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(Continued inside back cover.)

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# The Role of Competition in Human Abilities Revealed Through Auditory Tests

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# TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

# ABSTRACT

This study explores the relationship between abilities identified through the application of factor analytic procedures and some recent experimental findings regarding cerebral lateralization and competition tasks. The selection of thirteen markers for psychometric factors was guided by the theory of fluid (Gf) and crystallized (Gc) intelligence, and particularly by those aspects of the theory which derive from the study of the auditory modality. All psychometric tests were given under three conditions of presentation, i.e., monaurally through each ear and simultaneously through both ears. The main outcome of the first part of the study in which these conditions were compared using a sample of 98 subjects was that the evidence for lateralization is relatively poor. On the other hand, the hypothesized abilities did show up in factor analysis.

The seven competition tasks can be divided into the following three broad groups: a. Dual Task, i.e., two psychometric tests given simultaneously to different ears; b. Distraction and distortion tasks, i.e., processing of a task accompanied by irrelevant and distracting stimulation; and c. Binaural sensory interaction tasks and measurements, i.e., simple assessment of differential sensitivity of two channels. Correlations between the psychometric tests and competition tasks indicated that Dual Tasks may have a direct effect on the general factor. When a task involves an easy version of another task that would otherwise be accepted as a proper marker for a primary mental ability, introduction of distortion or distraction increases the common factor variance of that easy task. Finally, binaural sensory interaction tasks have a relatively small effect on processes tapped by the psychometric tests. These findings could have practical significance in that they provide a new way for testing intellectual abilities within the high ability groups. More important are the theoretical implications since they suggest that an attentional mechanism may underlie the positive manifold commonly found when one correlates cognitive variables.

Acknowledgements

The work reported here was financed by the University of Sydney research grant. Without generous help from two of my students and colleagues, Gerry Fogarty and John Crawford, it would have been impossible to complete this study; they gave their time and advice at all stages of this work. I am also grateful to Dr Lucy Sullivan who did the editing of the manuscript and to Assistant Professor Robert Sternberg who provided facilities at Yale during my writing. Finally, I want to express my gratitude to the following gentlemen who commented on an earlier draft of this paper: Professors R. Crowder, J.L. Horn, E. Hunt and Assistant Professor R. Sternberg.

# CHAPTER I

# INTRODUCTION

This paper examines the relationship between performance on typical psychometric tests and on a particular class of cognitive tasks in which competition between in-built components of the task occurs. The term "competition" is used in a generic sense to refer to two major types of processes. Firstly, cognitive processes occurring in the performance of tasks in which there is information overload. Processing of the required information is impaired through lack of the necessary "central capacity" for complete processing. These tasks have been studied in the field of selective attention (e.g. Broadbent, 1971; Kahneman, 1973). Secondly, the operation of physiological mechanisms, during the dual or multichannel processing of information, which produces such effects as cerebral lateralization (Kimura, 1967) and fused images from disparate channels (e.g. Van den Brink, 1974).

The underlying aim of the study is to provide an improved understanding of the nature of the individual differences which give rise to well-established psychometric factors, its working hypothesis being that investigation of the relationship between competition tasks and the cognitive abilities tapped by typical intelligence tests will shed light on the nature of these processes.

## 1. Structural Aspects of the Theory : Psychometric Framework

Human intelligence, in relation to intelligence tests, has historically often been conceived in hierarchical terms. It may be useful to illustrate the hierarchy with a diagram used by psychometricians in the past (see Humphreys, 1962). Figure 1 displays typical results from a hierarchical factor analytic solution with cognitive tests. At the bottom of this Figure are the variables or psychometric tests, the middle row represents primary abilities, and the highest level shows some broad second-order factors.

A geological analogy (Cattell, 1971; Gorsuch, 1974; Stankov, 1971) can be employed to elucidate the relationship of psychological tests to primary mental abilities. The types of cognitive processes - sensorial, perceptual and higher mental processes—correspond to the earth's layers—crust, mantle and core, respectively—and psychological tests correspond to a drill. In the process of reaching the core (or higher mental processes) the other layers (lower-order processes) will also unavoidably be extracted.

In the present analysis, a more elaborate interpretation of the hierarchical structure of mental abilities than that described above will be employed.

Structurally, the theory of fluid and crystallized intelligence (Gf/Gc) as elaborated recently by Horn (1981) and Horn and Stankov (1982) provides

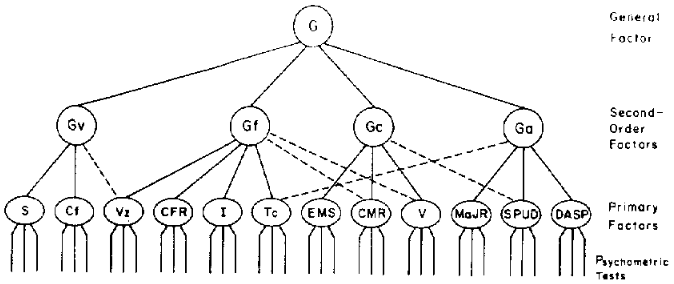

*Figure 1.* Diagramatic representation of a hierachical factor-analytic solution. Second-order factors are: Gf = fluid intelligence, Gc = crystallized intelligence, Ga = broad auditory function, Gv = broad visual function. Primary factors are: S = spatial orientation, Cf = flexibility of closure, Vz = visualization, CFR = figural relations, I = induction, Tc = temporal tracking, EMS = semantic systems, CMR = semantic relations, V = verbal comprehension, MaJR = maintaining and judging rhythm, SPUD = speech perception under distraction/distortion, DASP = discrimination among sound patterns (see Footnote 3 for its relationship to tonal memory). (After the four-factors solution of Horn and Stankov, 1982; see also Horn, 1981.)

a general framework. This empirically based hierarchical theory organizes established primary mental abilities into several broad categories. These include, besides Gf and Gc, a broad visualization function (Gv), a broad auditory function (Ga), a short-term acquisition and retrieval function (SAR), a tertiary storage and retrieval function (TSR), and a broad speediness function (Gs).

In this theory, fluid intelligence represents the abilities involved in solving such tasks as letter series, matrices, block designs, common word analogies etc., and crystallized intelligence represents abilities involved in understanding verbal communications, making judgements about a best course of action, doing numerical analysis, dealing with protocol etc. Crystallized intelligence comprises abilities that are highly valued within a culture. The high evaluation of these abilities is expressed in systematic, societal procedures for inculcating them—e.g. schooling. The abilities of fluid intelligence can be seen to be less specifically associated with the systematic influences of acculturation. They are in part a function of the effects of casual, non-systematic influences.

## 2. Dynamic Aspects of the Theory : Varieties of Competition Tasks

Stankov (1980) hypothesized that the ability to deal with competition among the stimuli on their way to different cortical centers is an essential aspect of broad auditory function (Ga). The notion of competition between stimulus inputs has been adopted from work on selective attention involving the simultaneous presentation of more than one "message". Such studies have commonly employed binaural (two or more inputs to both ears) or dichotic (different messages to each ear) listening. In this context at least two broad classes of input tasks can be distinguished : a) tasks in which one has to do two relatively complicated things at the same time (e.g., the Dual Task); b) tasks in which processing of a message is accompanied by some sort of irrelevant and usually distracting stimulation (e.g., the White Noise Masking test).

Although competition in this literature typically means competition between the processing demands of two (or more) sources of stimulus input, three further specific sources of competition will be considered in this paper: a) competition due to occlusion of ipsilateral by the contralateral messages as postulated by Kimura (1967) in her work on lateralization; b) competition originating at the sensory level due to acuity differences in threshold levels between ears; and c) competition between the internal rate of physiological functioning and externally introduced rhythmic events. Although the term "competition" may seem to imply that one of the tasks ultimately "wins" or that the overall performance is impaired, it is equally conceivable that the tasks may interact with each other in a variety of different ways.

All the above examples of competition derive from the exercise of the primary abilities of broad auditory organization (Ga) which, according to theory, represents predominantly the perceptual processes of hearing, not the higher mental processes of fluid and crystallized intelligence. However, several recently elaborated theories about intellectual abilities imply that competition, or attentional processes of some kind, play a role in higher mental processes. Thus Horn (1981) found that a) the very short-term memory that contributes to fluid intelligence is related to either a capacity or inclination to maintain close attention under conditions of high demand for attention; and b) clerical/perceptual speed is related to the ability to divide attention, as in holding some things in mind while doing other things.

In his recent writings on verbal ability and intelligence, Hunt (1978, 1980) also attaches great significance to its attentional aspects. In his schema, a distinction between two kinds of mechanistic processes in verbal ability (the controlled and the automatic) is defined largely in terms of the attentional demands imposed upon the organism. Hunt points to a possible relationship between his classification and Jensen's Level I/Level II distinction. Although still inadequately founded in hard data (see Stankov, Horn and Roy, 1980), it appears that Level I abilities impose little demand upon the attentional resources as compared to Level II abilities.

Extension of the investigation of competition to the area of higher mental processes demands that this notion takes on a meaning beyond that of competition among stimulus inputs. A complete taxonomy of the kinds of tasks in which competition occurs is, of course, lacking at present. Intelligence tests for which deeper analysis shows that some steps of the solution process compete with each other (e.g. when one has to keep in mind several bits of information and transform them in order to reach the solution) and tests in which stimulus input and response compete (as in "shadowing", in which a continuous verbal message is simultaneously listened to and repeated) would seem to embody necessary extensions of the concept.

## 3. The Aims of this Study

In the present study, only tasks which are presented auditorily are examined. It can be conveniently divided into three sections. The main purpose of the first part (Chapter 3) is to establish that the intended psychometric factors are being measured with the present sample of subjects and variables. Additionally, the contents of Chapter 4 are intended as a replication of previous results of Stankov (1980) regarding ear differences and the implied cerebral lateralization of auditory tasks.

The main purpose of the second section (Chapter 5) is to detail the relationship between psychometric factors and the various paradigms and measures used by experimental psychologists. The overall plan of the study was to administer twenty tests - thirteen to establish psychometric structure, and seven for their competition content. The latter tasks were chosen to provide instances of a number of different kinds of interference and interaction.

The relationship between the two types of tests will be examined using a variety of possible ways of combining correlational and experimental procedures without assuming superiority of one over the other. Methods of accessing these possibilities include a) observing changes in correlations as a consequence of experimental treatment; b) constructing tests with the within-subjects treatment designs which would allow for entering total scores in factor analysis and then teasing out parts due to treatment effects and their interactions; and c) simply correlating new variables which originated in experimental psychology with factor scores. The general spirit of this work is to bring a rich body of theoretical findings which spring from recent experimental work to bear upon the findings on individual differences.

The final part (Chapters 6 and 7) represents an attempt to explore some implications of the major findings for the broader issues of structure and dynamics of human cognitive abilities. It seems possible to formulate some rather broad principles governing the role of different kinds of competition in human abilities, using a variety of competition tasks.

# CHAPTER II

# METHOD: PSYCHOMETRIC TESTS

## 1. Subjects

Subjects (N = 98) who participated in this study were recruited in the following way. The majority of them (47) came from the Adult Education classes at the University of Sydney, Australia. This group contained a somewhat larger proportion of females who came from quite different social groupings. The second group (29) were firemen stationed at the Central Fire Station in Sydney. The last group (22) comprised adult subjects taking evening painting and similar classes at two primary schools in the Western Suburbs of Sydney. This group was somewhat less academically minded than the first group. All subjects were volunteers[1].

Although our obtained sample is not universally representative, it is obvious from Table 1 that variability with respect to age and education is reasonably high. These two variables are particularly important for the theory of fluid and crystallized intelligence as being instrumental in producing the adult structure of human abilities. Table 1 contains some other possibly relevant statistics concerning our sample. Since we used some musical tests, the extent of musical education of our subjects may be relevant. Since some cerebral lateralization studies indicate that hand preference might be important, information about this variable is supplied. Finally, hearing acuity of our subjects was checked with a portable audiometer (Angus - Robertson). For every frequency, absolute threshold was determined by using both ascending and descending series in the method of limits. The mean of these two values was employed in further calculations. People with absolute thresholds below 20dB should have no problems in everyday listening situations. People with hearing loss of up to 55-60 dB at middle frequencies may be aware of some hearing problems. Typically, they do not use hearing aids and can get along rather well in most social situations. Mean values for various frequencies closely followed the typical audiogram: the largest hearing loss was at the extreme frequencies for both ears. Since standard deviations appeared rather high, it was necessary to check for people in our sample with hearing difficulties. It turned out, however, that for the crucial frequencies of 1,000 Hz and 2,000 Hz there were only two to three people with a hearing loss of 35 dB in one of the ears. Most subjects, therefore, had normal hearing. In the whole sample, there was only one person with a hearing loss of about 50-60 dB for the above frequencies in his left ear. He wore a hearing aid during the testing.

---

[1] In order to establish that peculiar influences due to subjects' recruitment procedure did not operate, correlations between group membership and factor scores are given in Table 4 (variables 26-28). They are all close to zero indicating that there is no evidence for this possibility.

Table 1

Some Descriptive Statistics For The Sample

(N=98)

| | Variables | | $\bar{X}$ | s |
|---|---|---|---|---|
| 1. | Age | | 34.42 | 13.13 |
| 2. | Sex (Male=1) | | .46 | .50 |
| 3. | Years of formal education | | 12.09 | 3.07 |
| 4. | Musical classes (Yes=1) | | .30 | .46 |
| 5. | Right-hand preference | | .87 | .34 |
| 6. | Left-hand preference | | .06 | .24 |
| 7. | Ambidexterous | | .07 | .25 |
| 8. | 500 Hz acuity | Left ear* | 17.81 | 11.04 |
| 9. | 1000 Hz acuity | | 11.30 | 13.65 |
| 10. | 2000 Hz acuity | | 10.69 | 13.11 |
| 11. | 3000 Hz acuity | | 11.99 | 16.57 |
| 12. | 4000 Hz acuity | | 19.57 | 18.10 |
| 13. | 500 Hz acuity | Right ear* | 14.51 | 11.37 |
| 14. | 1000 Hz acuity | | 10.07 | 10.78 |
| 15. | 2000 Hz acuity | | 7.70 | 10.78 |
| 16. | 3000 Hz acuity | | 10.18 | 13.71 |
| 17. | 4000 Hz acuity | | 17.40 | 16.82 |

*Hearing acuity was checked with (Angus-Robertson) portable audiometer. For every subject the score represents a value in dB for which (s)he indicated that the tone was heard. The psychophysical method of limits was employed and the score represents the mean for ascending and descending series.

## 2. Tests and Hypothesized Primary Factors

Twenty different tests were administered, but this section deals only with the 13 psychometric tests. The test battery was chosen so that the first two primary factors, Tonal Memory (Tm) and Temporal Tracking (Tc), could be well overdetermined. The titles of the primary factors, descriptions of the tests, and the number of items in each test were as follows[2]:

### A. Tonal Memory (Tm)

1. *Pitch Change in Chords.* Two chords were presented one after the other. The task was to indicate whether a note had gone up or down or whether it was the same in the second presentation. Source: Wing (1966). No. of items: 15.

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[2] When the same test items were used under Left, Right and Both ears presentation conditions, this is indicated by writing 3 x the number of items.

2. *Seashore's Tonal Memory.* Pairs of tonal sequences were presented. Each sequence consisted of 3, 4 or 5 tones. The task was to indicate which note changed in the second presentation. See Figure 3 for an illustration. Source: Seashore et.al. (1960). No. of items: 21.

3. *Chord Decomposition.* A three-tone chord was followed by three individually played tones. The task was to indicate whether individual tones were the same as those of the chord or whether a note had gone up or down relative to a corresponding note in the chord. See Figure 2 for an illustration. Source: This study. No. of items: 3 x 18. Principles used in item construction: Two chords consisting of three notes were employed (C-major and A-minor). For one chord, nine items were constructed by moving either low, middle or high tone up or down or by playing the same tones as those in the chord. The tones were moved either by a whole tone or a semitone relative to their positions in the chord.

4. *Notes per Chord.* A chord consisting of 1 to 4 notes was played. The task was to indicate how many notes it involved. Source: Wing (1966). No. of items: 15.

### B. Temporal Tracking (Tc)

5. *Letter Reordering.* Three letters (R, S and T) were spoken. Subjects were asked to "label" these letters with numbers corresponding to the order in which they were presented. After a short pause, the same three letters were spoken but in a different order. The task was to write down the number "labels" in the order corresponding to the order on this second hearing. Source: Stankov and Horn (1980). No. of items: 3 x 12.

| Example: | | |
|---|---|---|
| | R S T: | 1st presentation |
| | 1 2 3 : | number attached |
| | T R S: | 2nd presentation |
| | 3 1 2 : | numbers to represent answer. |

Principles used in item construction: All six permutations of RST were recorded and randomly assigned a position within the test.

6. *Tonal Reordering.* The same as Test 5 except that the stimuli were piano tones rather than letters. See Figure 3 for an illustration. The three notes used (middle C, E, G) were treated as letters R, S, T in the Letter Reordering test, and the same principles of item construction were employed. Source: Stankov and Horn (1980). No. of items: 3 x 12.

7. *RST test.* The three letters were each repeated several times. Subjects were asked to count the number of times each letter appeared and to write this down at the end of the presentation. After Massaro (1975). No. of items: 3 x 9.

Example: RSSRTST
2 3 2 : Numbers to indicate that, in the above list
R was spoken twice, S three times, and T twice.

Principles used in item construction: There were three items of each length (7, 8 or 9 stimuli) in the list. Maximum number of times any letter could appear in the list was 3 and the minimum was 1.

8. *Do - Mi - Sol test.* The same as Test 7 except that stimuli used were piano tones (middle C, E and G) rather than letters. Principles of item construction were exactly the same as those of Test 7. See Figure 2 for an illustration. Source: This study. No. of items: 3 x 9.

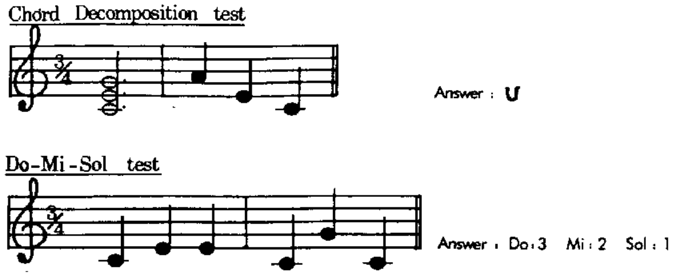

*Figure 2.* Examples for Chord Decomposition and Do-Mi-Sol tests. Verbal descriptions of these tests are given in the text.

C. Maintaining and Judging Rhythm (MaJR)

9. *Tempo A.* The task was 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. Source: Drake (1954). No. of items: 3 x 7.

10. *Tempo B.* The same as test 9 except that an interfering beat was introduced after the established beat ceased. Source: Drake (1954). No. of items: 3 x 7.

D. Auditory Verbal Comprehension (Va)

11. *Spoken Synonyms Vocabulary.* Choose a synonym for a spoken word from among five alternatives spoken after a short pause. Source: Stankov and Horn (1980). No. of items: 24.

12. *Rapid Spelling.* Write familiar words which are spelled through the earphones very quickly. Source: Stankov and Horn (1980). No. of items: 24.

E. Auditory Memory Span (Msa)

13. *Number Span Forward.* Number sequences from the WAIS were used. No. of items: 3 x 6.

An unusual feature of the test battery is the fact that, but for the content (letters vs. tones), the two Reordering tests and also Tests 7 and 8 have exactly the same item format. We found here, as elsewhere in our work with auditory abilities, that working with musical material is harder than working with speech stimuli for a sample of unselected subjects. This is easily ascertained by comparing the arithmetic means. This has no direct bearing on the central issues of the study and for that reason will not be considered in detail here.

From among the three underdetermined factors one, Maintaining and Judging Rhythm, typically appears even though only tests 9 and 10 are included in the auditory battery. It would be of little surprise if tests 11, 12 and 13 define one factor each or indeed, presuming a sufficient amount of shared variance among them and given the absence of additional markers, one factor only. Markers for primaries MaJR, Va and Msa are included because of a possibility that some aspects of the Temporal Tracking factor involve letters and may depend on immediate memory span.

## 3. Procedure

All tests were recorded on tape, and all of them were presented through a reel-to-reel stereo tape recorder (Revox). Decibel level for sound reproduction was kept at a comfortable level of 50 - 70 dB throughout. When two tasks were given together through different ears (see competition tasks, later) their respective energy levels were equated. Speech-based tests and instructions for all tests of the battery were recorded in a sound-proof room within the University and most tests based upon musical sounds were recorded at a professional recording studio.

Nine of the thirteen tests were presented under the following three conditions: 1/3 of the items were given to both ears, 1/3 were given to the left, and 1/3 to the right ear. The items were blocked. This procedure was not followed in tests 2, 4, 11 and 13, which had items ordered with respect to difficulty. In these cases the first three items were given under different conditions and the same was done for the next three items, etc. Subjects were told that ear of presentation would change and that they should pay no attention to that but work through the tests in the normal way.

The total battery took approximately four hours to administer. The tests were presented by the author and a research assistant to groups ranging in number between three and twelve persons. All groups but the very last one (Group 12) were given the tests in two sessions (each lasting about two hours) at the same time of day but a week apart. After approximately one hour of testing there was a rest period of 10 to 15 minutes.

An important improvement in procedure as compared to Stankov (1980) has already been mentioned: for most tests, the same items were repeated three times. The second improvement consisted in varying the order of presentation of both (B) and left (L), and right ear (R) conditions. This was fixed in the 1980 study. For the present study, the tapes were prepared in such a way as to allow us to employ all six permutations of the BLR order but, due to the increased time and cost involved, the decision was made to use only three of them. These were: 1. BRL with N = 30; 2. BLR with N = 28; and 3. RLB with N = 40. Preliminary analysis using a multivariate analysis of variance program showed no differences among the three groups.

### 4. Statistical Analyses

All analyses aimed at recovering the factor structure of our battery of tests are based on Little Jiffy, Mark IV (LJIV; Kaiser and Rice, 1974). A particular application of LJIV in hierarchical solutions is described in Stankov (1979) and Stankov (1980) shows how these hierarchical solutions can be used when the experimental design provides information regarding both-, left-, and right-ear conditions. Little Jiffy represents a package of programs which embodies image analysis at the factor extraction stage and orthoblique rotation as a means of achieving a stronger version of simple structure - the independent clusters solution. This method has been employed with a large number of empirically obtained data matrices in our laboratory and it has produced satisfactory solutions when compared with other methods of factor analysis. It also has certain advantages, particularly regarding the calculation of factor scores which will be used in this paper. The GENSTAT package, which was developed in Britain and has been in wide use in Australia, was employed for the analysis of variance (see Wilkinson and Rogers, 1975).

## CHAPTER III

## STRUCTURE AMONG THE PSYCHOMETRIC VARIABLES

In order to establish whether the hypothesized factorial structure obtains with the present data, the first set of analyses employed total scores - i.e. the sum of scores obtained under both, left, and right ear conditions of presentation. This is justified by a finding (Stankov, 1980; Stankov and Spilsbury, 1978) that total scores provide a similar factor pattern to that obtained under free-room listening conditions (e.g. Stankov and Horn, 1980). Additional justification for such a pooling comes from the finding of no differences between the mean vectors (see Table 6) and from the occurrence of similar factorial structures across the conditions (see Table 5).

The correlational matrix for thirteen variables, together with total scores' means and standard deviations, is given in Table 2 and the Little Jiffy first-order solution, obtained with the total scores, is given in Table 3. Repeated analysis of the factor inter-correlation matrix produced one factor at the second order. When backward semi-orthogonal transformation of the Schmid-Leiman type as described by Stankov (1980) was performed, the second-order factor shown in the last column of Table 3 appeared.

A glance at the last two columns of Table 3 is sufficient to show that some tests of our battery (Tests 4, 6, 7 and 13) have unusually low squared multiple correlations. On the other hand, although the second-order factor has relatively high loadings from all tests, it is notable that loadings of the typical intelligence subtests (Spoken Synonyms Vocabulary, Number Span Forward, Rapid Spelling) appear to be lower. This could be interpreted to mean that the present second-order factor is not a general factor (G) but rather approximates the broad auditory factor Ga of Stankov (1978) or Horn and Stankov (1982).

It can be seen that three first-order factors have been replicated. The first factor, Tonal Memory (Tm), has salient loadings from all four postulated markers[3]. In some previous analyses, typical tonal markers for this factor were tests using sequential presentation, like our Test 2. The loadings from tasks involving both single tones and chords implies that there is something fundamentally similar between these two kinds of musical material. Maybe

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[3] The label "Tonal Memory" for this factor follows the example of French (1951). It should be mentioned, however, that in a study by Stankov and Horn (1980) which involved a larger number of variables and subjects than any other study of the present series, the above tests measured "Discrimination Among Sound Patterns" factor (DASP). In that study, this factor was not restricted to musical content; it also had noteworthy loadings from variables tapping the ability to understand compressed and expanded speech, the ability to discriminate between two rhythmic patterns, and the ability to discriminate whether a voice or a tone has appeared in a series of similar voices or tones.

## Table 2

Means, Standard Deviations and Correlations Between Psychometric Variables Based Upon the Total Scores*

| Tests | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | X̄ | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Pitch Change in Chords | 100 | | | | | | | | | | | | | 8.56 | 3.21 |
| 2. Seashore's Tonal Memory | 65 | 100 | | | | | | | | | | | | 16.39 | 4.41 |
| 3. Chord Decomposition | 55 | 61 | 100 | | | | | | | | | | | 31.51 | 10.11 |
| 4. Notes Per Chord | 32 | 34 | 40 | 100 | | | | | | | | | | 7.41 | 2.46 |
| 5. Letter Reordering | 32 | 50 | 28 | 11 | 100 | | | | | | | | | 24.65 | 7.39 |
| 6. Tonal Reordering | 24 | 26 | 17 | 12 | 37 | 100 | | | | | | | | 8.61 | 6.89 |
| 7. RST test | 08 | 11 | 12 | -04 | 44 | 23 | 100 | | | | | | | 8.76 | 6.40 |
| 8. Do-Mi-Sol test | 36 | 31 | 36 | 12 | 32 | 41 | 27 | 100 | | | | | | 2.28 | 2.38 |
| 9. Tempo A | 10 | 41 | 21 | 18 | 27 | 10 | 25 | 07 | 100 | | | | | 16.53 | 11.02 |
| 10. Tempo B | 12 | 32 | 09 | -01 | 39 | 16 | 31 | 27 | 67 | 100 | | | | 18.60 | 11.29 |
| 11. Spoken Synonyms Vocabulary | 16 | 23 | 30 | 20 | 31 | 19 | 06 | 00 | 10 | 02 | 100 | | | 11.02 | 3.87 |
| 12. Rapid Spelling | 14 | 14 | 06 | 18 | 16 | 07 | 03 | -01 | 13 | 02 | 55 | 100 | | 16.19 | 4.20 |
| 13. Number Span Forward | 16 | 19 | 07 | 01 | 36 | 11 | 17 | -06 | 14 | 07 | 27 | 40 | 100 | 7.67 | 3.09 |

*Decimal points omitted.

## Table 3

Little Jiffy's Factor Pattern.
Solution Based On Correlations From Table 2.

| Tests | Factors | | | | | |
|---|---|---|---|---|---|---|
| | Tm | Tc | MaJR | Va(Ms?) | $R^2$ | 2nd Factor |
| 1. Pitch Change in Chords | 69 | 08 | -13 | -02 | 52 | 40 |
| 2. Seashore's Tonal Memory | 67 | 03 | 16 | 02 | 66 | 53 |
| 3. Chord Decomposition | 73 | -04 | -05 | -01 | 54 | 39 |
| 4. Notes per Chord | 51 | -22 | 02 | 10 | 24 | 21 |
| 5. Letter Reordering | 04 | 57 | 05 | 02 | 54 | 50 |
| 6. Tonal Reordering | 05 | 50 | -14 | -01 | 26 | 25 |
| 7. RST test | -22 | 55 | 09 | -02 | 30 | 29 |
| 8. Do-Mi-Sol test | 25 | 48 | -14 | -25 | 40 | 32 |
| 9. Tempo A | 08 | -11 | 72 | -05 | 59 | 39 |
| 10. Tempo B | -08 | 19 | 63 | 10 | 57 | 39 |
| 11. Spoken Synonyms Vocabulary | 10 | 05 | -06 | 54 | 44 | 26 |
| 12. Rapid Spelling | -03 | -02 | 02 | 59 | 48 | 20 |
| 13. Number Span Forward | -11 | 19 | -02 | 42 | 29 | 23 |

Factor Intercorrelations:

| | Tm | Tc | MaJR | Va(Ms?) |
|---|---|---|---|---|
| Tm | 100 | | | |
| Tc | 64 | 100 | | |
| MaJR | 40 | 59 | 100 | |
| Va(Ms?) | 37 | 19 | 34 | 100 |

*Salient loadings from Little Jiffy are underlined. Decimal points omitted.

the relationship among the tones represents a critical datum of musical memory (see Dewar, Cuddy, and Mewhart, 1977; Dowling, 1978; Moore and Rosen, 1979).

The second factor of Table 3, Temporal Tracking (Tc), has salient loadings from all four postulated markers for it. There are several possible interpretations of the processes tapped by this factor (see Stankov and Horn, 198O). One of these is along the lines of Massaro's (1975) analysis of his QRST task. This may be a simple measure of working memory; in all the tests of this factor, one has to keep in mind a certain number of elements and also perform some kind of manipulation with them. On the other hand, it may be that the "bottleneck" which gives rise to individual differences in these tasks derives more specifically from the need to keep track of the order in which stimuli have been received. There is some evidence, for example, that both temporal and spatial order information should be distinguished from item information (e.g. Bjork and Healy, 1974).

There are very few things to say about the third factor, Maintaining and Judging Rhythm, MaJR. Since there are no other rhythm tasks in this battery, only the two Drake tests define it. The emergence of this factor possibly reflects individual differences in biological clocks which underlie the perception of rhythm.

The last factor is hard to interpret. Because the two tests with higher loadings represent markers for Auditory Verbal Comprehension, this factor could be called by that name. However Test 13, Number Span Forward, measured in the past not only a different primary factor (Auditory Memory Span, Msa) but also a different second-order factor (either fluid intelligence, Gf, or short-term acquisition and retrieval function, SAR, see Horn, 1981). We shall see later that some other tasks which are akin to Msa also have loadings on this factor. Because of that, it is probably inappropriate to label this factor simply Va; "Va(Ms?)" will be used, temporarily, for this purpose.

In order to facilitate the interpretation of factors it is always useful to consider the correlations which factors have with the extension or external variables. These correlations are given in Table 4. They support the claim that the second-order factor and the first three first-order factors (Tm, Tc, and MaJR) represent largely a measure of Ga. The tentative Auditory Verbal Comprehension factor, Va(Ms?), has a rather different pattern of correlations with external variables. For example, according to the Gf/Gc theory, age should correlate positively with measures of crystallized intelligence. It can be seen in Table 4 that the correlation of Va(Ms?) with age is .1O. Traditional crystallized intelligence markers (Spoken Synonyms Vocabulary and Rapid Spelling tests) here have correlations of .23 and .22 with age, while Memory Span Forward test which is typically a marker for Gf or SAR, correlates negatively (-.11) with it. Stankov and Horn (198O) report that measures of Ga such as Discrimination Among Sound Patterns (DASP) and Speech Perception under Distraction/Distortion (SPUD) correlate negatively with age. DASP's correlation has been replicated here since Tonal Memory is one of its aspects (see Footnote 3). The only measure of SPUD included in the present battery, White Noise Masking test, shows a correlation of -.44 with age. This is the first time that Maintaining and Judging Rhythm (MaJR) factor has shown such a notable correlation (-.45) with age, and the fact that Temporal Tracking behaves in the same way probably indicates that this latter factor in the present battery measures the broad auditory function, Ga, to a larger extent than on previous occasions.

Variables 2 and 3 from Table 4 refer to formal education. According to the Gf/Gc theory they should correlate positively with primary measures of crystallized intelligence. This, it can be seen, is indeed what happens for Va(Ms?) and Tc. Temporal Tracking therefore still contains elements of intelligence; it is not just another measure of Ga.

Some involvement of musical experience is present in Tonal Memory performance and, to a much smaller extent, in Temporal Tracking. We may recall that Tonal Memory contains loadings from tests which are used in the selection of students of music and therefore the present correlation is in accordance with expectation. This is not to say that selection effects were operating to some extent in the obtained sample. It simply means that if somebody has had musical training and is given a test which is sometimes used for selecting the students of music, (s)he should obtain a higher score. Of course the observed correlation does not necessarily preclude self-selection in musical training. Musical ability may create preferences, inclination, etc. towards musical training. It may be relevant to note that experience in playing an instrument correlates .47 with Tonal Memory, while formal musical training correlates .3O. Tonal Memory's correlation with sex can be explained by the fact that there is a larger number of females than males who had some form of musical training which, of course, may in turn relate to innate ability. This study has replicated previous findings of virtually zero correlation of handedness with the auditory factors.

In the past it had been found that measures of hearing acuity have higher correlations with primary factors of Ga than they do with the measures of Gf and Gc. This has been replicated here since it can be seen in Table 4 that Tonal Memory, Maintaining and Judging Rhythm, and Temporal Tracking have higher correlations with acuity measures than does the Va(Ms?) factor. The present sample is older on average than the other samples which took auditory tests. Therefore noteworthy correlations of Va(Ms?) with acuity can be attributed to declining acuity plus declining Gf with increasing age.

We shall consider variables 18 to 23 of Table 4 in greater detail in later sections of this report. It is to be noted that the White Noise Masking test correlates more with the Ga measures than it does with Va(Ms?). Also, binaural diplacusis and the Dichotic Chords test correlate with Tonal

Table 4

Correlations Between Factor Scores
And Some External Variables*

| | External variables | Primary Factors Tm | Tc | MaJR | Va(Ms?) |
|---|---|---|---|---|---|
| 1. | Age | -15 | -37 | -45 | 10 |
| 2. | Years of formal education | 10 | 21 | 07 | 13 |
| 3. | School completed | 18 | 27 | 04 | 29 |
| 4. | Formal musical training | 30 | 13 | 07 | 00 |
| 5. | Play an instrument | 47 | 23 | 02 | 13 |
| 6. | Sex (Male=1) | -21 | -01 | 03 | -11 |
| 7. | Prefer to use right hand | 09 | -05 | 01 | -05 |
| 8. | 500 Hz | -29 | -33 | -16 | -22 |
| 9. | 1000 Hz | -20 | -25 | -15 | -24 |
| 10. | 2000 Hz Left ear | -32 | -30 | -21 | -17 |
| 11. | 3000 Hz | -34 | -32 | -27 | -16 |
| 12. | 4000 Hz | -31 | -40 | -38 | -23 |
| 13. | 500 Hz | -15 | -18 | -11 | -16 |
| 14. | 1000 Hz | -21 | -22 | -21 | -19 |
| 15. | 2000 Hz Right ear | -22 | -25 | -23 | -26 |
| 16. | 3000 Hz | -31 | -31 | -32 | -22 |
| 17. | 4000 Hz | -31 | -41 | -43 | -26 |
| 18. | White Noise Masking | 49 | 50 | 42 | 27 |
| 19. | Binaural Diplacusis | 27 | 17 | 21 | 08 |
| 20. | Binaural Diplacusis (2000-3000cps) | 33 | 14 | 29 | 10 |
| 21. | Binaural Diplacusis (3100-4100cps) | 05 | 13 | 01 | 02 |
| 22. | Ear dominance (Dichotic Chords test) | 18 | 02 | 00 | -02 |
| 23. | Dichotic listening (total) | 28 | 51 | 22 | 36 |
| 24. | Dichotic listening (right-ear scores) | 28 | 52 | 16 | 23 |
| 25. | Dichotic listening (left-ear scores) | 14 | 26 | 13 | 41 |
| 26. | Adult Education Classes (N=47) | -01 | 13 | 04 | 07 |
| 27. | Firemen (N=29) | -07 | -04 | 08 | 02 |
| 28. | Evening Classes (N=22) | 09 | 12 | -13 | -11 |

*Decimal points omitted.

Memory. Both observations are in accordance with our interpretations of Tonal Memory and Ga.

It can be concluded that the present data have replicated three primary factors (Temporal Tracking, Tc; Tonal Memory, Tm; and Maintaining and Judging Rhythm, MaJR) obtained in previous studies of auditory abilities. The fourth primary factor (Va(Ms?)) is composed of markers for Auditory Verbal Comprehension, Va, and Auditory Memory Span, Msa, and can be seen as a consequence of underdetermination of the latter factors in this battery. Evidence presented here also indicates that the Tonal Memory and Maintaining and Judging Rhythm factors represent Ga processes and that Va(Ms?) behaves like a marker for fluid and crystallized intelligence. Finally, the Temporal Tracking factor has features which make it similar to both Ga and Gf.

# CHAPTER IV

## HEMISPHERIC LATERALIZATION

There are at least two reasons why it is important to consider here the evidence for lateralization of cognitive functions. First, at least two theories of the nature of human abilities make serious use of this evidence. Das, Kirby and Jarman's (1975) theory of simultaneous-successive synthesis relies on these findings and Bock's (1973) arguments for the need to distinguish "words" and "images" derive, in part, from a lateralization of functions hypothesis.

Second, the literature on cerebral lateralization is replete with univariate experiments even though the general conclusions (that the left hemisphere is specialized for speech and right hemisphere for the perception of visual or auditory form) are certainly multivariate in their nature. Typical studies involve the following simple logic. If a task, say Synonyms Vocabulary test, is better performed by the left hemisphere and another task, say Rapid Spelling test, is also performed better by the same hemisphere, then the left hemisphere is specialized for whatever these two tasks have in common—verbal ability. This conclusion is based upon the differences between the means for items supposedly presented to the two hemispheres. To a student of individual differences such a situation poses an obvious question about correlations. It is conceivable that within both hemispheres, correlations are zero (or in different directions) and therefore the tasks do not tap the same ability in at least one accepted use of the term. In one multivariate study (Stankov, 198O) it was found that tests defining the Verbal factor and the Tonal Memory factor show ear differences in agreement with the lateralization of functions hypothesis. One of the aims of the present study was to replicate this finding.

For a while it was thought that dichotic listening procedures were necessary in order to be able to study lateralization with auditory stimuli. It has become apparent, however, that simple presentation of a stimulus to one ear (left or right) can demonstrate ear advantage (see Henry, 1979). Darwin's (1974) description of functional decussation in terms of Kimura's (1967) theory about occlusion of ipsilateral pathways by the contralateral ones could represent a theoretical basis for this approach. All our tests designed to explore the problems of lateralization used monaural presentation.

In the following discussion we shall first consider relevant factor-analytic evidence and then turn to the traditional type of data in this area.

### 1. Factor Analysis

If one performs separate analyses with the correlational matrices obtained under different conditions of presentation (Both, Left, and Right car), the resulting solutions typically differ among themselves and also from the solution based upon total scores. Stankov (1980) postulated that higher-order factors might disclose a hidden similarity between the conditions of presentation. Evidence for this appeared through the application of hierarchical factoring in two different ways. Although both suggested approaches have their own strong points and weaknesses, the outcomes of previous analyses showed that they lead to similar conclusions. For this reason only one method is employed here.

The results presented in Table 5 were obtained by calculating correlations between all variables over all three conditions of presentation. The initial correlational matrix thus contained 3 x 13 rows and columns. If correlations between the same tests over different conditions exceed correlations that the tests have with the other tests within the conditions, one should expect to obtain as many factors as the number of tests within the battery (here 13). Every factor, of course, should have salient loadings from the same test across the conditions of presentation. At the second-order one should obtain the same number of factors as that obtained in Table 3 and the third-order solution would depend on the correlations between the second-order factors. Backward semi-orthogonal transformations should then show basic similarity between the second and third-order factors obtained in this way and first- and second-order factors from the total scores.

There are at least two difficulties with the above approach. First, the number of variables which enter the analysis is three times larger than when one proceeds with the total scores only. This may lead to an unfavourable ratio between the number of subjects and the number of variables. The second difficulty derives from the presence of both common and condition-specific components in the observed scores. The above approach allows both these components to enter correlations across the conditions of presentation[4].

The first-order solution produced 13 factors that gave four second-order and one third-order factor. The hierarchical solution is presented in Table

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[4] An alternative method consists of carrying out separate analyses with the variables in every condition, neglecting for a moment correlations between the conditions. Crucial for this approach is the fact that LJIV provides exact factor scores, not factor score estimates. This means, for example, that factor intercorrelations are exactly the same as factor scores' intercorrelations. These factor scores from every condition are then correlated and the second-order Little Jiffy solution is obtained. In that way we arrive at correlations among the common factors only; specific condition variance of a variable does not affect factor structure. Of course, one can then proceed to higher orders.

This second approach obviously manages to get around the second difficulty of the approach that was described in the main body of the paper. Seemingly it also gets around the first difficulty. Its own problem is that communalities obtained must be lower than those of the first approach. In both cases the decision about the number of factors at the second order is arbitrary. The first approach is used in some work of Eysenck and the second approach is akin to Cattell's ideas on "parcel factoring". This second approach also has some similarity with Jöreskog's suggestions for hierachical factoring.

Table 5

Hierarchical Solution Based On 39 Variables*

| Variables | | 3rd Order | Second-order | | | | First-order | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tm | Tc | MaJR | Va(?) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1. Pitch Change I Chords | (B) | 28 | 52 | -05 | -01 | -06 | 02 | 05 | 14 | 04 | 01 | -10 | -05 | -09 | 10 | 28 | -16 | -03 | -21 |
| 2. " | (L) | 33 | 46 | 00 | 06 | -06 | 06 | -08 | 17 | -15 | -01 | 17 | -06 | -07 | 05 | 32 | -05 | -11 | 02 |
| 3. " | (R) | 19 | 40 | 15 | -26 | 02 | 03 | 01 | -08 | -01 | -01 | -12 | 07 | 08 | -08 | 48 | 06 | 05 | 02 |
| 4. Seashore's Tonal Mem. | (B) | 45 | 46 | 03 | 15 | 04 | 02 | 02 | 34 | 06 | 06 | -01 | 05 | -07 | -01 | 06 | 11 | 05 | 00 |
| 5. " | (L) | 45 | 54 | -04 | 18 | 00 | 03 | 05 | 45 | 02 | -01 | 01 | 00 | 02 | 01 | -02 | 00 | 04 | 00 |
| 6. " | (R) | 37 | 52 | -03 | 08 | -03 | -04 | 06 | 32 | -14 | 16 | 08 | -09 | -06 | 06 | 04 | -06 | -08 | 01 |
| 7. Chord Decomposition | (B) | 26 | 52 | -02 | -04 | -12 | -07 | 47 | -10 | -11 | 09 | 17 | -09 | 00 | -13 | 06 | 02 | 05 | 11 |
| 8. " | (L) | 28 | 56 | -03 | -06 | -07 | -04 | 58 | 08 | -01 | -03 | -02 | 01 | 02 | 00 | -04 | 00 | -06 | 02 |
| 9. " | (R) | 33 | 53 | -03 | 00 | 03 | 05 | 47 | 02 | 13 | -10 | -06 | 05 | 04 | 00 | 06 | 02 | 08 | -11 |
| 10. Notes Per Chord | (B) | 14 | 27 | -11 | 03 | 12 | 13 | 12 | -21 | 02 | 06 | 12 | -07 | -06 | -03 | 08 | 03 | 33 | -17 |
| 11. " | (L) | 15 | 39 | -10 | -04 | 04 | 00 | -12 | 18 | -01 | 03 | -04 | -02 | -03 | 01 | -01 | -04 | 46 | 05 |
| 12. " | (R) | 07 | 21 | -09 | 02 | -02 | -09 | 03 | -07 | -04 | -14 | 15 | 08 | 02 | 01 | 10 | -06 | 28 | 09 |
| 13. Letter Reordering | (B) | 40 | 10 | 34 | 02 | 15 | 03 | 05 | 03 | 10 | 43 | -11 | 02 | 12 | 01 | -07 | 06 | -06 | 02 |
| 14. " | (L) | 43 | 10 | 36 | 04 | 06 | 01 | -02 | 03 | 01 | 50 | -03 | 05 | -02 | -07 | 00 | -06 | 07 | -01 |
| 15. " | (R) | 45 | 19 | 28 | 08 | 09 | -03 | -06 | -01 | -02 | 53 | 04 | -02 | 03 | 00 | 01 | 11 | 05 | 00 |
| 16. Tonal Reordering | (B) | 24 | 13 | 25 | -06 | 01 | 70 | 03 | 01 | -08 | 02 | 07 | 03 | 02 | 01 | -07 | -05 | 05 | -03 |
| 17. " | (L) | 25 | 13 | 27 | -07 | -01 | 72 | -01 | -09 | 00 | 04 | 04 | -10 | 02 | 03 | 07 | -07 | -02 | -02 |
| 18. " | (R) | 23 | 09 | 33 | -12 | -01 | 77 | -03 | 06 | 01 | -03 | -05 | 05 | -01 | -04 | -02 | 06 | 00 | 02 |
| 19. RST test | (B) | 29 | 04 | 26 | 08 | -05 | -08 | 12 | -03 | 01 | 11 | 01 | 49 | -01 | 13 | -03 | -26 | 03 | -14 |
| 20. " | (L) | 26 | -14 | 41 | 03 | -01 | -05 | -03 | 04 | -02 | -04 | 00 | 67 | 03 | -01 | 01 | -01 | 00 | 00 |
| 21. " | (R) | 24 | -18 | 40 | 04 | 00 | -03 | 03 | -09 | -01 | 08 | 04 | 57 | -07 | -03 | 03 | 08 | -05 | 05 |
| 22. Do-Mi-Sol test | (B) | 29 | 18 | 23 | -05 | -13 | 09 | 03 | 06 | 08 | 06 | -05 | -02 | 04 | 01 | 01 | -05 | 11 | 35 |
| 23. " | (L) | 27 | 20 | 23 | -03 | -14 | 25 | 27 | -13 | 13 | 04 | -05 | -05 | -09 | 25 | 02 | -24 | -08 | 18 |
| 24. " | (R) | 13 | 17 | 18 | -10 | -26 | -02 | 08 | 01 | -01 | -02 | -01 | 06 | -09 | 00 | 11 | -06 | -04 | 34 |
| 25. Tempo A | (B) | 33 | -01 | -08 | 53 | 05 | -04 | 00 | 03 | -03 | 04 | 45 | 03 | -06 | 02 | -11 | 02 | 00 | -02 |
| 26. " | (L) | 36 | 02 | -02 | 49 | 04 | 02 | 01 | -01 | 02 | -06 | 46 | 03 | 10 | -07 | -01 | -01 | 00 | 02 |
| 27. " | (R) | 35 | 05 | -08 | 49 | 08 | -02 | -02 | 07 | 12 | -10 | 30 | 02 | 09 | 00 | 01 | 02 | 03 | -03 |
| 28. Tempo B | (B) | 39 | -07 | 08 | 51 | -08 | -05 | -01 | 02 | 43 | -02 | 05 | 05 | -02 | -01 | 01 | 01 | 02 | 03 |
| 29. " | (L) | 43 | -06 | 13 | 50 | -05 | 04 | -12 | -01 | 28 | 08 | 17 | -02 | -02 | -01 | 11 | -01 | -10 | -02 |
| 30. " | (R) | 34 | -10 | 08 | 48 | -06 | 02 | 03 | 01 | 53 | 02 | -06 | -07 | 00 | -01 | -05 | 01 | 00 | -01 |

Table 5 (Continued)

| Variables | | 3rd Order | Second-order Tm | Tc | MaJR | Va(?) | First-order 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31. Spoken Syn. Vocabulary | (B) | 13 | 15 | -04 | 01 | 27 | -03 | 23 | -25 | -03 | 24 | 10 | -18 | -06 | 17 | 03 | 05 | 01 | -11 |
| 32. " | (L) | 20 | 07 | 08 | 00 | 42 | 19 | 14 | 04 | 02 | -01 | -01 | 06 | -03 | 09 | 01 | 40 | -09 | -07 |
| 33. " | (R) | 12 | 06 | 06 | -07 | 39 | 02 | 08 | -15 | -03 | 24 | 01 | -02 | -12 | 03 | 12 | 27 | 07 | -08 |
| 34. Rapid Spelling | (B) | 11 | 02 | -06 | 04 | 53 | -04 | -03 | 06 | -03 | -04 | 01 | -02 | 03 | 55 | -05 | -02 | -02 | -02 |
| 35. " | (L) | 14 | -01 | 04 | 00 | 50 | -03 | -03 | -06 | 05 | 02 | -03 | 02 | 00 | 45 | 00 | 06 | 09 | 04 |
| 36. " | (R) | 17 | 04 | 07 | -02 | 49 | -04 | -03 | -06 | -02 | -03 | 05 | 05 | 02 | 32 | 12 | 21 | 04 | 12 |
| 37. Number Span Forward | (B) | 17 | -05 | 10 | 05 | 38 | -10 | -10 | 00 | 04 | 00 | 01 | -03 | 57 | -02 | 11 | 06 | 00 | -02 |
| 38. " | (L) | 21 | -01 | 20 | -03 | 37 | 04 | 03 | -06 | 00 | 01 | 01 | 01 | 65 | 03 | 03 | -05 | 01 | 00 |
| 39. " | (R) | 20 | 02 | 16 | -04 | 39 | 03 | 06 | 08 | -06 | 03 | -01 | 02 | 60 | 02 | -07 | 02 | -04 | 00 |

* For the first-order, underlined are all loadings which were salient in the Little Jiffy's solution; for the second-order, all loadings above 20 are underlined. Decimal points are omitted.

5[5]. It can be seen from this Table that the second- and third-order factors correspond closely to the first- and second-order factors from the total scores. As mentioned before, the same result appeared in the work of Stankov (198O). The third-order factor represents a broad ability resembling the broad auditory factor (Ga) and at the second-order we have Tonal Memory (Tm), Temporal Tracking (Tc), Maintaining and Judging Rhythm (MaJR), and Auditory Verbal Comprehension-Memory Span (Va(Ms?)) factors. It should be noted that loadings of the third-order factor are not as high as have been found in the past; most variance is retained within the lower orders. All higher-order factors contain variance from all three conditions of presentation (i.e., from B, L, and R scores). Reliance upon the first-order solution only would have made interpretation of the results considerably more difficult.

## 2. Ear Differences in Terms of the Differences Between Arithmetic Means

The idea that individual differences in the ability to deal with competing stimuli are responsible for the emergence of the broad auditory factor, Ga, derived initially from the interpretation of arithmetic mean differences between L, R, and B scores. Stankov (198O) observed that verbal tests show right ear and therefore left-hemisphere superiority but that musical tests of Tonal Memory show left ear and right-hemisphere superiority. (Markers for the other two primaries of Ga–Maintaining and Judging Rhythm and Speech Perception Under Distraction/Distortion–did not show left vs. right ear differences.) Contrary to expectations, the both-ears condition showed the lowest mean for most chord-based variables of the Tonal Memory factor. This condition would be expected to produce the best performance for at least two reasons. First, if we presume that all subjects have equal sensitivity in the two ears, the well-established phenomenon of loudness summation would lead to an assumption that two ears would convey a louder and possibly more intelligible message. Second, if we assume differential sensitivity of the two ears, it is reasonable to expect that our binaural listening should not be any worse than listening with a better ear. That too would lead to an expectation that the arithmetic mean over all subjects for the both-ears condition should be higher than any single-condition mean. This indicates that there is something peculiar to both-ears perception of musical material and it was hypothesized that, beside possible acuity differences between the

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[5] Since with the hierachical solutions based upon image analysis one cannot, in general, obtain orthogonal higher-order factors, factor intercorrelations should be reported. On the other hand, since there is a link between lower-order anti-image covariances and higher-order factor intercorrelations, one can use LJIV's measure of sampling adequacy (MSA) as a rough guide to the relative magnitude of these latter correlations. In fact, Stankov (1979) has suggested that if we decide to retain as many anti-image factors as there are variables in the correlational matrix, one can assume that if MSA at every factoring order is satisfactory, the loss incurred by excluding factor intercorrelations is going to be comparatively small. With the present data, the overall measures of sampling adequacy were .72, .69 and .67 for the 1st, 2nd and 3rd order respectively. A value below .50 would be considered unacceptable by Kaiser.

ears which should affect any listening performance, the phenomenon of binaural diplacusis might operate. This describes the situation in which the same tone, presented to different ears, sounds different with respect to pitch or different tones sound the same. This form of competition between the stimuli arriving at different ears can be viewed as a process akin to the competition between external and internal rhythm (which is responsible for the Maintaining and Judging Rhythm factor) or the competition between the possible loci for processing distorted verbal material (Speech Perception Under Distraction/Distortion factor).

Table 6 displays means, standard deviations and F-values for the differences between the means. These are less marked than in Stankov's (1980) study; only three variables showed significant differences. Table 7 compares the results of the two studies. It can be seen that for two Tonal Memory variables, the both-ears condition has the lowest mean, and that the left-ear mean is higher than the right-ear mean. This is in accordance with previous findings regarding lateralization and with the idea of competition. For the Pitch Change in Chords test, the present order on means is closer to the expectation than the previous result. With the Rapid Spelling test, the right-ear condition still shows a higher mean than the both-ears condition but that contrast is no longer significant.

Table 6

Means, Standard Deviations and F-tests
For the Differences Between the Conditions
Of Presentation

| | | Both ears | | Left ear | | Right ear | | F |
|---|---|---|---|---|---|---|---|---|
| | | X̄ | s | X̄ | s | X̄ | s | 2,95 |
| 1. | Pitch Change in Chords | 2.61 | 1.31 | 3.07 | 1.86 | 2.88 | 1.35 | 5.46* |
| 2. | Seashore's Tonal Memory | 5.50 | 1.51 | 5.38 | 1.71 | 5.51 | 1.68 | .71 |
| 3. | Chord Decomposition | 10.55 | 3.72 | 10.63 | 3.97 | 10.33 | 3.68 | .56 |
| 4. | Notes Per Chord | 2.15 | 1.05 | 2.82 | 1.20 | 2.44 | 1.20 | 11.70* |
| 5. | Letter Reordering | 8.08 | 2.85 | 8.37 | 2.80 | 8.20 | 2.67 | .86 |
| 6. | Tonal Reordering | 2.81 | 2.52 | 2.97 | 2.55 | 2.84 | 2.45 | .51 |
| 7. | RST test | 2.92 | 2.25 | 2.99 | 2.49 | 2.85 | 2.55 | .25 |
| 8. | Do-Mi-Sol test | .82 | 1.06 | .79 | 1.09 | .67 | .94 | .87 |
| 9. | Tempo A | 5.92 | 5.32 | 5.47 | 3.59 | 5.14 | 3.80 | 2.02 |
| 10. | Tempo B | 6.18 | 4.24 | 6.12 | 4.14 | 6.30 | 4.09 | .17 |
| 11. | Spoken Synonyms Vocabulary | 3.94 | 1.63 | 3.57 | 1.57 | 3.55 | 1.81 | 2.85 |
| 12. | Rapid Spelling | 5.64 | 1.48 | 5.22 | 1.68 | 5.33 | 1.74 | 4.65* |
| 13. | Number Span Forward | 2.45 | 1.19 | 2.63 | 1.14 | 2.55 | 1.16 | 2.97 |

*Significant at .05 level

Table 7

Ordering On Arithmetic Means

| | Variable | Stankov (1980) | This Study |
|---|---|---|---|
| 1. | Pitch Change in Chords | R = L > B | L > R = B |
| 2. | Seashore's Tonal Memory | B > L > R | * |
| 3. | Chord Decomposition | L = R > B | * |
| 4. | Notes Per Chord | L > R > B | L > R > B |
| 5. | Letter Reordering | B > R > L | * |
| 6. | Tonal Reordering | * | * |
| 7. | RST test | Not used | * |
| 8. | Do-Mi-Sol test | Not used | * |
| 9. | Tempo A | * | * |
| 10. | Tempo B | * | * |
| 11. | Spoken Synonyms Vocabulary | R > B = L | * |
| 12. | Rapid Spelling | R > B = L | B > R = L |
| 13. | Number Span Forward | * | * |

*F-test not significant. R = right ear mean; L = left ear mean;
B = both ears mean

Overall, the present findings are not in direct contradiction with the previous results, but the effects here are not as strong as before. Verbal abilities, in particular, did not show evidence of lateralization whereas two out of four Tonal Memory variables show results in accordance with the hypothesis. This, of course, calls for an explanation.

The present study differs from previous work in several important ways. First the sample of subjects differs with respect to age, education, and degree of visual impairment (there was a subsample of blind children in the previous study). It may be that the effects appear strongly with the younger sample but not with the older, and that these two studies reflect genuine differences due to age. Although data regarding lateralization during life-span development are scarce and inconclusive at present, there is some evidence to suggest trends towards reduced lateralization (see Johnson, Cole, Bowers, Foiles, Nikaido, Patrick and Woliver, 1979).

Second, there are two potentially important procedural changes in the present study. One of these is that in most tests used here, the same items were repeated three times (i.e., under every condition of presentation). It could be that since this was not the case before, items of different difficulty were given under different conditions of presentation and this, not lateralization, was responsible for the obtained effects before. Although some tests of the present study are identical to those used previously it is impossible to obtain an unconfounded check of this possibility. This is because of the changing order of the conditions of presentation. It will be recalled that for one group the order was, say BLR, and for another it was BRL, etc. Such an arrangement means that, for those four tests which are identical with the tests used before, the first group of subjects obtained one set of items in their left ear and the second group of subjects was given the same items in their right ear.

It is therefore possible that sample and procedural changes introduced in this study led to a weaker showing of lateralization effects than should ideally emerge. This study provides a warning that chance variations in item difficulty, irrespective of whether the same or different items are used under various conditions of presentation, may contribute to a particular pattern of ear differences and lead to erroneous conclusions. This should be checked in studies of lateralization.

Summarizing Chapters 3 and 4, the psychometric findings concerning the factorial structure of auditory abilities have been replicated. In Stankov's (1980) study, ordering on the conditions-of-presentation means closely followed groupings of the variables based on factor analysis, i.e., variables defining the same factor showed similar orderings on means. In this study, only three variables showed significant differences between presentation means, so that this section of the data was poorly replicated. Since the procedure used in this study is more rigorous, the previous findings might be questioned, but one cannot rule out the possibility that discrepancies occurred due to genuine age-related differences between the samples.

It has been mentioned before that the notion of competition in this context derived from the field of experimental psychology and since some of those findings (relating to lateralization) did not replicate overall, one can ask whether the idea itself should be abolished. This would be a premature reaction not only because there is a need for further investigation but for other reasons as well. For example, a critical finding for bringing the idea of competition into focus was that for Tonal Memory the both-ears condition had the lowest mean. In the present data, this holds for two out of four variables of this factor. Also, the notion of competition in the case of other primaries (MaJR and SPUD) depends on quite a different set of experimental findings. It is obviously necessary to test the concept in a more direct way by using tasks which clearly involve competition. The remainder of this report examines some tasks of this nature.

# CHAPTER V

## COMPETING TASKS: AUDITORY INTERACTION AND INTERFERENCE

One way to investigate the role of competition in intellective factors consists in developing tests that on an a priori basis can be seen to involve it. The most direct examples are those tasks in which one message (or task) comes through one channel and a different message (or task) comes through another channel. Such tests can then be related to the abilities tapped in accepted psychometric tests. The tests chosen for the purposes of this study were tasks in which two markers for different primary abilities are given simultaneously, tasks in which processing of a message is being interfered with through distraction or distortion and simple tasks in which binaural processing is being studied.

### 1. The Dual Task : Simultaneous Performance On Two Psychometric Tests

An important feature of the auditory modality is that it is easy to use two ears as separate channels for presenting information. This has been done extensively in work on dichotic listening but that literature typically does not employ putative intelligence tests. Baddeley and Hitch (1974), however, employed a dual task, one component of which was a proper intelligence (reasoning) task. In one of their experiments, subjects were asked to memorize a set of digits, then work on a reasoning task, and, finally, reproduce the memorized digits. They found that performance increasingly deteriorated as the number of digits to be remembered approached the subject's memory span. This concurrent load task was interpreted as evidence for a "working memory" but also suggests the presence of competition between the tasks. As one task takes up increasingly more of the subject's "central capacity" the other task was decreasingly performed.

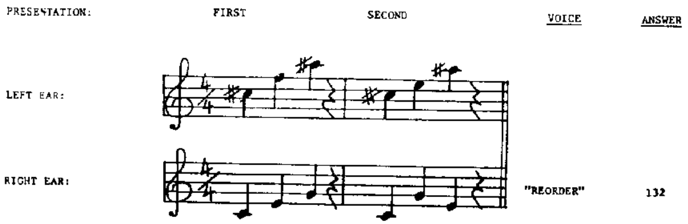

*Figure 3.* Examples for Tonal Memory (upper part, left ear) and Tonal Reordering (lower part, right ear) tests when these are given under the Dual Task condition of presentation. In the Tonal Memory component, one has to indicate which tone changed during the second presentation. Correct answer for this example is "2". In the Tonal Reordering component, subjects are asked to label the tones during the first presentation by attaching numbers corresponding to their order. When the tones are presented for the second time, subjects have to write down the labels in accordance with the order of this presentation. The correct answer is given in the Figure. After both presentations, a voice says either "Reorder" or "Memory" This indicates which component is to be answered.

*Procedure.* With the aim of combining desirable features of dichotic listening and "working memory" tasks, the Dual Task we employed consisted of presentation of two of our psychometric tests simultaneously and dichotically. Seashore's Tonal Memory test (Test 2) and the Tonal Reordering test (Test 6) were the tests employed. Subjects were presented with the items as shown in Figure 3.

In this example, the subjects heard the top line of notes, the Tonal Memory test, in the left ear. The bottom line shows the Tonal Reordering test which was presented in the right ear. Since both Test 2 and Test 6 had been given before the Dual Task, subjects were familiar with them. Items of the Dual Task were made easier relative to the single tests[6]. In the memory test, only three notes were used (in Test 2, up to five notes were employed) and in both the memory and the reordering components of the Dual Task, the first three notes were always those illustrated in the above example. In constructing the items for this task, six permutations of the tonal reordering stimuli were paired with the changes in first, second or third note of the tonal memory component. This generates eighteen items. Our intention was to have a 36-items test by repeating the 18 items twice but, due to power failure in one group, only 33 items were given to all subjects. This task was given twice, the two adminstrations being separated by a one week interval. In the second presentation the positions of the tasks by ear were reversed.

An important feature of the Dual Task was that subjects were asked to give their answers to only one of the two components but they did not know which task that would be until after presentation of the tasks. When all six pairs of the stimuli for a given item were presented, the instruction either "memory" or "reorder" was given in the same ear in which the corresponding task was played, and only then did the subjects write their answers. This made it inefficient for subjects to focus on only one component of the task, and provided a more accurate assessment of actual processing performance than would a requirement to write down both answers. In the latter situation, achieved processing of one task would be lost during the capacity-consuming task of writing down the answer to the other. In 17 items, reordering was post-cued and in 16 items the same was done for the memory component.

*Results.* Since this form of the Dual Task has not been used before and since the Tonal Reordering test, when given on its own appeared difficult, it is important to consider first some basic descriptive statistics provided in Table 8. Inspection of the component means (section (a)) indicates that Tonal Reordering was the more difficult component of the Dual Task in spite of the fact that it contained a larger number of items. The drop in scores for

Table 8

Statistics Regarding The Dual Task

a) Correlations between two presentations of the Dual Task

| | R1 | M1 | R2 | M2 | $\bar{X}$ | s | α* |
|---|---|---|---|---|---|---|---|
| Reordering, 1st test (R1) | 1.00 | .47 | .56 | .42 | 5.14 | 2.83 | .60 |
| Memory, 1st test (M1) | | 1.00 | .32 | .58 | 7.29 | 3.30 | .63 |
| Reordering, 2nd test (R2) | | | 1.00 | .50 | 5.33 | 3.12 | .66 |
| Memory, 2nd test (M2) | | | | 1.00 | 6.33 | 3.65 | .71 |

b) Correlations between single presentations and Dual Task presentations of the Tonal Memory and Tonal Reordering Tests

| | SR | SM | DR | DM | α* |
|---|---|---|---|---|---|
| Reordering, single (SR) | 1.00 | .26 | .41 | .23 | .72 |
| Memory, Single (SM) | | 1.00 | .50 | .57 | .69 |
| Reordering, dual (DR) | | | 1.00 | .55 | |
| Memory, dual (DM) | | | | 1.00 | |

c) Idealized factor matrix illustrating overlap (F) and reproduced correlational matrix ($\bar{R}$)

| | Factors | | |
|---|---|---|---|
| | I | II | $h^2$ |
| 1. | .7 | .0 | .49 |
| 2. | .0 | .7 | .49 |
| F = 3. | .5 | .5 | .50 |
| 4. | .5 | .5 | .50 |

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. | | .00 | .35 | .35 |
| 2. | | | .35 | .35 |
| $\bar{R}$ = 3. | | | | .50 |
| 4. | | | | |

*α = Cronbach's coefficient alpha

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[6] It is important to note this particular feature of the Dual Task since most currently popular theories of attention (see Broadbent, 1971; Kahneman, 1973; Kantowitz and Knight, 1974; Norman and Bobrow, 1975; Posner and Snyder, 1975; Spelke, Hirst and Neisser, 1976; Sternberg, 1969) rely on direct comparison between performances under single and dual task conditions. In particular, they use exactly the same tasks in single and dual presentations and conclusions are drawn on the basis of the decrement which may occur. Since we have only the easiest items in our Dual Task, this decrement is a built-in feature. The emphasis in this paper is not on decrement in performance (which undoubtedly occurs) and associated interpretations of it, but rather on correlations which component tasks have among themselves and with other variables.

Actually, all items of the Dual Task are present in single tests. Comparisons would be meaningless mainly because they are too easy. This particularly holds for Seashore's Tonal Memory test. Comparisons would also be unreliable because of the small number of items.

the memory task on the second presentation is notable and difficult to account for.

In subsequent analyses, the scores obtained during the two presentations of the Dual Task are combined in order to achieve higher reliability. Thus, Tonal Memory scores have the mean of 13.62 and standard deviation of 6.18 and corresponding values for Tonal Reordering are 10.47 and 5.26. The last column in section (a) of Table 8 provides Cronbach's coefficient alpha for every variable used.

Section (b) of Table 8 shows the correlations between Seashore's Tonal Memory and the Tonal Reordering tests when they were given as single and as Dual Tasks. The correlation between these tests rises from .25 when they are single to .55 when they are presented dichotically. The significance of this will be discussed later.

The Dual Task components were included in factor analyses with the original 13 tests and the result is presented in Table 9. (This Table also contains some other variables which will be treated later.) The factors of Table 9 are comparable to those of Table 3 which did not include the Dual Task results. Hence the link provided by the first analysis to previous findings is extended to the novel Dual Task domains.

An immediately apparent outcome of factor analysis is that both the Seashore's Tonal Memory and the Tonal Reordering components of the Dual Task load on the Tonal Memory and the Temporal Tracking factors. This is usually referred to as "overlap". Since an important characteristic of the orthoblique rotation employed by Little Jiffy is that it provides an independent clusters solution that avoids overlap among the factors, the present outcome is surprising.

Using an accepted psychometric interpretation of factor-analytic results, it can be said that, within the Dual Task, Seashore's Tonal Memory becomes similar to, or shares a part of its variance with Temporal Tracking, and that the Tonal Reordering test becomes similar to the Tonal Memory factor. Experimental manipulation introduced by presenting two tasks at the same time led to a change in their factorial complexity.

Although Thurstone's simple structure criteria do allow for overlap, subsequent work, particularly Guilford's search for the markers for his Structure of Intellect, seems to have emphasized the absence of it. For the theory of fluid and crystallized intelligence, overlap is a fact of life, dictated by the nature of human psychological make-up. This has been pointed out by both R.B. Cattell and J.L. Horn. It is accepted in this theory that there is an overlap between fluid and crystallized intelligence factors which, according to Horn (1967), can be understood in terms of "alternative mechanisms". By this he means that variables that show overlap represent tasks that can be solved either by using Gf or Gc processes.

Table 9

Little Jiffy's Factor Pattern Matrix
For Original 13 Variables And Some
External Variables*

| | Variable | Primary Factors | | | | | |
|---|---|---|---|---|---|---|---|
| | | Tm | Tc | MaJR | Va(Ms?) | Ac | $R^2$ |
| 1. | Pitch Change in Chords | 72 | 06 | 10 | -01 | 01 | 63 |
| 2. | Seashore's Tonal Memory | 69 | 01 | 24 | 05 | 01 | 73 |
| 3. | Chord Decomposition | 78 | -05 | 07 | -05 | 03 | 61 |
| 4. | Notes Per Chord | 64 | -37 | 01 | 05 | 08 | 32 |
| | Dual Task - Memory | 33 | 50 | 01 | -10 | -07 | 59 |
| | Dual Task - Reordering | 54 | 30 | -14 | 00 | -12 | 60 |
| 5. | Letter Reordering | -04 | 61 | 07 | 14 | 08 | 58 |
| 6. | Tonal Reordering | 00 | 49 | -15 | 01 | 01 | 36 |
| 7. | RST task | -28 | 60 | -07 | -05 | 02 | 34 |
| 8. | Do-Mi-Sol test | 16 | 48 | 13 | -24 | 13 | 48 |
| 9. | Tempo A | 12 | -12 | 70 | 03 | 07 | 64 |
| 10. | Tempo B | -14 | 26 | 61 | -07 | 02 | 61 |
| 11. | Spoken Synonyms Vocabulary | 21 | -05 | -14 | 51 | 17 | 50 |
| 12. | Rapid Spelling | 09 | -19 | 01 | 74 | 05 | 63 |
| 13. | Number Span Forward | -12 | 28 | 01 | 52 | -09 | 46 |
| | Ms Order Interference | -12 | 23 | 03 | 69 | -09 | 62 |
| | 500 Hz Left Ear | -02 | -09 | 23 | 03 | 80 | 66 |
| | 4000 Hz Left Ear | 00 | -02 | -09 | 03 | 78 | 76 |
| | 500 Hz Right Ear | 01 | 06 | 21 | 00 | 76 | 59 |
| | 4000 Hz Right Ear | 02 | 02 | -16 | -05 | 75 | 76 |

Factor Intercorrelations:

| | Tm | Tc | MaJR | Va(Ms?) | Ac |
|---|---|---|---|---|---|
| Tm | 100 | | | | |
| Tc | 43 | 100 | | | |
| MaJR | 42 | 49 | 100 | | |
| Va(Ms?) | 27 | 32 | 19 | 100 | |
| Ac | 34 | 43 | 42 | 27 | 100 |

*Decimal points omitted. $R^2$ = squared multiple correlation coefficient.

The Dual Task used here appears to provide another legitimate context for the occurrence of overlap. In the situation in which the subject must work on both components of a task since he/she does not know what aspect will be post-cued, compensation between the two components of the task may occur. High Tonal Memory or high Temporal Tracking ability will allow more efficient work on one aspect of the Dual Task and therefore leave more time for work on the other. This would typically lead to a higher correlation between the components of the Dual Task relative to the single tests' correlation. In this situation it may be appropriate to talk in terms of a "compensation hypothesis" as a parallel to "alternative mechanisms" hypothesis i.e. in the competitive situation of the Dual Task, subjects can improve their relative standing on the task on which they typically perform poorly.

If the four variables (two single tests and two components of the Dual Task) have approximately the same communality and we know that there is an overlap for the two Dual Tasks' components, these components should correlate higher than the single tests. High correlation, on the other hand, does not imply an overlap. This is illustrated with an artificial example at the bottom of Table 8. The example was constructed by assigning a communality value of approximately .5O to four variables and then distributing factor loadings in such a way as to obtain an idealized overlapping factor matrix displayed at the bottom left-hand side. That factor-pattern matrix generates the correlational matrix, R, on the right-hand side.

There are at least three possible models that can account for overlap or "factorial complexity" of any variable[7]. Assuming that in fact two "alternative mechanisms" can be involved in the performance of a task and that these two mechanisms correspond to two factors that are established, through the use of other tasks that permit the use of only one mechanism, the models are as follows:

Model I: One (substantial) subset of the sample uses Mechanism A to do the task, while the remainder uses Mechanism B. In factor analysis of the data for the total (pooled) group, this could cause factorial complexity, i.e., a loading of the test on Factor A and also a significant loading on Factor B.

Model II: Two alternative mechanisms are possible, and every subject uses Mechanism A on some subset of the items, and Mechanism B on the remainder. This also could result in factorial complexity for the total score.

Model III: The two "mechanisms" are not really "alternative"; rather, both mechanisms are involved (at least to some substantial extent) in performance of the task. Thus, the factorial equation appropriate for every subject has two significant weights (as opposed to the equations for Model I, which would be different for different subjects, or the equations for Model II which might differ as a function of item).

Of course, the true situation might be a mixture of the above models and, with the present data, it cannot be decided which model or combination of models to choose. However, given accepted practice in test construction (i.e., we typically aim to achieve unifactorial scales) Model II is implausible (but see Hunt, 1974). The real choice is between Models I and III.

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[7] This point was stressed by a reviewer of an earlier draft of this paper.

My preference is for Model I for reasons which, at present, can be backed only by indirect evidence. When information processing psychologists choose to talk about individual differences, they do so mostly in terms of Model I. Evidence has accumulated (see, for example, Cooper, 1976; Macleod, Hunt and Mathews, 1978) to show that in certain tasks one group of subjects uses one strategy and another group uses a different strategy. For example, a sentence verification task in which one has to establish the truth or falsity of simple sentences like "The star is above plus" is solved by some subjects with a verbal strategy whereas others employ spatial algorithms (Macleod et al, 1978). Returning to factor analysis, it has the advantage of parsimony to view the effect of whatever stimulus dimension is introduced with the Dual Task—be it complexity or difficulty—as dependent on already identified abilities and brought about through a mechanism of compensation.

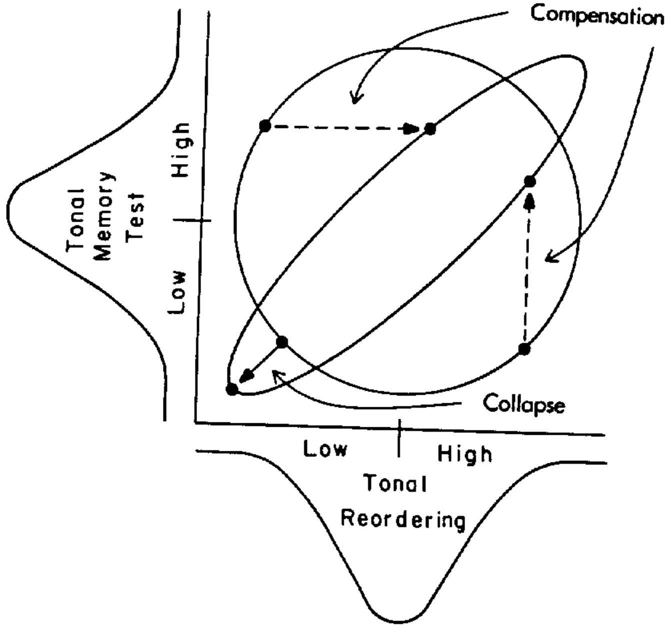

*Figure 4.* Possible explanations for the increased correlation between the components of the Dual Task. The circle represents low correlation between single presentations of the two tasks and the ellipse stands for an increased correlation under the Dual Task condition. According to Baddeley and Hitch's (1974) results performance would be worse on the Dual Task but those who were below average on both singly presented tasks would be most affected. According to Horn's alternative mechanisms explanation, those who were high on one task but low on the other become more proficient in the latter.

Baddeley and Hitch's (1974) paper (which prompted the construction of the Dual Task) sheds further light on the findings through its analysis of the performance of individuals who are low on both test components. On the basis of their results it would be predicted that subjects who have both low Tonal Memory and low Temporal Tracking ability would fare still worse in the Dual Task. They will have the greatest trouble in working through this test, they may collapse, and therefore will contribute to a high correlation. Figure 4 depicts the assumed processes which in this case lead to a higher correlation between the components of the Dual Task.

Since the compensation hypothesis can be formulated in terms of correlation scatterplots, evidence relevant for its predictions can be gained through inspection of the movement of subjects from one quadrant of Figure 4 into the other. For this purpose, of course, one should first transform raw scores into z-scores. When this is done for the data on Tonal Memory and Tonal Reordering, it becomes obvious that they generally support the compensation hypothesis. Of 98 subjects, 37 were performing above the mean on one task and above the mean on the other task when these were given as single tests. The movement of these subjects is directly relevant for checking the predictions. Under the Dual Task presentation, 7 remained in the same quadrant providing no test of the hypothesis and 18 improved their performance on the task on which they were poor originally. The remaining 12 became worse on the task on which they did well before. It can be concluded that there is some support for compensation hypothesis in the present data[8].

If we admit the compensation hypothesis and the poor performance-collapse interpretation as explanations for the higher correlations among the Dual Tasks' components than among the single tests, it can be seen that these processes could also be responsible for the presence of a positive manifold and its consequence - the emergence of general or group factor(s). In this context it is interesting that, for the present data, the correlation between the Reordering component of the Dual Task and years of formal education is .16 (the single Tonal Reordering test had r = .00) and that the Tonal Memory component of the Dual Task correlates .22 with the same variable (single Seashore's Tonal Memory test had r = .06). In both cases there is an increase in correlation with formal education.

## 2. Distraction and Interference Tasks.

Three of the seven competition tests consisted of tasks in which distortion of the signal was used to produce interference. In general, interference prevents optimal performance on a primary task, whether representative of fluid or crystallized intelligence or of other broad cognitive factors. Work on sharpening and levelling cognitive styles (Gardner, Holzman, Klein, Linton and Spence, 1959) has suggested that the ability to deal with interference may be a broad function cutting across different tests. This could be checked by taking the easy items from a variety of tests and superimposing interfering stimuli on them. If these easy items have higher correlations among themselves than they do with the more difficult items of the same task, there is evidence for generality. If they correlate with the difficult items of the same task, the inference is that interference exaggerates individual differences in much the same way as item difficulty does. These outcomes have different implications for the relationship between interference-type competition and intelligence.

One of the selected tasks, a White Noise Masking test, represents a marker for the Speech Perception Under Distraction/ Distortion factor (see Stankov and Horn, 1980). For this test, when presented in a free-room situation, it can be hypothesized that variation between subjects in the localization of the distorting stimuli relative to the channel of input may account for individual differences. When the effects due to the locus of signal and mask are partialled out, the residual scores (or fitted values) may show different correlations with other variables than do the raw scores.

The second task, Memory Span Order Interference test, had not been used previously so that it was not known what factor it would measure. Since experimental manipulations with this test and the White Noise Masking test were similar, they are described together. The third task was the Dichotic Listening test that has been used extensively in studies dealing with cerebral lateralization. Dichotic Listening differs from the other two interference tasks in that interference does not derive from an extrinsic source. In our previous work, this test defined a Memory Span factor.

### 2.1 The White Noise Masking Test (WNM)

Several variables involving masking have been used in our previous studies. In all of them subjects were asked to recognize a word or a sentence spoken under some kind of masking background—another voice reading an excerpt from a text, noise caused by cafeteria—type activity, traffic noise,

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[8] Although the compensation hypothesis has an intuitive appeal, one may face considerable difficulties in trying to test it within the correlational framework. Assuming the usual precautions in the selection of subjects and variables, problems can be of three kinds: a. *Statistical.* For example, even though single tasks may have normal distribution, these same tasks are likely to produce skewed distributions under Dual Task conditions. Considerable skill will be required during the item selection stage in order to ensure that the easier items used with the Dual Task have satisfactory distributional characteristics. b. *Definitional.* As it stands, the definition is too broad and vague. Given that Model I holds and that differences in strategies underlie overlap, one is faced with a question about the nature of strategy choice. It could be that some intrinsic characteristic of the stimulus makes it likely that the majority of subjects will use a particular strategy even though it would be to a disadvantage to some of them. For example, if one makes a Dual Task by administering dichotically a test based on tones and another test based on letters, most people would find letters easier to work with. c. *Interpretational.* One is always faced with a need to specify the cut-off points. Using the mean for this purpose is arbitrary. What considerations should be made in order to make it more rational? Is it the case, for example, that individuals' standing with respect to population at large, not the sample to which (s)he belongs, determines the use of compensatory strategies?

white noise, etc. In this study control over several variables which have been neglected in the past was provided for.

*Test Materials.* Items for the White Noise Masking test consisted of a word that was masked and a list of four words including the previously masked word itself. The other three words were phonetically similar, commonly used words. The basic unit for the test consisted of ten different lists of four words. These ten lists were used to form a 3O-item test by choosing one word from among each group of four words as the word to be masked on three separate occasions. For example, if an item consisted of the words "same, fame, shame, blame", when it appeared in the first block of ten items, "fame" could be masked, when it appeared for the second time "blame" could be masked and, in the last block, "same". A 3O-item test was repeated three times in order to form a 9O-items long test. These 9O items were recorded with white noise superimposed. Masking was done according to the following scheme:

| | | Ear which received white noise | | |
|---|---|---|---|---|
| | | Left | Right | Both |
| | Left | 1 | 2 | 3 |
| Ear which received signal | Right | 4 | 5 | 6 |
| | Both | 7 | 8 | 9 |

Every cell in the above diagram contained 1O items. Presentation of nine signal-noise combinations was organized in a completely balanced randomized design.

Signal to noise ratio for satisfactory communication should normally be higher than +6dB (i.e. signal should be more than 6dB higher than noise) and OdB ratio produces 5O% correct detection. In this task presentation the signal to noise ratio was set at +3dB. Subjects recorded their answers by writing down the ordinal number in the four-word group of the word which was the same as the masked word.

Table 10

Arithmetic Means For The White Noise Masking Test

| | | Locus of Mask | | | |
|---|---|---|---|---|---|
| | | Left | Right | Both | |
| | Left | 7.17 | 9.65 | 3.97 | 6.93 |
| Locus of signal | Right | 9.65 | 4.24 | 8.50 | 7.47 |
| | Both | 9.57 | 9.79 | 6.92 | 8.76 |
| | | 8.80 | 7.90 | 6.46 | |

*Results.* The arithmetic means for performance on the masking task are presented in Table 10. All three sources of variation, i.e. the two main effects (locus of presentation of signal and mask) and their interaction, were significant (locus of signal : F(2,776) = 155.5O; locus of mask : F(2,776) = 244.76; interaction : F(4,776) = 429.6) at .O1 level. The ordering of main effects' means can be explained in terms of cerebral lateralization of speech detection and by the fact that, possibly due to loudness summation, the both-ears condition is superior in detecting the signal and produces the greatest interference through masking. Cerebral lateralization would predict, in agreement with the present findings, that right ear compared with left ear presentation of the signal, produces superior performance. Also it predicts that masking on the right ear leads to inferior performance relative to left-ear masking. Much more pronounced than the main effects is interaction. This is mainly due to a very strong effect of peripheral masking which is indicated by the fact the diagonal cells (i.e. both signal and mask come through the same channel(s)) show lower means overall. When the signal comes from one side and the mask comes from the other, there is little interference with the processing of a message (cells 2 and 4 show almost perfect performance). When the signal comes through both ears but only one channel is masked, performance is almost perfect as well (see cells 7 and 8). These data indicate that central, as opposed to peripheral, masking is weak.

The finding that poor performance occurs when the signal is delivered to the left ear and both ears are masked is surprising in view of the phenomenon of "masking level differences, MLD" (see Moore, 1977). It has been found that when both signal and noise are delivered to the same ear so that the signal cannot be recognized, if a masking stimulus is presented to both ears, the signal itself suddenly becomes recognizable. This occurs both with pure tones and words as signals. MLD would appear to imply that when a signal goes to one ear and both ears are masked, performance should be better than when both signal and mask go to the same ear. With the present results, this holds for the right ear but it does not hold for the left ear; performance on left ear is in fact worse when the mask goes to both ears.

The finding that the major portion of variance in the White Noise Masking test can be attributed to interaction and peripheral masking indicates that it taps broad perceptual processes of audition, Ga, and not the central processing abilities. Correlational evidence to support this view will be presented in a later section.

## 2.2 Memory Span Order Interference Test (MsOI)

Martin (1978) reported that individual differences in memory span are due mostly to a memory for temporal occurrence of events and not to the memory for the stored items themselves. In view of the fact that memory span has been ascribed such an important role in several recent papers on intelligence (Bachelder and Denny, 1978; Horn, 1979; Hunt, 1978), it is important to explore this suggestion.

The Memory Span Order Interference test (MsOI) was devised for the purpose of checking memory for order. An item in this test consists of a spoken series of numbers which have to be recalled in their exact order. After presentation of the series (four, five, or six digits long), there is a break, just long enough to serve as a marker and then the same voice repeats numbers from the previous series in a randomized set of 12 digits. The subject is then required to write down the first series in their correct order. A sample item from this test is as follows:

84362 - 348263843286 Answer : 84362.

As one of the aims of the present study was to explore ear- differences, the above test was presented with a design similar to that of the White Noise Masking test. If we consider the list of digits to be remembered as "signal" and the interfering numbers as "mask", there are nine possibilities for combining them, (using both ears, left ear, and right ear presentation). Every cell of the design contained six items—two with four, two with five, and two with six digits as "signal". The score was the number of series reproduced in their exact order. Unlike the White Noise Masking test, items were not given in blocks. Instead, all 54 items were randomly assigned a position within the test and all subjects received them in the same order.

The analogy with the White Noise Masking test is not ad hoc. It could be argued that interfering numbers act in the same way as do the masking stimuli. In fact, the effect of the so called backward masking (see Crowder, 1978) may be similar in nature to what might be assumed to happen in the present version of the MsOI test. If this were the case, one would expect to obtain similar results to those of the White Noise Masking test and, by analogy, conclusions regarding the role of peripheral and central processes in memory span may be possible to deduce.

Table 11

Arithmetic Means For The Memory Span Order Interference Test

| | | Locus of interference | | | |
|---|---|---|---|---|---|
| | | Left | Right | Both | |
| Locus of signal | Left | 4.29 | 4.33 | 4.96 | 4.52 |
| | Right | 4.67 | 5.21 | 5.30 | 4.99 |
| | Both | 4.11 | 4.28 | 4.84 | 4.41 |
| | | 4.29 | 4.61 | 5.03 | |

*Results.* Arithmetic means for all cells of the design are given in Table 11. Both main effects were significant (locus of signal : $F(2,776) = 36.06$, $p < .01$; locus of interference : $F(2,776) = 53.45$, $p < .01$). The interaction effect, although significant ($F(4,776) = 5.09$, $p < .01$), was relatively small. It is apparent from the inspection of means, that subjects found this test, overall, relatively easy; the maximum score for each cell was 6 and the overall mean was 4.64. The worst performance occurred when the signal was given to both ears and the left ear received the interfering stimuli, while the best performance occurred when the signal was given to the right ear and both ears received interference. In terms of main effects, the ordering on means was B>R>L for locus of interference and R>L=B for locus of the signal presentation.

This pattern of means differs from that for the White Noise Masking test, indicating that the same processes do not underlie both test performances. The conclusion is supported by the finding that the correlation between the WNM total score and the MsOI total score is $r = .12$. Left vs right ear comparison for the locus of signal main effect is in accordance with the lateralization hypothesis. The overall pattern of means, however, suggests additional influences which, at present, are not entirely clear.

A comparison of this test with the Number Span Forward test (variable 13 in Table 6) shows very similar ordering for the locus of signal means. It will be argued that the two tests measure basically the same ability, namely immediate memory span. Correlational evidence which supports this view is presented in Section 2.4.

## 2.3 Relationship Between the WNM Test, Primary Factors and External Variables

So far, the White Noise Masking test and Memory Span Order Interference test have been examined by the methods of experimental psychology, and not of differential psychology. The experimental findings have implications for findings of individual differences in typical psychometric tests of this nature. In a free-room situation with speakers somewhere at one end of the room and subjects in rows as in a classroom, to some of the subjects the sound will come predominantly to the left ear, to others it will come to the right. Additionally, there will be acuity variation among the subjects and uncontrolled head movements. Accordingly, when one controls for the effects of the channel through which signal and mask are given and obtains significant effects, a proportion of variation in scores is accounted for or "explained". The residual term, which in theory contains "error" and various higher-order subjects by treatments interactions, is typically deemed in experimental situations to be a less interesting, unavoidable nuisance and relatively small in comparison to other effects.

To make this argument more convincing, it should be shown that residual scores in comparison with the total or raw scores, change their common-factor's variance. Ideally, this could be checked by calculating the sum of all residual scores for every subject, including this sum in the factor analysis, and observing changes in factor loadings. Residual scores do not contain variance due to main effects and their interactions, and it may be concluded that the change should be attributed to experimental manipulations. There are many fine points of a statistical nature that should be tackled and understood before one can effectively employ the strategy suggested above. What is reported below represents a very rough first approximation to what is required[9].

Table 12 shows the correlations among the nine cells of the White Noise Masking test and the factor scores. The top section of Table 12 gives the raw-score correlations, the middle row provides total-score correlations and the bottom section contains residual score correlations. It is important to note the following: a) total-score correlations are, on average, higher than the raw-score correlations (this is because of the correlations among the cells of the design) but they display the same trend; and b) residual-score correlations are lower than raw-scores' correlations and generally closer to zero. The first observation establishes the link between individual differences under various signal/mask combinations and overall performance on the White Noise Masking test. This latter test, as argued before, is measuring the same trait as it did in previous studies, i.e. the Speech Perception Under Distraction/Distortion factor. The second point emphasizes that, if main effects and their interactions are partialled out, residual scores no longer correlate with the external variables in the same fashion and to the same extent as did the raw scores. The argument works in the opposite way as well, i.e., the presence of White Noise Distraction in an otherwise easy task leads to an increase in the common factor variance. The change in correlations is due to experimental manipulation. The situations which may arise when one applies this procedure to observe changes in correlations are quite varied and may be surprising in some cases. For example, it is possible to have significant effects in the analysis of variance and simultaneously have only minute changes in a measured trait's variance.

A wealth of other detailed information is contained in Table 12. For example, analyses of the kind suggested by Fleishman (1975) regarding changes in correlations or factor structure as a function of experimental levels can easily be performed with the present data. This will not be done here for lack of space.

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[9] The procedure employed in the main body of this paper suggests that one should use the sum of the residual scores which would be analogous to the total scores employed in previous factor analyses. This is impossible to do, since with the randomized block designs (or repeated measures designs) the sum of the residual scores for every subject equals zero. The first step in the approximation requires a proof that raw scores for every cell show the same pattern of correlations as does the total score, and then one can use residual scores' correlations in order to discern the relationship of interest.

Table 12

Correlations Between Factor Scores
And White Noise Masking Test

(Raw scores, Total score, Residual scores)

| White Noise Masking | | | Primary Factors | | | |
|---|---|---|---|---|---|---|
| | | | Tm | Tc | MaJR | Va-Ms |
| Raw scores | | | | | | |
| | Mask | Signal | | | | |
| 1. | Left | Left | .21 | .10 | .33 | .05 |
| 2. | Right | Left | .29 | .04 | .23 | .19 |
| 3. | Both | Left | .20 | .07 | .35 | .17 |
| 4. | Left | Right | .30 | .36 | .30 | .05 |
| 5. | Right | Right | .32 | .09 | .22 | .14 |
| 6. | Both | Right | .36 | .23 | .30 | .22 |
| 7. | Left | Both | .37 | .45 | .35 | .20 |
| 8. | Right | Both | .25 | .42 | .21 | .07 |
| 9. | Both | Both | .35 | .26 | .34 | .24 |
| Total score | | | .49 | .34 | .50 | .27 |
| Residual scores | | | | | | |
| | Mask | Signal | | | | |
| 1. | Left | Left | -.03 | -.08 | .12 | -.09 |
| 2. | Right | Left | -.15 | -.28 | -.23 | -.05 |
| 3. | Both | Left | -.01 | -.10 | -.16 | .07 |
| 4. | Left | Right | -.28 | -.05 | -.30 | -.26 |
| 5. | Right | Right | .04 | -.12 | -.08 | -.01 |
| 6. | Both | Right | .18 | .10 | .09 | .13 |
| 7. | Left | Both | .03 | .29 | -.01 | .02 |
| 8. | Right | Both | -.24 | .12 | -.30 | -.20 |
| 9. | Both | Both | .16 | .13 | .15 | .15 |

## 2.4 Relationship Between MsOI Test, Primary Factors and External Variables

The Memory Span Order Interference test was not originally factor-analyzed together with the other auditory variables of our battery but is included in the factor analysis reported in Table 9. Inspection of this Table

Table 13

Correlations Between Factor Scores And
Memory Span Order Interference Test
(Raw scores, Total score, Residual scores)

| Memory Span Order Interference | | | Primary Factors Tm | Tc | MaJR | VaMs |
|---|---|---|---|---|---|---|
| Raw scores | | | | | | |
| | Interference | Signal | | | | |
| 1. | Left | Left | .25 | .17 | .33 | .62 |
| 2. | Right | Right | .14 | .01 | .26 | .45 |
| 3. | Both | Left | .04 | -.02 | .14 | .49 |
| 4. | Left | Right | .17 | .09 | .29 | .48 |
| 5. | Right | Right | .04 | -.02 | .23 | .46 |
| 6. | Both | Right | .08 | .13 | .22 | .49 |
| 7. | Left | Both | .17 | -.04 | .34 | .45 |
| 8. | Right | Both | .19 | -.07 | .15 | .48 |
| 9. | Both | Both | .17 | .13 | .35 | .43 |
| Total score | | | .19 | .06 | .34 | .64 |
| Residual scores | | | | | | |
| | Interference | Signal | | | | |
| 1. | Left | Left | .22 | .22 | .19 | .36 |
| 2. | Right | Left | .00 | -.05 | .03 | .00 |
| 3. | Both | Left | -.17 | -.11 | -.19 | -.01 |
| 4. | Left | Right | .06 | .08 | .10 | .06 |
| 5. | Right | Right | -.20 | .10 | -.14 | -.21 |
| 6. | Both | Right | -.15 | -.10 | -.16 | -.19 |
| 7. | Left | Both | .02 | -.12 | -.10 | -.08 |
| 8. | Right | Both | .09 | -.15 | -.12 | .06 |
| 9. | Both | Both | .02 | .13 | .11 | -.13 |

shows that MsOI provides yet another measure of the Va(Ms?) factor. Among the Va(Ms?) variables, it has its highest correlation with the Memory Span Forward test (r = .61). Therefore, if Va(Ms?) were to be split into two factors, these would undoubtedly be Va and Msa Va(Ms?) contains about equal proportions of variance from Memory Span and Auditory Verbal Comprehension. It will be referred to as the Va-Ms factor in the remaining sections of this paper.

Table 13 contains the same information for the MsOI test as was provided for the White Noise Masking test in Table 12. As would be expected from the results of the factor analysis, the total score correlates highly (r = .64) with the Va-Ms factor and it has a noteworthy (r = .34) correlation with the Maintaining and Judging Rhythm factor. The raw-scores' correlations show the same relationship. Just as with the WNM, experimental manipulation (presenting signal and interference to different ears) has reduced the amount of common variance present in the residual scores. It should be noted that underlying mechanisms in the MsIO are less clear than what was the case with the WNM test. On the other hand, it can be observed that although the F-tests were much smaller with the MsOI test than they were with the WNM test, the reduction in the residual scores' correlations is approximately the same in both. This implies that the size of experimental effects may have little to do with the pattern of individual differences in some situations and suggests that the analyses described here may provide useful information[10].

## 2.5 Dichotic Listening Test

The dichotic listening paradigm is accepted as a means of investigation of hemispheric lateralization with the intact brain (Kimura, 1967). This study used the dichotic listening test in its classical form which consists of the simultanous presentation of three pairs of digits to each of the two ears. Thus, the left ear may be presented with 7, 2, 5 and the right ear simultaneously with 1, 8, and 3, and so on. It has been reported that people usually have better recall for digits presented to their right ear, as occurred in the present study with 54% of our sample reporting more right-ear digits, 29% reporting more left-ear digits and the remainder showing no ear superiority (11%) or ceiling effects (6%). Right ear superiority has been attributed to the left hemisphere's specialization for speech signals and the occlusion of ipsilateral pathways by the contralateral ones.

Since all items of this test contain only six numbers to be reproduced, without the element of dichotic presentation it would be simply a memory span measure and its variance would be considerably reduced. The experimental manipulation would be expected to increase the common factor variance of this task. In a previous study (Stankov, 1980) a dichotic listening test correlated primarily with a Memory Span factor. The correlations among all four primary factors and some of the Dichotic Listening scores in the present study are displayed in Table 4. It can be seen that the highest correlation is with the Temporal Tracking factor (r = .51) and that the

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[10] It should be mentioned that partialling out the ear differences (conditions of presentation effect) for 13 variables which was reported in the first part of this paper did not lead to a dramatic change in correlations. Raw scores and residual scores had the same correlations with factor scores. This means that experimental manipulation does not have to have the same effect as is reported here for the White Noise Masking and Memory Span Order Interference tests.

correlation with the Va(Ms?) factor is the second highest (r = .36). It should be remembered that the Va(Ms?) composite was formed by adding the Synonyms Vocabulary, the Rapid Spelling, and the Memory Span Forward scores. When the Memory Span Order Interference test was added to the composite (which factor loadings indicated was appropriate-see Table 9), the correlation between the composite and the Dichotic Listening test increased to r = .48. The high correlation which Temporal Tracking has with Dichotic Listening is mainly due to Letter Reordering and RST tests variance; both contain speech stimuli.

Table 4 also shows the correlations between the primary factors and scores representing the number of items for which only digits presented to right (and also left) ear were correctly recalled. These correlations indicate that the person who is better at recalling right-ear numbers also has a better Temporal Tracking score and that the person who is better at recalling the left-ear numbers is also better on the Va-Ms factor. An interpretation suggested by this result is that Dichotic Listening performance depends differentially on Temporal Tracking and Va-Ms processes. This finding may have implications for the calculation of laterality indices based on the dichotic listening paradigm (see Repp, 1977, for review), for presentation to one ear may implicate a different process from presentation of the same material to the other ear.

A comment on the role of interference: This study has not provided a detailed answer to the question of whether interference tasks produce a factor which cuts across different primary tasks. However, the evidence from this sample of three tests argues against such a possibility. All items used in the tests of this section were easy in themselves. Interference increased individual differences in performance in a way similar to increasing task difficulty. For all three tests, introduction of interference made an easy task into a task with a significant amount of shared systematic variance with other markers for the corresponding primary factors.

## 3. Binaural Sensory Interaction Tasks and Measurements

We now consider yet another class of competition tasks. These involve perceptual and sensorial processes peculiar to binaural hearing. In essence, they involve measurement of differential sensitivity for the two ears. Competition derives from the fact that different messages have to be combined before being processed. In particular, we shall be concerned with ear preferences, binaural diplacusis, and hearing acuity differences among the ears.

### 3.1 Ear Preference for Tones

In a study by Efron, Bogen and Yund (1977) an ingenious method for investigating ear preference or dominance for tones was employed with

commisurotomized patients. The method itself, the Dichotic Chords test, is described below. In normal subjects, ear dominance does not correlate either with handedness or with ear advantage for dichotically presented speech sounds. In fact, Efron et al. (1977) state that "ear dominance for pitch information contained in dichotic chords involves mechanisms quite distinct from the one responsible for producing the small right or left ear advantage when speech or musical stimuli are used". This calls for checking ear dominance prior to any work on lateralization with auditory stimuli. Deutsch (1975), for example, interprets similar results to those indicating ear dominance, as providing evidence for cerebral lateralization.

The Dichotic Chords test consists of the following type of presentation:

| | | | |
|---|---|---|---|
| Left ear | 1900Hz | | 1500Hz |
| Right ear | 1500Hz | | 1900Hz |
| | 320msec. | 600msec. | 320msec. |

In this example, the left ear is presented with a 1900 Hz tone and, shortly afterwards, 1500 Hz tone. The right ear receives the same two tones in the opposite order. Thus subjects receive two dichotic chords, one after the other.

According to Efron *et al.* (1977), with a small frequency difference between the dichotic tones, subjects hear a single fused sound image. The task is to state whether the first or the second successively presented pair of stimuli was higher in pitch; this is a forced-choice task. Under these conditions, approximately 1/3 of the subjects will report in the above situation that they hear the low-pitched tone first and these people are labelled (in terms of the sequence given in the example) as right-ear dominant. Another 1/3 of the subjects will give the opposite reply, and the rest will show no ear dominance.

The particular stimulus material used to test ear dominance was selected in order to check two things. Firstly, we wished to replicate a finding of Efron and Yund (1975) which indicates that frequency difference of up to 400 Hz produces the ear dominance effect and for this purpose we used two intervals : 400 Hz and 200 Hz. Secondly, in most of their reported work, Efron and Yund employ a relatively high set of frequencies (above 1,500 Hz). Deutsch (1975), however, used frequencies of 400 Hz and 800 Hz and this may account for the conflict in interpretation. Items in the present study covered a range of frequencies from 400 Hz to 4,000 Hz.

There were three blocks of items (Low-, Middle-, and High- frequency blocks). Blocks of 24 items were constructed in the following way. For the low-frequency blocks, 10 frequencies were used: 400, 500, 700, 800, 900, 1100, 1200, 1300, 1500 and 1600 Hz. The first two items were made of 400-800 Hz and 500-700 Hz pairs. These were repeated once on the same ears, and twice with the channels reversed. Another two items were made of 800-1200 Hz and 900-1100 Hz tones. Again, they were

Table 14

Arithmetic Means For The Ear Dominance Test
(Dichotic Chords test)

| | | Frequencies[a] Low | Middle | High | |
|---|---|---|---|---|---|
| Frequency Differences | 200Hz | 6.40 | 6.17 | 5.86 | 6.14 |
| | 400Hz | 6.41 | 6.76 | 6.60 | 6.59 |
| | | 6.40 | 6.46 | 6.23 | 6.36 |

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[a] Low = 400 Hz to 1,600 Hz; Middle = 1,600 Hz to 2,800 Hz; High = 2,800 Hz to 4,000 Hz.

presented four times. The final two items consisted of 1200-1600 Hz and 1300-1500 Hz tones. In this way we obtained 12 items with 200 Hz difference and another 12 items with 400 Hz difference. Items were randomly assigned to a position within a block. The ten "middle" frequencies ranged between 1600-2800 Hz and the "high" block employed 2800-4000 Hz with intervals of the same magnitude as those for the "low" block.

The test was scored by assigning "1" to those items for which the subject reported the left ear sequence and "O" to those for which the subject reported the right ear sequence. The results were analyzed using the ANOVA procedure for a 2 x 3 design with the main factors being frequency difference and frequency level. The results are presented in Table 15.

It is apparent that there are no differences in ear dominance across the range of frequencies (low-, middle-, and high-) investigated here (F(2,485) = 1.00, $p > .05$) and therefore it is likely that the same processes are involved at both high and low frequencies; Deutsch and Efron and Yund were referring to the same phenomena. On the other hand, the difference between the two levels of frequency differences (200 Hz vs. 400 Hz) is significant (F(1,485) = 10.01, $p > .05$). This was not anticipated, but it can be understood in terms of an increased differential threshold for high frequency tones. This would lead to a chance performance on the 200 Hz difference for high frequencies, and the obtained cell mean of around 6.00 (i.e. 6.17 for the "middle" block and 5.86 for the "high" block) implies such an interpretation. The interaction term was not significant.

Correlations between the Dichotic Chords test and the primary factors are given in Table 4. This task has virtually zero correlation with three of the primary factors but its correlation with the Tonal Memory factor is .18, indicating that some, admittedly relatively small, part of Tonal Memory's variance is accounted for by ear dominance.

## 3.2 Binaural Diplacusis

Binaural diplacusis (see Ward, 1970) refers to a phenomenon in which the same tone presented to two ears sound differently, or different tones sound the same. In the past, this was viewed as pathological condition which occurs rarely in a population. However, some of the more recent Dutch work on residue pitch indicates that the presence of binaural diplacusis is a more common phenomenon than was previously thought (see Van Den Brink, 1974; Ward, 1970; Efron, 1979). The reasons for this phenomenon's possible importance here have been discussed in Chapter IV.

In order to obtain diplacusis measurements, tones at ten different frequencies were given to both ears four times generating 40 items. The frequencies used were 2000, 2100, 2500, 2600, 3000, 3100, 3500, 3600, 4000, and 4100 Hz. Another 50 items were generated by presenting tones separated by 100 Hz, e.g. a 2000 Hz tone to the left ear and 2100 Hz tone to the right ear. This was done using every pair of adjacent frequencies separated by 100 Hz intervals. All 90 items were randomly assigned a position within the test. The task was simply to state whether the tones presented to the two ears were the same or different.

Scoring was in terms of number correct and the correlations with the psychometric factors are presented in Table 4. Although the Tonal Memory factor scores have the highest correlation with binaural diplacusus ($r = .26$), Tc and MaJR correlate with it comparably ($r = .20$ and $.21$, respectively). These correlations may follow from the fact that all these primaries represent a measure of Ga. Since the magnitudes of these correlation coefficients were not particularly high, the items of the test were divided into two groups: "lower" frequencies included items involving 2000 to 3000 Hz tones, and "higher" frequencies involved 3100 to 4100 Hz tones. It was reasoned that diplacusus for the higher frequencies would affect mainly higher-order harmonics and that lower-order harmonics and actual tones themselves would be more affected by diplacusis at lower frequencies. This proved to be the case: diplacusis for lower frequencies has a higher correlation with Tonal Memory ($r = .33$), than does the diplacusis for higher frequencies ($r = .05$). Correlation of binaural diplacusis and the Maintaining and Judging Rhythm factor ($r = .21$ and $r = .29$) can perhaps be understood through its link with the broad auditory factor, Ga.

There are three possible explanations for the finding that the role of binaural diplacusis in Tonal Memory is relatively smaller than expected. Firstly, an insufficiently sensitive measure of diplacusis may have been used. In some studies, a method of adjustment has been employed. In this method one has to adjust a continuous tone coming to one ear to sound the same as a tone presented to the other ear. Secondly, it is possible that if the range of frequencies below 2000 Hz were employed, higher correlations would be obtained. Thirdly, Total Memory involves processes that are too complex to be strongly related to the essentially sensorial measures of binaural diplacusis. This last hypothesis is supported by a finding that the Tonal Memory factor correlates with both general and musical education.

### 3.3 Hearing Acuity Correlations

Another class of sensorial tasks used in this study are the audiometric measures of absolute thresholds for different frequencies. If the ears display different sensitivity to the same frequency, the combination of the two signals coming from them would represent an example of competition in the sense discussed here. In practice, however, it is hard to assess the resulting percept received by the central nervous system. For this reason we have not obtained a separate "competition" scores for acuity. Instead, we have chosen to study the relationship between the individual measurements and other variables of the battery.

Correlations between the audiometric measures (variables 8 to 17) and factor scores are given in Table 4. These correlations are lower with the Va(Ms?) factor than they are with the other three factors (Tm, Tc, MaJR) of the battery. This supports the view that the latter factors represent markers for the Ga. These correlations are also somewhat higher than Binaural Diplacusis (variables 19 to 21) and Ear Dominance (variable 22) have with the psychometric factors. This suggests that competition due to acuity differences between the ears may have a greater generality than Ear Dominance and Binaural Diplacusis.

The factor matrix presented in Table 9 contains a factor with (reflected) loadings from four hearing acuity measurements. These were the threshold values for the extreme frequencies employed in this study (500 Hz and 4,000 Hz) for left and right ears. The hearing acuity factor (Ac) was related to Ga in a study by Horn and Stankov (1982). The result of factor analysis is in agreement with the primary factors/external variables correlations presented in Table 4. It is apparent that correlations among the acuity measures are high enough to form another factor and this new factor correlates higher with the Ga markers than it does with Va(Ms?).

## CHAPTER VI

## BEYOND COMPETITION

This study was designed in order to explore the relationship between psychometrically defined abilities and experimental tasks characterized by the presence of some kind of competition. Figure 5 organizes the major findings of the study. The second bottom row of the hierarchy summarizes the outcomes of factor analysis as presented in Tables 3 and 9.

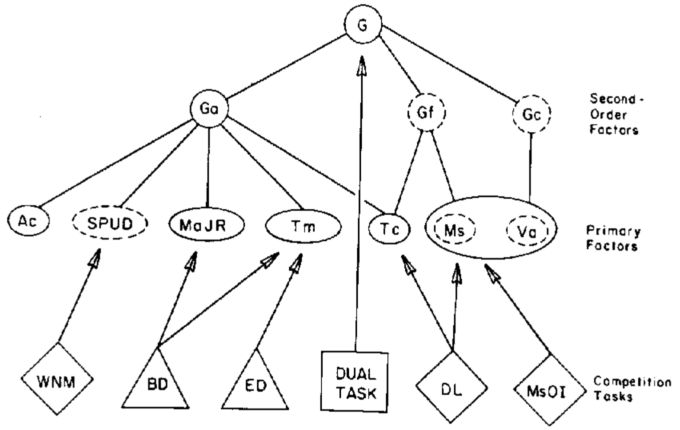

*Figure 5.* Summary of the main findings of this study. The solid lines indicate obtained results and dashed lines represent assumed or obtained weak relationships. All lines including arrows indicate correlations. The shapes of the boxes for competition tasks (diamond, square, triangle) indicate that they are conceptually different as described in the text. G = the highest-order factor, Gf = fluid intelligence, Gc = crystallized intelligence, Ga = broad auditory function, Ac = acuity factor, SPUD = speech perception under distraction/distortion, MaJR = maintaining and judging rhythm, Tm = tonal memory, Tc = temporal tracking, WNM = white noise masking, ED = ear dominance measured by the dichotic chords test, BD = binaural diplacusis, DT = dual task, DL = dichotic listening, MsOI = memory span order intereference test.

Evidence was found for Tonal Memory (Tm), Temporal Tracking (Tc), Maintaining and Judging Rhythm (MaJR) and Auditory Verbal Comprehension—Memory Span (Va-Ms) factors. Two slight modifications are introduced in the Figure. First, although Va-Ms was treated as a single factor throughout the study, it is represented as two separate primary factors—Auditory Verbal Comprehension (Va) and Memory Span (Ms)—in the diagram. There is no doubt that if there were more markers for Va and Ms in our test battery, they would stand apart, and it is important to distinguish them because they are markers for crystallized and fluid intelligence respectively. The second modification is the inclusion of a separate Speech Perception Under Distraction/ Distortion factor. This factor did not appear in the analyses because there was only one marker for it—the White Noise Masking test. Correlations of this test with other variables were in accordance with previous results, justifying the use of this test as a marker for SPUD primary.

The second top row of the hierarchy represents the obtained broad auditory function (Ga) and the assumed fluid and crystallized intelligence (Gf and Gc) second-order factors, and at the top is a general factor (G). Ga was supported by an adequate number of markers whereas Gf and Gc were under-determined in the present study.

In the bottom row of Figure 5 are the presumed competition tests (psychometric tests represented in Figure 1 are not presented in Figure 5). The arrows linking them to the hierarchy indicate correlations, not established causal relationships. The variations in the strengths of relationships are not depicted in the diagram.

The concept of competition has hitherto been used mainly in a descriptive sense. Basically, it has been descriptive for certain elements common to several factors of the broad auditory function (Ga) and to the experimental variables selected for this study. This is unsatisfactory in the long-term because description is only the first step towards understanding. We have gone beyond description with the introduction of the idea of compensation as a means for explaining overlap among the factors of Table 9. This explanation of individual differences in terms of the adoption of variable solution strategies may transfer to some competition tasks (i.e., the Dual Task).

## 1. Competition, Attention and Working Memory

Another possible explanation of individual differences compatible with the results presented here, is provided by a model which proposes that three basic "compartments"—sensory analysis, working memory, and archive—are concerned in the processing of information. The third of these "compartments", the archive, which contains information received in the past, was not investigated extensively in the present series of studies and we shall not elaborate on its role any further.

The most important for the present study is the working memory "compartment". Earlier in this paper the concept of working memory was introduced in relation to the work of Baddeley and Hitch (1974), in order to account for individual differences in the Temporal Tracking tasks and the possibility of collapse in the concurrent load tasks. For our present purposes, it can be best understood as the joint operation of two functions—a passive part which holds information immediately needed for task execution, and an active part which performs operations upon the stored information.

Two essential assumptions underly this conceptualization. First, the system has a limited processing capacity and second, there is a dynamic relationship between active and passive parts such that the more capacity is used for storing information in the passive part, the less capacity is left free for active operations.

Those familiar with the recent literature on attention will recognize the above model as a version of Norman and Bobrow's (1975) "Limited Resources" model. Hunt (1978; 1980) elaborated on a similar set of ideas. As we shall see, this model is already in need of modification. First, we shall consider briefly some data which were collected subsequent to the work reported here.

## 2. Working Memory and Intelligence

A study by Crawford and Stankov (1983) was designed in order to correlate measures of the active and passive aspects of working memory with the primary factors which represent the accepted markers for fluid and crystallized intelligence. It was found that fluid intelligence has higher correlations with the active part of working memory than it does with its passive aspects. In other words, operations performed on information in working memory are more indicative of fluid intelligence than is the ability to hold this information in working memory.

The second study (Fogarty and Stankov, 1982) was designed to check some of the findings presented in this monograph. In particular, six dual tasks were constructed with the expectation that both the increased correlation between the components and factorial overlap would replicate. Increased correlation was indeed observed in four tasks which were scored in a manner comparable to that employed here. Evidence for overlap was, however, absent.

A particular aim of the study was to discover whether any lawful features of factorial structure could be attributed to the presence of competition. It was found that components of the competing dual tasks have somewhat higher loadings on the general factor. This is depicted in Figure 5 by an arrow linking the Dual Task to "G". In dual tasks, both passive and active parts of working memory are taxed because of the need to keep in mind twice as many items of information and simultaneously perform two different sets of operations upon them. This in turn suggests that individual variations in processing capacity may be a contributing factor to general intelligence.

## 3. Sensory Competition

The sensory "compartment" of the model, has a relatively small role in intellective performance. This is apparent from the fact that, in this study, sensory competition tasks had noteworthy (although low) correlations only with the primaries of the broad perceptual auditory factor, Ga. The findings do, however, justify the hypothesis that a special kind of competition involving the mechanisms of masking, inhibition or interference underlie the perceptual factors. Similar ideas were put forward by Witkin and his co-workers (see Witkin, Dyk, Faterson, Goodenough, and karp, 1962) in order to account for the concept of field dependence and field independence.

## 4. Competition and Attention

Although it is probably true that the attention tasks, particularly those that are close to our Dual Task (i.e. divided attention tasks), exhibit the phenomenon of, and can be treated as, competition tasks, it is not so certain that the processes investigated in studies of mental concentration, search, and vigilance bear close relation to these phenomena. These tasks, one suspects, would not load on the same factor and some of them (e.g. vigilance) would have low correlation with intelligence. The same holds, as we have seen, for the variety of competition tasks chosen for this study. It is sensible to ask, therefore, whether competition and attention refer to the same thing. With the present definition of words, the answer is obviously "no". There are competition tasks (notably sensory interaction and interference) which would not be called attentional by most people and attentional tasks (e.g. vigilance) which do not implicitly involve competition. Nevertheless, the overlap between the two definitions is founded in reality, and suggests the need for a process of "precipitating out" whereby the tasks from both areas which involve competition at the level of central processing be abstracted and grouped together to form a new category of tasks - which is the central concern of this paper and the one which, it is hypothesized, is most likely to be closely related to general intelligence.

Quite apart from this ambitious possibility, however, the link between attention and competition means that a large literature on attention can be brought to bear upon our understanding of individual differences in intelligence. Further work on the Dual Task should be of both intensive (varying difficulty levels of the components) and extensive (using a variety of components in Dual Task combinations).

## 5. Some Qualifying Remarks Regarding the Role of Competition

A question which must at some time be asked is whether some kind of competition plays a role in every factor depicted in Figures 1 and 5. The chances are that there are abilities in which individual differences do not come about through the presence of competition (or limitations on capacity). On the other hand, it is likely that there are abilities which exist because of a specific yet undefined form of competition. Visual abilities are the candidates for further research into the role of competition.

Finally, it is important to note that the existence of a single pool of attentional resources has been questioned recently on theoretical grounds

(Allport, 1980) and on the basis of empirical findings (Hunt, 1980). Both these authors suggest that it is more reasonable to assume that there are several pools of resources rather than a single one. This suggestion is particularly well supported by the existence of a variety of psychometric factors. The view espoused in this article is that there is a general pool and some smaller pools of resources.

# CHAPTER VII

## SUMMARY AND DISCUSSION

The study reported here provides information at several different but interrelated levels. It is, at the same time, an essay in replicating previous findings and an attempt to extend our knowledge about cognitive functioning. At another level, it demonstrates the application of some new methods of data collection and analysis to the above issues. All these aspects have implications for our understanding of the structure and dynamics of cognitive abilities.

The design of this study was guided, in part, by the structural theory of fluid and crystallized intelligence (Gf/Gc) which acknowledges the existence of several broad functions among cognitive test performances. A particular emphasis in this study is given to primary abilities that define a broad auditory function, Ga. These include Tonal Memory (Tm), Maintaining and Judging Rhythm (MaJR) and, in this case somewhat less well defined, Speech Perception Under Distraction/Distortion (SPUD). Since separate factors of Temporal Tracking (Tc) and Auditory Verbal Comprehension- Memory Span (Va-Ms) also appeared, it became possible to draw inferences about fluid and crystallized intelligence as well.

One of the concerns of this article was to provide a replication of previous findings of ear and hemispheric differences in test performance. The results indicate that although a similar factor structure obtains under monaural and binaural stimulus presentation, it cannot be claimed that all verbal tasks are better performed by the left hemisphere and that all tonal tasks are better performed by the right hemisphere. Lateralization of functions has led to a large number of empirical studies and speculative statements by both biologists and psychologists. The reason for excitement, although never explicitly stated, derives from the possibility that this may call for a re-examination of the "doctrine of human faculties". Factors have often in the past been likened to "bumps in the head" and the work on lateralization of this large group of scientists, together with the writings of Bock (1973), opens the prospect of returning factors to their old status. Stankov (1980) reported a direct relationship of factors and ear differences data and it appeared that some aspects of the old doctrine could stand if viewed in the light of new findings. Only partial success in replicating the original results here suggests that further hypothesizing in this direction should be postponed.

The major concern of this paper was to investigate the relationship between psychometric factors and experimental competition tasks. These latter tasks have been conveniently divided into three groups—the Dual Task, the distraction and interference tasks, and the sensory interaction tasks.

The most interesting is the Dual Task in which two markers for primary abilities are given simultaneously to two ears. The present study provides evidence that components of the Dual Task have higher correlations among themselves than when they are given separately. These components also have higher correlations with measures of academic achievement than their single counterparts. Another study (Fogarty and Stankov, 1982), shows that six Dual Tasks have higher loadings on the general factor of their battery than do the corresponding single tests. Overall, this evidence suggests that the Dual Task represents a good measure of intelligence.

It is important to note that the competition tasks that have the greatest contribution to G (i.e. the Dual Tasks) are also those which are most similar to a particular type of attention task which involves competition of inputs and which has been understood in terms of a limited central processing capacity. Central processing capacity in turn, has been related to intelligence by attention theorists (see Hunt, 1980) and the high contribution of these tasks to G supports this view. At the same time, this relationship provides us with an insight into what a large component of the essence of intelligence may be—i.e. large central capacity or, as most of these tasks involve multiple processing, ability to process more than one input at once. These are obviously interrelated and at present it is not clear which has dominance.

The present study, and indeed the research on individual differences in general also suggests that the idea of a single central capacity processor is not a completely comprehensive conceptualization. In particular, the existence of different ability factors indicates that, in addition to a general pool of resources, it is meaningful to consider also the existence of some smaller and more specialized pools of resources.

These concepts can contribute to an explanation of individual differences in Dual Task performance. A suggestion, based on the findings of this paper, is that a particular kind of compensatory mechanism might be operative. If a person has a high ability on one component of the Dual Task, he/she can solve that component efficiently, leaving extra capacity free for working on the other component.

In this paper, the concept of the limited capacity central processor is explicitly linked to the concept of working memory which, in turn, is understood to consist of two parts - a passive part and an active part. The findings of Crawford and Stankov (1983) indicate that the active part (which operates upon stored information) is implicated in intelligence.

In a rival analysis, the Dual Task represents merely an increase in complexity; two tasks must be more complex than either one alone. This viewpoint can be traced back to at least Spearman's and Binet's work at the beginning of this century. The evidence provided in support of this view was not entirely satisfactory however, because increase in complexity was subjectively defined on the basis of a psychological analysis of item content, and in most cases the tasks were completely different. With our Dual Task, the same variables are used, and the possibility that it may be measuring different traits is greatly reduced.

On the practical side, dual competing task can provide a new way to test intelligence particularly in samples of higher ability. Such a test would need less time to administer and it could lead to the development of new indices for expressing an individual's standing with respect to the population. It can utilize, for example, information about a person's movement within the scatterplot depicting single and dual presentation (see Figure 4).

In the competing tasks which do not relate highly to the general factor, G, competition occurs peripherally. This is best illustrated by the sensory interaction tasks—Binaural Diplacusis, Dichotic Chords Test, and hearing acuity measurements. It is also apparent in two of the distraction and interference tasks—the White Noise Masking test and the Memory Span Order Interference test. In both these tests, the peripheral quality of the competition is indicated by the fact that localization of signal and mask (although acting differently in the two tests) provide a significant contribution to the total variance. It has been argued at least once (see Horn, 1981) that the third interaction and interference task—the Dichotic Listening test—also involves peripheral processes. The problem with this interpretation derives from the fact that in experimental studies the Dichotic Listening test is treated as a measure of central processing capacity, not of peripheral processes. It is possible that in this study (and maybe in Horn's work as well) the test of Dichotic Listening employed was too easy and central processing capacity was not taxed sufficiently in order to show the involvement of the general factor. Processing of only six items of information was involved, and this is within the range of normal memory span.

In the distraction and interference tasks, the presence of distracting or competing input is an essential component because without it the task would be too easy and the variance of the tasks would disappear or would be greatly reduced. The introduction of competing stimuli also increases the common group variance of the test.

Weak relationships were found between the primary factors (mainly Tonal Memory) and sensory competition tasks like the Dichotic Chords test and Binaural Diplacusis. These two variables, as measured here, contribute relatively little to individual differences in higher mental processes. On the other hand, hearing acuity, assessed through the use of audiometric procedures, is related to several aspects of the broad auditory function, Ga.

Certain sections of this study were methodologically determined by the wish to replicate Stankov's (1980) findings on ear differences. Hierarchical factoring was applied to a correlational matrix consisting of the same set of variables given under three conditions of presentation (left, right, and both ears). Although interpretation of the first order solution would have been difficult, the second and third order factors were very clearly defined. This illustrates the usefulness of hierarchical solutions and recommends it as a method for comparing factorial structure when the same test battery is given repeatedly to the same group of people.

An additional methodological issue raised in this paper concerns the question of how to bridge the gap between the "experimental" and "correlational" disciplines in psychology. The present approach was to start with mental abilities as they have been established through the correlational approach, and to relate experimental variables to them by factorial techniques. The established mental abilities can then be understood in greater depth via the theories relating to the same experimental variables. A promising beginning to taking this process further appears to be to proceed by constructing tasks to measure proper mental abilities and allowing sufficient variation within the tasks in order to be able to examine the role of various within-task components.

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