# Domains of Cognitive Ability

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2:30 - 5:30 pm.

After last year's AAAS meeting, a UPI newspaper story carried the headline "Scientists Trace Intelligence to Myth." The story went on to relate how the panelists at a AAAS session on testing claimed that the intelligence tests used in World War I "didn't work then and they're not much better now." The social psychologist Franz Samelson of Kansas State University was quoted as saying that "testing is still at the Model T stage ... What people dreamed up in 1917 is still the basic model. The format is the same. There's been no breakthrough. Psychologically, I doubt that we have gone much farther."

Because I didn't attend that meeting I can't judge the accuracy and completeness of this newspaper story, but I was prompted to organize the current session in order to present a different view of these matters. As I told the reporter who consulted me by telephone while preparing the story, I believe we have made many breakthroughs in intelligence testing since World War I. But what is more important, I believe that we are now at a phase of studying intelligence--or as I prefer to call it,



cognitive ability,-- in which further useful breakthroughs are being made or are about to be made. It is the purpose of this session to give an account of current theories and studies of cognitive abilities. My colleagues and I propose to give a more optimistic report of present-day activity in this field than appears to have been given a year ago.

It was unfortunate that the newspaper report gave the impression that intelligence is "a myth." Not even critics of intelligence testing--and I know there are many--believe that intelligence is "mythical". They would agree, I believe, that individual differences in intellectual ability exist; the question they raise is whether it is adequately measured by so-called intelligence tests, and that is a valid question, one to which we may still not have satisfactory answers. But I know of nobody who wants to reject the concept of intelligence, or cognitive ability, out of hand. To do so would fly in the face of a multitude of facts and research data, as well as common experience and observation.

On the subject of "breakthroughs"--well, it depends on what you call a breakthrough. Truly enormous scientific advances in the study and measurement of cognitive abilities have been made since 1917. Based on literally thousands of studies, we know much more than we did then about the nature of cognitive abilities, their origin, and ways of measuring them. Although the basic format of many mental tests may appear to be somewhat the same as it was in 1917, there has been much progress in the devising and selection of test materials. As compared to that in the physical sciences, progress has been slower, partly because of the nature of psychological research, but it has been solid and steady.

There are many reasons for pursuing the serious scientific study of cognitive abilities:

(1) Most generally, we must continue to explore the undoubtedly important roles of cognitive abilities in the various tasks of a technological society, as well as in everyday life, in the planning of careers, in schooling, and in the formation of educational policy.

(2) There is need for further knowledge about how abilities develop in the child, about the effects of maturation, schooling, training, and so forth. In particular, there is need for more knowledge of the extent to which abilities can be improved or enhanced through suitable training, modifications of the environment, and other interventions.

(3) We need to know how to select and properly use ability measurements in monitoring and gauging the effects of aging, toxic substances, adverse environments, and other influences. We need to know exactly what abilities are affected by these influences.

(4) As cognitive psychology develops more knowledge about cognitive processes, we need to know how these processes interact with abilities.

(5) Given that various separate abilities exist and play important roles in many activities, it is imperative to investigate the best ways of measuring them.



Note, by the way, that we need make no initial assumptions about the extent to which abilities are inherited or otherwise determined by genetic influences, as opposed to being trainable and subject to development. The available evidence suggests that most, or perhaps all abilities are changeable and trainable to some extent; how they may be changed is the more important issue since it is more within our powers to change them than to affect them through genetic means. Nevertheless, it is conceivable that some abilities are more subject to genetic influences than others, and if so, we need to know the details of such matters.

Thus far I have, in effect, been giving a general introduction to the topic of this symposium--a topic which is vast and has many ramifications. I wish now to introduce the particular aspect of this topic that I will address here. For the past several years, I have been reviewing, reanalyzing, and synthesizing a particular domain of the scientific literature. Mainly, I have been surveying the results achieved by the method of factor analysis--a method originated by Spearman more than 80 years ago, in 1904, but which has been under constant development and refinement since that time. This line of investigation has had two main goals: (1) to determine what kinds of cognitive abilities can be identified; and (2) to specify the "structure" of intelligence. This latter goal turns out to be, in my opinion, that of finding out how general or specific the various abilities are.

Before describing the results of my survey (and I have to emphasize that this is only a progress report), I think it is useful to consider a question, relevant to this discussion, that seems to have an obvious answer, but which actually presents rather subtle technical problems. The question is: What is an ability? We speak of various types of ability--reasoning ability, musical ability, clerical ability, athletic ability, and so forth. But what do we mean by "ability"? The answer I favor is that an ability is something inferred from the fact that people differ among themselves, and within themselves at different times, in performance on some particular class of tasks. Consider, for example, one type of athletic ability--jumping ability. Admittedly, this ability is not very "cognitive", although it undoubtedly can have cognitive components. It is, however, an ability that we can think and talk about rather concretely, thus providing a paradigm for thinking about other kinds of abilities. There are various standard tasks for observing jumping ability, principally the standing high jump and the running high jump. The exact conditions for these tasks, as athletic events, are specified by relevant authorities, and this is not unlike setting the conditions for various psychological measurements. Consider the running high jump: a person is allowed to run a certain distance before trying to jump over, and clear, a bar that can be set at various heights from the ground. One can set the bar at 1 foot, 2 feet, 3 feet, etc. up to the world record, which is somewhat over 7 feet. A person with world-record jumping ability could usually clear the bar at all positions up to something over 7 feet; a person with low ability, let us say, might barely clear



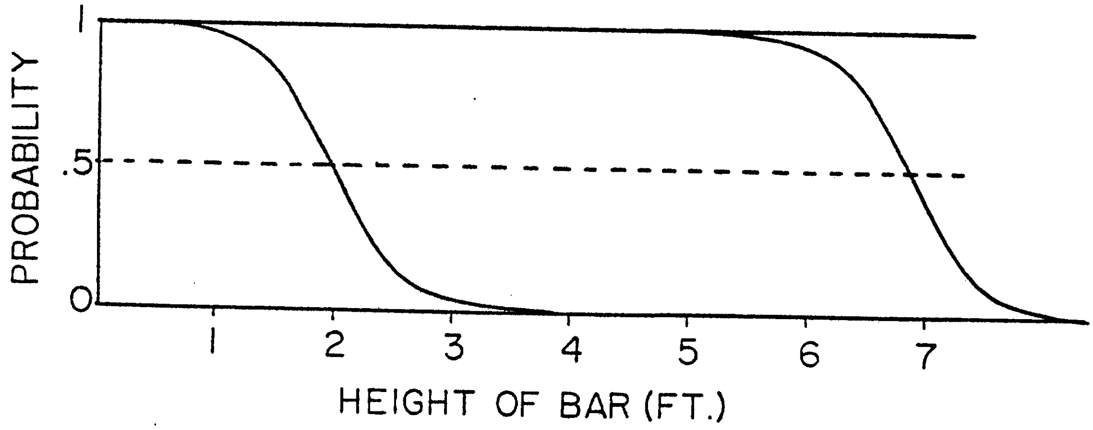
the 2-foot position--more accurately, have only a 50% probability of clearing the bar at 2 feet. We could in fact draw a curve for each person showing the probability that the person could clear the bar at various positions, over different trials. These curves, as shown in Visual #1, would have a characteristic form--technically, a negative normal ogive curve. Differences in jumping ability would be revealed in the overall position of the curve with respect to the baseline, or more conveniently, by the "threshold" values where the curves intersect the 50% probability value on the ordinate. Jumping ability would be defined by the differences in these curves.

Insert Visual No. 1 about here

Now let's consider another ability, pitch discrimination ability as tested by one of the Seashore Tests of Musical Talents. Here are some data from this test. (Show Visual #2). The chart shows the probabilities of detecting various pitch differences, beyond chance guessing, for successive tenths of the total score distribution for about 1100 college students. Clearly, there are differences in ability. The psychometric curves show how the probabilities vary as a function of pitch difference, and the individual differences in ability show up as differences in threshold values.

Insert Visual #2 about here

This model, or something like it, may be assumed to apply to <u>any</u> ability, whether of a cognitive or non-cognitive type.


PROBABILITY
1
.5
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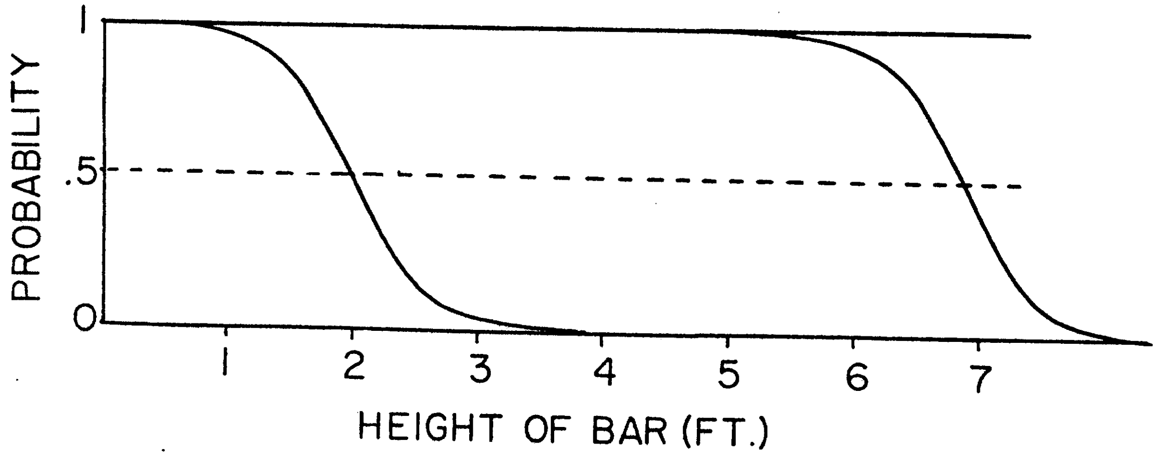
HEIGHT OF BAR (FT.)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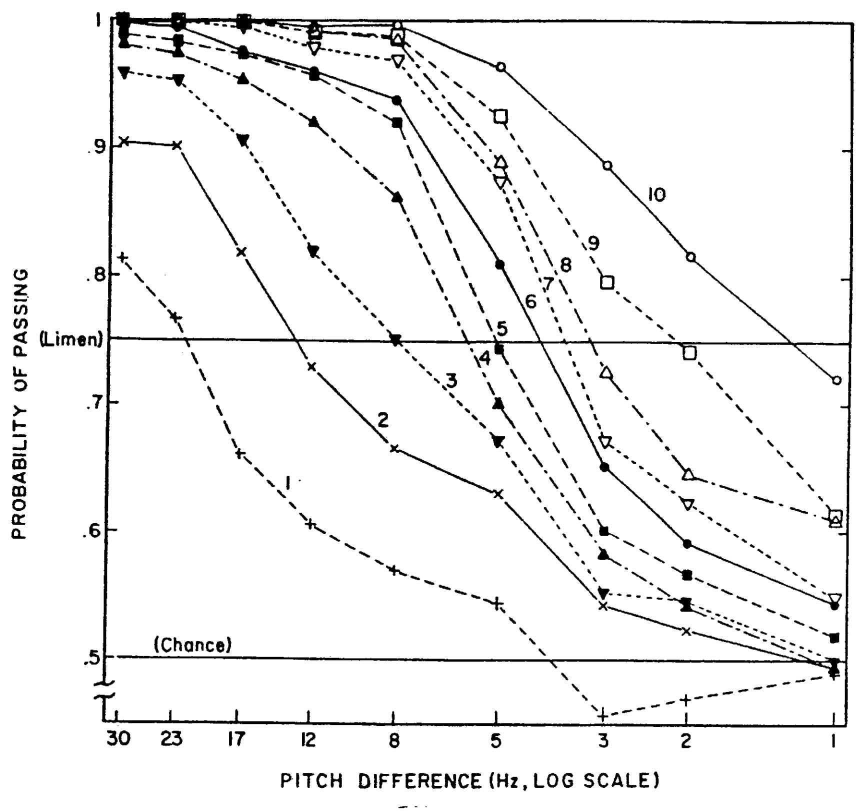


Figure 1. Person characteristic functions for the Seashore Sense of Pitch test, averaged for deciles of the total score distribution. (Data collected by Carroll; N = 1082)



Unfortunately, little application of this model has been done. Conventionally, psychological tests often have tasks arranged in order of "difficulty," but there has been relatively little study of what makes tasks easy or difficult; such study, as this symposium may make clear, is only beginning, in cognitive psychology.

We get nice, clean results in the case of jumping ability and in the case of pitch discrimination ability because the possible tasks differ in only a single attribute--the height of the bar to be cleared, or the difference in pitch. I leave you to imagine what kind of results we might get if the tasks arranged along the baseline were a jumble of varied tasks. To an extent, some intelligence tests are like that--the various items may be a jumble tapping different abilities. One of the purposes of various psychometric techniques--principally factor analysis and item response theory--is to find how to select tasks so as to measure a single ability, or a single cluster of abilities. There have been considerable advances in these techniques in recent years, perhaps not always well reflected in available psychological tests.

To return to my survey, my main concern has been with factor-analytic studies designed to investigate the dimensions and structure of cognitive ability.

A word about factor analysis: there are now two main types--"exploratory" and, in the last 20 years or so, "confirmatory." The latter is now favored because it provides better statistical tests of results, but the basic assumption is the same in both cases--that psychological variables, such as test scores, can be expressed as linear functions of latent variables or "factors." Both types start with the analysis of matrices of correlations among variables; the purpose is to determine what latent variables, that is, "factors," can account for these correlations according to the multivariate linear model. Exploratory and confirmatory analyses, if properly done, yield similar patterns of results. Most of the old arguments about how data should be analyzed have been resolved among current users of the technique. For reasons of economy, I have used mainly exploratory factor analysis, with a hierarchical model whereby some factors are allowed to be more general than others.

The literature of factor analysis, in both its methodological and its substantive aspects, is very extensive. On the basis of bibliographical surveys, I estimate that more than 2000 datasets involving cognitive ability tests have been reported on in the literature. I have selected about 300 of these for examination, and in most cases, reanalysis, by currently accepted techniques. These datasets include most of the "classic" factor-analytic studies of Spearman, Thurstone, Guilford, and others, as well as various studies that I deemed of special interest and relevance, for example, factorial studies of imagery ability--a topic of current interest in cognitive psychology.

The analysis of these datasets has yielded an enormous volume of results that are still under study. Fortunately, most of the



work of this rather ambitious undertaking has been facilitated by use of microcomputers. Many difficulties have been encountered, but a number of conclusions are beginning to emerge.

First and foremost, it has become clear that there exist only a relatively _small_ number of identifiable, replicable abilities. If there is any mythology about intelligence, it is that associated with the widely cited "Structure-of-Intellect" theory proposed by J. P. Guilford (1967), according to which there are more than 100 different independent abilities composing intelligence--somewhere between 120 and 180, Guilford has claimed. Here I can't go into the technical reasons for rejecting this theory; I will simply say that most of Guilford's factors are statistical artifacts of one kind or another. I am not alone in rejecting the Structure-of-Intellect theory; it is rejected also by most current experts in factor analysis.

Instead, the model of cognitive abilities first proposed by Thurstone around 1938 now seems to be confirmed in many of its essential details. As is well known, Thurstone claimed that there are about seven "primary" abilities, named Verbal Comprehension, Word Fluency, Inductive Reasoning, Spatial Visualization, Numerical Facility, Memory, and Perceptual Speed. In later studies, Thurstone refined these, and added several other factors to his list. Most of these factors have been replicated and confirmed since Thurstone's time, and with some further refinements, my reanalyses also confirm them. Where Thurstone was wrong--at least in his earlier statements--was in his initial opinion that the basic, "primary" factors are uncorrelated. Later, before his death in 1955, he retracted this opinion, admitting that there could be "higher order" factors of greater generality than the primary factors. In the 1950s, Schmid and Leiman accomplished the mathematical formulation of a so-called "hierarchical" model to take care of higher-order factors. This model turns out to be much the same as the model originally proposed by a number of British psychologists, and Thurstone's later model fits neatly into the hierarchical model. (Incidentally, I regard the mathematical development of the hierarchical model as truly a "breakthrough" in factor analysis.) The hierarchical model is also supported by work using "confirmatory" factor analysis, as illustrated in a recent study by Gustafsson (1984). It is worthwhile to examine Gustafsson's results, shown in Visual #3. That diagram is, however, a little too complicated to explain here, so I have simplified these results and converted them into a more conventional format. (Visual #4).

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Insert Visuals #3 & #4 about here

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Gustafsson studied the correlations among 20 variables--17 of which were scores on various psychological tests, and 3 were grades in Swedish, English, and Mathematics for 981 6th-grade students in two different communities in Sweden. These 20 variables are listed down the first column of the table. The remainder of the table shows the "loadings" or coefficients of these variables on 14 factors. The first factor is a "general"

Visual #3

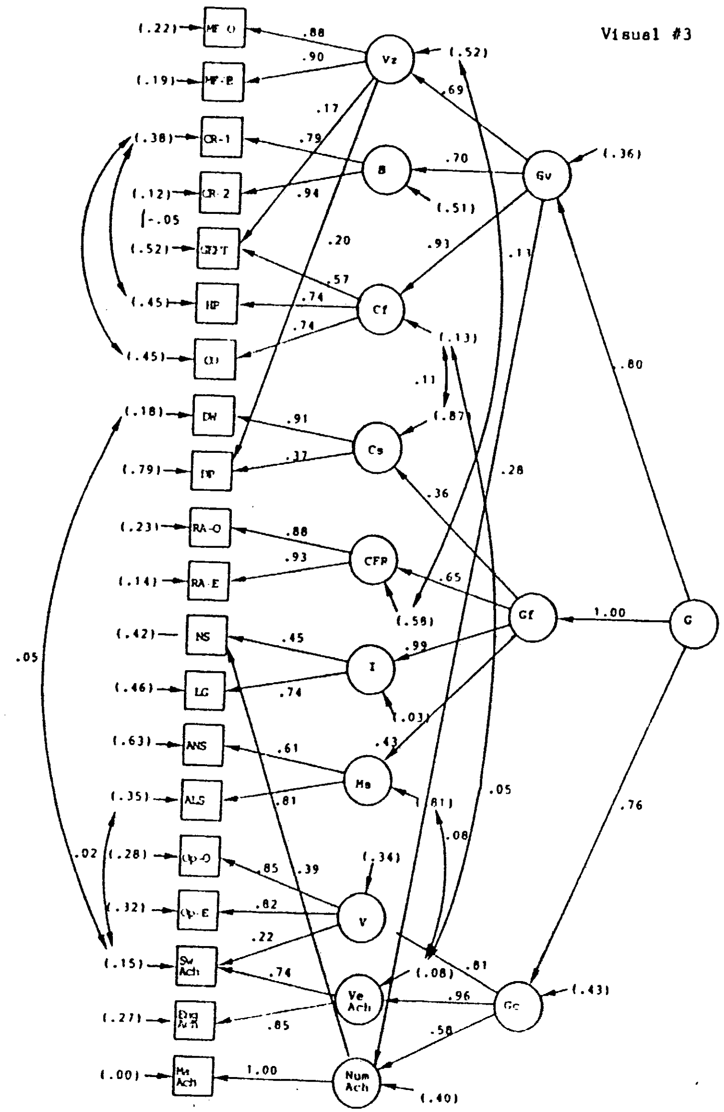


FIG. 1. The LISREL model with 1 third-order and 3 second-order factors

Visual #4

| | G | Gf | I | CFR | Ms | Cs | Gc | V | VAch | NAch | Gv | Cf | S | Vz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Letter Grouping | 73 | 04 | 11 | | | | | | | | | | | |
| Number Series | 70 | 02 | 07 | | | | 15 | | | 24 | | | | |
| Raven - Even | 60 | 04 | | 71 | | | | | | | | | | |
| Raven - Odd | 57 | 03 | | 67 | | | | | | | | | | |
| Aud. Letter Span | 35 | 02 | | | 73 | | | | | | | | | |
| Aud. Number Span | 26 | 02 | | | 55 | | | | | | | | | |
| Disguised Words | 33 | 02 | | | | 85 | | | | | | | | |
| Disguised Pictures | 24 | 01 | | | | 34 | | | | | 08 | | | 14 |
| Opposites - Odd | 52 | | | | | | 45 | 50 | | | | | | |
| Opposites - Even | 51 | | | | | | 43 | 48 | | | | | | |
| Eng. Achievement | 62 | | | | | | 52 | | 25 | | | | | |
| Swed. Achievement | 68 | | | | | | 57 | 13 | 21 | | | | | |
| Math. Achievement | 66 | | | | | | 66 | | | 62 | | | | |
| Hidden Patterns | 55 | | | | | | | | | | 41 | 27 | | |
| Copying | 55 | | | | | | | | | | 41 | 27 | | |
| Gp.Emb.Figs. | 52 | | | | | | | | | | 39 | 21 | | 12 |
| Card Rotations II | 53 | | | | | | | | | | 39 | | 67 | |
| Card Rotations I | 44 | | | | | | | | | | 33 | | 56 | |
| Metal Folding-Even | 50 | | | | | | | | | | 37 | | | 65 |
| Metal Folding-Odd | 49 | | | | | | | | | | 36 | | | 64 |



factor, labeled G, that enters, to various extents, into all variables. Next we have three second-order, "group" factors, called Gf, Gc, and Gv, each of which enters into only certain broad groups of the variables. The loadings of the variables on these factors are shown in the first column of each group of factors as listed across the top of the chart. The names of these factors derive from a hierarchical description of intelligence proposed by R. B. Cattell and John Horn: Gf is "fluid intelligence", regarded as entering into tasks requiring such higher-level mental processes as reasoning, analogizing, and inducing relationships. Gc is "crystallized intelligence," described as functioning in tasks that call upon general skills with language, number, and other types of "real-world" information, acquired through general experience and schooling. Gv is a factor regarded as appearing in all tasks having visual, figural content--it is the ability to visualize and manipulate spatial relationships.

Finally we have 10 "first-order" factors that enter into still smaller groups of variables. Grouped within the Gf or "fluid intelligence" factor we have I, Induction; CFR, Cognition of Figural Relations; Ms, Memory Span; and Cs, Speed of Closure. Grouped within the Gc or "crystallized intelligence" factor we have V, Vocabulary; VeAch, Verbal Achievement; and NumAch, Numerical or quantitative Achievement. And grouped within the Gv or "general visualization" factor are Vz, Visualization; S, Spatial Orientation, and Cf, Flexibility of Closure. Each of these first-order factors represents a source of variance that is specific to a small number of variables, over and above the variance contributed by the 2nd- and 3rd-order factors. Many of these 1st-order factors are identical or similar to some isolated by Thurstone; that would be true, certainly, of Vz (visualization), S (spatial orientation), Cf (Flexibility of closure), I (induction), Ms (memory span), and V (vocabulary or verbal ability). Not all of Thurstone's factors appear here because this particular battery of variables was designed to capture only some of them.

According to Gustafsson's model, the third-order "general" factor is identical, or very closely related, to the second-order Gf or "fluid intelligence" factor, and this model is supported by other studies that I have surveyed.

One other comment is in order, and this pertains to the hierarchical factor model. The table in Visual #4 presents loadings on 14 factors that can be treated as if they were independent sources of variance. That is, the coefficients shown could be used, if desired, in predicting the individual variables without taking into account the fact that the underlying factors will be found to be somewhat correlated in representative human populations.

This table (as presented in Visual #4) is typical of many such tables that I have developed in my reanalyses. Certain factors appear over and over, and when I assemble all the data, there are not more than about thirty different factors or sources of variance. Some of these factors are highly specific to certain



kinds of tasks or test content--they may represent abilities that some people have developed through quite specific experiences.

At the other extreme, we find that some factors enter into many groups of variables. Certainly we find repeatedly that some kind of "general" factor contributes variance to most cognitive variables. Often, such a factor can be attributed to differences in the developmental cognitive level of the group tested, particularly if that group is a sample of children, as it was in the case of Gustafsson's data. Regardless of the special abilities that may be involved, people differ in the extent to which they can perform tasks of high cognitive difficulty and complexity. In my view, the exact nature of this "general factor of intelligence" could be further explored through examination of the attributes of tasks that make them complex and difficult along this general dimension.

Similar remarks could be made about the 2nd-order "group" factors that emerge from these studies. Besides the Gf, Gc, and Gv factors, there are indications of several other moderately general factors. Parallel to the Gv or general visualization factor, there is an auditory perception factor that enters into tasks involving perception of musical pitch, tonality, rhythm, and other auditory stimulus attributes. Possibly this is a factor that underlies what we ordinarily think of as musical ability. Further, it appears that there is a general memory factor, a general "idea production" or creativity factor, and a general "mental speed" factor. Time limitations do not permit giving the multitude of details that I could give about these factors. I hope, however, that brief scanning of my next visual will give an impression of such details. (Show Visual #5) Here I have listed the various primary or 1st-order factors, grouped according to the higher-order factors with which they are most closely associated.

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Insert Visual #5 about here

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On the average, about half the common factor variance of psychological test variables comes from the higher-order factors, but this still leaves important variance coming from 1st-order factors. Thus, there is more to cognitive ability than just "general intelligence."

There are admitted limitations in all this. There are many points at which the available database is inadequate to answer all the questions that arise. Investigators have often been careless in selecting and designing the psychological tests on which many of the results are based. They have been particularly neglectful, I believe, in using test variables that have unknown proportions of "level" and "speed", so that we cannot confidently say whether a given factor of cognitive ability has to do more with speed of mental activity than with level of difficulty that can be mastered. One of my hopes has been that critical analysis of the factorial literature would disclose the major gaps in our knowledge--gaps that need to be filled by further research. It now appears that there are indeed many such gaps.

Some will argue that a basic flaw in all these results arises



Table 1

Tentative List of Factors, at Different Orders, Confirmed by Re-analyses of Extant Factor-Analytic Literature (First-order factors arranged under second-order factors)

"g" (3rd-order) General intelligence

Gf (2nd-order, possibly identical to g) Fluid intelligence
- I Induction
- RG General reasoning (mainly deductive)
- RL Logical reasoning
- IPA Information-processing accuracy
- IPSA Accuracy of semantic information processing

Gc (2nd-order) Crystallized intelligence
- V Verbal comprehension
- LX Lexical knowledge
- WS Word Sense (knowledge of properties of words)
- PC Phonetic coding
- GS Grammatical Sensitivity

Gv (2nd-order) General visual perception
- SR Spatial relations
- VZ Visualization
- CF Flexibility of closure
- CS Speed of closure

Ga (2nd-order) General auditory perception
- TT Temporal tracking
- DSP Discrimination among Sound Patterns (Pitch sense)
- SPD Speech Preception under Distraction
- MJR Maintaining and Judging Rhythm

Gs (2nd-order) General speed
- P Perceptual speed
- NA Naming speed
- RT Reaction time

Gi (2nd-order) General idea production (fluency)
- FA Associative fluency
- FE Fluency of expression
- FF Figural fluency
- FI Ideational fluency
- FS Speech fluency
- FW Word fluency
- FP Practical ideational fluency (sensitivity to problems, conceptual foresigl
- O Originality

Gm (2nd-order) General memory capacity
- MA Associative memory
- ME Episodic memory
- MS Memory span
- MV Visual memory

from the fact that they come from psychological test data. Like other tests of a behavioral nature, psychological tests have various inherent limitations. Nevertheless, they do present "cognitive tasks," and on the assumption that most people who take psychological tests are motivated to do as well as they can with them, they constitute valid data. How else might one present "cognitive tasks"? Even if these tasks are given in a tightly controlled experimental laboratory, some of the same limitations obtain.

Identifying dimensions of ability is, of course, only a first step in the investigation of these abilities, but I regard it as an essential first step. As in the physical sciences, it is important to know what the basic variables are. If we do not know what abilities exist and how they can be measured, further studies are thereby vitiated. If, for example, we want to study the declines of mental abilities that appear to take place in Alzheimer's disease, or as the result of exposure to toxic substances, we need to know exactly what mental abilities to examine, and to provide ourselves with the best possible instruments for assessing them.

Factor-analytic studies have sometimes been criticized because they do not disclose much about mental processes. Early proponents of factor analysis, such as Spearman and Thurstone, may have been overoptimistic in hoping that the technique could identify psychological processes. My view is that factor analysis cannot be expected to identify psychological processes, or explain



their nature. That is a task for other approaches in psychology, some of which will be discussed, I trust, in other papers in this symposium.

At the same time, it is not unreasonable to assume that different abilities involve different processes, different kinds of interactions between mental processes and task attributes, and different strategies of responding to such attributes. I would again draw your attention to the model of "ability" that I discussed earlier--and the notion that an ability inheres in a special kind of relation between person characteristics and task attributes. Further elucidation of the nature of the various abilities identified by correlational, factor-analytic techniques can come through the investigation of what attributes of cognitive tasks cause them to interact with the abilities they call on. This is a field of investigation worthy of intensive pursuit in the future. It will require, for one thing, a further elaboration of the mathematical theory of psychological performances to take account of the almost universal finding that even the "simple" tasks embodied in psychological tests involve at least two or three independent abilities.