Drake subtests are notably different, not simply parallel forms of the same test, and the fact that in some of Horn's (1973b) analyses, only one of the Drake subtests was included, and a rhythm factor still emerged. Also of importance in this regard is the above-mentioned evidence that rhythm is involved in understanding speech.

Factor Relationships With Extension Variables

It can be seen in Table 3 that the factors are not appreciably related to hearing acuity but are related to a number of variables pertaining to the development and expression of intellectual abilities. Of particular interest in this regard are the correlations with education, general intelligence (G), and age. Correlations of .20 or larger are significantly different from zero at the .01 level in a sample as large as the present study.

Correlates of educational level and general intelligence. In an effort to ferret out possibly different meanings of the idea of formal education, three measures were tried out: (a) Grade level completed before the 18th birthday. It was thought that in contrast to Variable c below, this would represent conformance with the values of school systems. (b) Whether or not graduated from high school. It was thought that this, too, would well represent conformance, since in Colorado a diploma is given primarily in recognition of time in service rather than ability. (c) Grade level completed after the 18th birthday. The hypothesis of this variable was that it would best represent educational continuance "pushed," as it were, by intellectual ability (in contrast to "pulled" by conformance).

An Otis test measure of general intelligence was obtained from prison records. This, too, is an indication of educational achievement, although the pattern of achievement represented by this kind of measure is broader and more firmly consolidated than the pattern represented by years of schooling. Also, an Otis measure has some variance associated with fluid intelligence influences that are largely independent of educational/acculturational factors.

It can be seen that the third measure of educational level has the largest correlations with the auditory factors. This could mean that education enhances the abilities in question, or that the higher the ability, the more likely one will continue in formal education, or that both of these kinds of influences are at work.

In any case, the factors symbolized as Va, Tc, and ACoR had the largest correlations with educational level. Since amount of education/acculturation is a principal correlate of Gc, these results suggest that Auditory Verbal Comprehension, Cognition of Relations, and Temporal Tracking will best represent Gc. Msa and DASP have low but significant correlations with the educational level measures. This suggests that they, too, measure the intelligence of academic achievement. It is noteworthy in this respect that Msa correlates nearly as high with the Otis measure of G as does Va, but it has substantially lower correlations with educational level measures. This suggests that Msa is related to the Gf component of the Otis measure of G. Somewhat the same thing is indicated by the pattern of correlations for DASP, although the relationships with G are lower than for Msa. SPUD and the rhythm factor (MaJR) appear to have little in common with the intelligence of educational level or that of Otis G.

Correlates of musical training/experience. To generate some ideas about how, if at all, the auditory factors might be related to musical education, questionnaire measures of the following variables were obtained: (a) musical training through formal lessons; (b) ability to play a musical instrument; and (c) voice training, as in choir or chorus. Interestingly, the pattern of correlations of these variables with the auditory factors is somewhat different than the corresponding pattern for the formal education and G variables. In particular DASP has generally higher correlations with the musical training variables than with the general educational achievement variables, whereas the reverse is true for Va and Tc. To a considerable extent, DASP is defined by published tests of musical abilities. This suggests that the published tests measure the musical abilities they were designed to measure. This evidence also illustrates the concept of sentiment, as originated in the general personality theories of McDougal and Cattell (see Horn, 1966, for a discussion) and is supportive of the more recent developments of this kind of concept in Cattell's (1971) triadic theory of human abilities (see particularly investment theory).

Correlates of age. On first view it seems that the only auditory ability having substantial correlation with age is SPUD. This correlation is negative, thus indicating that older adults have more difficulty in hearing speech when it is distorted or must be heard in context of other (somewhat similar) sounds. It is worth noting in this respect that SPUD is the only factor that has significantly nonzero correlations with the acuity measures. In particular, it is correlated with acuity in hearing tones of lower frequencies in the range in which speech communication occurs. Together these results indicate aging decline in the ability to hear speech and thus speech that occurs under conditions of distortion and distraction. These findings are consistent with those of a number of studies of adulthood age differences in capacities for hearing.

The near-zero correlations of the other primary auditory abilities with age may be a reliable finding. At least there are reasons to believe that the results could represent what is likely to be found in subsequent study. There are reasons, also, to suppose that the near-zero correlations are not likely to replicate. It is overly speculative to consider these matters in any detail at this time. Further studies are needed, and indeed are under way, to explore plausible hypotheses in this regard.

Factor Intercorrelations

As noted before, the major finding in regard to factor intercorrelations is that they are generally positive. In an exploratory study of this kind, it is probably not wise to put much credence in differences between these kinds of correlations, unless the differences are large and consistent across the two methods of estimating factors. Some of the correlations do satisfy these criteria.

Listening Verbal Comprehension is significantly related to four of the factors, namely Tc, ACoR, DASP, and MaJR. Tc and ACoR are, in turn, significantly correlated, as are ACoR and DASP. Thus, Va, Tc, ACoR, and DASP form an intercorrelation cluster, and the Va part of this cluster may also relate to MaJR. Given the results that have preceded, particularly those pertaining to educational level, it seems likely that the cluster indicated here is representative of crystallized intelligence. This form of intelligence could be expected to have a moderate relationship with measures of rhythm, as in the Va–MaJR correlation. Since all of the tests would involve it to some extent, it could also be the basic influence operating to produce the other positive intercorrelations seen in Table 5. Further study of higher order organization among the auditory primary abilities is nearing completion (Horn & Stankov, Note 3).

Discussion

The results from structural analyses of a broad sample of auditory variables (based on the representative design concepts of Thurstone and Cattell) indicate seven overdetermined cognitive-perceptual abilities: Listening Verbal Comprehension, Auditory Immediate Memory, Temporal Tracking, Auditory Cognition of Relationships, Discrimination Among Sound Patterns, Speech Perception Under Distraction/Distortion, and Maintaining and Judging Rhythm.

Va and Msa are formally similar to well-established primary mental abilities V and Ms. However, there are differences between the auditory and the corresponding visual factors. For example, Va involves elementary perception of speech, whereas previous work on V has not indicated that it picks up any substantial proportion of variance in elementary perception of the printed word. This raises some possibly interesting questions for research to compare visual and auditory factors.

ACoR is also similar in formal respects to cognition of relationship factors identified in the work of Guilford and his co-workers. (See Guilford & Hoepfner, 1971 for a recent review.) Indeed, Guilford (1973) has expressed the view that the factor known as Cognition of Figural Relations in his system is the visual equivalent of the factor in Horn's (1973b) analysis that is the same as

ACoR. This suggests the interesting hypothesis that cognition of relationships is a central cognitive function that can be actuated, as it were, by information entering through either the auditory or visual (or other) modality.

SPUD is a fairly clear replication of a factor found in several previous studies of structure among auditory-input tests. Most of these previous studies would not have been designed within the context of a structural theory, however, so there is little previous indication that it is an ability of the same ilk as the primary mental abilities. The factor has low, but positive, correlations with the factors of the present study that seem to most involve the qualities of human intelligence. It seems, therefore, that the factor may pertain mainly to a feature of the input modality, a general auditory function similar to the general visualization function found in higher order analyses among the primary mental abilities.

Tc, DASP, and MaJR have few, or no, predecessors in previous work. Although tests of rhythm (i.e., parts of MaJR) have been used in music education selection batteries for many years, the finding of coalescence among different indicants of rhythm is an outcome of only the present line of research. Similarly, although tonal memory has been regarded as a worthwhile and measurable aspect of individual differences, the broad concept of pattern recognition among auditory-input stimuli (DASP) has not been well established in previous work. But Tc may be the most interesting novel result of this research. This has clear links to theories and hypotheses that have long been associated with the term *temporal integration*. Yet no factor of temporal integration has been identified in previous research. Perhaps the concept is not well represented in this way, but if it is, Tc may be the first shadowy indication of this fact.

The intercorrelations among the factors and the correlations of the factors with educational level, musical training, and age suggest that Va, Tc, ACoR, and DASP are indicants of crystallized intelligence, whereas Msa and DASP may represent feature of fluid intelligence. SPUD and MaJR could indicate a broad auditory function analogous to the broad visualization function that has been found among visual-input variables.[7]

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[7] Subsequent to the work reported here, essentially the same test battery was given to children in Yugoslavia (Stankov, 1978) and Australia (Stankov & Spilsbury, 1978). In Stankov and Spilsbury the sample included blind and partially sighted children as well as children of normal vision. The factor structure in each of these studies was highly similar to that reported here. Considering the variation in subject samples, such findings indicate hardy lawfulness in the observed behavior.

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Received February 28, 1979 ■