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Auditory and Visual Factors of Intelligence*

JOHN L. HORN
Department of Psychology, University of Denver, Denver, CO 80210

LAZAR STANKOV
University of Sydney

In a sample of 241 convicts, most of whom were between 20 and 35 years of age, a sample of 18 primary mental abilities was factored to explore the idea that in performances that are believed to indicate human intelligence there are organizations among visual and auditory functions that operate independently from the relation-perceiving and correlate-educing functions of fluid and crystallized intelligence. Objectively rotated results suggest that, indeed, reliable overlapping (common-factor) functions of Auditory Acuity (Ac), Auditory Organization (Ga), Visual Organization (Gv), Acculturational Eduction (Gc) and Fluid Eduction (Gf) represent separate components of individual differences in performances on intellectual tasks broadly conceived.

Whatever one may mean when he uses the term "intelligence" to characterize human functioning, and people can mean different things when they use this term (Sternberg, Conway, Ketron, & Bernstein, 1981), he usually has reference to a number of capacities that can involve any one of, or all of, our sensory/perceptual modalities. The intelligence of Bach was manifested to a large extent in intricate and sensitive comprehension of sounds; Renoir's intelligence was expressed through profound awareness of the ways in which color and form can convey meanings; Helen Keller realized great understanding largely through use of touch. In each of these examples intelligence can be seen to involve exceptional utilization of the capacities of a stimulus-receiving and stimulus-generating modality.[1] In each case, too, it seems that something of the modality itself is tied up in what is recognized as intelligence. In general, it seems that to adequately describe and explain the phenomena of human intelligence, we must come to know the basic forms in which it is manifested in each of our sensory-perceptual modalities.

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[1]That is, to compose music is not merely to comprehend the complexities that can reside in sounds; it is also to realize how to produce these complexities. A remarkable quality of Helen Keller was exemplified by the way she could use her language of touch to communicate to people who had not themselves really mastered this means of communication.

Given this premise, it is interesting that although hundreds of factor analytic studies have been done to study the ways in which various kinds of intellectual performances are interrelated, only a handful—less than a dozen—have been done with what might be called non-visual intellectual ability tasks (see Horn, 1973; Stankov & Horn, 1980 for review). At the time this study was undertaken, there had been no second-order studies based on primary mental ability factors defined in different sensory modalities.[2]

THEORY AND RATIONALE FOR THE STUDY

The design for this study was derived from a theory of fluid (Gf) and crystallized (Gc) intelligence that has been evolving for several years (see Cattell, 1971; Horn, 1979; 1980; and 1982 for recent statements of the theory). Our concern in the present study was with the structural, as distinct from developmental, features of the theory. In the work on which this part of the theory is based, we have asked the general question: what are the necessary and sufficient abilities of human intelligence? And we have attempted to provide clues to the answer to this question by identifying regularities in covariations among different kinds of test performances. The theory thus represents what we think we can infer about such regularities on the basis of results now in hand.

Since the general theory has been rather fully stated in several recent and readily available publications (as cited previously), only a very brief description of major concepts is needed to indicate the rationale for the present study.

Figure 1 provides a schematic layout of major structural concepts of the theory. Each solid-line circle in the figure represents, operationally, a common factor identified among estimates of primary mental abilities, as these have been identified in previous research and in review summaries such as the summary of Ekstrom, French, and Harman (1979).[3] The factors appear to represent distinct

[2]Studies have followed from this study, however; the findings have been generally consistent with the results reported here (Horn, 1973; Stankov, 1978).

[3]The dotted-line circles in Figure 1 represent either factoring results that have been obtained in only a couple of studies and thus are not well replicated or, in the case of Ga, an hypothesis that follows from reasonable extrapolations from empirically-based theory. The arrows in the figure represent statements that are even more provisional than the statements represented by the dotted-line circles. The absence of an arrow should not be interpreted as a strong hypothesis that a path does not exist.

In general, although the figure looks very much like what many today are referring to as a model, we prefer to avoid suggestion that we have a model in any epistemologically strong sense of this concept (as developed by, for example, Scriven, Ayer, Braithwaite and others in Brody's 1970 collection of the positions of philosophers of science; see also Horn & McArdle, 1980). The figure is best regarded as a summarizing heuristic, a way of describing what "seems to be," as suggested by some empirical findings, and therefore a reasonable starting point for further investigation, but by no means an indication of strong-law explanation of cognitive phenomena.

Incidentally, this is no more an apology for Gf-Gc theory than it is an apology for the whole of theory about cognitive phenomena. By our reckoning, there is no strong-law theory in this field.

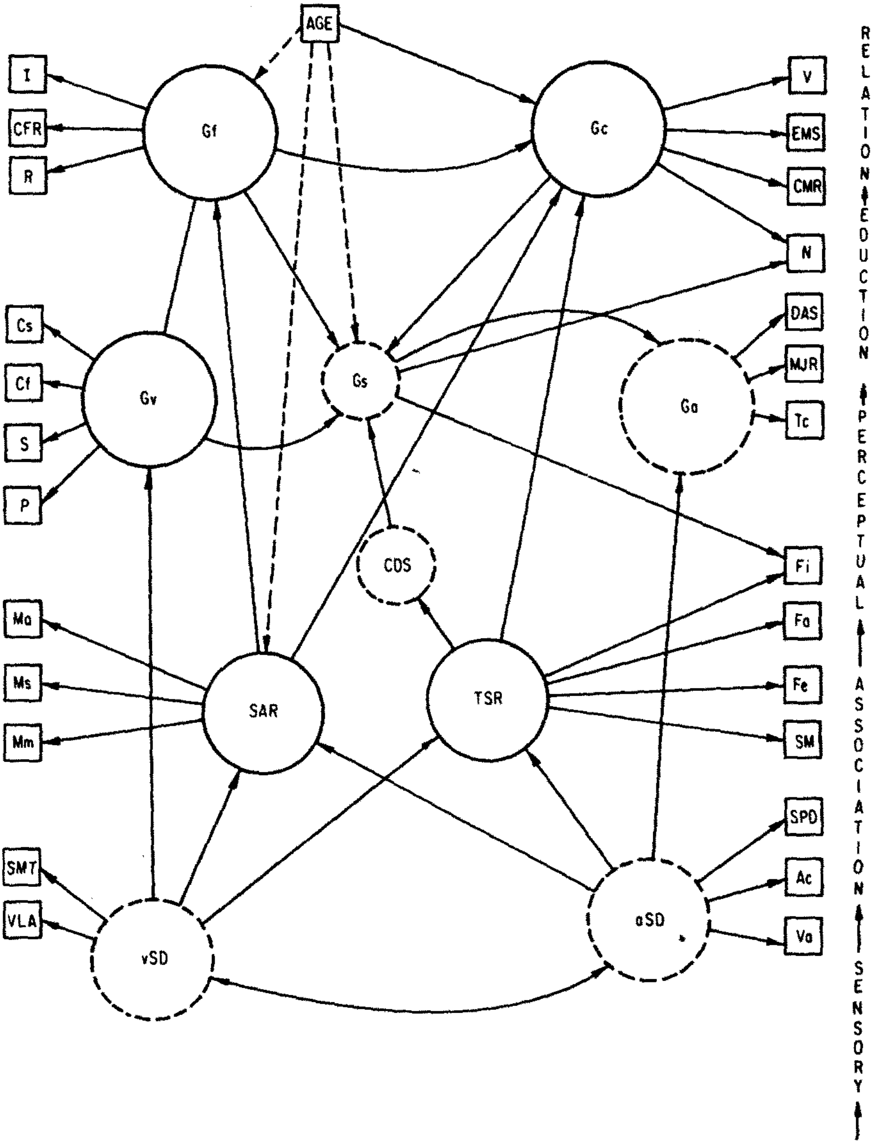

FIG. 1. Function Organizations of Intellect. Dotted Arrows represent negative relations. Dotted circles represent hypotheses or findings that have yet to be well established. The symbols are given names in the Appendix, Table 1 and the text.

organizations among thinking processes that are actualized when one attempts to cope with an intellectual task—processes of memory, educing relations, drawing conclusions, reasoning, forming concepts, problem solving, etc. All such processes work together at a most general level when one deals with intellectual tasks, much as the arms, the legs, the trunk, etc., work together in running, but subsets of processes are closely related functionally (as the various muscles of an arm) relative to other subsets (the muscles of a leg). Some tasks require more of one such subset organization than of another, and so patterns in the covariations among task performances can indicate separate thinking-process organizations. The domain of processes that enter into such organizations is our referential definition of intelligence (Humphreys, 1979).

The upward-directed arrows to the right in the Figure are intended to suggest that the organizations represented by circles in the lower part of the Figure are directed at preparing information for the processing that is represented by circles in the upper part of the diagram. These arrows also represent increasing correlation with those abilities that are most widely accepted as indicating mature human intelligence. Also, these arrows crudely represent a course of development from the simple sensorimotor circular reactions of infancy to the complex abstract thinking processes of adult intelligence.

Although the circles in the figure represent empirical findings, the hierarchical structure indicated in the figure does not necessarily reflect a comparable hierarchy in analyses of performance, as first-order and second-order factors. Humphreys (1962) has pointed out that there is nothing about a particular linear combination of scores that makes a factor intrinsically first-order, second-order or higher-order. The order of a factor is largely a matter of design of a study (although adequate designs will not lead to results that misrepresent reality). In fact, most of the factors indicated in Figure 1 have been defined at the same order. The Figure thus more nearly represents ideas about order of cognitive processing and stages of development than ideas about strata of factors.[4]

The circle in the Figure 1 that is labeled SAR (representing short-term acquisition and retrieval) illustrates the nature of the concepts of Gf-Gc theory. SAR involves a variety of apprehension and retention processes of the kind that are discussed under such headings as primary memory, secondary memory, span memory, immediate memory, paired associate memory, serial learning, short-term memory and retrieval, and information processing (as discussed in Craik, 1977; and Kintsch, 1970). The SAR factor represents a finding that there are positive and substantial (relative to reliabilites and specific factor variances) intercorrelations among measurements of these processes. More specifically, SAR represents a finding that the primary-level factors of associational memory

[4]This is not to take issue with a claim (see Cattell, 1950) that to the extent that one can achieve the ideal of representative design in a structural study, order of factors in factor analyses can be indicative of level of function.

(Ma), span memory (Ms), and meaningful memory (Mm) form an intercorrelational cluster (Horn, 1982 for review; and Hundal & Horn, 1977; Stankov, Horn, & Roy, 1980, for recent findings). Such results and the results indicating several factors (as shown in Figure 1) suggest that at a general level many rather diverse short-term apprehension and retrieval functions are organized somewhat separately from other cognitive functions—i.e., the organizations among long-term storage and retrieval (TSR) processes, fluid intelligence (Gf) capabilities, crystallized intelligence (Gc) abilities and visualization (Gv) processes.

Consideration of SAR as an example of a major concept in Gf-Gc theory is particularly useful for indicating how the theory is part of cognitive theory more broadly conceived. However, the rationale for the present study derives most directly from findings indicating a distinction between the factors symbolized as Gc, Gf and Gv.

The Gc organization involves abilities that reflect knowledge of a culture and adeptness in the use of this knowledge. These abilities are highly valued in a culture and for this reason are conveyed from one generation to another by means of complex but systematic forces of acculturation.

A huge number of acculturational influences operate within the home and school, through the mass media of communication, and in other ways. Throughout development, these influences interact with hereditary potential to push individuals toward the goal of incorporating valued abilities within their particular cognitive structural systems. For many reasons, this goal is better realized in some individuals than in others. As development unfolds, individual differences emerge in abilities that largley reflect acculturation. It is believed that Gc represents an amalgam of these abilities.

The abilities that define the Gc amalgam in a given study are only a small sample from the myriad of abilities that could be sampled to make up the true Gc of any individual. An operational definition of the Gc factor provides only a crude means for identifying (approximately) the concept (latent attribute) for purposes of empirical study. Other identified factors also are only samples of the abilities referred to in the concepts of Gf-Gc theory.

Although cognitive abilities are acquired largely through the systematic processes of acculturation, not all of learning is thus systematized: some learning is not included in the grand design of acculturation. This kind of learning (referred to as "casual") also interacts with genetic capabilities to produce cognitive abilities that are commonly regarded as indicating intelligence. It is believed that Gf is largely comprised of such abilities and thus reflects casual learning interacting with genetic capability over the course of development. Because the individuals who experience the best casual learning are not always among those who experience the best acculturation, Gf can develop somewhat independently from Gc. Also, some empirical evidence suggests that the abilities of Gf are more immediately and irreversibly affected by neurological damage than are the abilities of Gc.

Since many influences that affect neurological structure and function are not effects of, or powerful influences on, acculturation, these influences, too, can help bring about separateness of Gf organization relative to Gc organization.

The abilities that define the Gv factor are in some respects similar to the abilities of Gc and Gf, particularly the latter. The differences between Gv and Gf are not as easily described verbally as they are demonstrated by pointing to the separate sets of tasks and performances. The tasks of Gf, for example, more or less clearly involve reasoning, abstracting, dealing effectively with complex relationships, drawing valid inferences and forming concepts—in general, capabilities that are widely accepted as indicating the most advanced expressions of intelligence. Performances that are indicative of Gv, on the other hand, involve visualizing in a broad sense of this word, as in attaining closure of an incomplete image, rotating shapes in one mind's eye, imagining how objects would look from different perspectives, and finding a shape embedded within a swirl of other shapes. When Gv is properly overdetermined in a factor analytic study, almost all tasks that can be seen to measure visual perception correlate with the factor. Gv thus seems to represent broad organization among seeing capabilities.

As was pointed out in early publications (e.g. Horn, 1968), the distinction between Gv and Gf is not easily drawn in factor analytic work. It is necessary to amply overdetermine Gv and extract enough factors to allow it to emerge. In many quite reputable treatments of ability data (e.g. Humphreys, 1967; Matarazzo, 1972; Vernon, 1969), the distinction is not drawn. Yet there is considerable evidence from a variety of sources—not simply factor analytic work—to suggest that the distinction is of scientific value (e.g. Galton, 1904; Jaensch, 1930; Karlin, 1942; Smith, 1964; Witkin & Goodenough, 1981; Zaidel, 1978).

Consideration of the factor analytic separation of Gv and Gf, and contemplation of other sets of evidence, suggested that a broad factor analogous to Gv might be found among auditory indicants of cognitive functioning (Horn, 1968). More recently Corso (1977), reacting mainly to studies of development, has suggested that there appears to be a distinction between what is referred to as central and peripheral auditory functions.

When the idea of a broad auditory factor, Ga, was proposed (in 1968), there was nothing in the realm of listening abilities that was at all comparable in the auditory realm to the primary abilities of visualization on which the second order Gv dimension has been built. A number of auditory tests had been constructed to measure musical abilities and speech comprehension, and some factor analytic work had been done with these tests (e.g. Drake, 1939; Guilford, 1967; Hanley, 1956; Harris, 1964; Karlin, 1942; McLeish, 1950; Solomon, Webster, & Curtis, 1960; and Spearitt, 1962), but the tests had not been designed to be auditory indicants of the abilities of intelligence and there was very little replicated work to suggest anything like the system of primary abilities (see Horn, 1972 for review). Since that time, however, some evidence has accumulated to suggest a primary mental ability system among auditory measures (Stankov, 1980; Stankov & Horn, 1980; Stankov & Spilsbury, 1978). Some seven factors have been identified among auditory tests that were designed to be indicants of some of the same processes as are indicated by the primary abilities. Thus it is now possible to explore the idea that auditory factors are organized at a broad level in the manner of Gv. Moreover, it is desirable for other reasons to begin to explore the relationships between auditory and visual factors identified at the level of primary abilities. The present study begins such exploration.

METHOD

Subjects

The sample for this study is the same as the sample used in our first study of primary abilities of hearing (Stankov & Horn, 1980). As in most of our previous research on Gf-Gc theory, the sample was drawn from the inmate population of prisons—in this case, the Colorado State prison system.[5] A total of 241 men provided useable data. Each man was a volunteer. A $2.00 payment for doing the tests was provided as an incentive for volunteering. The sample was concentrated around a mean age 26 years, but a few of the men were as young as 17 and others were in their 50s. A majority of the men had completed grade school and had done some high school study. All were able to read at or above the 9th grade level. The mean Otis IQ for the group was slightly above 100 (actually 100.42). The hearing acuity of the men was within the normal range, but there was notable variation on several measures of acuity. This variability will be considered at a later point in this report.

Variables

Two different kinds of variables were sampled: (1) visual primary-ability factors that either have been markers for identifying Gf, Gc, and Gv in previous studies or, in a few cases, new tasks for which there was an hypothesis that the variable would help to define the second-order dimensions; and (2) auditory primary-level factors indicated by the previous study of Stankov and Horn (1980). The two kinds of variables are briefly described in Table 1.

If more than one test was used to measure a primary factor, the test scores were converted to standard-score form, and added to provide the measurement. In the case of each visual factor, all tests thus combined were given the same nominal weight (Horn, 1963) in the composite. The auditory tests, however, were combined with weighting proportional to each test's loading on the primary factor in

[5]We thank George Levy and his staff, the Warden and other prison staff, as well as the men who served as subjects, for valuable assistance in the conduct of this research. We are particularly indebted to L. C. Hurd and John Martinez for helping in obtaining and scoring these data.

TABLE 1
Primary-level Factors and Tests Used to Measure Them

Primary Factor	Symbols* Here	Horn 1973	Stankov 1978	Marker Tests+
Auditory				
Discrimination among Sound Patterns	DASP	Mr	Pr	Pitch Differences (29), Tonal Classification (35), Timbre (23), Tonal Memory (31), Pitch Change in Chords (28), Memory for Pitch (32)
Maintaining and Judging Rhythm	MaJR	Ry	Ry	Seashore's Rhythm (36), Tempo A (41), Tempo B (42)
Temoral Tracking of Sounds	Tc	Tr	Tc	Loudness Reordering (17), Tonal Reordering (15), Detection of Repeated Voices (18), Nonsense Syllables Reordering (14)
Auditory Cognition of Relations	ACoR	Ra	ACoR	Notes per chord (26), Musical Memory (30), Chord Parts Decomposition (27), Tonal Series (22), Chord Series (23), Chord Decomposition (25)
Listening Immediate Memory	Msa	Sp	Msa	Tonal Figures (12), Memory for Emphasis (11), Sound Blending (44)
Speech Perception under Distraction/Distortion	SPUD	MSC	Rp	Talk (Intellective) Masking (34), Cafeteria Noise Masking (40); Expanded Speech (38), Compressed Speech (37)
Listening Verbal Comprehension	Va	DDS	V	Intelligibility (1), Cloze (4), Rapid Spelling (2), Hi Pass Filter (8), Low Pass Filter (7), White Noise Masking (6)
Auditory Acuity	Ac	Ac	Ac	Left Ear and Right Ear Acuity at 500, 1,000 and 4,000 cps
Visual				
Verbal Comprehension	V	V		Wide Range Vocabulary
Semantic Systems	EMS	EMS		Social Situations
Semantic Relations	CMR	CMR		Esoteric Verbal Analogies
Induction (Reasoning)	I	I		Letter Series
Figural Relations	CFR	CFR		Matrices, Figure Series
Visualization	Vz	Vz		Punched Holes, Paper Form Board
Figural Classes	CFC	CFC		Figural Classification
Speed of Closure	Cs	Cs		Gestalt Completion, Mutilated Words
Flexibility of Closure	Cf	Cf		Designs (Embedded Figures)
Spatial Orientation	S	S		Figures, Cards
Visual Memory	Mv			Recognizing Objects

*Stankov and Spilsbury (1978) also provide a table indicating factor labels and symbols used for basically the same auditory factors in different studies of the present authors.

+Numbers in parentheses indicate test number in Stankov and Horn (1980) where detailed descriptions of the auditory tests can be found.

the Stankov-Horn (1980) study. These procedures for factor measurement have been shown to provide more stable estimates, and better indications of factor intercorrelations, than other, seemingly more elegant methods (Dawes, 1979; Wackwitz & Horn, 1971).

To indicate major features of study design, it is probably best to describe the visual factors first.

Visual Primaries. Since the major objectives of the study were most closely tied to studying the auditory factors, and because previous studies had provided fairly clear indications of how to identify Gf, Gc, and Gv with indicants of visual primary factors, only a relatively small amount of the limited time available for testing was used to measure the visual factors. In several cases, a factor was identified with only one test, as can be seen in Table 1. However, care was taken to ensure that the single test had substantial correlation with the primary factor, and tended to relate to this factor alone. Also, as noted, serious consideration was given to evidence that the test had been a reliable marker for Gf, Gc, or Gv in previous second-order studies.

Verbal Comprehension (V), Semantic Systems (EMS), and Semantic Relations (CMR) have been consistent markers for Gc. Usually CMR has also had a significant relationship with Gf, this representing the principle of alternative mechanisms (Horn, 1968, 1979). Here, however, the Esoteric Analogies test was used to measure CMR in an effort to reduce this cooperativeness and thus provide a purer overdetermination of Gc.

Induction (I), Figural Relations (CFR), and Visualization (Vz) were expected to be the principal markers for Gf. The Matrices task of CFR involves substantial variance on Gf, but in some studies it has also involved Gv to a considerable extent. Similarly, in some studies Letter Series measures of the Induction factor have involved Gc as well as Gf. Although the CFC primary has helped to define Gf in previous study, the particular test used to measure the primary factor in the present study had not been used in our earlier work. Thus the CFC measure should be regarded as representing an hypothesis of relationship with Gf rather than as a marker for Gf. The task also was expected to involve Gv variance. In general, alternative mechanisms can be expected to produce some cooperativeness between Gf and the other factors, Gc and Gv.

The speed of Closure (Cs), Flexibility of Closure (Cf), and Spatial Orientation (S) were included as major markers for Gv. Judging from previous results, each of these primaries could also have some variance in Gf, depending on the level of Gf of the subjects. As the level of Gf becomes low, visualization tasks can tend to require more reasoning (of Gf) than is indicated when the ability of a group is high. If good overdetermination of factors is achieved, this last-mentioned kind of cooperativeness is captured in the correlations between factors (Gf and Gv), rather than in shared loadings on two or more factors, but at our present level of knowledge and with only limited understanding of a sample of subjects, it is very difficult to estimate whether a test will work best to measure one factor or another—Gf or Gv. In our early work (Horn & Cattell, 1966), for example, the Punched Holes and Form Board tests of the Vz (Visualization) primary ability were most strongly indicative of Gv, but in our more recent studies (largely unpublished, but see Horn, 1978, particularly Table 1), these variables have been substantially correlated with Gf. The Vz measure thus can be expected to help define Gf as well as Gv.

The study design represented by this sampling of primary ability variables, while far from ideal (due in part to lack of time for measurement), should yield a satisfactory overdetermination of the Gf, Gc, and Gv dimensions.

Auditory Primaries. The auditory primary abilities have been identified only recently and are not yet very well understood. Probably, therefore, it is worthwhile to describe them rather fully. In Table 1 we provide a summary of the results from the study in which the factors were first identified (Stankov & Horn, 1980). Here we indicate the factor labels, abbreviation symbols for these labels and (in parentheses) matrix numbers for the variables of the Stankov-Horn study. In some of our other work, the auditory primary factors were identified with different labels than are now used. To aid the task of relating the present study to this other work the symbols corresponding to labels used in two of our other studies are also indicated in Table 1.

The first factor of Table 1, DASP, represents an ability in detecting patterns in sounds. In the Tonal Memory marker test, for example, a simple melody (of 3 to 10 notes) is played, then played again but with one note changed; the task is to identify the changed note. In another of the marker tests, Tonal Classification, the task is to identify which one of five chords does not belong with the others. A pattern of performance similar to that of the DASP factor was recently identified in a study by Dewar, Cuddy, and Mewhart (1977) where it was interpreted as indicating sensitivity to relational cues in sounds.

The second factor listed in Table 1, MaJR, is defined by abilities in identifying and maintaining rhythm. The marker tests require a subject to continue a metronome beat after the metronome has stopped, to do this when a new beat is imposed, and to indicate whether two beats played moments apart are the same or different.

Temporal Tracking (Tc), the third factor of Table 1, is indicated by tasks in which one must attend carefully to the order in which sounds occur and then be able to reorder these sounds in ones mind's ear. For example, in Nonsense Syllables Reordering, the subject first hears three nonsense syllables such as dos, vup, and pif and then 5 to 10 seconds later, these same sounds are presented again but in a different order. The task is to indicate which sound on the second occasion was heard first, second, and third on the first occasion. Other marker variables similarly involve attending to the order of auditory stimuli, holding this order in awareness, and then detecting a new order for the stimuli. The task requirements seemingly involved here are similar to processes discussed under the heading of working memory (e.g, Massaro, 1975; Horn, Donaldson, & Engstrom, 1981) and temporal integration (e.g., Hearnshaw, 1956; Pollack, 1969).

The ACoR factor seems to reflect how well one comprehends the Gestalt of a small pattern of notes (sounds). In Chord Parts Decomposition, for example, one first hears a chord involving three notes (played simultaneously) and then hears sets of three notes played separately. The task is to identify the set of three notes that contains the same three notes as were present in the chord. In Tonal Series one must comprehend the pattern in a set of notes played one after another in order to indicate (infer) which one of several presented notes should come next in the series. The factor can thus be seen to involve an elementary form of reasoning and, in fact, could be an auditory version of the Induction primary identified in Thurstone's (1938) pioneering study.

Immediate memory measured through listening (Msa) is defined by Tonal Figures, Memory for Emphasis, and Sound Blending. In the first of these tests, subjects hear four notes presented in either ascending or descending order of pitch. The task is to identify these same notes from among four sets of notes presented in opposite order of pitch. As suggested by the factor label and symbol, this factor appears to be an auditory version of the well-established memory span (Ms) primary ability.

The SPUD factor represents an ability to comprehend speech when it is mutilated or when it is masked by other similar sounds—i.e., a white-noise masking task does not load the factor. The principal markers require a subject to identify words or phrases when these are spoken against a background of talk or the kind of conversation and noise that can be heard in a noisy cafeteria. Variables correlating at a somewhat lower level with the factor require one to identify the meaning of speech played on a tape recorder at faster or slower speeds than the speed at which it was recorded.

The Listening Verbal Comprehension (Va) factor is identified by tests of understanding spoken language when it is incomplete in several senses of the term incomplete. In the Cloze test, for example, one must understand sentences in which some words have been omitted; one needs to, in thinking, fill in the missing words in order to understand the sentences. In the Intelligibility test, one must distinguish between words having similar sounds but different meanings. In Hi Pass Filter the task is to comprehend speech in which certain sound frequencies have been deleted. This gives speech an unusual clipped quality. The factor is similar in some respects to an ability, measured in school children, that Atkin, Bray, Davidson, Herzberger, Humphreys, and Selzer (1977) found to be more predictive of school performance four years after initial measurement than any of the usual predictors of school achievement that were used in their battery.

Other Variables. The acuity measure of Table 1 was not identified as a factor in the Stankov-Horn (1980) study, but it was noted that the various submeasures of a standard audiogram examination intercorrelate as if they measured a common

TABLE 2
Intercorrelations (Above Diagonal) and Residuals After 5 Factors for Auditory and Visual Abilities Squared Multiple Correlations (Initial Communality Estimates) Are in the Main Diagonal

	DASP	MaJR	Tc	ACoR	Msa	SPUD	Ac
Discriminate Sound Patterns	62	35	61	55	50	35	04
Maintain and Judge Rhythms	03	27	31	15	15	13	06
Temporal Track Sounds	02	08	59	48	46	10	−01
Auditory Cognition Relations	−03	07	−09	47	48	11	05
Auditory Immediate Memory	−04	00	−08	−04	52	10	03
Perceive Distorted Speech	06	02	01	−01	−02	45	38
Auditory Acuity	00	06	08	13	05	05	24
Listening Verbal Comprehension	−06	05	−12	−19	−09	07	09
Verbal Comprehension	00	−03	−01	06	03	−03	−02
Semantic Systems	02	03	01	−02	−07	−04	01
Semantic Relations	−03	04	03	−03	−02	04	03
Induction	−17	04	−03	−16	−19	03	08
Figural Relations	07	06	12	01	15	03	04
Visualization	−01	08	01	−12	−09	04	04
Figural Classes	−03	19	15	−06	−11	04	07
Speed Closure	−03	07	−03	−13	−05	02	10
Flexibility of Closure	−06	14	−02	−13	−13	−03	18
Spatial Orientation	−05	09	06	−15	−16	04	12
Visual Memory	−05	14	−04	−12	−02	03	08

factor. Also, of course, in diagnosis and other clinical work, the submeasures are often used as if they measured a common factor of acuity. On this basis, therefore, and because it is desirable to study the relation of the auditory primary abilities to acuity, the Ac variable was obtained as indicated in Table 1. Standard audiometer techniques were used at 500, 1,000, and 4,000 cps for both ears.

The Visual Memory variable of Table 1 also was not found to represent a factor in previous study. It was included on the assumption that it might help to define Gv.

Analyses and Results

The intercorrelations among the factor measures (obtained as described previously) are shown in Table 2.[6] The principal components of Table 2 were obtained using the Jacobi algorithm, as described in Mulaik (1972). The Kaiser-Dickman-Guttman (KDG) root-one criterion for the number of factors (as described in Horn, 1965) was considered. This indicated five factors, an answer also suggested by application of the scree test (Cattell, 1966; Horn & Engstrom, 1979). Accordingly, communalities were estimated for this number of factors, the Jacobi proce-

[6]Because the methods of measuring factors in the present study are somewhat different than the methods (implicit) in the Stankov-Horn (1980) study, the factor intercorrelations of Table 2 are a bit different from those of Table 5 of our previous study.

TABLE 2 *(continued)*

Va	V	EMS	CMR	I	CFR	Vz	CFC	Cs	Cf	S	Mv
56	26	24	39	36	42	40	12	37	17	18	14
30	02	13	15	14	12	15	27	16	24	16	22
50	38	32	54	58	51	48	28	36	25	30	21
47	45	31	50	47	40	37	09	30	17	12	13
36	40	13	46	45	59	43	−06	35	07	03	16
28	−23	−21	−03	06	07	08	08	21	−07	12	−09
00	−26	−24	−17	−05	00	−03	03	12	05	09	−10
61	44	47	54	52	38	36	23	48	24	21	21
03	63	53	72	51	38	37	05	25	07	01	28
02	01	46	51	40	20	19	16	19	09	06	23
−06	04	−02	69	61	49	49	18	39	15	06	39
−16	−10	−01	−11	57	56	52	25	37	22	22	28
01	07	03	10	04	54	59	07	42	21	20	16
−14	01	−02	03	−12	16	49	16	45	30	26	17
−03	−03	02	06	14	03	09	24	16	22	25	11
−06	00	01	01	15	09	03	06	39	24	29	18
−14	00	−02	−01	−05	03	03	12	02	27	35	19
−19	01	01	05	−03	03	00	15	03	06	26	07
11	00	−04	09	−01	01	03	02	03	03	−05	22

dure was applied to yield principal axes factors; these factors were rotated, first in accordance with the normal Varimax criterion (Kaiser, 1958) and then using the Promax procedure (Hendrickson & White, 1964) with power set at 5.[7] The results from these analyses are presented in Table 3.

A four-factor solution, based on the same procedures as were described above, was also obtained. This will be mentioned in discussion, but it is not as adequate a representation of the data as the solution of Table 3, and is not sufficiently different from this latter to warrant using space to print it here.

To reduce confusion in subsequent discussion, the factors of these analyses will be referred to as dimensions in order to distinguish them from the primary-level factors on which this factoring was based.

[7]In several previous studies we have used different powers and different prior targets with the Promax procedure. In general, the higher powers and the more the rotational procedures tend toward variable simplicity (Crawford & Ferguson, 1970), the more highly correlated are the factors. Although we have not done a really systematic study of this question, power set at 5 seems to best represent the kind of simple structure solution that is sought in visual and other well regarded rotational schemes. Humphreys has pointed out (personal communication) that this matter is intricately linked to size of communality. Clearly, the choice of initial target is important. A Monte Carlo study of the kind conducted by Horn (1965), Wackwitz & Horn (1971), and Humphreys, Ilgen, McGrath, & Montanelli (1969) might help to provide a better basis for deciding on a power in Promax rotation. In such a study, one would need to vary N and communality estimates as well as initial target and power. Such a study is not unrelated to questions about the replicability of results obtained with structural equation modeling procedures (Jöreskog, 1969; Horn & McArdle, 1980).

TABLE 3
Five Second-order Promax (Oblique) Reference Vector Dimensions and Intercorrelations: Determined on Auditory and Visual Primary Factors

		Second-Order Factors					
Primary Factors	Symbol	Ga	Ac	Gc	Gf	Gv	h^2
Auditory							
Discrimination among Sound Patterns	DASP	*50*	15	00	*21*	−04	68
Maintaining and Judging Rhythms	MaJR	*35*	−04	−07	−09	*29*	32
Temporal Tracking of Sounds	Tc	*29*	−07	04	*26*	*20*	61
Auditory Cognition of Relations	ACoR	*23*	08	17	*24*	−11	47
Auditory Immediate Memory	Msa	*22*	−01	−04	*55*	−18	59
Speech Perception under Distraction/Distortion	SPUD	11	*61*	−02	−05	−08	53
Auditory Acuity	Ac	−01	*39*	−15	01	04	26
Listening Verbal Comprehension	Va	11	*30*	*43*	08	03	66
Visual							
Verbal Comprehensioon	V	−07	−16	*50*	16	−16	69
Semantic Systems	EMS	02	−11	*51*	−16	−01	50
Semantic Relations	CMR	−03	−04	*47*	17	−05	73
Induction	I	−07	01	*28*	*26*	13	59
Figural Relations	CFR	00	−05	−04	*57*	09	61
Visualization	Vz	−05	−05	00	*46*	*24*	54
Figural Classes	CFC	01	02	10	19	*40*	28
Speed of Closure	Cs	−09	*22*	14	19	*20*	41
Flexibility of Closure	Cf	02	−15	−11	08	*50*	32
Spatial Orientation	S	−05	02	−10	06	*47*	31
Visual Memory	Mv	04	−16	16	00	16	18
	Ga	–	28	54	39	44	
Factor	Ac	28	–	00	28	34	
Intercorrelations	Gc	54	00	–	62	49	
	Gf	39	28	62	–	41	
	Gv	44	34	39	41	–	
Σr		1.91	1.15	1.63	1.70	1.67	

GENERAL DISCUSSION

The results are relatively easy to interpret in a reasonable manner. The simple structure for the five dimensions is good; the intercorrelations among the dimensions are much as one would expect for intellectual ability data.

The first dimension suggests that at a fairly general level, there is organization among auditory abilities that is distinct from the ability organizations represented by Gc, Gf and Gv. Moreover, the finding of a distinction between this, the Ga dimension, and the second, acuity (Ac) dimension suggests that organization among auditory primary abilities is not simply a manifestation of auditory acuity. Notice that Ga has substantial correlations with the other ability dimensions—Gf, Gc, and Gv—while the corresponding correlations for Ac are notably lower.

The primary-level factors that define Ga can be characterized as requiring, in a variety of different ways, wholistic comprehension of sounds and patterns among sounds. Auditory tests that in any sense require the subject to deal with multilated and incomplete sounds define Ac rather than Ga. In Ga, there are tests of memory, tests of reasoning, tests of temporal reorganization, each requiring that the subject gain comprehension of fairly complex auditory problems. The distinction between this factor, and Gc, and the absence of Va in the factor, suggests that the auditory comprehension of Ga is not highly dependent on, or well expressed in, semantic structure, as such. Just as one can comprehend a painting without being very articulate about what it is that one comprehends, so one can comprehend a fugue or a sonata without being able to say much more than "ain't that grand." Such ability to comprehend appears to be dimly adumbrated in the Ga dimension.

The Ac dimension, on the other hand, is characterized by variables that point to very elementary processes of simply being able to hear sounds and discriminate between them. The dimension thus seems to represent acuity, rather than perception. The SPUD factor that helps define the Ac dimension is a measure of identifying particular sounds within a din of noise. A major proportion of the variance of the Va factor is involved in the verbal intellectual comprehension that is represented by crystallized intelligence (the Gc dimension), but in the distraction-distortion tasks that define Va there is a requirement, also, that one hear and discriminate between sounds. This is the requirement that brings Va into the definition of the Ac dimension.

Ac thus seems to represent organization among sensory detector functions of hearing. In some of our other work, we have found sensory detector functions to be only very weakly related to adulthood aging differences in either Gf or Gc (Horn, Donaldson, & Engstrom, 1981). This has led us to regard such functions as low in the hierarchy of the mental processes that are characteristic of quintessential developments of human intelligence.

If only four dimensions, rather than five, are extracted and rotated, the distinction between Ga and AC is lost; the two factors collapse into one. In other respects the solution is much the same. The situation in this regard is quite analogous to that which arose in the early work on the distinction between Gv and Gf. If one less factor was extracted in the Horn-Cattell (1966) study, for example, Gv and Gf collapsed into one factor (cf. Humphreys, 1967).

Which is the "correct" solution in such situations? There is no simple answer to such a question. Certainly the question is not answered simply by applying maximum-likelihood confirmatory procedures (e.g. Joreskög, 1969) to "fit a model," as one critic has suggested. In this exploratory study there is error due both to sampling of subjects and sampling of variables, and we have let the rotational results "tell us" what the patterns are for Ga and Ac. In "model fitting" there can be much capitalization on the chance represented by these procedures; such capitalization is likely to produce non-replicable results (Horn & Engstrom, 1979; Horn & McArdle, 1980). It is probably true, however, that the principal contributions of the development of covariance modeling procedures are not to model fitting, as such, so much as they are to systematic thinking: they virtually force investigators to be thoughtful about their variables (if not about their subjects). Thus in future, less exploratory work it probably will be desirable to use chi-square differences for model fits to examine the likelihoods of different hypotheses about Ga and Ac. But the essential question of a distinction between Ga and Ac will continue to be one of substantive scientific utility, not an issue that can be handled by any simple statistical or psychometric test. The evidence of the present study indicates that a distinction between perceptual and sensory auditory organization can be made empirically. The important scientific question is this: does the distinction make a difference in theory, which is to say does it make a difference in the relationships that indicate the construct validity of the two dimensions? This vital question cannot be answered with a single study, and therefore not with this study.

The third dimension indicated in Table 3 is a clear replication of previous findings indicating the organization we label crystallized intelligence, Gc. As expected, the Listening Verbal Comprehension factor (after sensory detector variance has been partialled in the Ac dimension) helps to define Gc.

The fourth dimension is also easily seen to indicate the factor we have interpreted as fluid intelligence in previous research. As in several previous studies, the Induction primary ability has part of its variance in Gf and part in Gc. Induction is the only factor in this study for which there is indication of alternative mechanisms expressed through Gf and Gc.

Several auditory factors help to define Gf. Auditory memory is particularly prominent. This finding is consistent with an hypothesis that the good reasoning of Gf requires that one maintain the elements of a reasoning problem within the span of immediate apprehension (Horn, 1968). As mentioned earlier, processes of this kind are also referred to as indicating working memory. But no matter how such processes are described in words, the results of the present study indicate that a capacity for maintaining awareness is involved in several of the auditory tasks that help define Gf—i.e. in DASP, Tc, ACoR. In the tasks of these factors, the sound stimuli that must be comprehended emerge, pass by, and disappear. One must capture this stream in a snapshot of awareness of each significant moment if correct answers are to be produced. In other studies, also, a capacity for freezing different components of a problem in immediate awareness has seemed to be a central feature of fluid intelligence (Horn, 1979; 1982; Horn, et al., 1981; Welford, 1980).

The CFC measure obtained in this study does not have a very large correlation with Gf, although it is probably significantly larger than expected by chance. The items of this test were of rather low difficulty. It may be, therefore, that the items did not so much call for the reasoning of Gf as they did for the fluent perception of forms that is represented by Gv.

The Gv dimension is clearly indicated. The present results provide some basis for considering alternative interpretations of this dimension. For example, there is the idea that it represents organization among visual perception processes. However, the dimension might also be regarded as indicating a stylistic quality in approach to tasks. The primary-level factor that is most highly correlated with Gv is measured by the kinds of paper and pencil tasks that Witkin and his co-workers (see Witkin & Goodenough, 1981) have used to provide an operational definition of a concept of field independence (also called by other names). The theory of field independence thus can be seen to be a kind of alternative to, or different way of looking at, the perceptual organization interpretation of Gv. (These alternatives, and recent evidence for them, have been considered in Horn, 1973; 1976, as well as in Witkin & Goodenough, 1981.)

The loadings of MaJR and Tc on Gv might be interpreted as providing some support for an hypothesis that the dimension represents field independence. Both variables can be seen to require the subject to maintain orientation with respect to the ground of one's own perception and resist distracting influences of the field, and neither would seem to involve visual processes. However, the SPUD factor contains tasks that are formally similar to the embedded figures tasks that most often have been used as a marker for field independence, and this factor has a −.08 correlation with Gv. Also, our multitrait-multimethod analyses of panmodality hypotheses were not supportive of the idea that field independence pervades auditory and visual organization (Horn, 1973). The hypothesis is intriguing, however, and should not be prematurely laid aside.

The intercorrelations among the five dimensions are not remarkable. The Gf-Gc correlation is a bit higher than has been found in some previous studies, but it is well within the bounds of sampling fluctuation around an average correlation of about .50 that represents the findings of other studies.

The results obtained in the present study are in major respects similar to the results that have been obtained in a follow-up study (Stankov, 1978) based on a sample of Yugoslavian children 11 to 12 years of age. The factors were as clearly defined in that study as in the present results, but the Ga and Gv perceptual factors were narrower—i.e., defined by somewhat fewer marker variables. The differences in results could relate to differentiation through development. Further work is needed to explore this possibility.

It is perhaps worth noting in conclusion that the results obtained here might well be expected to differ from results obtained in studies of trained musicians. Most of the subjects in the present sample would have had relatively little formal training in music and for this reason might be expected to listen to musical stimuli melodically and rhythmically, rather than harmonically. Trained musicians could be expected to also listen harmonically in several of the tests (Shuter, 1968). This could notably alter some aspects of the factor patterns. Similarly, if a sample contained an appreciable number of people with absolute pitch, the results in regards to the loading patterns on particular factors, and even in regards to the number factors, might be rather different. Carroll (1975), for example, found that subjects who displayed absolute pitch were characterized by a factor of long-term memory storage of tone chroma that was not characteristic of subjects who did not display absolute pitch.

SUMMARY

The principal outcome derived from this study is the suggestion that there is organization among auditory abilities, as in Ga, that is distinct from auditory sensory detector capacities, Ac, the organization among visual abilities, Gv, and the central factors of intelligence—Gf and Gc. The results thus give some indications of how auditory abilities are involved in the totality of abilities of human intelligence. Of course, it did not take this study to inform us that much of human intelligence must be developed and expressed through comprehension of auditory phenomena. Indeed, studies such as that of Atkin, et al. (1977) suggest that expression of abilities in auditory tasks may be more indicative of human intelligence than expression through visual tasks.

At a rather mundane level, the present results indicate how, in practice, one might go about measuring listening comprehension capacities somewhat independently of both visualizing comprehension capacities and the rather focused concepts of intelligence that are represented by Gf and Gc. When almost all of these various capacities are regarded as parts of the totality of human intelligence, the present results suggest how one might consider combining different components—Ga and Gv and perhaps even Ac, as well as Gf and Gc—to obtain broadly valid measures of intelligence. Looking at the other side of this coin, there is the idea that measurement of intelligence (Gf or Gc) might be confounded with the individual differences represented by Gv, Ga, and Ac. Looked at in this way, the results suggest how one might obtain "purged" measures of Gf and/or Gc, perhaps for purposes of partitioning variance attributable to developmental influences (as in Horn, et al., 1981).

In general, the results provide indications of the ways in which performances that involve intelligence are dependent on organizations at different levels of functioning—sensory, associational, perceptual, and relation-eduction.

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APPENDIX
WORD LABELS FOR THE SYMBOLS OF FIGURE 1

The following symbols are described in the text or Table 1: DAS = DASP, MJR = MaJR, Tc, Ac = ACoR, Va, V, EMS, I, CFR, Cs, Cf, S.

The other symbols of Figure 1 may be labeled as follows.

R	Problem Solving Reasoning
P	Perceptual Speediness
Ma	Associative Memory
Ms	Span Memory
Mm	Memory for the Memorable
SMT	Seeing Many Things
VLA	Visualizing Local Associations
N	Number Comprehension
Fi	Idiational Fluency
Fa	Associational Fluency
Fe	Expressive Fluency
SM	Memory Following Sorting
Gs	General Intellective Speediness
CDS	Correct Decision Speediness
vSD	Visual Sensory Detection
aSD	Auditory Sensory Detection