DOCUMENT RESUME

ED 227 115 TM 830 043

AUTHOR Gustafsson, Jan-Eric
TITLE Visualization Processes in Learning as a Function of Method of Presentation and Individual Differences. 1982:09.
INSTITUTION Goteborg Univ., Molndal (Sweden). Dept. of Education.
SPONS AGENCY National Swedish Board of Education, Stockholm.; Swedish Council for Research in the Humanities and Social Sciences, Stockholm.
PUB DATE 82
NOTE 42p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Academic Aptitude; Aptitude Treatment Interaction; Attention; Foreign Countries; Individual Differences; Intermediate Grades; *Learning Processes; *Listening Comprehension; Memorization; Pictorial Stimuli; *Reading Comprehension; Sex Differences; Suppressor Variables; *Visualization
IDENTIFIERS LISREL Computer Program; Sweden

ABSTRACT

Starting with laboratory research on the suppression of visualization in reading, this study investigates effects of treatments (reading vs. listening and pictures vs. no pictures, in a 2x2 design) and aptitudes on the learning of verbal and spatial types of content. Approximately 100 fifth grade pupils were given a battery of four ability tests, learning materials dealing with the heart and the flow of blood, and immediate post-tests to assess acquisition of verbal and spatial aspects of the content. The Joreskog LISREL technique was used to analyze the main effects and interactions. It was found that acquisition of spatial content is superior in the audio-visual treatment, and that girls high in general ability perform better when listening than when reading. The results are interpreted in relation to research on visualization suppression and sex differences in lateralization of processing. (Author/PN)

1982:09

Visualization processes in learning as a function of method of presentation and individual differences

Jan-Eric Gustafsson

(The research reported here has been financially supported by the Swedish Council for Research in the Social Sciences and Humanities, and by the National Board of Education in Sweden.)

Table of Contents

ABSTRACT

With a starting point in laboratory research on suppression of visualization in reading, the study investigates effects of treatments (reading vs listening and pictures vs no pictures, in a 2 X 2 design) and aptitudes on the learning of verbal and spatial types of content. Subjects were about 100 5th grade pupils in each treatment, whom were given a battery of 4 ability tests, a learning material dealing with the heart and the flow of blood, and immediate post-tests to assess acquisition of verbal and spatial aspects of the content. For analyzing main effects and interactions the Jöreskog LISREL technique is used. The most important findings are that acquisition of spatial content is superior in the audio-visual treatment, and that girls high in general ability perform better when listening than when reading. The results are interpreted in relation to research on visualization suppression and sex differences in lateralization of processing.

1 INTRODUCTION

The present study investigates effects of pictures and modality of presentation in learning verbal and spatial types of content. Not only main effects are considered, but also differential effects of treatment as a function of individual differences.

The theoretical background of the study is derived from a series of studies conducted by Brooks (1967, 1968) on suppression of visualization in reading. In a typical experiment Brooks (1967) presented subjects with two types of messages. In one of these spatial relations were described, while the other type of message was nonspatial. Subjects listened to some of the messages, and for others an accompanying written copy of the message was provided. The task was to repeat the message verbatim after presentation.

Subjects made fewer errors on the spatial type of message when listening then they did when both listening and reading. The reverse pattern of results was found for the non-spatial messages. These results may be interpreted to indicate that reading interferes with the generation of an internal representation of spatial relations.

Brooks' (1967) research was replicated and extended by Peterson, Thomas and Johnson (1977). They introduced a series of modifications of the experimental tasks but were still able to replicate the original findings. They also asked subjects to perform mental rotations, and showed that information obtained through reading had typical characteristics of verbally represented information, while information obtained through listening had the typical characteristics of spatially represented information.

While it does seem to be a well established fact that reading interferes with visualization, different specific interpretations may be advanced to account for this. Brooks (1967) suggested two possible interpretations.

One is based on the hypothesis that visualization uses mechanisms specialized for visual perception. Since reading is a visual process as well, the two processes compete for the same limited resources, and cannot be performed simultaneously. Thus, in this interpretation the similarity with respect to sensory modality of reading and visualization is stressed.

This hypothesis is indirectly supported by research showing a functional similarity of imaging and perceiving (e.g. Peterson, 1975; Podgorny &

Shepard, 1978; Sheehan, 1975). Furthermore, in several pieces of research it has been found that visualization is disrupted also by other visual stimuli, which is, of course, a necessary, but not sufficient, condition for this interpretation to be true (Baddeley, Grant, Wight & Thompson, 1975; Janssen, 1976; Salthouse, 1975; Yuille & Ternes, 1975). Negative results have been reported too (Baddeley et al., 1977, Exp III; Kosslyn, Holyak & Huffman, 1976; Sherman, Kulhavy & Burns, 1976; Wright, Holloway & Aldrich, 1974). However, given the frequency of positive results, it is difficult to judge what weight should be attached to negative results, since the specific combination of visualization and perception tasks may be of great importance in determining whether any interference will occur (cf Janssen, 1976).

In the other interpretation suggested by Brooks (1967) it was suggested that reading interferes with reorganization into spatial representations because "reading forces the subject to deal with information in a more exclusively verbal form than does listening" (Brooks, 1967, p. 289). Thus, in this interpretation the difference in nature of reading and visualization processes is seen as the cause of suppression of visualization in reading.

Imagery and visualization processes have been shown to be of a global, holistic, analog kind, in which functional relations among imagined objects mirror functional relations among the objects as actually perceived (cf Shepard, 1978; but for contrasting views see Pylyshyn, 1973 and Anderson, 1978). Reading processes, in contrast, are sequential and logical, and recent theoretical accounts of the process of reading (e.g. Goodman & Goodman, 1977; LaBerge & Samuels, 1974) stress the hierarchical and automatized organization of subskills. Thus, according to these theoretical accounts the processes of reading and visualization are quite different in nature. To visualize, therefore, it is necessary that the entire system of hierarchically arranged reading processes is disrupted. Since the content of the visualization processes is provided through the reading processes, such disruptions must be frequent, which may be so taxing that the visualization processes are suppressed.

On the basis of the laboratory studies conducted by Brooks it is impossible to make a choice between these two interpretations of the cause of suppression of visualization in reading, and both seem to be supported by some indirect evidence. Before continuing this discussion, however, there is reason to consider a broader range of research on modality of presentation, and also research on the effects of pictures in learning materials.

Studies have shown reading to be more effective than listening in the learning of nonsense syllables (e.g. van Mondfrans & Travers, 1964), but in studies of real subject-matter the results are more varied. Sewell and Moore (1980) taught college students use of the library, and found reading a text to be more effective than listening to an audio recording. Clark (1978) tested the hypothesis of suppression of visualization by reading and compared, among other treatments, reading and listening in the learning of geometric designs. No significant difference in level of recall was found, but subjects did spend more time reading, which result was interpreted as supporting the hypothesis. Taken together these studies seem to indicate an interaction between modality of presentation and type of subject matter, such that reading is better when the subjects matter is verbal, while listening is better when the subject matter is spatial.

However, there are likely to be interactions involving other factors as well, such as the age level or reading level of the subjects. Wilkinson (1980) studied interactions between grade level and oral reading versus looking-listening. The results suggested a three-stage model in the development of skilled reading. In the first stage the child reads accurately but slowly so that there is loss of comprehension and memory. At the second stage, at about the fourth grade, the child is able to read at a rate equal to normal speaking rate, and recognition of words is no more demanding visually than auditorily. At this stage understanding is equivalent in reading and listening. At the third stage, finally, the child is able to read efficiently and rapidly, so that when engaged in a looking-listening task the child can listen and read simultaneously, and is thus able to review and clarify important information.

Research on the effects of pictures accompanying printed text exhibits a most varied pattern of results, showing in some studies positive effects, in others negative effects, and in still others no effects (for reviews see Lindström, 1980; Peeck, 1974; Samuels, 1970). Levin and Lesgold (1978) concluded, however, that granted that some ground rules are followed, pictures almost invariably have positive effects on learning and comprehension. One of these ground rules states that the verbal information should be presented auditively, which does suggest that reading interferes with extraction of pictorial information.

Given the functional similarity of imaging and perceiving such a result is in line with the findings of suppression of visualization by reading, and the same basic interpretation should apply in both instances. In one of the interpretations considered above it is argued that reading and visualization cannot be performed simultaneously because both are visual processes.

However, while it is true that reading and picture interpretation cannot take place simultaneously, these processes may be performed sequentially, and unless this hypothesis is complemented with the assumption that one visual process interferes with another visual process occurring later in time it is not able to account for interference between reading and picture interpretation.

The other interpretation considered states that reading and visualization (or picture interpretation) are incompatible types of processes, and that it is difficult to switch between these types of processes. Since reading tends to be the primary process, extraction of information from pictures is hampered.

It would thus seem that the latter hypothesis is the more powerful one of the two suggested interpretations. It must be stressed, however, that the empirical basis for this conclusion is quite shaky. Only few pertinent studies have been conducted, and among these many are laboratory studies of doubtful external validity. The present study was designed, therefore, to investigate simultaneously modality of presentation (i.e. reading versus listening) and pictures versus no pictures in the learning of verbal and spatial types of content. Before proceeding to describe the study there is reason, however, to consider another source of variation, namely individual differences.

In none of the studies considered so far have individual differences been addressed as a source of variation. However, if treatments encourage different kinds of processing, and if there are individual differences in the ease with which the processes are carried out, not only main effects of treatments would be expected, but also interactions with aptitude variables. Such aptitude x treatment interactions (ATI´s) may have great theoretical import (Snow, 1978; Underwood, 1975), as well as practical significance (Cronbach & Snow, 1977).

In ATI-research hierarchical models of the structure of abilities seem particularly useful (Gustafsson, Note 1; Snow, 1980). Such models include aptitudes of different levels of generality and they therefore are parsimonious, while they at the same time allow as detailed a description of narrow abilities as may be desired.

The particular model relied upon here is referred to as the HILI-model (hierarchical LISREL-based model; Gustafsson, Note 1; Gustafsson, Lindström & Björck-Åkesson, Note 2). This model includes the primary factors of the Thurstone (1938) and Guilford (1967) models, the second-order factors of the

Horn and Cattell (1966) model, as well as a third-order G factor. The G* factor is identical with the Gf (Fluid intelligence) factor in the Cattell-Horn model, which factor is a non-verbal reasoning ability, supposed to reflect influences of biological factors and incidental learning on intellectual development. Among the second-order factors, Gc (Crystallized intelligence) and Gv (General visualization) are the most important ones: Gc represents cognitive performances which have been acquired through experience and education, while Gv represents the ability to perceive and transform visual patterns.

One frequently studied ATI-hypothesis states that treatments employing pictures, illustrations, graphs and other visuals should be particularly helpful for pupils high in Gv, while treatments using written text as the main vehicle of exposition should be particularly helpful for pupils high in Gc. No strong support has been obtained for this hypothesis, however (for reviews see Cronbach & Snow, 1977; Gustafsson, 1976; Yalow, Note 3), and the relationships appear to be considerably more complex than anticipated.

However, even though the results are complex some tentative generalizations may be made (Gustafsson, 1976; Snow, 1977). It thus seems that pictorial treatments may be particularly helpful to pupils low in G. However, this effect seems to be restricted to fairly low-level types of learning, such as acquisition of terms (Gustafsson, 1976, Lindström, 1980), and it seems to be of low durability (Yalow, Note 3). The empirical results also afford the conclusion that pupils high in Gv are good at acquiring pictorial information (Gustafsson, 1976). But frequently acquisition of the pictorial information is not sufficient for answering correctly the post-test questions, and it may in fact be negative (Hollenberg, 1970; Samuels, 1967). Thus, only when learning the pictorials themselves helps achievement, Gv may be expected to be highly related to achievement in a pictorial treatment.

For the present study the specific prediction may be made that in the treatments not involving reading, and therefore no suppression of visualization, Gv is more highly related to acquisition of spatial content than in treatments involving reading. There is the possibility, however, that such a relationship is moderated by sex. Research indicates not only sex differences in level of performance on spatial tests, but also that males and females tend to adopt different strategies in the solution of such tasks, such that females more often adopt a verbal-reasoning approach (Gustafsson, 1976). If this is so it might imply that high-Gv males in particular should be able to take advantage of the better possibilities for visualization processes in treatments involving listening.

2 METHOD

Some parts of the present data have previously been analyzed by Gustafsson (1976, 1978) in substantive and methodological studies. Here the analysis of substantive questions will be carried one step further through a simultaneous analysis of the effects of 4 treatments. Methodological problems in the analysis of ATI-data are also considered since the rather new LISREL technique (Jöreskog & Sörbom, 1978) is relied upon in the analyses.

2.1 Treatments and subjects

The 4 treatments in the study were obtained by crossing the treatment variables reading vs listening and pictures vs no pictures:

The READVERB treatment. Subjects in this treatment group read for 17 minutes a mimeographed copy of the instructional material (see below), which did not contain any illustrations. During the allotted time most subjects read the material at least twice.

The READPICT treatment. This treatment was in all respects the same as the READVERB treatment, except that subjects read an illustrated version of the instructional material (see below).

The LISTVERB treatment. Subjects in this treatment listened to a presentation via taperecorder of the same material as was read in the READVERB treatment. The tape was played twice, with a pause of about 30 seconds between presentations. In all the presentations required about 17 minutes.

The LISTPICT treatment. This treatment was the same as the LISTVERB treatment, except that the illustrations, which were identical with those in the READPICT treatment, were presented as slides.

Each treatment group consisted of 6 5th grade classes, with the following total number of subjects in each group: READVERB N=120, READPICT N=109, LISTVERB N=120 and LISTPICT N=118. The treatments were administered within regular classes.

2.2 The instructional materials

The instructional materials dealt with the nature and functions of the human heart, and the circulation of blood in the body. The verbal part, which was the only information given in the READVERB and LISTVERB treatments, consisted of some 850 words.

In the materials some general information about the lungs and the body's need for oxygen is first given. In this context blood is described as consisting of, among other things, blood plasma and red blood cells. Transportation of blood in the body with the heart as a "pump" is then explained, along with information about the size, location and parts (left and right auricle, left and right ventricle) of the heart. It is also stated that when you see a picture of the heart the right half is located on the left in the picture.

In the main part of the remainder of the materials a red blood cell, called "Berra Blodis", is followed on a trip through the body. The trip starts in the lungs where the blood-cell picks up oxygen. Berra Blodis then enters into the left ventricle and goes from there into the left auricle. At this point it is mentioned that blood can flow only from the auricles to the ventricles because there is a kind of door, the valve, which prevents blood from going the other way. When the ventricle is filled with blood, the valve closes, the walls contract, and the blood flows out into the arteries. These divide into smaller and smaller ones, and when Berra Blodis arrives in the thinnest arteries he delivers his oxygen with the muscles and the other parts of the body. He then starts his way back to the heart through veins that become progressively thicker. When Berra Blodis gets back to the heart he has finished what is called the systemic circulation.

The blood cell comes back into the right auricle and goes, when the valve opens, into the right ventricle. When the ventricle is filled with blood the valve closes, the walls contract, and the blood flows through a vein to the lungs, where the blood cell again picks up oxygen.

It is then repeated twice that the circuit the blood makes when it delivers oxygen is called the systemic circulation, and that the circuit the blood makes from the right ventricle through the lungs back to the left auricle is called the pulmonic circulation.

The present content was chosen because some parts were judged to be of a verbal nature, while other parts were judged to be of a spatial nature.

The pictorial information (i.e. the additional information given in the READPICT and LISTPICT treatments) consisted of 14 illustrations. The illustrations are all rather stylized black and white drawings with little detail. The instructional material for the READPICT treatment is in its entirety translated into English and reproduced in Gustafsson (1976, pp. 202-208).

2.3 Post-tests

Immediately after subjects had received instruction they were given 2 post-tests: one with verbally formulated questions requiring verbal answers, and one with pictorial items.

The verbal post-test consists of 16 questions, some of which are hypothesized to refer to spatially demanding content, and some of which are hypothesized to refer to verbal content (see Gustafsson, 1976, pp. 209-210). From a subset of these items 2 scales were constructed. One, which will be referred to as VERB, consists of 10 items in the verbal content category. The items in this scale mainly ask for terms, and in some cases explanations of phenomena are asked for. Examples of items in this scale are the following: "What are the tubes called that blood moves in?", and "What different things does blood consist of?". The other scale constructed from the items in the verbal post-test consists of 4 items that ask to and from which chamber of the heart blood flows in relation to specified parts of the body. Since these questions test understanding of the relationships and relative localizations of the parts of the system, they are hypothesized to be of a spatial nature. This scale is referred to as the V-SPAT scale.

In the pictorial post-test there are 5 main questions, all of which, however, consist of a different number of sub-questions. From these items 4 have been selected which are pictorial counterparts to the items in the V-SPAT scale. In these items a picture is shown of the heart in which the flow of blood is indicated, and the task is to identify from where the blood is coming and to where it is going. This scale will be referred to as the P-SPAT scale.

The internal consistency of the scales has been investigated with procedures for testing fit of data to the Rasch model described by Gustafsson (1980) and by techniques for factor analysis of dichotomous data described by Muthen (1978). Both these types of analyses indicated that the 3 scales are unidimensional, and that they measure different dimensions.

2.4 Aptitude variables

Out of a somewhat larger set of aptitude variables available in the study, the following will be considered in the present analysis:

Opposites (Op) is a test designed to measure verbal ability. The test consists of 40 items in which the task is to find the antonym of a given word among four choices. The time limit is 10 minutes.

Metal Folding (MF) is constructed to measure spatial visualization ability. There are 40 items in the test and the task is to find among 4 choices the 3-dimensional object that can be made from a flat piece of metal with bending lines marked on the drawings. 15 minutes are allowed for completing the test.

Number Series (NS) is designed to measure inductive reasoning ability. It consists of 40 items where the task is to complete a series of 8 numbers, 6 of which are given. The time limit is 10 minutes.

A Paired Associates (PA) learning task was given to assess associative memory ability. The PA test was administered on 2 occasions, separated about 3 weeks in time, as 2 parallel forms. Each form consists of 22 object-pairs. For 11 of the pairs pictures of the objects are drawn adjacently and for 11 of the pairs labels of the objects are written adjacently. Within each form the pairs of pictures and words are randomly distributed, with the constraint that no more than 2 pairs of the same item type may appear consecutively. There exist 2 such random orders for each form. At presentation a slide was projected onto a screen at the front of the class-room and left for 4 seconds. The set of 22 pairs was shown twice, in the 2 orders. After the subjects had seen the pairs twice, they were given an answer sheet on which the label of the left-member of each pair was written, with instructions to fill in the label of the right-member. The number of correct answers to the two types of pairs was counted separately, but was collapsed over occasions. These scores will be referred to as PA-PICT and PA-WORD respectively.

The first 3 tests described above were constructed by Svensson (1971), while the PA test was constructed for the present study. For Op, MF and NS the number of correct answers on odd and even items was summed and used as half-test scores in the analysis.

2.5 Method of statistical analysis

Multiple regression (MR) analysis is the recommended statistical technique for analysis of data from ATI-studies (Cronbach & Snow, 1977). However, MR assumes that the independent variables are fixed, i.e. that the observed scores for any randomly chosen subject represent the true scores in which we are interested. But most psychometric instruments yield scores which are contaminated with errors of measurement, and often an observed score reflects more than one construct. The assumption that the aptitude variables are perfectly reliable and valid is, therefore, violated by most empirical data.

Violation of the assumption of perfect reliability results in biased estimates of the within-treatment regression coefficients, and as a consequence estimates of ATI-effects are biased as well. The amount of bias is a function of the unreliabilities and intercorrelations of the aptitude variables. However, even with typical reliabilities and correlations the bias is likely to be so severe that the risk of drawing incorrect conclusions about ATI's on the basis of an MR analysis is high (Gustafsson & Lindström, Note 4).

Recently, however, a new class of statistical techniques has been developed in which these problems are given elegant solutions, and which techniques bring other advantages as well. These methods are referred to with different labels such as structural equation methodology, structural relations analysis, and covariance structure analysis (for a review see Bentler, 1980), but all techniques belonging with the class may be viewed as combining confirmatory factor analysis with MR (or path analysis).

In the present context it is impossible to give anything but a very cursory introduction to this methodology, but a short description aiming at an intuitive understanding will be attempted. The particular technique relied upon here is the linear structural relations (LISREL) method of Jöreskog and Sörbom (1978, Note 5).

In LISREL a distinction is made between the measurement model and the structural model. In the measurement model relations between unobserved (or latent) variables and observed (or manifest) variables are specified in a confirmatory factor analytic model (e.g. Jöreskog, 1969). In the structural model, relations between the latent variables are specified in much the same fashion as in path analysis.

In the present study there are 8 observed variables (i.e. the 6 half-tests and the 2 PA-variables). These observed variables may be hypothesized to measure 4 latent variables: the 3 "true" variables underlying performance on the 3 tests Op, MF and NS, and a PA-factor (or Ma, for associative memory). This hypothesis is expressed graphically in Figure 1.

Insert Figure 1 about here

In the Figure observed variables are enclosed in squares and latent variables in circles. A straight one-way arrow indicates a causal influence of one variable on another, while a curved two-way arrow indicates a covariance, without any assumption about causation.

The 2 half-tests derived from Op are hypothesized to reflect the latent variable Gc. It is, of course, true that Gc is formally a higher-order factor, while the latent variable defined by the two half-tests also includes the specificity of the test and the specific part of the primary factor Verbal Comprehension (V). However, the contributions of these specific variances is likely to be quite small in comparison with the contribution from the second-order factor Gc (cf. Gustafsson et al., Note 2). In the same manner the two half-tests derived from MF are supposed to reflect Gv, and the two NS half-tests are supposed to identify Gf.

In the parametrization of the LISREL model the relations among variables and covariances among variables are specified in a series of parameter matrices. Given specification of a model, maximum likelihood estimates of the parameters can be obtained from the observed covariance matrix (see Jöreskog & Sörbom, Note 5). Under the assumption of a multinormal distribution of observed scores, a chi-square test of the goodness of fit of the model can also be obtained.

The parameters in the model in Figure 1 were estimated from the covariance matrix for the pooled set of subjects. The goodness-of-fit statistic yielded a chi-square of 20.27. With 18 df this statistic is non-significant ($p < .32$), so we cannot reject the model as fitting the data.

The model shown in Figure 1 is an oblique factor model. The correlations among the latent variables in this model are all positive and rather high, ranging between .57 for the correlation between Gc and Gf, and .26 for the correlation between Ma and Gf. This indicates that the latent variables have a general factor (or, perhaps, several "general" factors) in common.

It is possible to formulate higher-order measurement models within LISREL (cf. Gustafsson et al., Note 2). Such a model is shown in Figure 2. This model assumes that the 4 latent variables are caused by another latent variable (G). In addition to the common G-factor, each of the first-order factors is affected by a specific factor (Gc´, Gv´, Gf´ and Ma´, respectively) which is orthogonal to G. Here the specific factors are treated as latent variables which makes them available for further analysis.

Insert Figure 2 about here

The test of the model shown in Figure 2 resulted in chi-square = 25.46 with 20 df. Since the difference between the test-statistics for the two models is not significant (chi-square = 5.19, df = 2, $p < .08$) it may be concluded that it suffices with 1 higher-order factor to account for the relationships among the first-order factors. Since the higher-order model is the more parsimonious one it will be used as the measurement in the study of ATI-effects.

If the treatment groups are random samples from the same population, estimates of all parameters should be the same, within statistical limits, for the treatment groups. LISREL handles several groups of persons and it is possible to constrain parameters to be equal over groups which makes it possible to test such hypotheses about equality of groups of persons. A model estimated from the within-treatment covariance matrices, in which all parameters were constrained to be equal over groups, resulted in chi-square = 133.03 with 128 df. The alternative model in which no equality constrints were imposed gave chi-square = 86.34 with 80 df. Since the difference between these test statistics is not significant (chi-square = 46.49, df = 48, $p <$

.54) it may be concluded that the treatment groups are samples from the same population.

In some of the analyses of ATI-effects higher-order interactions with sex will be considered. This makes it necessary to investigate whether the same measurement model holds for both sexes, and a sequence of models were tried to test this. In these, the model shown in Figure 2 was modified to take into account the means on the latent variables as well (cf Gustafsson & Lindström, Note 4; Jöresko, & Sörbom, Note 5).

The same model did not fit both boys and girls (chi-square = 103.94, df = 64, $p < .001$), so one or more of the estimated parameters should be allowed different estimated values for the sexes. Further tests indicated that girls had a higher mean on the Ma' factor, while boys had a slightly higher mean on the Gc' factor. Differences also were found in the estimated error variances for the PA-scales, girls having a higher estimated error variance for PA-WORD and boys having a higher error variance for PA-PICT. Allowing these 4 parameters to take on different values for boys and girls a good overall fit was obtained (chi-square = 63.21 df = 60, $p < .36$).

So far we have only dealt with the measurement model for the aptitude variables, but it is necessary to specify a measurement model for the outcome variables as well. This model will here be taken to be a very simple one, in which the 3 observed outcome variables (VERB, V-SPAT and P-SPAT) are each taken to be identical with a latent variable. This model thus assumes that there are no errors of measurement in the outcome variables This assumption is, of course, false but it may easily be demonstrated that errors of measurement in the dependent variables do not bias estimates of within-treatment regressions.

The full LISREL model is obtained when the measurement model for the aptitude variables is put together with the measurement model for the outcome variables. This model is shown in Figure 3.

In this model the outcome scales are hypothesized to be affected by G, and these relations correspond with estimates of within-treatment regressions in MR. There may, of course, also be relations between one or more of the outcome scales and one or more of the specific latent variables, but for reasons of parsimony these are not included in the basic model.

The within-treatment regressions onto the latent variables may be tested for equality in the study of ATI-effects. As has already been mentioned it is

---

Insert Figure 3 about here

---

also possible to estimate parameters representing the means of the latent variables and the intercepts of the outcome scales. A sequence of LISREL models provides, therefore, all the information necessary for a complete analysis of ATI-effects.

3 RESULTS

In the first step of the analyses the model shown in Figure 3 was fitted within each treatment group to see whether any of the specific latent aptitude variables had a significant relationship with the outcome scales. Some such relationships were indeed found. In the READVERB treatment the regression of VERB on MA´ was significant, as was the regression of V-SPAT on Gv´. Within the READPICT treatment the regressions of V-SPAT and P-SPAT on Gv´ were found to be significant. These findings indicate the presence of ATI-effects in the data, even though no firm conclusions may be drawn from these analyses alone. However, in the model used for investigation of ATI-effects these further relationships were allowed for within all treatments.

The analysis of the results of the study was conducted as a sequence of increasingly complex models, in which main effects were first studied, then first-order ATI-effects, and finally higher-order interactions involving sex.

3.1 Main effects

The overall test of significance of the main effects for all 3 outcomes simultaneously is highly significant (chi-square = 65.89, df = 9, $p < .001$). It is meaningful, therefore, to go on to study the effects with respect to particular outcomes and treatments.

The design of the study is such that 2 treatment dimensions are fully crossed in a 2 X 2 design. With LISREL it is not possible to investigate simultaneously the main effects and the interaction, as it would be in an ordinary 2 X 2 analysis of covariance. However, by performing a sequence of analyses in which the intercept terms are constrained to be equal in pairs of treatments, it is possible to emulate tests of main effects of the reading/listening and illustrations/no illustrations factors, as well as of the interaction between the factors. The results from these tests are presented in Table 1.

Insert Table 1 about here

The overall effect of the treatments is significant for all outcomes, and most highly so for the P-SPAT outcome. For the VERB scale the separate tests of main effects show the LIST/READ factor, but not the VERB/PICT factor to be significant. Since the effect of the listening/reading factor completely accounts for the overall effect with respect to this outcome it may be concluded that there is no interaction between the two treatment factors for this outcome. For the other 2 outcomes both tests of main effects are significant, while at the same time none is able to account completely for the overall effect, which does indicate an interaction between the treatment factors.

The nature of the interaction is revealed from the estimated within-treatment intercept parameters presented in Table 2. The highest level of outcome on the V-SPAT and P-SPAT scales is achieved in the LISTPICT treatment, while in the other treatments there are no large differences in level of achievement. The better achievement in the LISTPICT treatment accounts completely for the overall treatment effect found with respect to V-SPAT and P-SPAT (V-SPAT:

chi-square = 15.55, df = 1, p < .001; P-SPAT: chi-square = 34.08, df = 1, p < .001).

Insert Table 2 about here

According to the theory of suppression of visualization by reading, a higher level of performance is expected in the listening treatments than in the reading treatments with respect to the spatial type of outcomes. No clear support is obtained for the prediction, even though the descriptive pattern of results to some extent favors the hypothesis. However, the interaction between the treatment factors does indicate that interpretation of pictorial information is unfavorably affected by reading. It also may be noted that that with respect to the verbal type of outcome listening is inferior to reading.

3.2 ATI-effects

An overall test of ATI-effects is obtained if the fit of a model in which all within-treatment regression coefficients are constrained to be equal in all treatments, is compared with the fit of a model in which they are allowed to vary. This overall test is highly significant (chi-square = 32.76, df = 18, p < .018).

Table 3 presents results from statistical tests carried out to indicate for which particular combinations of aptitudes, treatments and outcomes interactions are found.

Only for the regressions of P-SPAT on G and Gv´ the overall interaction is significant. However, in the more powerful tests based on the treatment contrasts more regressions are significantly different across levels of the LIST/READ treatment factor. These include the regression of V-SPAT on G, the regression of VERB on Ma´ and the regression of V-SPAT on Gv´.

The estimated within-treatment regression coefficients are presented in Table

Insert Table 3 about here

4. For the interactions involving G the pattern is such that the regressions are steeper in the 2 LIST treatments than they are in the 2 READ treatments. For the regression of VERB on Ma´ higher coefficients are found in the READ treatments than in the LIST treatments, which is also true for the regression of V-SPAT on Gv´. There is thus a pattern such that G has a higher relationship with the spatial types of outcome in the treatments involving listening, while there for some combinations of specialized aptitudes and outcomes are higher relationsips in treatments involving listening.

Insert Table 4 about here

The overall interaction is significant for the regression of P-SPAT on Gv´, but none of the treatment contrasts is significant for this combination of variables. The coefficients in Table 4 indicate that this is because Gv´ predicts P-SPAT in the READPICT treatment, but not in any of the other treatments. Allowing only the parameter in the READPICT treatment to be free causes a large improvement in the test-statistic (chi-square = 8.39, df= 1, $p < .004$), which improvement completely accounts for the overall interaction found with this combination of variables.

In the final step of the statistical analysis of first-order ATI-effects a model was fitted in which only parameters with significant differences between treatments were not constrained to be equal. This model fitted so well (chi-square = 275.95, df = 261, $p < .25$) that any attempt at further improvement of fit would have to rely on chance effects.

3.3 Higher-order interactions with sex

However, even though this model fits well there may, of course, be higher order interactions with sex, and possibly with other factors as well.

The overall test of interaction between sex and the treatment factors is not significant (chi-square = 18.62, df = 12, p < .098), and nor do separate analyses of each of the 3 outcomes disclose an interaction between treatment and sex. Higher-order interactions between sex, treatment and aptitude were in the first step studied by investigating whether the final model from the analysis of first-order ATI effects is invariant for the sexes. This hypothesis had to be rejected (chi-square = 20.64, df = 11, p < .037), so in the next step the same sequence of tests as was conducted for the pooled sample was repeated within the sexes. The results are presented in Table 5.

Insert Table 5 about here

As may be seen in the table the results are dramatically different for boys and girls: for boys no significant interaction is found, while for the girls there are several significant interactions. The results obtained in the analyses of the pooled sample fall in between the results obtained in the within-sex analyses, thus indicating that the interactions found earlier are almost entirely accounted for by the girls' results.

There is one exception to this pattern, however. In the pooled analysis the regression of P-SPAT on Gv' was found to be steeper in the READPICT treatment than in the other treatments, but in the analyses conducted with the sample divided according to sex no significant interactions is found for this combination of aptitude and outcome. The most likely explanation for this is that the interaction holds true for both boys and girls, but that the loss of power resulting from division of the sample makes detection of the effect impossible.

Also presented in Table 5 are separate tests of interactions with each of the 2 treatment factors. From these it is clear that all the overall interactions are completely accounted for by differences between the regression slopes for the treatments involving reading on the one hand, and the treatments involving listening on the other.

Table 6 presents statistical tests of the differences between the regression coefficients for boys, which are taken to be invariant over treatments, and the regression coefficients for girls in the READ- and LIST-treatments, respectively.

Insert Table 6 about here

Since the coefficients for boys tend to fall in between those for the girls in the READ- and LIST-treatments, only few of the pairwise tests are significant. However, the regression of VERB on Ma´ is significantly steeper for girls in the READ-treatments than it is for boys. A very large difference is also found for the regression of V-SPAT on Gv´. For boys, and for girls in the READ-treatment this relationship is positive, while it is negative for girls in the LIST-treatments.

It will be remembered that in the analyses within sex the interaction involving P-SPAT and Gv´ was not significant, which was suspected to be due to loss of power. However, freeing the regression coefficients in the READPICT treatment but imposing constraints of equality over the sexes, a very large improvement in fit is obtained (chi-square = 17.74, df = 1, $p < .001$). Thus it may be concluded that the failure of this interaction to be significant in the analyses within sex was due to loss of power.

In the very last step of the statistical analyses a model was set up in which all parameters with a chi-square less than 1.0 for the difference between boys and girls were constrained to be equal. This model had an acceptable fit (chi-square = 602.68, df = 559, $p < .10$). The estimated within-group regression coefficients of this model are presented in Table 7.

The results presented in Table 7 summarize the ATI findings of the study. The most important interactions are found with respect to the 2 spatial outcomes, and in these interactions both G and Gv´ are involved. On the verbal test of spatial outcome high-G girls having a treatment involving listening perform well, while the high-Gv girls perform poorly in these treatments. On the

---

Insert Table 7 about here

---

pictorial type of spatial outcome the high-G girls that had a treatment involving reading perform worse than any other high-G group. Another finding related to the P-SPAT outcome is that in the READPICT treatment the high-Gv´ pupils perform better than the Low-Gv´ pupils, which is not the case in any other treatment.

The only interaction found with respect to the verbal type of outcome involves Ma´, such that among girls having a treatment involving reading there is a positive relationship between this aptitude and the VERB outcome.

4 DISCUSSION AND CONCLUSIONS

According to the theoretical framework sketched upon in the Introduction visualization processes are not compatible with reading processes. It was, therefore, predicted that on spatial types of outcome performance would be better in treatments involving listening than in treatments involving reading. It was also predicted that pupils having a good visualization ability would perform particularly well on this type of outcome when liste-ning. However, the results only partially conform with these predictions, and even though the findings do not overthrow the theoretical framework, it will need modification to accomodate the present results.

The highest overall level of performance on spatial outcomes was obtained in the audiovisual (LISTPICT) treatment. As predicted there was also a tendency towards a higher level of performance in the LISTVERB than in the READVERB treatment, but this finding failed to reach statistical significance. Some evidence in favor of the hypothesis of suppression of visualization in reading is therefore obtained, but the evidence is not strong.

However, the high level of performance in the LISTPICT treatment indicates that pictorial information is processed more efficiently when the verbal information is presented auditively, than when it is presented visually. This may be interpreted as supporting the hypothesis that reading suppresses interpretation and acquisition of pictorial information.

In the Introduction specific hypotheses about the mechanisms involved in the suppression were discussed. According to one hypothesis, reading and picture interpretation are both visual processes, and they can therefore not be performed simultaneously. According to another hypothesis, reading is an exclusively verbal process, which once started is not easily disrupted in favor of another kind of processing.

Reading the illustrated material involves shifts of attention within the visual modality, while the audiovisual treatment involves between-modality shifts of attention. It would seem, however, that the hypothesis in terms of similarity of reading and visualization is poorly equipped to account for the difficulty of the within-modality shifts, since this hypothesis only refers to processes performed simultaneously. The hypothesis in terms of the verbal nature of the reading process would, however, be able to account for the difficulty to shift between reading and interpreting pictorial information.

Almost all ATI effects found involve the treatment factor reading vs listening and the aptitude variables G and Gv'. This indicates that the treatments to different degrees support visualization processes, but that this is contingent upon individual differences.

Taken together, the results indicate that in the listening treatments the spatial type of achievement was especially poor for girls high in Gv' and low in other abilities, while in these treatments performance was especially good for girls high in all abilities. This may be interpreted to mean that it was easier to visualize in treatments not requiring reading, but that the visualization was harmful rather than helpful unless a high level of general ability ensured that the visualization processes were properly executed.

This may be because coordination and interrelation of processes is of great importance in the treatments involving listening. When listening the verbal information has to be decoded, and the spatial type of content has to be selected for further processing. But while the visualization processes are performed new information may arrive which must be decoded, and it is of course in each step necessary to take into account the results of previous processing steps. While each of the processes need not be difficult to perform the proper sequencing and interrelating of processes may be quite demanding, and it may be hypothesized that it was the pupils with a high general ability that were most able to perform these tasks.

This interpretation, which is also an interpretation what it means to have a high general ability, comes close to Snow's (1980; cf Gustafsson et al., Note 2) interpretation of Gf in terms of the efficiency of control and assembly processes. The interpretation also comes close to the theoretical framework developed by Wilkinson (1980) to account for the development of skilled reading. However, the findings were significant only for the girls, so the interpretation must be elaborated upon somewhat.

Research on hemispheric lateralization of cognitive functions indicate that for most persons verbal-logical processes are localized in the left hemisphere, while wholistic spatial processes are localized in the right hemisphere (e.g. Dimond & Beaumont, 1974; Nebes, 1969). However, several studies (e.g. Kimura, 1969; Levy, 1976) have shown females to display lateralization of function to a lesser extent than males do. These findings of incomplete lateralization of verbal and spatial function among females have been cited to account for the tendency for females to score lower on spatial tests than males.

If the interpretation of the ATI-findings suggested above is recouched in such neuropsychological terms, it might be said that the cooperation between the hemispheres is of great importance, and that G may index the efficiency of cooperation. However, for cooperation to be necessary it must be assumed that the processes are differentially localized. One might expect, therefore, that among two groups of persons, coordination and cooperation would be more important in the group with more complete lateralization. But the findings are just the opposite, showing a steep regression of spatial outcome on G for girls in the groups that listened. It would thus seem that the previously suggested interpretation is incompatible with the notion of incomplete lateralization of function among females.

There is reason to suspect, however, that the theory of sex differences in degree of localization of function is too simple. Hannay (1976) studied visual field effects in the perception of simple geometric designs. For females, performance in the right visual field was the same as in the left visual field. For males such tasks typically yield left field superiority, so the result for females might be interpreted to support the theory of incomplete lateralization of function. But Hannay (1976) also administered the WAIS Block Design test, which is a measure of Gf and/or Gv, and observed among females a correlation between test scores and visual field superiority, such that subjects with a left field superiority had significantly higher Block Design scores than had subjects with right field superiority. Among a group of males no such correlation was found.

These results indicate that the heterogeneity of lateralization of function is greater among females than among males, such that one subgroup of females has as complete lateralization of function as males, while another subgroup of females tends to solve visual/spatial tasks using left-hemisphere functions. It also seems that degree of lateralization among females is related to level of performance on tests of general or spatial ability.

Given this modification of the neuropsychological theory, it does seem to fit better with the proposed interpretation: In the treatments involving listening the interplay of verbal and spatial types of processing is crucial. Each type of process is performed most efficiently if lateralized along hemispheric lines, but it also requires coordination of the different types of processes. Among girls degree of lateralization is related to level of ability, and level of ability therefore predicts achievement in the treatments involving listening. In the treatments involving reading, however, subjects are forced into a more exclusively verbal kind of processing and degree of lateralization is not important.

So far the discussion has been concerned with the verbal test of spatial outcome. But for the other outcomes somewhat different patterns of results were obtained.

With respect to the pictorial test of spatial outcome (P-SPAT) a less steep regression onto G was found for girls in the treatments requiring reading. This result may indicate that the girls who read treated the material in a more purely verbal manner, not visualizing in the unillustrated treatment and not attending to the illustrations in the illustrated treatment, thus preparing themselves poorly for answering the pictorial type of post-test questions. Such an interpretation would be compatible with the observation that females more often than males adopt verbal-analytical strategies in solving spatial problems. The finding that Ma´ was related to the test of verbal outcome for girls in the treatments involving reading may be taken as another indication that they approached the task in a verbal manner.

For both boys and girls a positive relationship between P-SPAT and Gv´ was found in the READPICT treatment, while there was no association between these variables in any of the other treatment groups. It will be rembered, however, that a main effect was also found for this outcome, such that level of performance was higher in the LISTPICT treatment than in the other treatments. In the READPICT treatment subjects with a high level on Gv´

performed at the mean level in the LISTPICT treatment, so the interaction was ordinal.

This seems to be one of the few findings in support of the hypothesis that high Gv′ pupils perform better with an illustrated than with an unillustrated treatment. It is necessary, however, to explain why the same result was not found with respect to the verbal test of spatial outcome, and why the results in the LISTPICT treatment are different from those in the READPICT treatment.

From the Introduction it will be remembered that several studies may be interpreted to indicate that pupils high in Gv are better at learning illustrations than are pupils low in Gv. High-Gv pupils may therefore be expected to perform well in an illustrated treatment when acquisition of pictorial content is advantageous. With respect to the pictorial test of spatial outcome it does seem to be an advantage if the illustrations in the teaching material are remembered, while for the other outcomes this carries no special advantages. The finding that the interaction was restricted to the pictorial type of outcome provides, therefore, support for the hypothesis advanced by Gustafsson (1976) that Gv is of importance in an illustrated treatmenty when acquisition of the illustrations themselves is beneficial for achievement.

The fact that in the LISTPICT treatment no relationship was found between Gv′ and the P-SPAT outcome can probably best be accounted for with reference to the distinction between incidental and intentional learning. Sheehan (1971) has shown that spatial ability is related to incidental acquisition of pictorial information, but not to intentional learning of pictorial information. From the hypothesis of suppression of pictorial perception by reading follows that in the READPICT treatment the subjects′ focus of attention was directed more towards the text than towards the illustrations; learning the illustrations in the READPICT treatment therefore had the characteristics of incidental learning. In the LISTPICT treatment, in contrast, everyone could focus on the slides undisturbed by a reading requirement, which explains the higher general level of performance and the lack of relationship with Gv′.

Table 1. Results from tests of main effects and interactions between the treatment factors.

			Main effects			
	Overall effect		VERB/PICT		LIST/READ	
Outcome	Chi-sq	df	Chi-sq	df	Chi-sq	df
VERB	7.83*	3	0.03	1	7.55*	1
V-SPAT	19.01*	3	6.84*	1	11.59*	1
P-SPAT	38.49*	3	19.38*	1	16.13*	1

Note: * indicates significance at the 5 per cent level.

Table 2. Estimates of the within-treatment intercept parameters.

	Treatment			
Outcome	READVERB	READPICT	LISTVERB	LISTPICT
VERB	0*	-0.05	-0.58	-0.46
V-SPAT	0*	0.21	0.31	0.74
P-SPAT	0*	0.31	0.27	0.97

Note: * indicates a fixed parameter.

Table 3. Results from statistical tests of aptitude x treatment interaction effects.

Regression of	on	Overall interaction Chi-sq	df	Interaction with READ/LIST Chi-sq	df	VERB/PICT Chi-sq	df
VERB	G	4.01	3	1.71	1	0.10	1
V-SPAT	G	5.86	3	5.49*	1	0.08	1
P-SPAT	G	9.92*	3	9.13*	1	0.46	1
VERB	Ma'	6.72*	3	5.61*	1	0.63	1
V-SPAT	Gv'	4.49	3	4.17*	1	0.06	1
P-SPAT	Gv'	8.98*	3	3.71	1	1.65	1

Note: * indicates significance at the 5 per cent level.

Table 4. Estimated within-treatment regression coefficients.

Regression of	on	Treatment: READVERB	READPICT	LISTVERB	LISTPICT
VERB	G	0.83	1.13	1.24	1.10
V-SPAT	G	0.16	0.15	0.43	0.54
P-SPAT	G	0.20	0.25	0.55	0.70
VERB	Ma'	0.19	0.10	0.01	0.00
V-SPAT	Gv'	0.12	0.13	0.03	0.01
P-SPAT	Gv'	0.02	0.18	0.00	0.03

Table 5. Statistical tests of aptitude x treatment interaction effects separately for the sexes.

Regression of	on	Overall interaction Chi-sq	df	Interaction with READ/LIST Chi-sq	df	Interaction with VERB/PICT Chi-sq	df
BOYS							
VERB	G	1.23	3				
V-SPAT	G	3.22	3				
P-SPAT	G	3.01	3				
VERB	Ma'	1.30	3				
V-SPAT	Gv'	0.57	3				
P-SPAT	Gv'	5.64	3				
GIRLS							
VERB	G	6.19	3				
V-SPAT	G	8.60*	3	6.97*	1	0.11	1
P-SPAT	G	13.38*	3	11.81*	1	0.15	1
VERB	Ma'	8.39*	3	4.91*	1	0.15	1
V-SPAT	Gv'	12.30*	3	10.71*	1	0.08	1
P-SPAT	Gv'	5.37	3				

Note: * indicates significance at the 5 per cent level.

Table 6. Within-treatment regression coefficients for boys and girls, and tests of their difference.

Regression of	on	Coefficients: Boys	Coefficients: Girls READ	Coefficients: Girls LIST	Tests: Boys vs Girls-READ Chi-sq	df	Tests: Boys vs Girls-LIST Chi-sq	df
VERB	G	1.15	1.00	1.00	0.86	1	0.86	1
V-SPAT	G	0.27	0.22	0.56	0.10	1	2.87	1
P-SPAT	G	0.44	0.20	0.50	2.93	1	0.15	1
VERB	Ma′	0.03	0.18	0.02	4.10*	1	0.02	1
V-SPAT	Gv′	0.11	0.10	-0.10	0.01	1	9.10*	1
P-SPAT	Gv′	0.03	0.06	0.06	0.46	1	0.46	1

Note: * indicates significance at the 5 per cent level.

Table 7. Estimated within-group regression coefficients by sex and treatment.

Regression of	on	READVERB Boys	READVERB Girls	READPICT Boys	READPICT Girls	LISTVERB Boys	LISTVERB Girls	LISTPICT Boys	LISTPICT Girls
V-SPAT	G	0.25	0.25	0.25	0.25	0.25	0.57	0.25	0.57
P-SPAT	G	0.50	0.17	0.50	0.17	0.50	0.50	0.50	0.50
V-SPAT	Gv′	0.12	0.12	0.12	0.12	0.12	-0.13	0.12	-0.13
P-SPAT	Gv′	0.00	0.00	0.18	0.18	0.00	0.00	0.00	0.00
VERB	Ma′	0.03	0.17	0.03	0.17	0.03	0.03	0.03	0.03

Note: All numerically identical parameters are constrained to be equal.

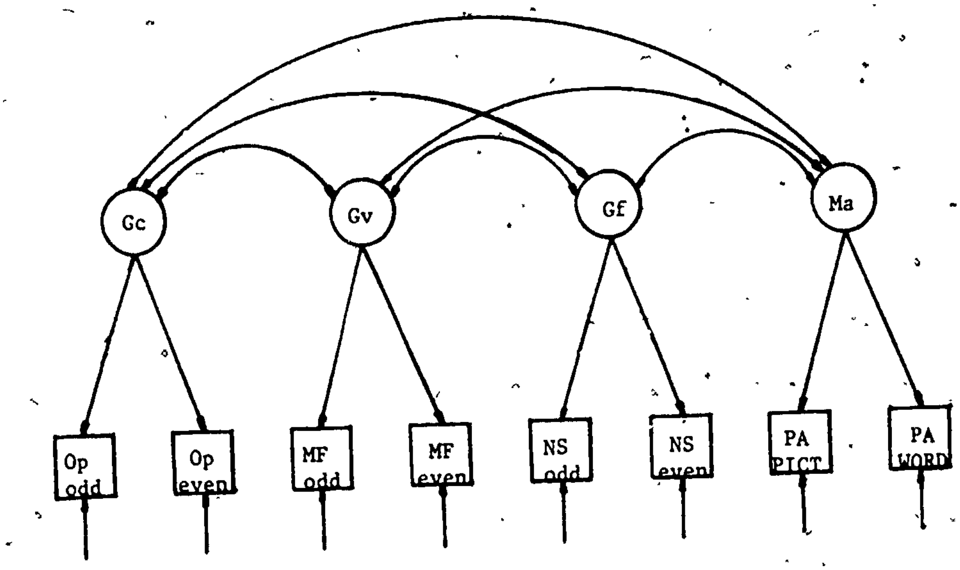

Figure 1. The first-order model for the aptitude variables.

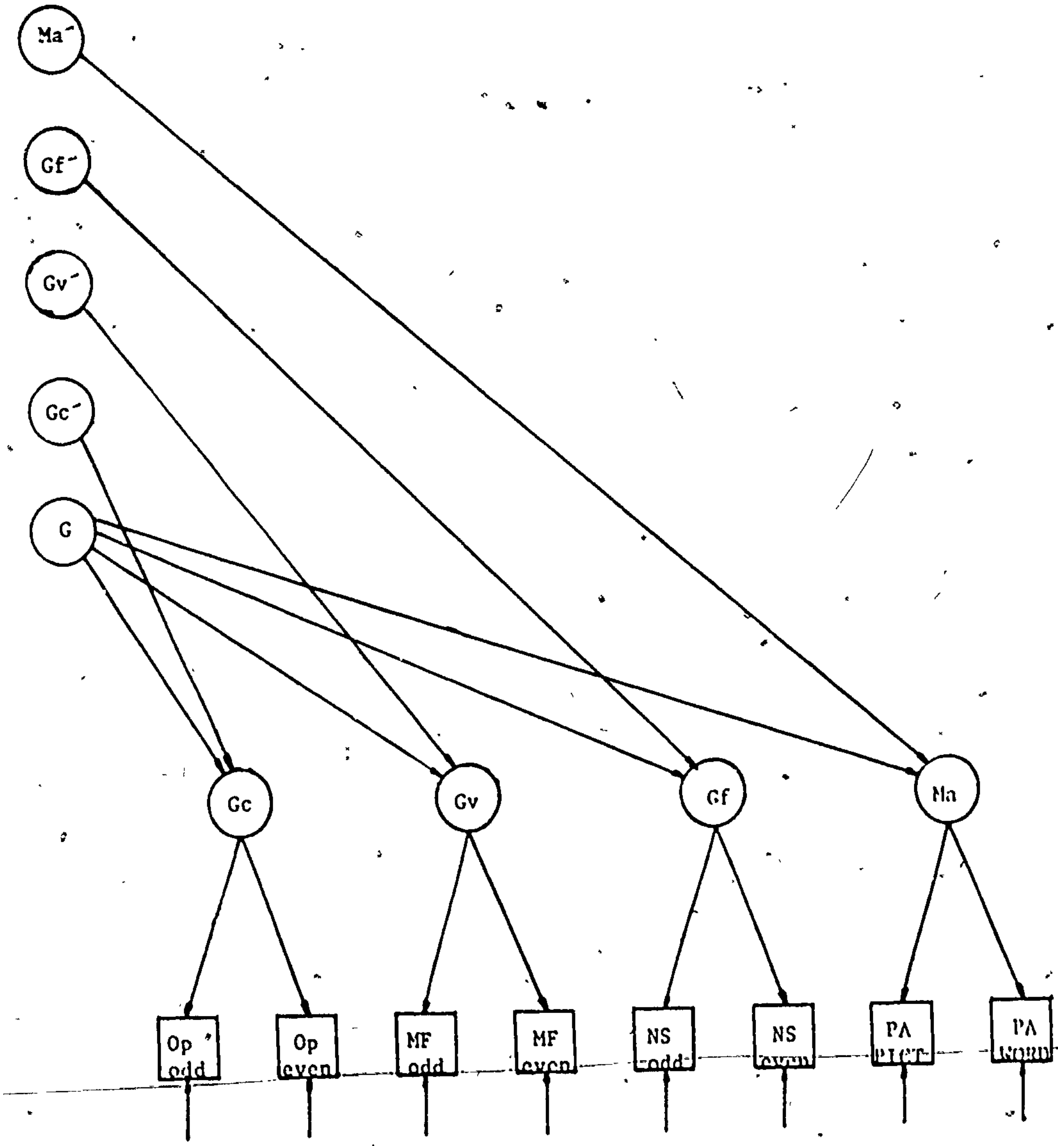

Figure 2. The second-order model for the aptitude variables.

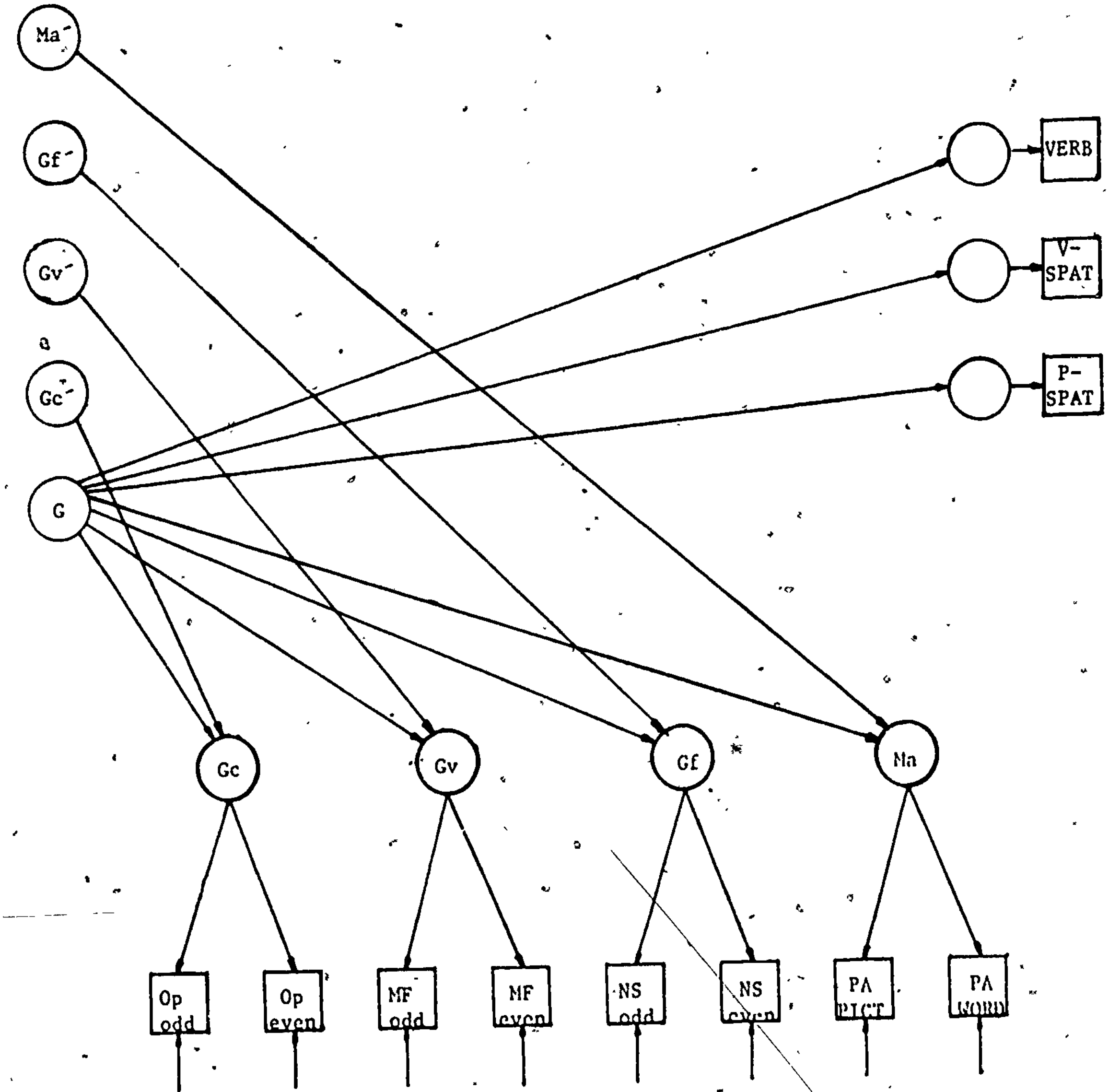

Figure 3. The full LISREL model used for the initial ATI-analyses.

REFERENCE NOTES

1. Gustafsson, J.-E. New models of the structure of intellectual abilities: Implications for testing and teaching practice. Report from the Department of Education, University of Göteborg, 1982:03.

2. Gustafsson, J.-E., Lindström, B., & Björck-Åkesson, E. A general model for the organization of cognitive abilities. Report from the Department of Education, University of Göteborg, 1981:06.

3. Yalow, E. Individual differences in learning from verbal and figural materials. Unpublished doctoral dissertation, Stanford University, 1980.

4. Gustafsson, J.-E., & Lindström, B. Analyzing ATI data by structural analysis of covariance matrices. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, 1979.

5. Jöreskog, K.G., & Sörbom, D. LISREL V. Analysis of linear structural relationships by maximum likelihood and least squares methods. Research report 81-8, University of Uppsala, Department of Statistics, 1981.

REFERENCES

Anderson, J.R. Arguments concerning representations for mental imagery. Psychological Review, 1978, 85, 249-277.

Baddeley, A.D., Grant, S., Wight, E., & Thomson, N. Imagery and visual working memory. In P.M. Rabbitt & S. Dornic (Eds) Attention and Performance. V. New York: Academic Press, 1974, pp. 205-217.

Bentler, P. Multivariate analysis with latent variables: causal modeling. Annual Review of Psychology, 1980, 31, 419-456.

Brooks, L.R. The suppression of visualization by reading. Quarterly Journal of Experimental Psychology, 1967, 19, 289-299.

Brooks, L.R. Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 1968, 22, 349-368.

Clark, R.L. Media, mental imagery, and memory. Educational Communication and Technology, 1978, 26, 355-363.

Cronbach, L.J., & Snow, R.E. Aptitudes and instructional methods. A handbook for research on interactions. New York: Irvington, 1977.

Dimond, S.J., & Beaumont, J.G. (Eds) Hemisphere function in the human brain. London: Elek Science, 1974.

Goodman, K.S., & Goodman, Y.M. Learning about psycholinguistic processes by analyzing oral reading. Harvard Educational Review, 1977, 47, 317-33.

Guilford, J.P. The nature of human intelligence. New York: McGraw-Hill, 1967.

Gustafsson, J.-E. Verbal and figural aptitudes in relation to instructional methods. Studies in aptitude-treatment interactions. Göteborg: Acta Universitatis Gothoburgensis.

Gustafsson, J.-E. A note on class effects in aptitude x treatment interactions. Journal of Educational Psychology, 1978, 70, 142-146.

Gustafsson, J.-E. Testing and obtaining fit of data to the Rasch model. British Journal of Mathematical and Statistical Psychology, 1980, 33, 205-233.

Hannay, H.J. Real or imagined incomplete lateralization of function in females. Perception and Psychophysics, 1976, 19, 349-352.

Hollenberg, C. Functions of visual imagery in the learning and concept formation of children. Child Development, 1970, 41, 1003-1015.

Horn, J.L., & Cattell, R.B. Refinement and test of the theory of fluid and crystallized intelligence. Journal of Educational Psychology, 1966, 57, 253-270.

Janssen, W.H. Selective interference in paired-associate and free-recall learning. Acta Psychologica, 1976, 40, 35-48.

Jöreskog, K.G. A general approach to confirmatory maximum likelihood factor analysis. Psychometrika, 1969, 34, 183-202.

Jöreskog, K.G., & Sörbom, D. LISREL IV user's guide. Chicago, Ill: International Educational Services, 1978.

Kimura, D. Spatial localization in the left and right visualfield. Canadian Journal of Psychology, 1969, 23, 445-458.

Kosslyn, S.M., Holyoak, K.J., & Huffman, C.S. A processing approach to the dual processing hypothesis. Journal of Experimental Psychology -- Human Learning and Memory, 1976, 2, 223-233.

LaBerge, D., & Samuels, S.J. Toward a theory of automatic information processing in reading. Cognitive Psychology, 1974, 5, 293-323.

Levin, J.H., & Lesgold, A.M. On pictures in prose. Educational Communication and Technology, 1978, 26, 233-243.

Levy, J. Cerebral lateralization and spatial ability. Behavior Genetics, 1976, 6, 171-188.

Lindström, B. Forms of representation, content and learning. Göteborg: Acta Universitatis Gothoburgensis, 1980.

van Mondfrans, A.P., & Travers, R.M.W. Learning of redundant material presented through two sensory modalities. Perceptual and Motor Skills, 1964, 19, 743-751.

Muthen, B. Contributions to factor analysis of dichotomous variables. Psychometrika, 1978, 43, 551-560.

Nebes, R.D. Hemispheric specialization in commisurotimized man. Psychological Bulletin, 1974, 81, 1-14.

Peeck, J. Retention of pictorial and verbal content of a text with illustrations. Journal of Educational Psychology, 1974, 66, 880-888.

Peterson, M.J., Thomas, J.E., & Johnson, H. Imagery, rehearsal and compatibility of input-output tasks. Memory and Cognition, 1977, 5, 415-422.

Pylyshyn, Z.W. What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

Salthouse, T.A. Simultaneous processing of verbal and spatial information. Memory and Cognition, 1975, 3, 221-225.

Samuels, S.J. Attentional process in reading: The effect of pictures on the acquistion of reading responses. Journal of Educational Psychology, 1967, 58, 337-342.

Samuels, S.J. Effects of pictures on learning to read, comprehension and attitudes. Review of Educational Research, 1970, 40, 397-407.

Sewell, E.H. Jr., & Moore, R.L. Cartoon embellishments in informative presentations. Educational Communication & Technology, 1980, 28, 39-46.

Sheehan, P.W. Individual differences in imagery and the function of imagery in incidental learning. Australian Journal of Psychology, 1971, 23, 279-288.

Shepard, R.N. The mental image. American Psychologist, 1978, 33, 125-137.

Sherman, J.L., Kulhavy, R.W., & Burns, K. Cerebral laterality and verbal processes. Journal of Experimental Psychology -- Human Learning and Memory, 1976, 2, 720-727.

Snow, R.E. Research on aptitudes: A progress report. In L.S. Shulman (Ed) Review of Research in Education, Vol 4. Itasca, Ill: Peacock.

Snow, R.E. Theory and method for research on aptitude processes. Intelligence, 1978, 2 225-278.

Snow, R.E. Aptitude processes. In R.E. Snow, P.A. Federico & W. Montague (Eds) Apitude, learning and instruction: Cognitive process analysis. New Jersey: Erlbaum, 1980.

Svensson, A. Relative achievement. School performance in relation to intelligence, sex and home environment. Stockholm: Almqvist & Wiksell, 1971.

Thurstone, L.L. Primary mental abilities. Psychometric Monographs, no 1, 1938.

Underwood, B.J. Individual differences as a crucible in theory construction. American Psychologist, 1978, 30, 128-134.

Wilkinson, C. Children's understanding in reading and listening. Journal of Educational Psychology, 1980, 72, 561-574.

Wright, P., Holloway, C.M., & Aldrich, A.R. Attending to visual information while performing other concurrent tasks. Quarterly Journal of Experimental Psychology, 1974, 26, 454-463.

Yuille, J.C., & Ternes, W. Attention and modality specific interference as determinants of short-term verbal and visual retention. Canadian Journal of Psychology, 1975, 29, 360-374.

Reports from THE DEPARTMENT OF EDUCATION UNIVERSITY OF GÖTEBORG

1980:01 Johansson, Britt: Need of knowledge in nursing and demand for knowledge in nursing education. July 1980

1980:02 Dahlgren, Lars-Owe och Franke-Wikberg, Sigbrit: Social Structure of Society through the Eyes of University Students. October 1980

1981:01 Svensson, Lennart: The concept of study skill(s). Paper presented at the Sixth International Conference on Improving University Teaching. Lausanne, Switzerland, July 9-12, 1980. March 1981

1981:02 Gustafsson, Jan-Eric: An introduction to Rasch's measurement model. March 1981

1981:03 Alexandersson, Claes: Amadeo Giorgis empirical phenomenology. March 1981

1981:04 Åsberg, Rodney: How to understand cognitive differences from a cross-cultural perspective? August 1981

1981:05 Reuterberg, Sven-Eric och Svensson, Allan: Financial aid and class bias in higher education. October 1981

1981:06 Gustafsson, Jan-Eric, Lindström, Berner & Björck-Åkesson, Eva: A general model for the organization of cognitive abilities. December 1981

1982:01 Englund, Tomas & Svingby, Gunilla: Scientification of teaching - a concept to be questioned. February 1982.

1982:02 Dahlgren, Lars-Owe: Higher education - Impact on students. June 1982

1982:03 Gustafsson, Jan-Eric: New models of the structure of intellectual abilities: Implications for testing and teaching practice. October 1982.

1982:04 Björck-Åkesson, Eva: Development of a sensation-seeking scale for preadolescent children. November 1982

1982:05 Gustafsson, Jan-Eric & Svensson, Allan: Family size, social class, intelligence and achievement: A study of interactions. December 1982.

1982:06 Marton, Ference: Towards a phenomenography of learning. I. Integrating experiential aspects. December 1982

1982:07 Marton, Ference & Svensson, Lennart: Towards a phenomenography of learning. II: A relational view of study skill. December 1982

1982:08 Marton, Ference: Towards a phenomenography of learning. III. Experience and conceptualisation. December 1982

1982:09 Gustafsson, Jan-Eric: Visualization processes in learning as a function of method of presentation and individual differences. December 1982