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ABSTRACT

Forty randomly selected school children, in four treatment groups of ten each (each comprised of children from the 5, 9, and 12 year age levels) participated in a study to determine the extent to which the capacity for information processed by a child increases in amount with development. Apprehension span (perception and transformation of aural or visual inputs leading up to reconstruction or verbal description output) was measured. A specially designed form board varying on three binary dimensions and thirty-two plastic geometric shapes varying on five binary dimensions was the basic test material to which a subject responded by either describing or reconstructing a given stimulus design. Scores were calculated on the basis of match between the reference subset of shapes and the form board performance. A 3 x 2 x 2 complete factorial design was used. Results indicate that there is a differential decrease in differences in the apprehension span of children with development. Correlations between the total of eight apprehension span tasks and the Primary Mental Abilities Test support the conclusion that information is processed through the non-verbal mode and bottlenecks in a child's processing of information are mainly those involving translation into and out of another medium such as language. (WY)

INTELLECTUAL DEVELOPMENT AND THE ABILITY TO PROCESS VISUAL AND VERBAL INFORMATION[1]

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How much information does a child process from the visual and the auditory world? This problem has its historic roots in Wundt's (1912) study of sensory perception. He found that the span of consciousness was sixteen, or eight pairs of clicks when the clicks were grouped in pairs. However, this span could be enlarged to forty clicks at one time for more complicated rhythmic pattern. Numerous published studies on digit span suggest a limit on the number of digits that can be processed and output by normal individuals. Miller (1956) generalized the case to include making judgments of length, time, etc., and concluded that the limit of capacity for processing information was seven plus or minus two. Chomsky (1965) points out the limits of embeddings one can process in grammar, a limit set not by the rules of grammar but by the memory span of the listeners. This study is concerned with the extent to which the capactiy for information processed by the child increases in amount with development.

Gibson (1966) has shown convincingly that the amount of information in in the visual world is unspecifiably large. Only a small amount of this may

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[1] Presented at annual meeting of American Educational Research Association, Minneapolis, Minnesota, March 2-6, 1970.

Only a small amount of this may be perceived by an individual. Sperling (1960) demonstrated that the amount of information of partial reports was a sharply decreasing function of the time at which the instruction was given. The asymptotic value of this function was the value for the whole reports (immediate memory reports). The masimum number of items an individual can give in a whole report is called his <u>span of immediate memory</u>.

It can be argued here that the reported information in all suck studies is not a mirror reflection of the stimulus portions which Ss could report but is rather a sequential process of input, storage (even momentary), transmission, and output. For the purposes of this study these limits of processing shall be considered as the child's "apprehension span"; in it shall be included the perception and transformation leading up to some performance. This term has some advantageous implications. Firstly, it is operational, that is, capable of being measured. Secondly, it implies that a child may have different apprehension spans for dealing with different forms of information (visual, auditory, etc.). Thirdly, it acknowledges the impossibility of assessing the amount of information picked up independently of some output, there being no access to the first part. Fourthly, and historically, apprehension has been used as a synthetic act, in which a perceived object is described in terms of time and space. With this conception of "apprehension span" it can be stated that this study is an attempt to show how apprehension span changes developmentally.

There are abundant non-empirical and qualitative generalizations prevalent in literature suggesting differential information processing by children at various developmental levels. For example, Bruner (1966) contended that "intellectual development if marked by increasing capacity to dela with several sequences during the same period of time, and to allocate times and attention in a manner appropriate to these multiple demands" (p. 6). For example, a child centers on only one dimension, i.e., "height" or "width", at a time in Piaget's conservation tasks during the pre-operational stage (2 to 7 years) whereas subsequently, he utilizes both aspects of the information available and gives an appropriate response -- both dimensions are specified by the child in his response. However, for the younger children, it is not at all clear as to where the problem lies. Is it that the older child is picking up more information? Or is he picking up the same information but just using it in a new and efficient way? These questions will be attacked by considering the apprehension spans of children at various developmental levels.

As apprehension span has been defined above to include both input and output phases, it follows that there is more than one apprehension span. It is one of the concerns of this study to examine the relationship between the visual apprehension span and the auditory apprehension span, particularly as they change with age. In this context the primary question will become the specification of the factors that either limit or expand that apprehension span. It is obvious that a child's response, for example, on Piaget's conservation task, is inadequate by adult criterion. It could be said here that the child is not processing the required information. But one would be unable to specify the limitation in terms of the locus of the difficulty. Is it a matter of information pickup, i.e., perception, or a matter of the output phase? As was previously suggested it is reasonable to expect that there are different apprehension spans for various types of input and output. Although these may all change with development, they may all change differentially; that is, relative to one another.

The output modalities of concern here are reconstruction (R) and verbal description (VD) of the visual (V) and auditory (AU) inputs. These will be described later.

The two output modalities in combination with the two input modalities and the intervening storage, transformations, etc. would give rise to four different apprehension spans. This means that a particular input and output combination would not necessarily yield the maximum output potentiality of the processor but instead would reflect the effect of input, storage, and transformational constraints.

For illustrative purposes, consider now the apriori developmental model implied by this view (Fig. 1). On the input side, the model postulates that children have differential capacity to perceive the stimulus array dependent upon the level of development. These capacities are represented by the diameters

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Insert figure 1 about here

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of the concentric conic sections for each of the V and AU modes for the input systems -- smallest for the younger children. This amount of perceived information is stored, transformed if necessary, and retrieved by the processor for performance into the specified output modality -- R or VD. Similarly, the capacities of children to output information under these output modes are represented by the diameters of the different output systems. In one sense then, a single cone for output in one mode is slightly misleading in that we may expect different amounts of output in one system depending on the form of the input. The same point holds for input. The diameters of conic sections in Figure 1 show the maximum capacities only.

Regardless of the process assumed to underlie children's performance in these tasks, it is clear that "apprehension span" will reflect the information processing limits of human Ss. The model indicates that the span increases with

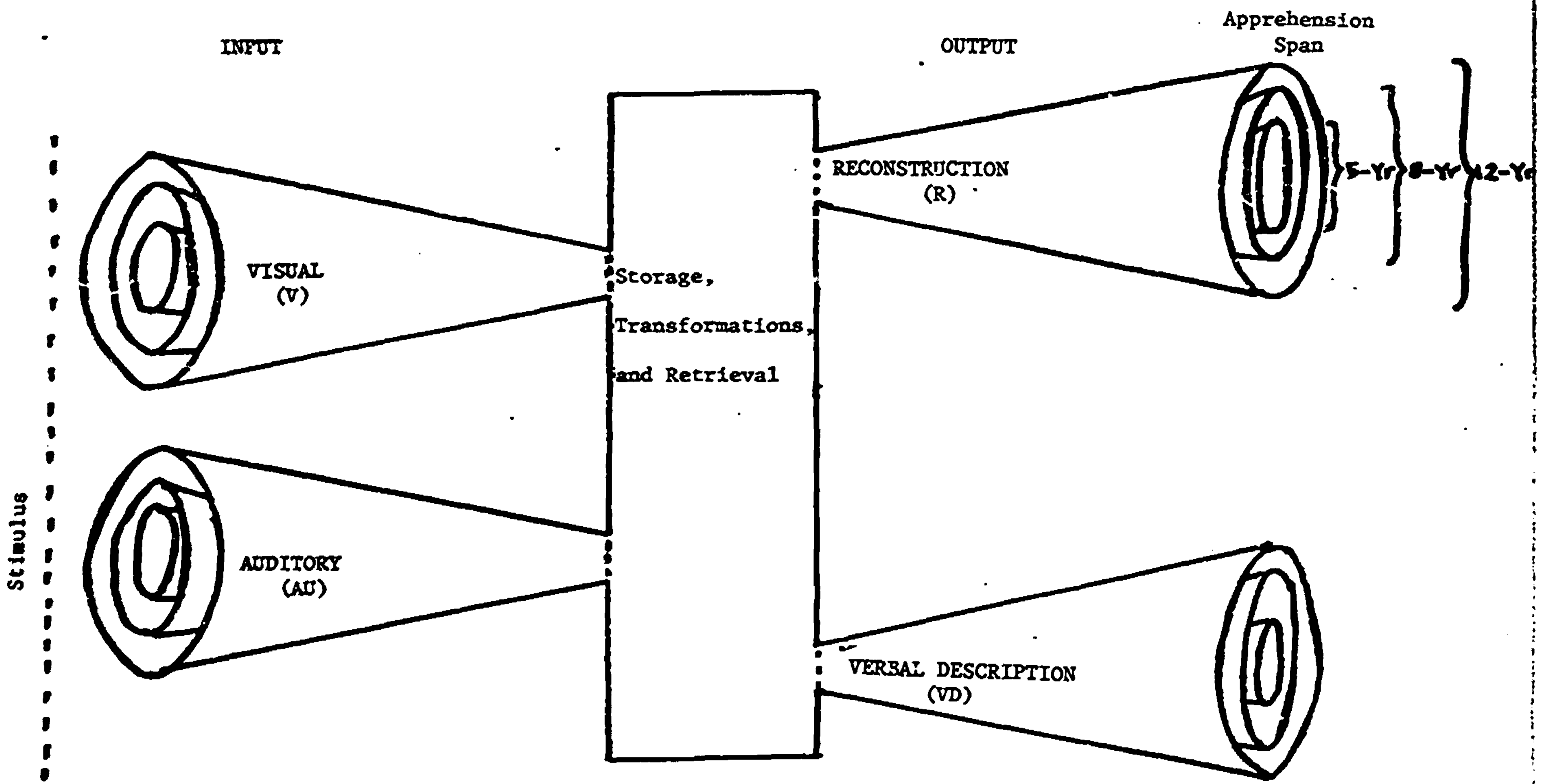

Fig. 1.—Developmental Model Indicating the growth of Apprehension Spans for two Input and two Ouput Modes.

development in all of these apprehension spans. The general assumption is that the amount of information perceived, stored, transformed, and output increases developmentally. As each "apprehension span" is operationally defined in terms of a form of input and a form of output, there are at least four such spans, and it is reasonable to expect that these spans may differ. Finally, one may focus on the manner in which these spans change developmentally, perhaps all increasing but perhaps some more radically than others. The model also suggests that "apprehension span" is a function of input and output systems. Thus developmental changes in each of these systems can be studied specifically.

This model has an advantage in that as apprehension spans differ from one another in only one way it becomes possible to specify the input or output components which are primarily restrictive in the information that may be processed. Thus is the AU-R apprehension span is restricted relative to the VOR apprehension span it is possible to infer that it is the verbal input that is the primary limiting factor.

The model has an additional advantage in that a transformational analysis for each input-output pair would enable us to determine the factors involved in different apprehension spans. For example, it may be hypothesized, that an S is presented a visual design and is required to reconstruct the design from the given materials immediately after the exposure, the S is faced with a matching problem. In order to describe a design verbally after its visual exposure in the context of the materials involved, a transformation is required--non-verbal images must be analyzed into components corresponding to words. On the other hand, when an S reconstructs a design after an auditory or verbal description, the S again must make a transformation of verbal audition into non-verbal equivalents, and of synthesis of the isolated components into a representative design. Finally, the task of a verbal description from an auditory display would, perhaps, require two transformations, verbal audition into non-verbal percepts and the non-verbal percepts into verbal equivalents appropriate for the task at hand; these speculations will be examined in the light of the data at the end of this study. The exact opposite could as easily be hypothesized. It is possible that the basic form of information storage for a verbal adult is in verbal mode in which case the perceptual-reconstructive task would involve the most transformations and the verbal-verbal ones t' least (Glanzer and Clark, 1963, 1964).

On the basis of empirical results from this study a posteriori model will be proposed.

Method

SAMPLE

The Ss were 40 children, comprising four treatment groups of ten each, from each of the 5,8, and 12 year age levels. These children were selected randomly from the children in attendance at a sub-urban junior and senior elementary school in Ontario.

MATERIALS

A form board varying on three binary dimensions and thirty-two plastic geometrical shapes varying on five binary dimensions (2^5) designed and described by Randhawa (1969) were used as the basic test materials. These shapes were placed in a tray arranged in four adjacent sub-sets of eight each suck that all of the five dimensions were equiprobable. Ten colored slides, to be used as visual stimulus and practice materials, were prepared with a randomly selected shape embedded in a form-board slot. Corresponding to these slides representing five each of the six and eight bits of stimulus information, which is based on the amount of reduction in uncertainty required for correct response -- $\log_2 n$ where n is the number of possible outcomes, verbal massages were pre-recorded in the same order as the order of visual stimuli for each S in V-R or V·VD treatment groups. The orderings were determined in advance so as to present both visual and auditory stimuli to the Ss in their respective treatment groups in suck a way that the subsets of stimuli of different type and complexity were randomized within their respective subsets with the order of the subsets fixed.

TASKS

The stimulus and the response modes of the four information processing tasks for measuring the four apprehension spans were V-R, V-VD, AU-R, and AU-VD. The stimulus information (bits) was calculated on the basis of the number of shapes in the referenc3 subset and the form-board. For example, for a six bit task, one of subsets of eight shapes and the form-board would be the relevant reference materials. Whereas for an eight bit task, all of the thirty-two shapes and the form-board would be the relevant reference materials. The response information (bits) was calculated on the basis of reduction of uncertainty in the context of reference subset of shapes and the form-board.

For the V-R and AU-R conditions, the S was required to reproduce the design with the given materials after each presentation of the stimulus. But for the V-VD and AU-VD conditions, the S was required to give a verbal description of the design after each presentation of the stimulus in the context of the reference materials.

DESIGNS

A 3 x 2 x 2 complete factorial design was used. The first factor was the three age levels (5, 8, and 12), the second factor was the two stimulus modes (visual and auditory), and the third factor was the two response modes (reconstruction and description). There were 10 Ss in each of the twelve groups and a S performed only one of the four tasks in one of the ten different orders selected so that the Ss in a group exhausted all of the orders.

PROCEDURE

About two weeks before the experiment proper all the selected Ss were given Primary Mental Abilities (PMA) tests. Raw scores of the Ss in the four subtests (verbal meaning, number facility, spatial relations, and perceptual speed) and the

total of PMA tests were converted into deviation quotient scores. These scores were used to determine the extent of correlations with the dependent var
variables, apprehension spans, under the four experimental conditions for the total group.

Ss in each group were randomly assigned to one of the four treatments. In all treatments, the *S* was first acquainted with the shapes and the form-board as the *E* read the instructions.

After giving instructions, two practice trials were given in the four treatments in the same order to all the *Ss*. During these presentations, any questions or misunderstandings of the instructions were clarified and the practice trials were repeated if necessary.

In the first treatment (V-R), the *S* was shown a design, projected individually on a white screen placed about ten feet in front of the *S*, for five seconds. Immediately after this presentation, the *E* uncovered the reference shapes and the assistant exposed the form-board. The *S* was then required to reconstruct the design, i.e., to pick a shape from the shapes shown and to put it in one of the slots of the form-board. The response in terms of codes was recorded.

In the second treatment (V-VD), the stimuli were presented exactly as in the first treatment. The *S*, at the instant the form-board and the reference shapes were uncovered, began a verbal description of the design. The *S* was practiced to use the remote control switch on the microphone of the tape recorder and was led to believe that his messages were transmitted into another area where one of his schoolmates was to make an identical design, as that seen and described by the *S*, from identical shapes and form-board. This prevented the *S* from simply pointing at the shapes and the form-board and saying "This one in this one", etc. Without such instructions and emphasis, responses of the above sort were evidenced in a pilot study done by the E. The assistant kept a record of the dimensions encoded by the S. These entries were checked against the tape recorded responses for accuracy.

The stimuli in the third and the fourth treatments were verbal messages tape recorded in advance, in ten different orders corresponding to the orders of the visual stimuli for presentation. The S in the third treatment (AU-R) was required to respond in the reconstruction mode exactly similar to treatment one after the presentation of the stimulus. While in the fourth treatment (AU-VD), the S responded in the description mode exactly similar to treatment two after the stimulus was presented.

SCORING

Ss' responses on each task were converted into scores in bits. The score in bits on a particular task responded in the reconstruction mode was the number of matching dimensions on the stimulus and the response in the case of non-redundant, all dimensions were relevant for perfect performance; while the 6 bit tasks contained 2 bits of redundancy, two of the dimensions were irrelevant--without attending to these dimensions perfect score was possible. The score on a task responded in description mode was simply the number of matching relevant dimensions in the stimulus and response. For example, if the relevant dimensions in a 6 bit stimulus taks were "small, green, circle, bottom, right, blue" and an S's response was "large, red, circle, bottom, left, yellow" then the score on this task for the S would be 2 bits.

Results

The main effects means on the apprehension span tasks are presented in Table 1 and MANOVA tests of significance on these tasks, using F-ratios as test statistics for testing the equality of mean vectors, are provided in Table 2. In general, the results in Tables 1 and 2 support the hypothesis of significant differences in apprehension spans of children at the three

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Insert Tables 1 and 2 about here

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age levels. The results uphold the hypothesis of significant differences in apprehension spans of children under the visual (V) and auditory (AU) input (stimulus) conditions and also under the reconstruction (R) and verbal description (VD) output (response) conditions. A significant interaction between age and response indicates a differential decrease in differences in the apprehension spans of children with development. Figures 2a and 2b present the average apprehension spans of the three age groups of children for the two response modes on one each of the 6-bit and 8-bit components. These figures show clearly that the average apprehension spans of children

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Insert Figures 2a and 2b about here

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for the two output modalities converge with development.

MANOVA tests for simple effects for apprehension span tasks are provided in Table 3. It is seen here that age effects are significant for each of the individual input and output modalities and also for each of input and output pairs. Also the stimulus effects are significantly different under each of

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TABLE 1

Task Main Effects Means

Variate	Effect						
	Age Group			Stimulus		Response	
	5	8	12	V	AU	R	VD
I	3.100	4.425	5.075	4.317	4.083	5.050	3.350
II	2.975	4.225	4.925	4.333	3.750	4.867	3.217
III	3.175	4.325	4.925	4.550	3.733	5.383	2.900
IV	3.000	4.250	4.850	4.583	3.483	4.900	3.167
A	3.675	5.925	6.600	5.633	5.167	6.650	4.150
B	3.600	5.257	6.500	5.483	4.817	6.617	3.633
C	3.525	5.357	6.225	5,317	4.767	6.133	3.950
D	3.800	5.175	6.550	5.250	5.100	6.567	3.783

TABLE 2

MANOVA Tests of Significance, Tasks

Source	df[1]	F	Probability
Age	16/202	10.35	0.0001*
Stimulus	8/101	4.94	0.0001*
Response	8/101	40.11	0.0001*
Age x Stimulus	16/202	1.48	0.1079
Age x Response	16/202	2.36	0.0031*
Stimulus x Response	8/101	1.94	0.0628
Age x Stimulus x Response	16/202	1.05	0.4037

[1]df for numerator/df for denominator in this and the following tables.

* indicates significance at .05 level in all the tables testing significance.

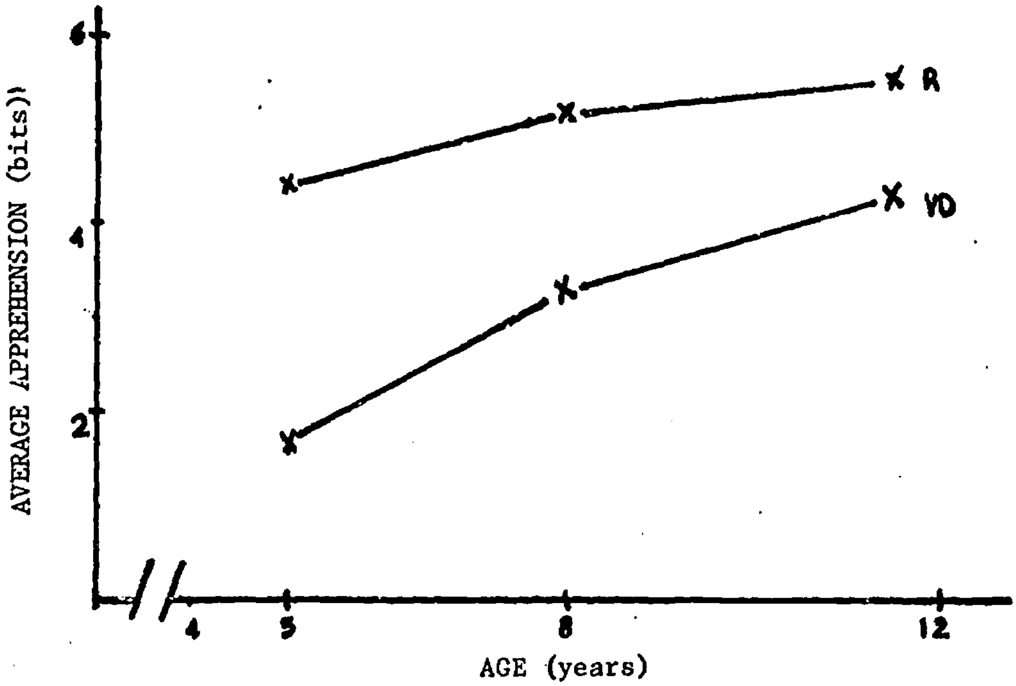

Fig. 2 (a.) -- Plots of Age vs. Average Apprehensions Spans of the two Response Modes for One of the 6 Bit Stimulus Components.

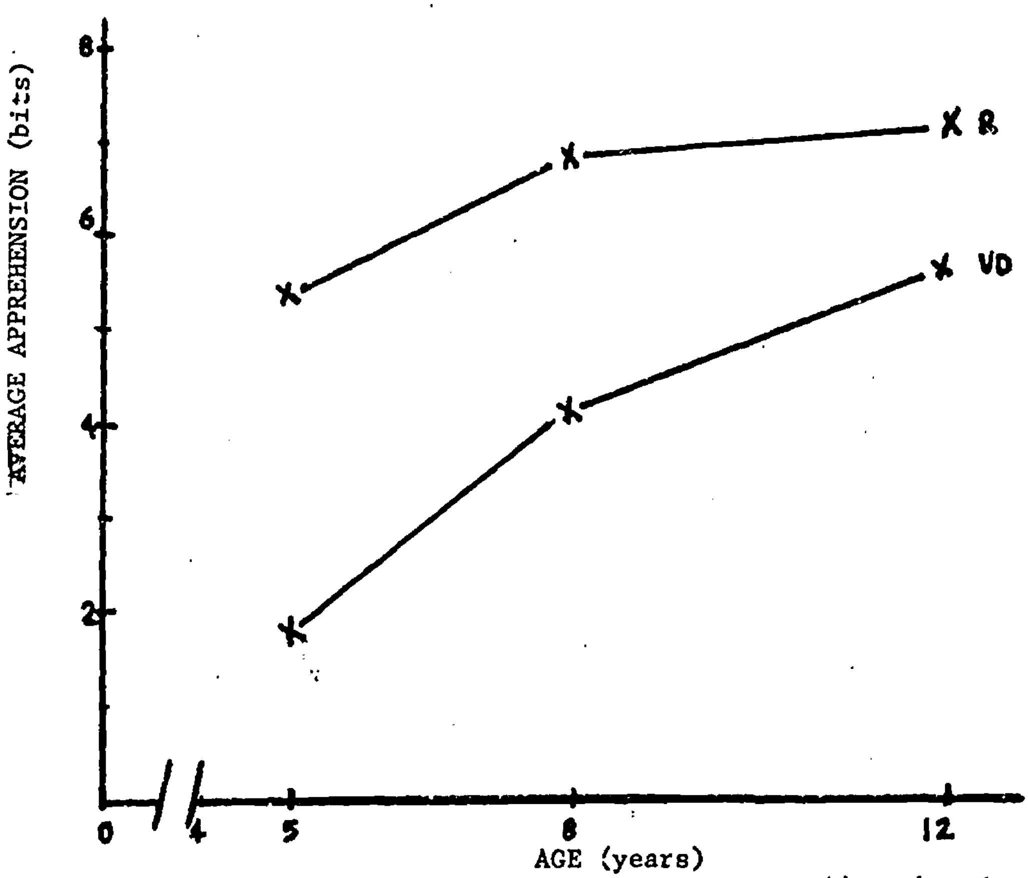

Fig. 2 (b.) -- Plots of Age vs. Average Apprehensions Spans of the two Response Modes for One of the 8 Bit Stimulus Components.

TABLE 3

MANOVA Tests for Simple Effects, Tasks

Source	df	F	Probability
Age for V-R	16/40	4.46	.0001*
Age for V-VD	16/40	5.47	.0001*
Age for AU-R	16/40	3.79	.0004*
Age for AU-VD	16/40	3.50	.0007*
Age for R	16/94	5.23	.0001*
Stimulus for R	8/47	3.79	.0017*
Age x Stimulus for R	16/94	1.23	.2584
Age for VD	16/94	5.78	.0001*
Stimulus for VD	8/47	3.40	.0037*
Age x Stimulus for VD	16/94	1.23	.2590
Age for V	16/94	6/60	.0001*
Response for V	8/47	25.32	.0001*
Age x Response for V	16/94	3.03	.0005*
Age for AU	16/94	6.37	.0001*
Response for AU	8/47	21.96	.0001*
Age x Response for AU	16/94	1.21	.2784

the two response modalities. The same is the case for the response effects under each of the stimulus modalities. The only significant interaction is noted between age and response modality for the visual stimulus modality.

It should be pointed out, however, that multivariate analysis of covariance with the total IQ as the independent variable gave almost identical results.

Combined correlations between the total of the eight apprehension span tasks and the PMA for the four experimental conditions are given in Table 4.

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Insert Table 4 about here

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Discussion

All the four apprehension spans, i.e., V-R, V-VD, AU-R and AU-VD, were found to increase with age as expected. Children's ability to process information from visual and auditory inputs regardless of the modes of output (reconstruction and verbal description) increases with development. Similarly the children showed significant improvement in their ability to process information in either reconstruction or verbal description mode of output regardless of the mode of input of information.

Two modes of information input in general as well as with regard to each of the two modes of information output had differential effects on apprehension spans such that apprehension spans for visual inputs were greater than apprehension spans for auditory inputs. Similarly, apprehension spans for reconstruction outputs were greater than apprehension spans for verbal description outputs.

It has been observed at each age level that the apprehension spans can be ordered with the decreasing order of size in the following manner: (1) Apprehension Span V-R; (2) Apprehension Span AU-R; (3) Apprehension Span

TABLE 4

Correlations between the Total of the 8 Apprehension Span Tasks and the PMA for the Four Conditions

PMA Tests	V-R	AU-R	V-VD	AU-VD
Verbal Meaning	.25	.06	.44*	.26
Number Facility	.06	.34	.24	.49*
Perceptual Speed	.63*	.79*	.71*	.69*
Spatial Relations	.21	.50*	-.20	.37*
Total IQ	.51*	.65*	.47*	.59*

V-VD; and (4) Apprehension Span AU-VD. It is apparent here that the two conditions involving unimodal transformations are at the opposite ends of the scale. Visual-recontruction input-output combination is the least difficult whereas auditory (verbally encoded messages)--verbal description in the context of the stimulus materials combination is the most difficult. From this it was inferred that Ss did not require any modality transformation for V-R tasks, i.e., visual percepts formed during the visual presentations had to be matched with the perceptual alternatives to construct the design. But Ss required two transformations in performing AU-VD tasks. From audition a transformation was needed to convert the information to a non-verbal form and in order to make an informationally adequate message Ss were required to transform the now non=verbal information back into a verbal form.

Similarly, the two intervening conditions AU-R and V-VD may be presumed to involve one transformation. AU-R condition would require a verbal to non-verbal transformation whereas V-VD demanded a visual to verbal transformation. This inference corresponds to the data that these tasks were of intermediate difficulty. The fact that AU-R is superior to V-VD leads to the conclusion that the encoding process into language is more demanding than the corresponding decoding transformation.

This interpretation is contrary to the contentions of Glanzer and Clark (1963, 1964). They proposed a verbal loop hypothesis by which Ss are expected to process verbal or visual information through the verbal mode. This would imply, of course, that Ss would find verbal-verbal processing easier than visual-verbal, verbal-visual, or visual-visual. This is precisely the opposite of what was found in the present study. The results and inference here, in line with that suggested by Rosenfeld (1967), is that information is processed through the non-verbal mode. This position is inherent in Olson's (1969) proposed theiry of the nature of the processing of semantic information. A pictorial representation of the nature of this information processing can be given as an elaboration of the illustrative model proposed at the beginning of this study. (See Fig. 3)

This model implies that the basic mode of information processing is that involving the perception of referent objects and events in the world and responding to these events which in the diagram is labelled cognition or semantics. This system of apprehending the world elaborates with development so

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that it can handle increasing amounts of information. This developmental growth is indicated by the concentric conic sections at the input and output ends of the model. Language input is presumed to be processed in two ways. Surface features of the language, syntax and phonological cues, may be processed in the language system inself independent of meaning (Chomsky, 1957). Semantics or meaning, however, is processed in terms of the perceptual or cognitive system elaborated by experience with référent objects and events. These transformations into and out of the semantic system are what impose the primary bottlenecks in information processing and it is these systems that appear to develop most significantly with age. This point shall come up again when the correlations of these apprehension spans with the PMA tests are discussed.

A general interaction between age and mode of output was significant such that differences between apprehension spans for reconstruction and verbal description modes of output decreased with development. However, this interaction between age and mode of output was significant only for visual input. These interactions imply that the apprehension spans are not developing

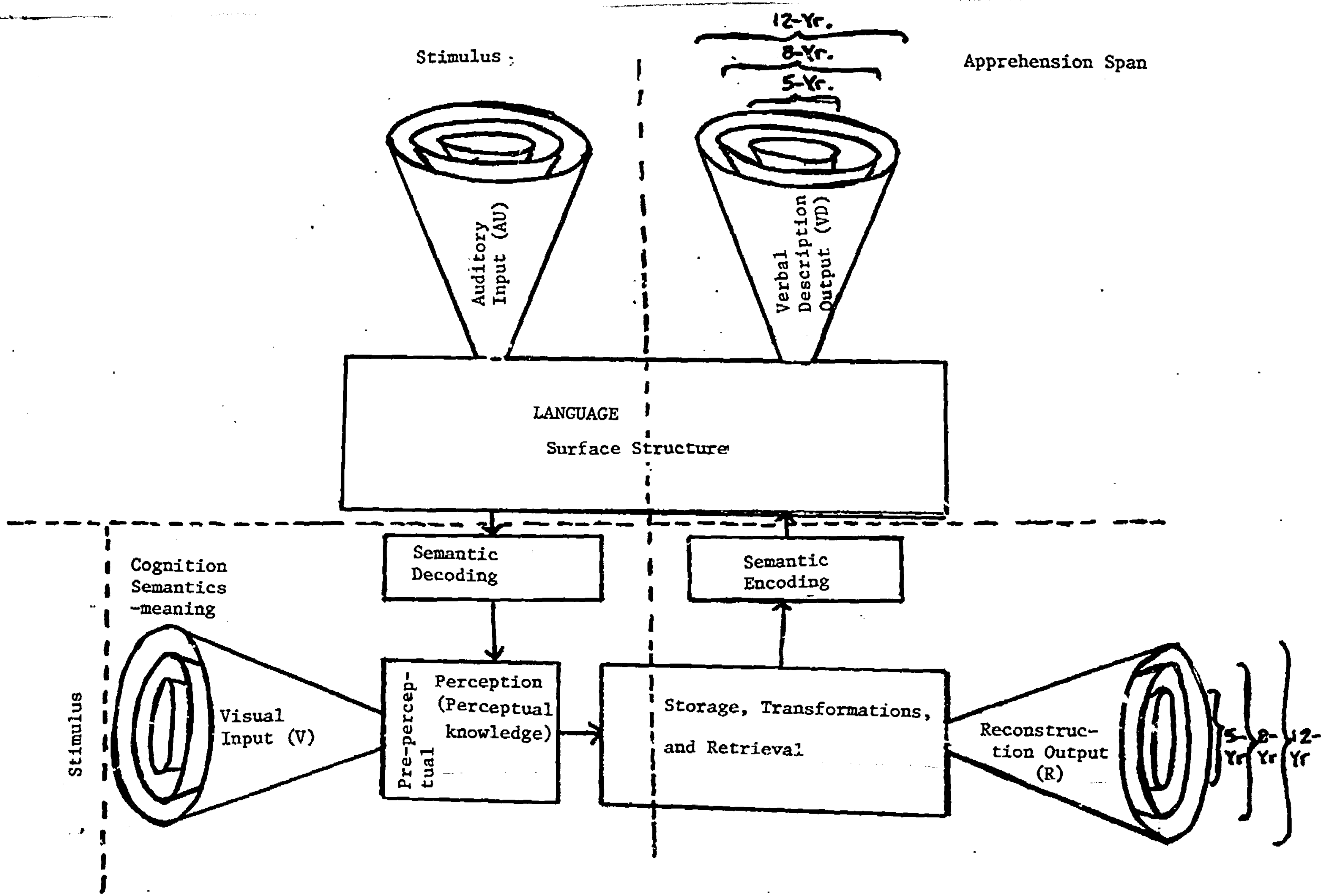

Fig. 3.--Elaborated Developmental Model for the Growth of Apprehension Spans for processing Verbal and Non-Verbal Information.

uniformly but rather that they are developing differentially, those involving verbal output appearing to change more with development than those not involving verbal transformations.

Previously some conjecture about intelligence was made, which can be construed as the ability to apprehend--implying preceiving, storing, and outputting--information. Specifically all four of the apprehension spans that have been examined increase with age. However, some aspects of this ability increase realitive to some others. The differential between these apprehension spans is dramatic for the 5 year olds as compared to that differential for the 12 year olds. That is, the apprehension span for young children in dealing with visual input is better than that for dealing with auditory information while for the 12 year olds that differential has considerably diminished. But in the output phase, a young child's non-verbal performance radically supersedes his ability to verbally describe what he has seen while for 12 year olds again this differential has been reduced.

This leads us to conclude that the bottlenecks in a child's processing of information are primarily those involving translations into and out of another medium, i.e., language. It is this skill which is primarily developmental. Some evidence for this point is found in the correlation with intelligence tests--the PMA. Performance on visual-reconstruction tasks correlated somewhat less with the PMA than do the verbally dependent apprehension spans. The magnitudes of these correlations indicate that the tasks used in this study measure to some extent what is conventionally called intelligence.

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Footnotes

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