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ABSTRACT

Visual and auditory stimuli were presented to children to measure symbol processing abilities. Slides which required matching the similarities in two objects in a group of three were presented. At times the matching criteria varied between function, color, and form. Reaction time was quicker when matching by color than by function, which was faster than when matching was done by form. An unconscious preference for matching by form was exhibited due to longer reaction times. Fatigue had a greater influence on performance among poor readers than among good readers. Familiarity with symbols facilitated synthesis of information especially when children used a robot monkey device whose activities they could program by pressing symbol-coded buttons on a control console. Through this device, children learned to form whole chains of symbols together. (SM)

CIP #259

The Development of Symbol Processing Abilities[1]

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Almost everything we worry about developmentally and educationally, almost all the interesting research and practical problems, are related in some way to the development of our capacities to process information that is represented symbolically -- in written or spoken words, graphic diagrams, numbers, mathematical equations, and even social signs and signals of various kinds. That is what we go to school to learn -- the four R's: reading, writing, arithmetic, and middle class rules. Certainly these are not all the same kinds of symbols, but they all involve the ability to detect a little piece of something -- a raised eyebrow, a few letters, an equals sign -- that represents something else -- quite different, and much more complicated. When we put the little pieces together -- which we can do quickly -- then we have also integrated that more complex information that was hooked on to the little pieces. Thus, by means of our ability to combine and recombine symbols, we can rapidly integrate and reintegrate very complex sets of information. It seems almost magical: when we say <u>the cow jumped over the fence</u>, there is instant comprehension. When we say, <u>No, I mean the cow</u>

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[1]Colloquium Talk, 1973-74. Also presented to the Central Pennsylvania Psychology Lecture Series, December 1973; and to the American Educational Research Association, April, 1974. The research reported here was conducted in collaboration with Lee Gregg and Herbert Simon, and was supported by Public Health Service Grant No. MH-7722, from the National Institute of Mental Health.

jumped over the moon the shift in meaning is almost instantaneously grasped, despite a long chain of new implications that rode in with moon.

How do we become able to do this? Not through rote learning, that's for sure. There is not enough time in the universe to teach a child, symbol by symbol, combination by combination, all the symbolic information he learns how to process. In fact it's not clear that we teach children much of anything about symbol processing. We may help; we *may* help; we like to think we help. But most of the learning is done by the child in ways we do not understand, and can scarcely even recognize while they're happening. If we're ever going to really help, our first job is to understand natural, spontaneous symbol processing capabilities that growing children appear to have.

Not all research methods are suitable for studying these natural capabilities. First of all, we want research materials that resemble naturally occurring stimuli, but that still give us an adequate degree of control over the experimental situation. Secondly, we are going to be interested in the kind of responsive behavior that tells us what kind of mental processing is going on in the head. We will not be interested merely in whether a response is right or wrong, but in whether (for example) it is a slow, thoughtful response, or a fast one. And if it is a slow one, is it slow enough to match a set of mental steps that we think might be happening. For example, if we ask a child "How much is 6 and 4?" is he just looking up the answer, bang, in a list of number facts sitting in his head? Or is he counting it out? If he's counting it out, he will take longer to answer. To make any sense out of response speeds, we must always have a theory or model of what we think is happening, mentally, during the pause.

So, we have naturalistic research materials, and a research procedure that permits us to make inferences about what is going on mentally. A third aspect of research in symbol processing growth is some kind of a general theory about what that growth involves. A useful step in developing such a theory is to pay attention to our own symbol processing experiences. What happens when we learn a new symbol system, in a college math course, for example. First of all, we have to learn to recognize the critical features of those symbols -- what can be substituted for what, for example. What are the variables, what are the constants, what part of an expression can be replaced by something else. Secondly, we become aware of certain fatigue problems. Things get confused, we lose track, all those X's and Y's run together and we can't remember what they stand for. Immediate memory capacities seem to be very critical to symbol learning. Once you get the important features of the symbol display located, you have to be able to hold onto them -- at least long enough to connect some of them up. A third very important aspect of symbol processing theory involves the implicit rules of symbol usage. Those of you who have done some programming will appreciate the term <u>formatting rules</u>. There are rules, in programming, about how you and the computer talk to each other. For example, in some programs, spacing matters; in other programs, it doesn't. In mathematics, there are all those rules about what happens inside parentheses vs. what happens outside of them. Or rules about the order of operations. In reading, there are implicit rules like "Don't try to understand this phrase until all the parts of it are in". That's how you keep out of trouble with reference to the distinction between flying planes are dangerous, and flying planes is dangerous. If you pull out a meaning for flying planes before you get to that verb, you're in trouble. The critical educational fact about these formatting rules -- as they occur in real life -- is that we are not aware of them, and therefore may not teach them.

Now, this is enough theoretical introduction, let me tell you about some research. First of all, let's consider some research on the first theoretical problem -- that of recognizing or detecting the critical features of symbolized information. Children certainly become able to detect such features long before they get to school. But one of the ways we like to think we help is by Headstart or kindergarten lessons in natural classification. When we help children become aware of the fact that they have a basis for deciding that birds belong together, or that foods belong together, or that animals belong together -- we are helping them detect criterial features. What are the features in that case?

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slide 1 on

When we say one of those bottom pictures goes with the top picture, what is the basis of our decision? Probably something about a common function -- both spinach and shredded wheat are to eat. But note they are also both roundish. Maybe the common form or contour is really the basis of

Description of Slides (pictures, in positions shown)

	Top	Bottom left	Bottom right
Slide 1	bowl of spinach	watch	bowl of shredded wheat
Slide 2	cow	ladder	pig
Slide 3	red tricycle	red fire engine	crane (bird)
Slide 4	blue turtle	ladder	blue bucket
Slide 5	blue turtle	ladder	yellow fox
Slide 6	curvy worm	curvy measuring tape	Indian bonnet
Slide 7	curvy worm	butterfly	Indian bonnet
Slide 8	curvy worm	butterfly	curvy measuring tape
Slide 9	robin	parakeet	dust cart

our belongingness judgment.

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slide 2 on

How about this one? We might say here, "Well, the pig and the cow go together because they are both animals." That's a way of saying that our judgment was based on a common name. Would it have to be? Would we want to say that preschool children would not recognize the similarity unless they knew the word animal? No, we would guess that a child could recognize similarities of shape, or perhaps he might recognize -- if he had just been taken on his visit to the country farm -- even a city child might think those are both something to pat, or something that lives together on a farm. Function, again. There is reason to believe that functional criteria are very important symbolic cues for young children. What about color? Does that fire engine go with the tricycle because both are

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slide 3 on

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to ride, or because both are red? How could we find out about all the possibilities?

You will have noticed, of course, that we are using naturalistic materials, and that we are presenting them in a way that makes it possible for us to compare -- say, speed of matching -- among different slides. We can be even more precise about how we do this. For example, suppose we want to ask the question: "if a child matches on the basis of color, will he do it as quickly as matching on the basis of function?" Remember, we need a theory about that to make any sense of such response speed differences. Our theory is that recognizing common functions is a two-step process: first you have to see the object -- the tricycle, say -- and then you have to recall something about its function. You can't get to the function unless you perceive the object first. But if you were matching on the basis of color, that might just be a one-step process. You just see the color, period . You don't even need to name it. So that if children matched on the basis of color -- that is, if they responded to a color feature -- they should do that faster than if they responded to a function cue. We tested that by showing slides like these.

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slide 4 on

We disentangled color from function. Here, unlike the case of the tricycle and the fire engine, the blue bucket matches the blue turtle (sort of) only on the basis of color. Turtles and buckets don't share a common function -- although you might be able to invent one, like both have something to do with water, but that's another experiment.

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slide 5 on

Here, the turtle is matched to the fox, which is a different color. The two are similar only on the basis of function. It turns out, as we expected, that kindergarten children can match on the basis of color more quickly than they can match on the basis of function. About a quarter of a second more quickly, which is a lot of brain time. So can adults. But the really interesting finding is this: relative to their color-processing speeds, that is, relative to their own general response speeds (which are slow), 5-yr-olds can take that extra function processing step as quickly as adults do. If we subtract color-processing time from function-processing time, function-processing will be a little longer for everybody. But it will be the same amount longer for 5-yr-olds as for adults. Now what about form vs. function?

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slide 6 on

Here, the worm can be matched to the measuring tape on the basis of form, with no function in common.

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slide 7 on

Here, the worm and the butterfly share a common function, but do not have form in common. We discovered from slides like these that kindergarten children are very slow in making that form match. Adults can do it quickly. It takes them a little longer than it takes them to match on color, but they match on form more quickly than on function. Again, function matching takes adults an extra step's-worth of time. Five-yr-olds are much slower to match on form than on function. But they like to do it. We would be wrong to conclude that children don't like to do what may be harder for them.

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slide 8 on

If we give children a choice like this, they are very likely to prefer to make the match on the basis of form -- even when they know both choices are right. Of more importance is this, however. Suppose we go back again to the type of match that has both form and function cues.

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slide 9 on

We can show children these mixed pictures, and ask: "Is their matching time very long, as if they were matching on the basis of form, or is it relatively short, as if they were matching on the basis of function?" The answer is, their time is long. It looks very much as if children unconsciously utilize form cues as a basis for classifications of this type.

So what does all this suggest? First of all, that by the age of 5, children are quite efficient at extracting color and function cues from naturalistic stimuli. And that although they are not so efficient at extracting form cues, they practice it -- probably because form information is very important, and very useful. It is, of course, especially useful for learning to read, which is what I want to talk about next.

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projector off

Let me first of all play for you 4 words being read by a 10-yr-old girl who is probably dyslexic. You can follow the sounding out process on these transparencies.

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tape recorder on

overhead projector on

Transp. 1 - 4

What seems to be wrong? Certainly, something about memory. But notice there are several possibilities here. Is it her auditory memory? Or her visual memory? Or both? Is it her memory for a letter she just saw, or is it her memory scanning ability -- her skill in going back over a word in her mind, and asking, "Now, what was that first letter again?" We might also worry about her ability to learn or to recognize common spelling patterns -- like the tion of solution, for example. She called it solutany.

So our experiment investigated memory problems of all those kinds: memory span (how well sets of letters can be remembered); memory scanning ability -- in both auditory and visual modalities; and letter pattern concepts. I'll tell you about this last part of the study first.

Unlike more traditional studies of reading ability, we did not try to find out if children knew the common English spelling patterns. Clearly, poor readers don't seem to know them, that's one of the reasons they get defined as poor readers. Our question was whether or not they

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SOLUTION (3)

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SO SOLU TA NY

"I THINK THAT'S RIGHT"

(Transparency 3)

U N C O M F O R T A B L E (4)

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(Transparency 4)

had the concept of a spelling pattern in the first place. So we gave children sets of letters -- Bs, Ss, Ks, and Ms -- which couldn't be made to spell anything, and asked them to make up patterns with them. We were quite explicit about what pattern meant. We used color names as an analogy, and said, "A color pattern might be blue, blue, red, red, green, green, or blue, red, green, blue, red, green. Now, you do something like that with your letters." All the 10-yr-olds knew what a color pattern was. Yet the poor readers in our study had a great deal of difficulty making up letter patterns. They just couldn't get the idea. They had 3 chances, and a lot of encouragement, but they seemed to lack the idea of a spelling pattern -- compared to the good readers.

The memory results are a little more complicated to explain. All the children repeated back letter sets, like "K B B M", or "B S M K". Half the time they heard the letters that they repeated back, and half the time they saw them. One group did the auditory sets first, and then the visual sets; the other group did the visual sets first, and then the auditory ones.

Now it is an important fact about normal memories for tasks of this type that they get tired, as trials go on. The letters get confused with each other, so performance goes down -- normally. But normally, when you switch from hearing letters to seeing them, there should be a recovery of ability. It's as if the new modality is fresh, and ready to go. If you've been listening hard to something, switching to looking at it will bring your accuracy back up. Or, if you have been looking hard at something, switching to listening will bring your accuracy back up. This is called "release from proactive inhibition" as those of you who have studied experimental psychology will recognize. But we do not find this release among poor readers.

Transp. 5

Here are the good readers (black circles) doing the first 2 visual trials, then the last two. They show the normal signs of fatigue. Now they are switched to the auditory letter sets, and you can see how they recover. But see what happens to the poor readers. They start here, and here, and recover only a little when they switch to auditory. The good readers, after switching, don't end up with as much memory fatigue as the poor readers start with, on the auditory trials. And see where the poor readers finally end up.

When the auditory trials are first, the same effect appears. The good readers start here, end here, and pop up to here when they switch to their visual trials. But the poor readers show no recovery at all.

The same type of difficulty appears when we look at memory scanning. In the memory scanning trials, the children heard letter sets like the ones before. But this time, they answered questions like, "Which letter came first? Which came last?" They answered those about lettersets they had seen, and those they had heard.

Transp. 6.0

(Transparency 5)

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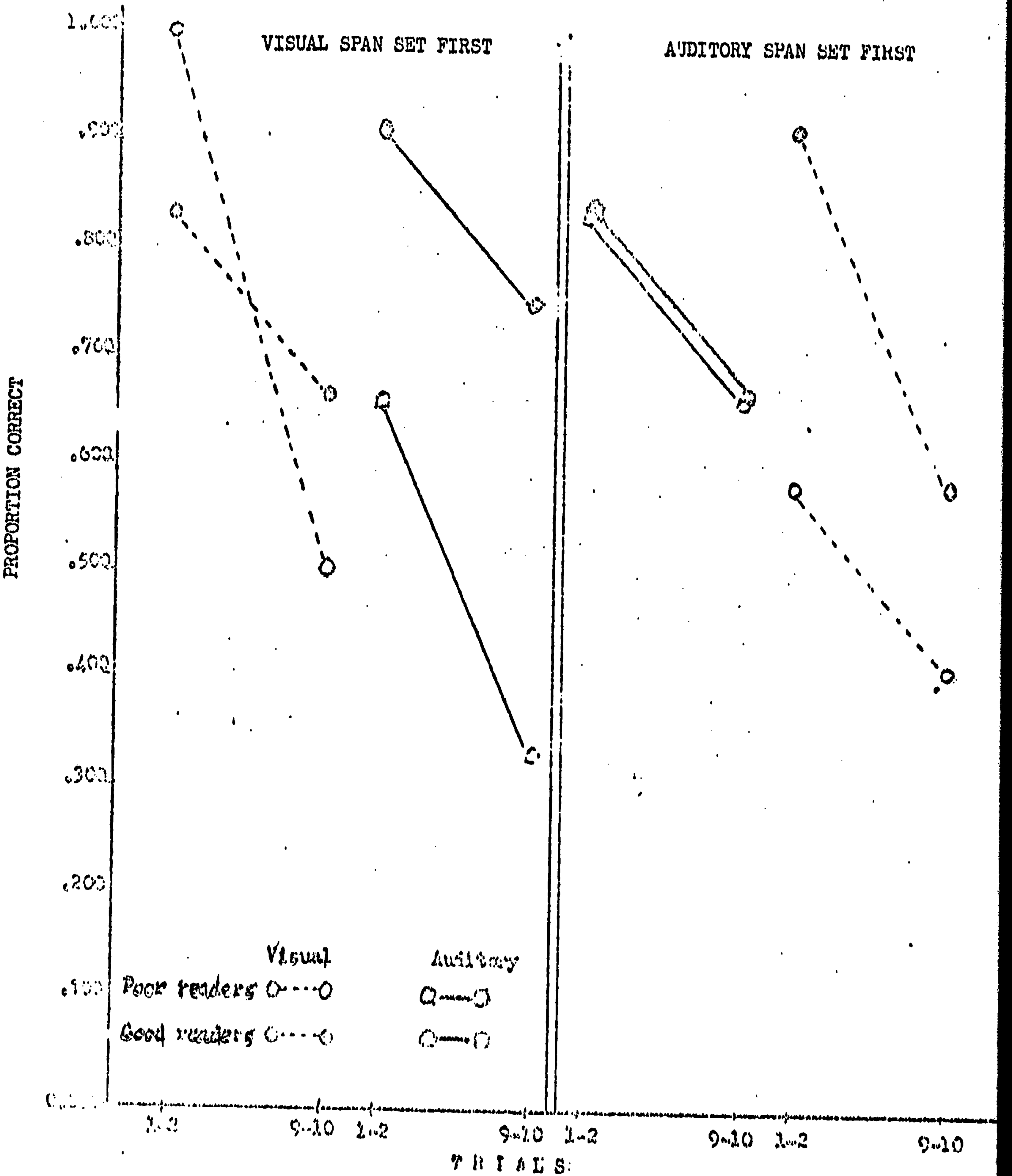


Here are the good readers, this is the amount of time it takes them to answer the First? and Last? question in the visual and auditory forms. You see how alike the curves are, as their trials go on. The visual and auditory curves are very similar -- showing that good readers can get a memory of a visual letter as quickly as they can get at a memory of an auditory letter. Now look at the poor readers.

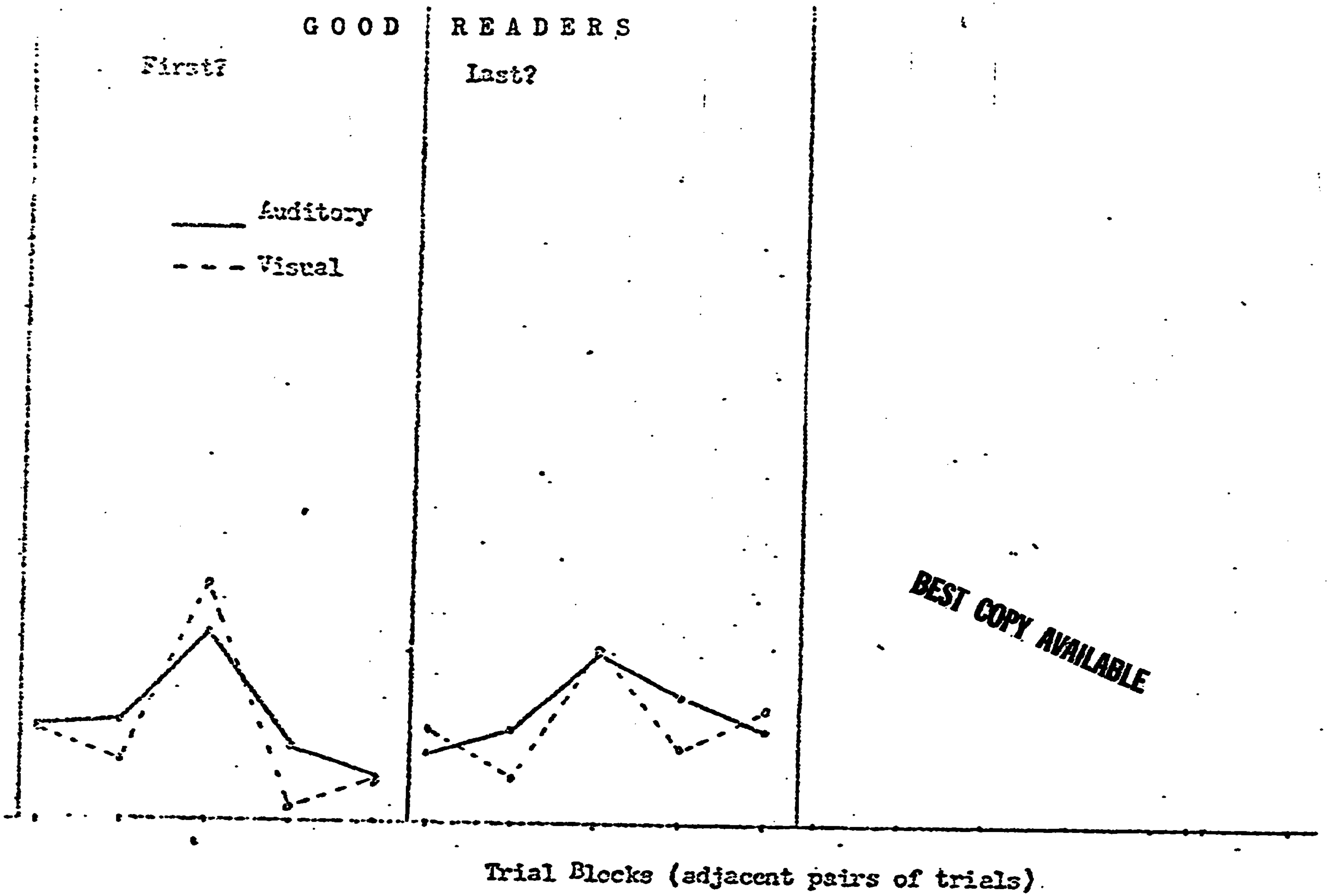
Transp. 6.5

They are slower to get at auditory letters, as trials go on and they get tired. There is a discrepancy or a lag between their ability to get at letters in visual memory, and letters in auditory memory. Perhaps this is why poor readers do so poorly on auditory-visual matching tests, like the Birch dot-tapping test. There is this spreading fatigue of the auditory memory system.

Transp. 7

Here are the kinds of errors most characteristic of good and poor readers. The good readers are likely to make whole word errors, if they make any errors at all. They're in column 1: <u>different</u> for <u>definite</u>, <u>square</u> for <u>screw</u>. The poor readers are most likely to make integration errors, shown in the next two columns. And these kinds of scrambled errors are predicted by that spreading fatigue, and by the failure to

(Transparency 6.0)



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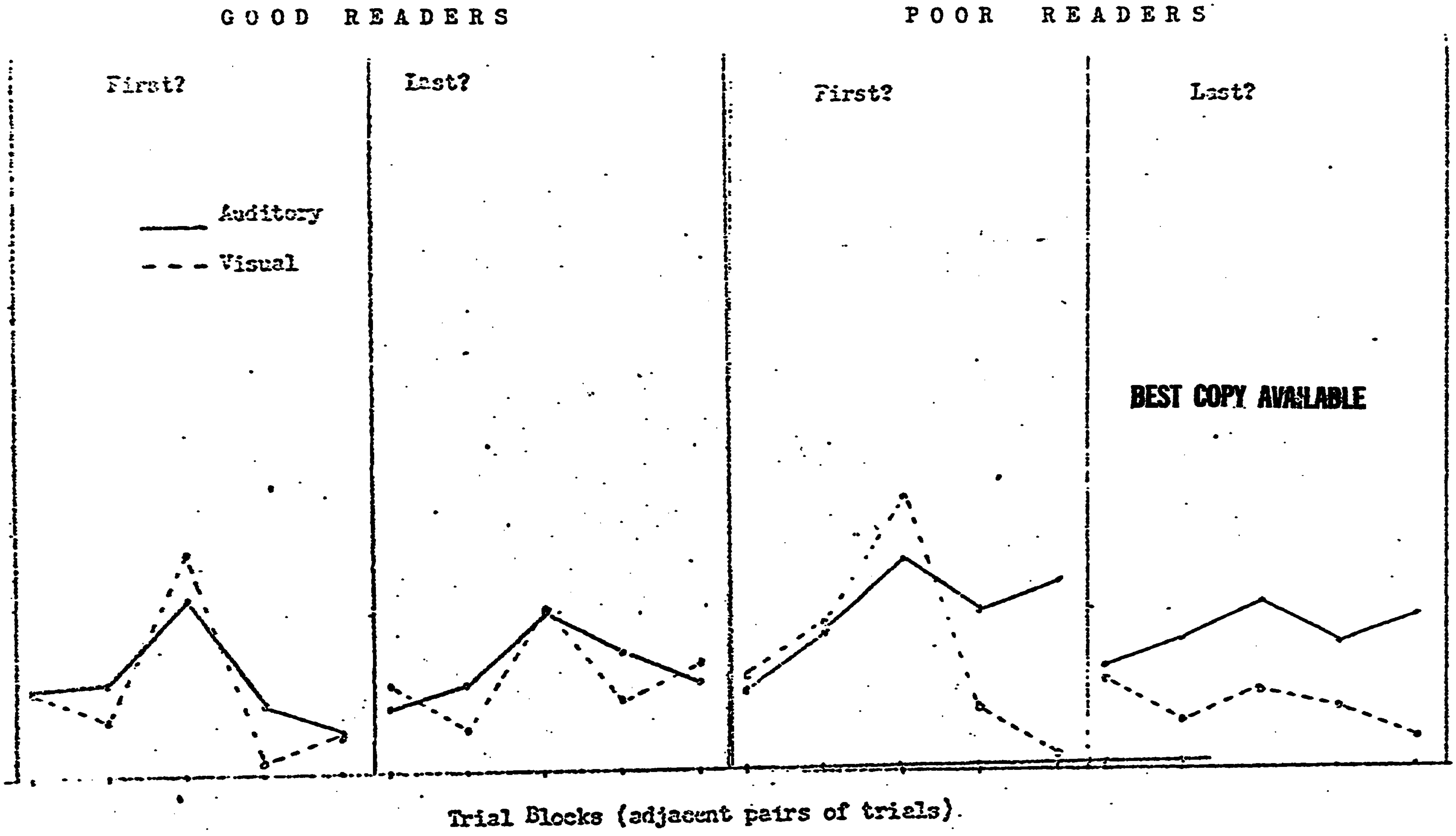


(Transparency 7)

	Words	Subject H1	Subject B1	Subject B2
1.	reindeer	reindeer	reindeer	reindeer
2.	pleasant	plenty	pleasant	pleasant
3.	freight	figure	frightened	fright
4.	knit	night	knight	knight
5.	shower	slower	shower	shower
6.	whether	whether	whether	whether
7.	adventure	adventure	adventure	adventure
8.	bracket	bracket	broket	breakit
9.	conceal	control	concol	corncurl
10.	kerosene	curious	consen	kares
11.	magnet	magenet	magnet	magnet
12.	notion	notice	notion	nawtion
13.	poetry	poetry	poetry	protrose
14.	screw	square	scree	gree
15.	alternate	attitude	alfoonite	elltornate
16.	companion	complete	compension	compension
17.	definite	different	defynit	definite
18.	estimate	instrument	extermate	essmate
19.	majesty	marijest	magjenate	majesty
20.	glitter	gillotte	glatter	groller
21.	particular	particulds	presenter	parature
22.	reverence	rejurious	revention	revensure
23.	solution	solitude	slotion	soltation
24.	uncomfortable	icomfort	uncomfortable	unforgridabl

recover when there is a memory switch. This seems very important, if you think about how your attention switches back and forth, from visual to auditory symbols, as reading progresses. We don't usually think of that switching as a rest-and-recovery mechanism, but that is what it appears to be -- for good readers.

Finally, let us take up the question of those hidden formatting rules. Some of this research was done a while back, but I will review it briefly, and then bring you up to date.

Notice that if we are studying one part of the symbol processing operation, we are careful not to confuse it with aspects of the other operations. When we studied feature extraction speeds, memory was not a factor -- the pictures were sitting right there. When we studied memory, we were careful to make the letters easy to distinguish -- we didn't use both E's and F's, or B's and D's -- because we were not studying feature extraction abilities. Now, to study formatting concepts, we want to eliminate both memory and feature extraction requirements. So we use large, easy-to-distinguish whole word symbols, and they are always visible for the child to see.

Transp. 8

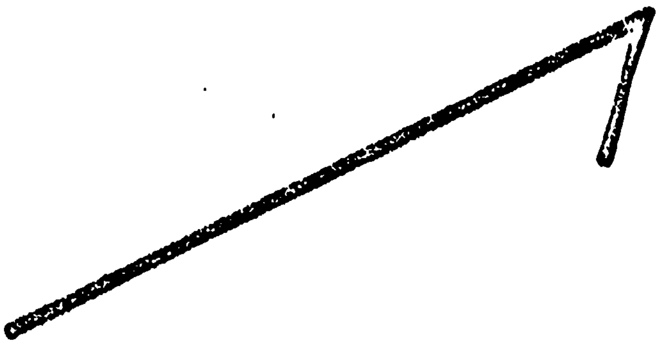
These are symbols that preschoolers learn for familiar words like jump and block. Then they see simple sentences like these.

Transp. 9

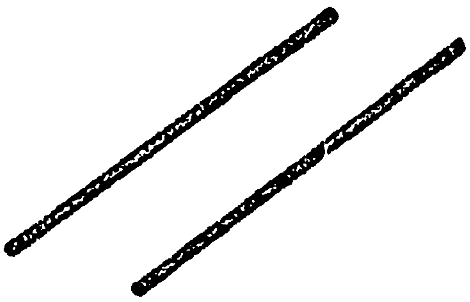
After they've read the sentences -- and they sound quite fluent --

(Transparency 8)

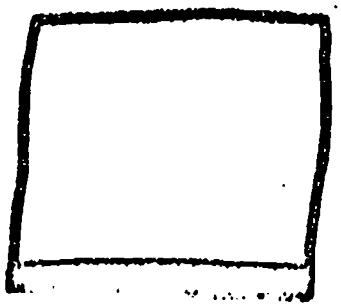
(1. JUMP)



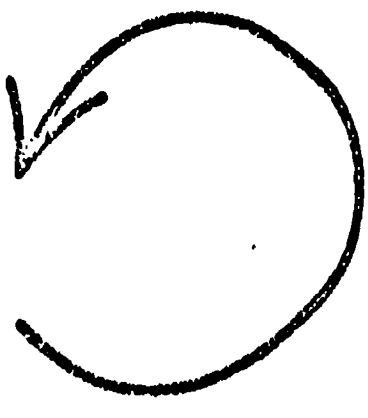
(2. WALK)



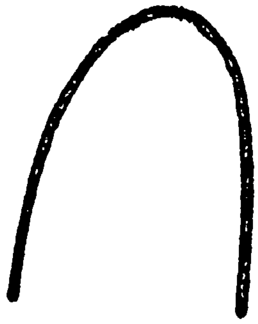
(3. BLOCK)



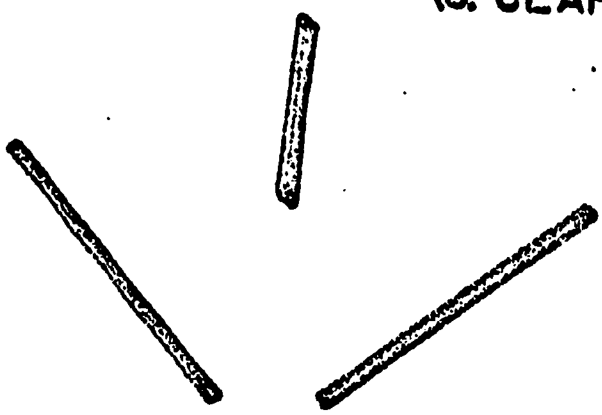
(4. AROUND)



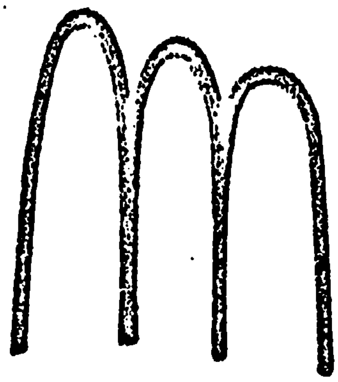
(5. OVER)



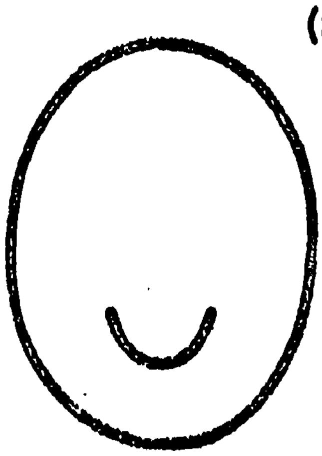
(6. CLAP)



(7. HANDS)



(8. TEACHER



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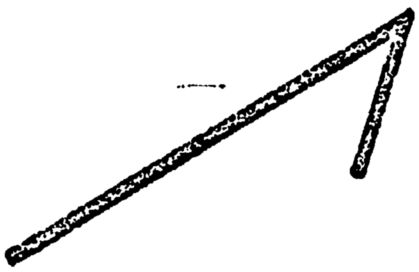
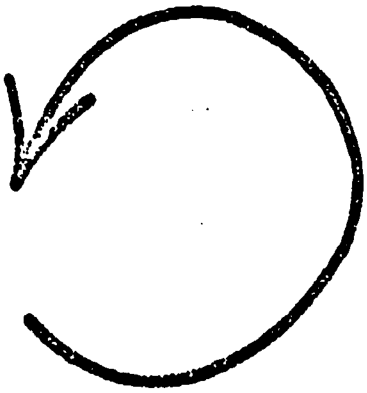
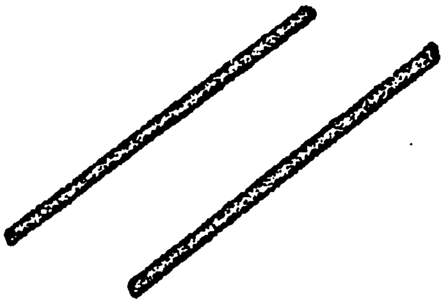


(JUMP

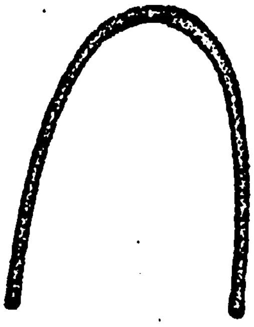


AROUND

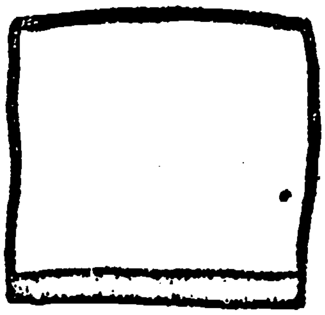
TEACHER.)



(WALK



OVER



BLOCK.)

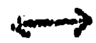
we ask them, "Now let me see you do it." The typical 5-yr-old, having read this sentence, takes a few steps, makes a sign for over, and points to a block on the floor. He is very pleased with himself for having invented such a clever response. A few minutes ago, he may have seen the block on the floor, and the experimenter asked him, "Would you walk over the block?" To which he responded by walking over the block. Now, however, with these visual symbols giving him the instruction, he figures it out differently. He does not coordinate or synthesize the information.

But we couldn't tell if this was because the visual symbols were newer to him, compared to sentences that he heard, like "Walk over the block", or because they were visual. So we taught children unfamiliar auditory sentences -- a nonsense language.

Transp. 10

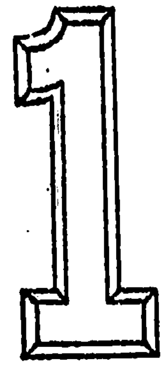
Here, they learned symbols for things -- monkeys and dolls -- and symbols for actions, and for locations. A sample sentence, combining the 3 types of symbols, might be "monkey hop box". They knew how to make the monkey hop on the box, but if they received the instruction from these newly-learned visual or auditory (nonsense) symbols -- they were unable to integrate the information. They pointed to the monkey, made a hopping motion, and pointed to the box. So it was unfamiliarity that made the difference, not modality. Here is another example of a formatting rule deficiency.

Transp. 11 and 12

The World		Visual Symbols (Logographs)	Auditory Symbols (Nonsense Words)
Nouns	wooden monkey		ooch
	doll baby (white)		miff
	doll lady (black)		keet
Verbs	hopping (on foot)		rad
	banging (with hands)		mog
	lying down		flin
Adverbs	on the table		zife
	on the floor		glug
	in the box		pope
Sample sentence:			
	monkey hop box		ooch rad pope

(Transparency 10)

(Transparency 11)



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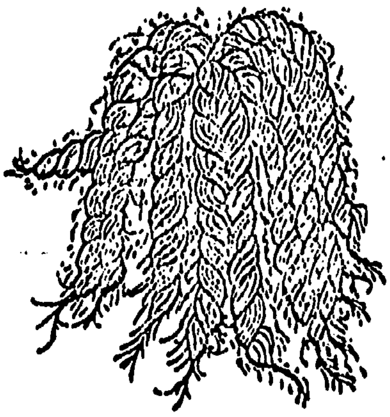
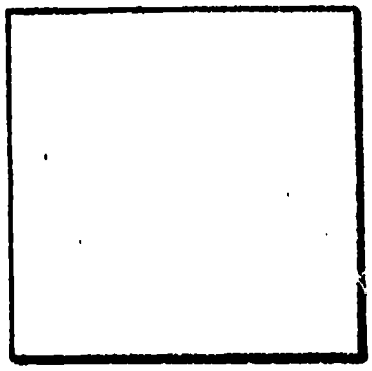
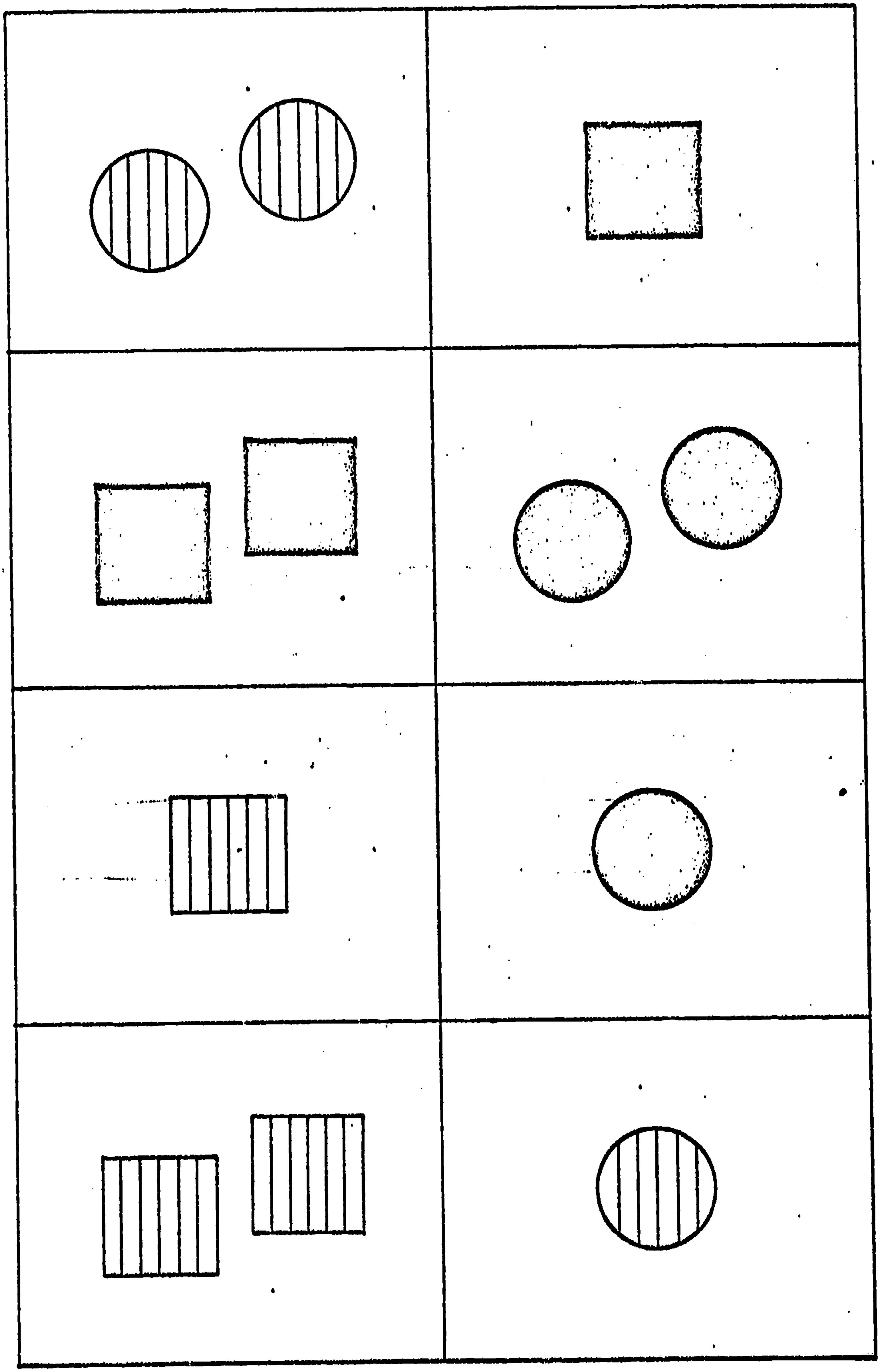


red
yarn



wooden
square

(Transparency 12)



In these studies, children read rebuses, like "one red square", and then point to the correct one here. But 5-yr-olds typically point to any old square -- they ignore both color and number information. Their rule is, "pay attention to the last thing you saw." We know this, because if we reverse the rebuses to read "one square red", then the children will point to any old red thing, and ignore number and form information. The change in their error patterns looks like this.

Transp. 13

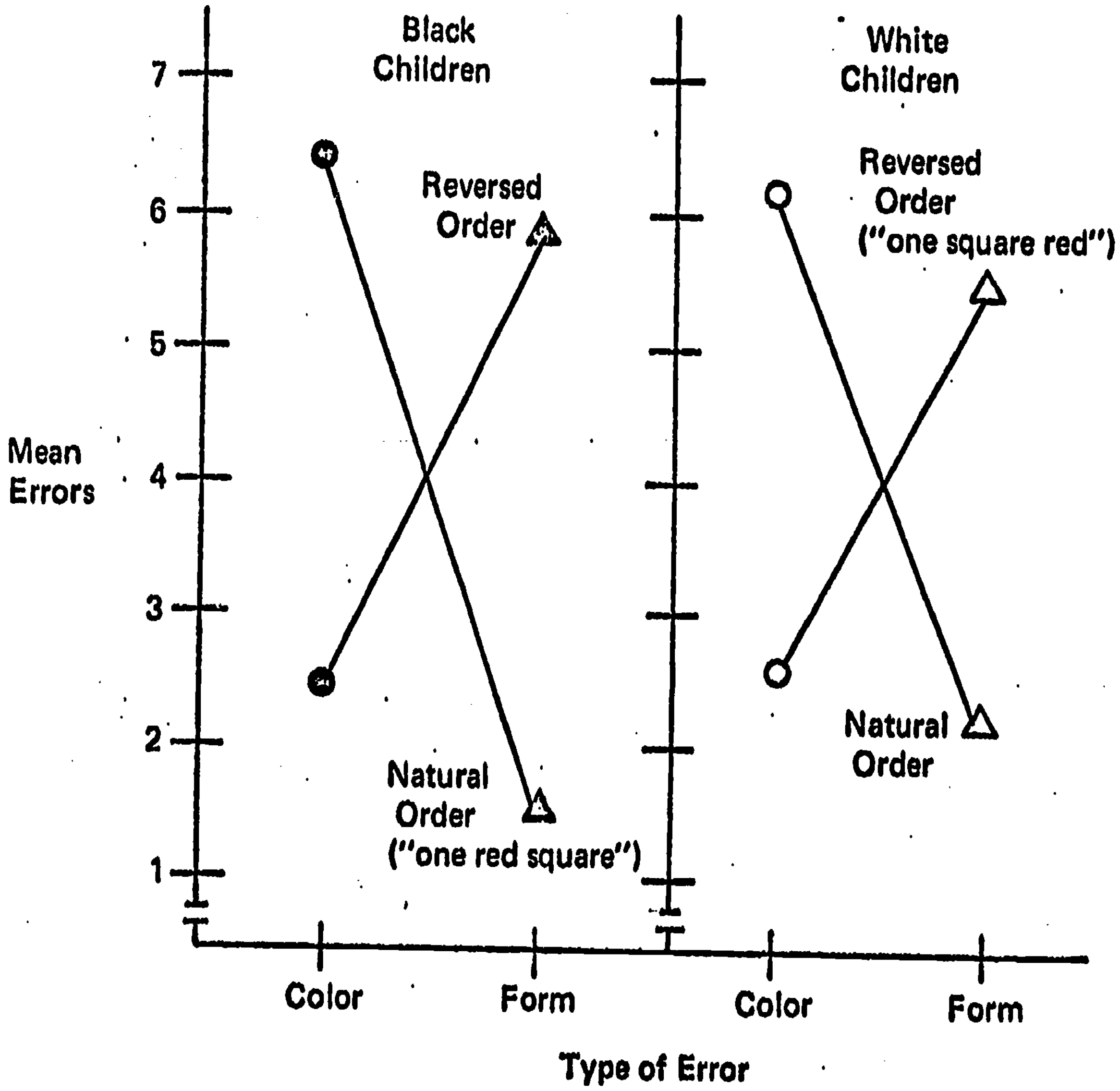
Here, the color errors are high, and the form errors are low, for the natural English order, "one red square." When we switch the rebuses, to "one square red", the form errors switch to high, and the color errors switch to low. Note: the same pattern in both black and white racial groups. But we can make it disappear. All we have to do, is persuade the children to pay attention to their own voices. We say, "What did you say?" and they answer "one red square" and we say, "now find (on the answer board, Transp. 12) what you said." When they listen to the information in their own language, they remember it all, and use it all.

So the natural formatting rules that child develop, to process new symbols, seem to be like the following:

-- find the meaning of one symbol at a time; or

-- find the meaning of the last symbol

(Transparency 13)



If we want them to adopt the rule:

-- wait until all the symbols are in before deciding what they mean,

-- use the information from all the symbols

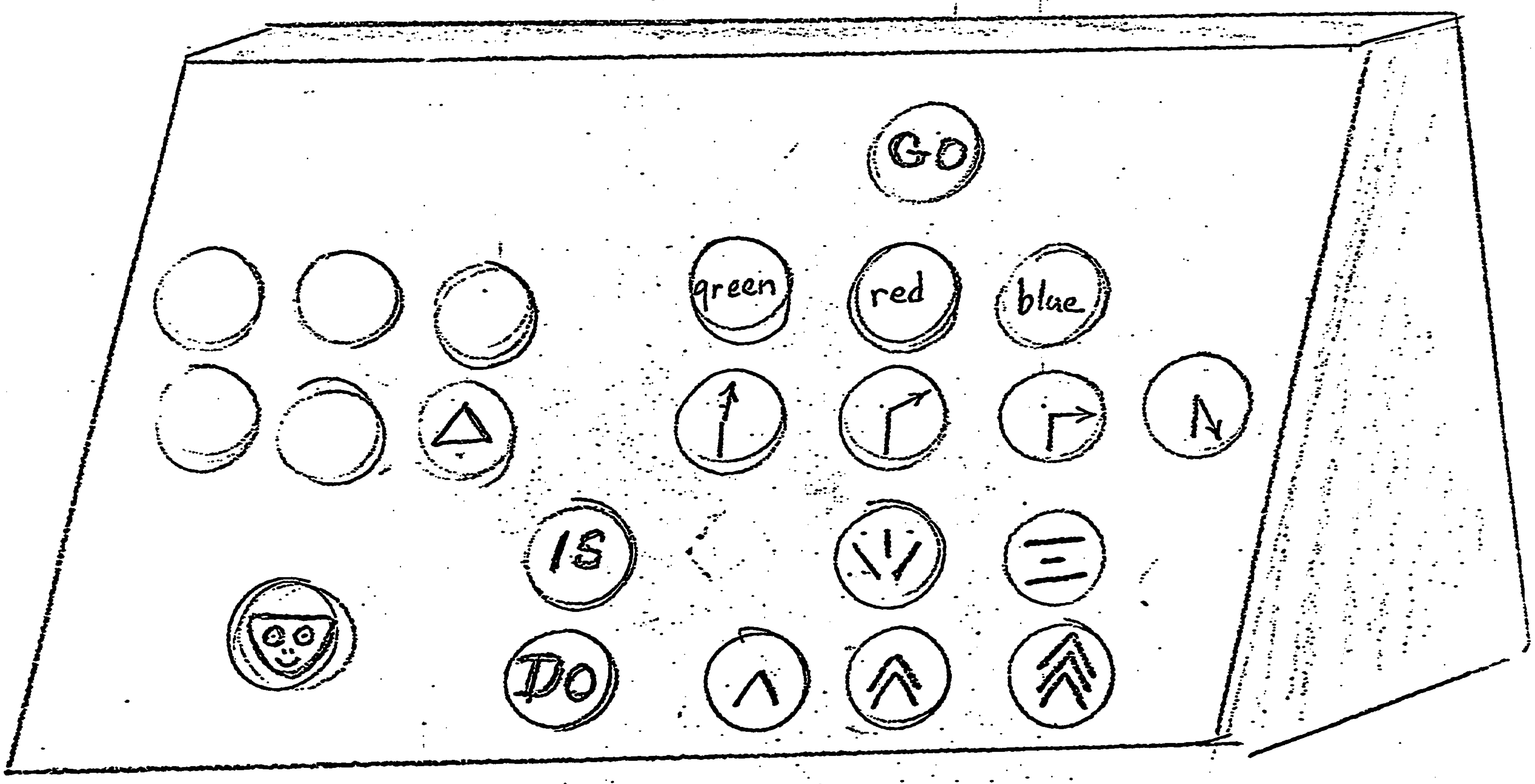
then we must use a familiar symbology, like their natural language, or we must translate their new symbology into the familiar one. And we must make sure they pay attention to the translation.

This, of course, leaves unanswered the question: how do children learn rules like "wait until all the symbols are in before deciding what they mean" in their natural, familiar symbology. And, would they learn these rules about a new symbology -- especially a visual one like reading -- if they had as much practice on that, as much opportunity for familiarization, as they have on natural spoken language?

To answer that question we need a very interesting experimental situation. Clearly we cannot force young children to practice the alphabet, or even whole word symbologies referring to walking over blocks, and jumping around teachers, and other fascinating events of that type. To keep children enthralled enough to practice a symbology a lot, we are bringing in a computer-controlled robot, called Turtle, which has been developed by Seymour Papert at MIT -- as a tool for educational instruction, and a general toy for computer scientists. We have devised a control panel which will look something like the following.

Transp. 14

(Transparency 14)



The robot is actually a small cannister on wheels. It has a pen which can be lowered, so it can draw, upon request. We envision 3 colors of pens, and also a light on top -- for eyes that open and close. Turtle will also sing several notes. So it has eyes, legs, hands, and a voice -- in its light, wheels, drawing pen, and music box. The problem the child faces is to teach the turtle all the things it can learn how to do. For example, if the child presses the green button, and then the Do button, the Turtle will go straight ahead for one foot, drawing a green line. If the child presses the Go button and then the Do button, the Turtle will go one foot without drawing a line. So far so good, but dull. Suppose the child presses a lot of buttons, and then the Do button. What will happen? Only the last button pressed before the Do button will be acted upon. Like the 5-yr-old reading "one red square". How to get the Turtle to do an integrated set of activities -- draw a red triangle, for example. This (red) makes one red line, this (120° angle) makes Turtle turn, ready to draw a line with the correct angle for a triangle, but will not make the Turtle move or draw. What is needed is for the Turtle to wait until all the symbols are in and then do something. But it shouldn't respond to only the last symbol it gets. Like any old 5-yr-old. So we're hoping our 5-yr-olds, with sufficient exploration and practice, will learn to do the following: first, they press the head button, signalling that something is going to be put in Turtle's head. Then, they could press the red button, the 120° angle, the red again, the angle again, and the red again. That adds up to a triangle. Then they press Is, and then This -- which is really a subroutine call button, with a red triangle pasted on it. The information is, then, red, angle + red, angle + red, angle <u>is</u> triangle. Clear? After that little program has been constructed, when the triangle button is pressed, the Turtle will zip through a routine of drawing a beautiful red triangle.

Five-yr-olds can construct verbal sentences which are much more complicated than the one I just described. If they practice enough with these interesting visual symbologies, will they become as skillful in putting the symbols together, at coordinating the information, at teaching Turtle how to wait until all the information is in, before acting on it? We will be especially interested to see if children who begin such practice at the age of 3 learn how to read more easily, when they enter school at the age of 6. Although they will have had some practice in learning to detect critical features, and some memory practice, their major practice will have been in learning formatting rules. But the question as to exactly how formatting rules, rules for waiting, rules for switching attention, might solve the memory problems of dyslexics, must await further research.