DOCUMENT RESUME

ED 084 908 FL 004 528

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TITLE	The Two-Fold Way for Speech.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	15 May 72
NOTE	29p.; Paper presented at the C.N.R.S. Conference on Psycholinguistics, Paris, France, December 12-17, 1971
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	Child Language; *Cognitive Processes; Deep Structure; Experiments; Kernel Sentences; Language Learning Levels; Language Patterns; *Linguistic Competence; *Linguistic Performance; Pictorial Stimuli; Semantics; Sentence Structure; Serial Ordering; *Speech; Surface Structure; Syntax; Tables (Data); *Time

ABSTRACT

On the basis of experimental data, the author makes the following observations: (1) the basic encoding processes in speech, the schemas of order, first produce elementary underlying sentences; (2) underlying sentence structure is the controlling step in the organization of speech; (3) underlying sentence structure plays a central role in regulating the duration of speech; (4) various processes that relate to speech take widely different amounts of time; (5) therefore, there is a definite correspondance between grammatical structure and linguistic performance. Tables containing data concerning temporal duration and a bibliography of references are included. (DD)

The Two-Fold Way for Speech

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As one produces or listens to speech, there are processes in the brain that correspond to and underlie the speech. It is a truism that there is continuous and general activity within the nervous system. Such activity now and then rises to the surface as speech. But there presumably also are brain processes that correspond specifically and exactly to particular utterances. Utterances that are heard, according to this view, trigger a certain series of processes in the brain that would not otherwise occur, while utterances that are spoken are the result of processes that lead up to a certain utterance and not to some other.

The processes I have in mind are closely linked to the ones involved in the problem of the serial order in behavior, as Lashley (1951) discussed this problem in a celebrated paper of that same name. Lashley said, for example, that "... syntax is not inherent in the words employed or in the idea expressed. It is a generalized [cerebral] pattern imposed on the specific acts as they occur" (p.119), and "This is the essential problem of serial order; the existence of generalized schemata of action which determine the sequence of specific acts, acts which in themselves or in their associations seem to have no temporal

*For the C.N.R.S. Conference on Psycholinguistics, Dec. 12-17, 1971, Paris, France. Supported by NSF GS-2860. Revised May 15, 1972.

valence" (p.122). The most obvious example of such sequences, as Lashley pointed out, is speech. The brain processes that are specifically associated with utterances have the effect of imposing a particular temporal valence, an order, on speech by determining the order of events at some point in the brain, where the production of speech is directed.

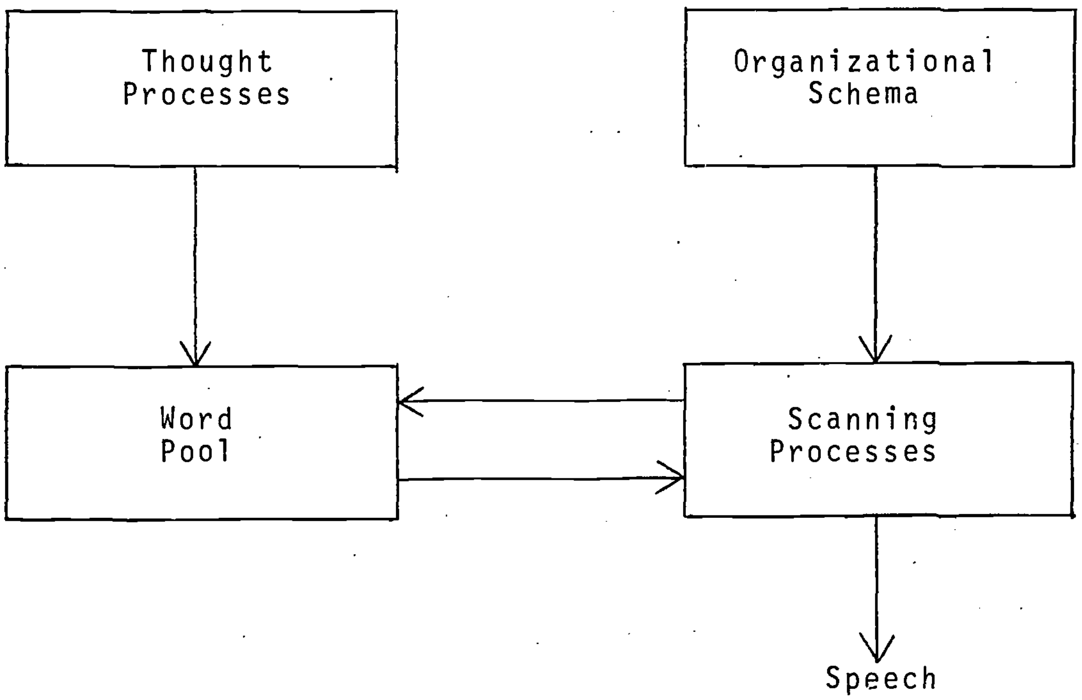
A striking fact of the speech of young children is that the grammatical relations of elementary underlying sentences appear in the earliest organized utterances by controlling word order. From the outset, children's patterned speech follows the general principle,

grammatical-semantic relations $\Longrightarrow$ ordered combinations of words.

Virtually every child, regardless of the language to which he is exposed, relies thus on word order to encode meanings (Slobin, 1971). The only well documented exception is one of the Finnish children described by Bowerman (1968) - a deviant and isolated case. For others, the question is, Why do children who are exposed to languages like English notice that word order is being used to encode meaningful relations? And why do children exposed to languages like Russian adopt word order on their own for encoding meaningful relations, when the adult language does not? The answer may be the same in both cases. At a certain level of development, the processes necessary for organizing words into a serial order become available, whereas previously they had not been, and these processes are incorporated into the child's speech. (Even in the case of highly inflected languages, a child who can organize words into a serial order could decide from any one adult utterance that word order encodes meaningful relations.)

Lashley considered the problem of serial order in speech to be unsolvable by so-called "chain" theories, in which successive words trigger each other (however, this theory has recently been revived for phonology by Wickelgren, 1969). Instead, according to Lashley, what is required is a theory that explains how a single underlying "schema" determines the order of words in the utterance of an entire sentence, the schema acting on the sentence as a whole and in advance of the actual linguistic performance.

Lashley argued not only against chain theories, but equally against the suggestion that the organization of speech can be identified with the order of ideas in thought. Thought has no intrinsic order, Lashley believed, and therefore cannot be used to explain the organization of speech. The phenomenon of Spoonerism, where words or syllables destined for early and late parts of a sentence are interchanged, shows that the conceptual operations that select words for speech are active for different words at the same time, or at least active for words at times that do not correspond to their order in speech (cf, Fromkin, 1971, for numerous examples of this type of speech error). Rather than explain the serial order of speech by positing a corresponding order in thought, Lashley suggested that the processes of thought behind speech create a "pool" of simultaneously activated words. This pool is then scanned in an order determined by the schema that determines the serial order of words in speech. Thus, in Lashley's view, there is a separation of the effects of thought from the mechanism of serial order. The production of speech follows two paths that converge when serial order is determined and the theory might thus be called "the two-fold way for speech":



The hypothesis to be suggested at this point is that the basic encoding processes in speech, the schemas of order, are ones that first produce elementary underlying sentences. These structures are unique among linguistic forms in that they (or their semantic equivalents) appear very early in children's speech (Bloom, 1970; Greenfield, Smith, and Laufer, 1972). Bloom, for example, gives instances of at least the following six relations:

1. Modification. E.g., black hair said of a doll's hair

2. Direct object of verb. E.g., Kathryn want a raisin

3. Location. E.g., foots flower when looking at a picture of a flower on a bare foot

4. Possession. E.g., Kathryn sock said of the child's (Kathryn) sock

5. Indirect object of verb. E.g., Kathryn ə bear said as Kathryn gives a raisin to her toy bear

6. Subject of sentence. E.g., Jocelyn said of a friend who had bruised her cheek.

This set of six relations is not an exhaustive list of the relations that occur within elementary sentence structures, but it includes all the major ones. Taken together, these relations imply the existence of elementary underlying sentences in the earliest patterned (hence, serially ordered) speech of children. The elementary underlying sentence is more highly developed at the outset of patterned speech than surface structure is, which, in fact, is highly restricted at this stage.

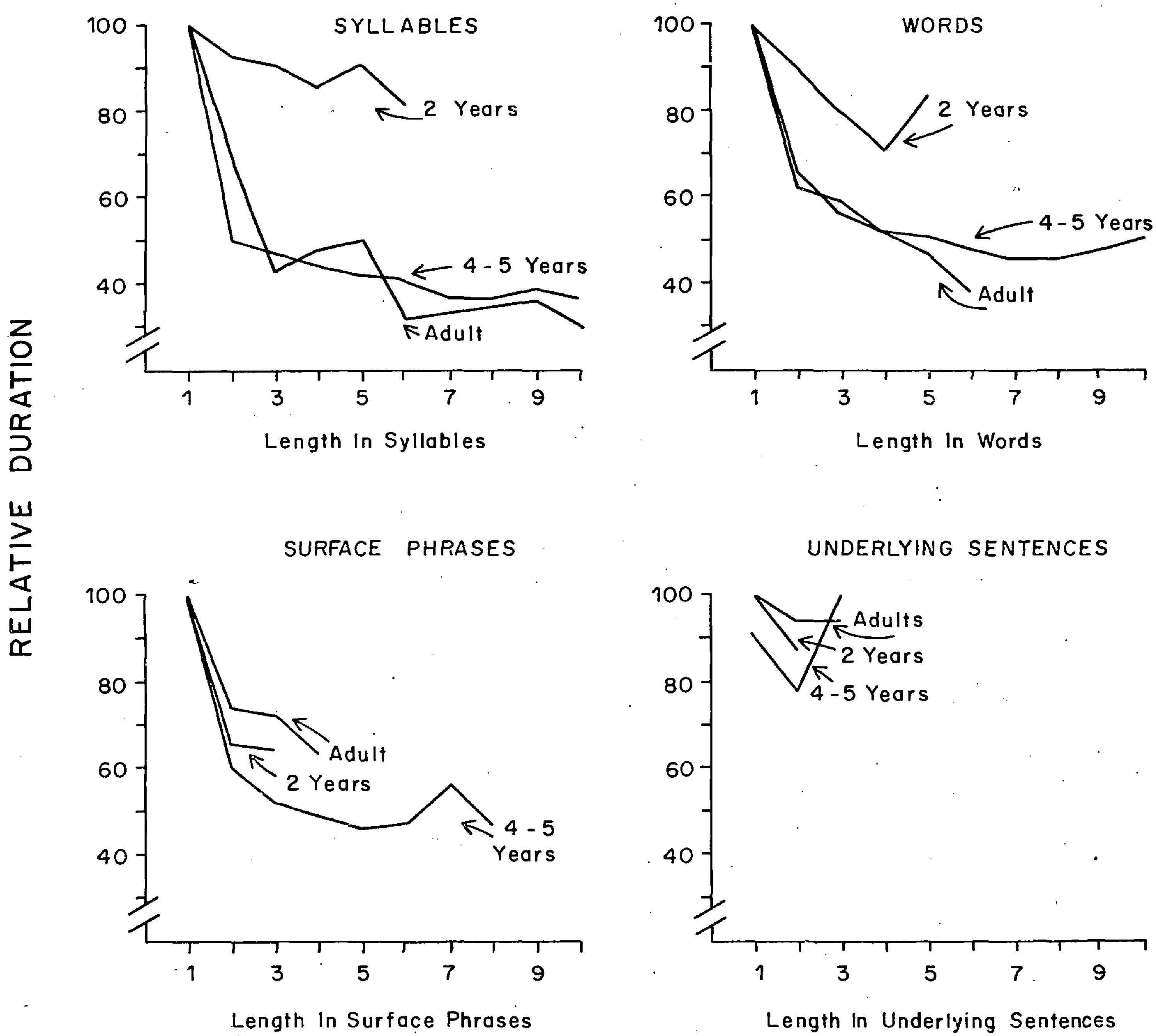
According to this hypothesis, the right-hand branch of the two-fold way for speech includes, at some level, the functional equivalent of what, in a linguistic description is represented as underlying "S". No particular theoretical claim is made for the internal analysis of "S". If the basic unit for speech corresponds to the elementary underlying sentence, then other more superficial units would be controlled in turn by this structure. Such an asymmetrical arrangement should have discernible consequences for the production of speech.

Fig. 1 here

Temporal regulation in speech. Figure 1 shows the average duration of syllables, words, surface phrases, and underlying elementary sentences in samples of the spontaneous speech of speakers of three widely different ages. The actual age range is approximately 16 months to 30 years. In order to compare linguistic units of different sizes and different absolute durations, all durations in Fig. 1 have been normalized to the percentage scale, by expressing the average duration at each length of a particular unit as a percent of the longest duration of that same unit. Absolute durations are given in Table 1.

Table 1 here

The average durations in Table 1 and Fig. 1 are calculated from the total duration of each utterance. The quotient, this duration divided by the length of the utterance in each of the four units, is the "average duration". (There is further



RELATIVE DURATION
SYLLABLES
2 Years
4 - 5 Years
Adult
Length In Syllables
WORDS
2 Years
4 - 5 Years
Adult
Length In Words
SURFACE PHRASES
Adult
2 Years
4 - 5 Years
Length In Surface Phrases
UNDERLYING SENTENCES
Adults
2 Years
4 - 5 Years
Length In Underlying Sentences
100
80
60
40
1
3
5
7
9

TABLE 1

AVERAGE DURATION OF LINGUISTIC UNITS (Sec)
(All lengths combined)

Age of Speaker	Underlying Sentences	Surface Phrases	Words	Syllables
Adults	1.46	.58	.33	.28
4-5 years	1.32	.68	.39	.30
2 years	1.15	.74	.61	.44

averaging across utterances, but this average is not the "average duration.") The assumption is that the duration of the internal encoding processes corresponding to each linguistic unit (syllables, words, phrases, underlying sentences) is correlated with the average duration of the vocalization that can be mapped onto the same linguistic unit. Thus, whatever internal processes specifically correspond to the production of syllables can be timed from the average syllable duration, as defined above. Similarly for the duration of the processes that correspond to elementary underlying sentences. These can be timed, making the same assumptions, by dividing the duration of an utterance by the number of elementary sentences it contains. The correlation between the duration of vocalization and that of internal processing probably is lower in the case of underlying sentences than in the case of syllables, but there seems to be no reason in principle not to treat the two measurements as equivalent, reliability aside. The measurements in Fig. 1 and Table 1 are based on not fewer than 10 utterances at each point in the figure (the number is much larger at shorter lengths) and not fewer than 300 utterances for each row of the table.

As can be seen in Fig. 1, there is little change in average duration with length when the unit is the underlying elementary sentence. The average duration of surface units is compressed, in contrast, especially in the speech of older speakers. The average duration of words in adult speech, for example, is compressed to almost 40% of their maximum duration (which occurs with single word utterances). It is impossible to say at present whether this compression comes from an acceleration of output or from a general adjustment of word and syllable duration that affects the duration of all words and syllables at a given length in the same way. Young children show the same constancy at the level of underlying structure as older children and adults do. If underlying structure is available to children at the beginning of patterned speech, which much evidence suggests, this constancy is predictable, given the hypothesis that the underlying structure comes from the operation of brain processes that are necessary for the organization of serial behavior. According to this hypothesis, even the youngest children, if they use word sequences to express grammatical or semantic relations, will follow the time constraints that older children and adults follow.

Figure 1 shows relative durations, each linguistic unit providing its own baseline. When absolute durations are considered (Table 1) it becomes clear that children resemble adults not only in consuming equal relative increments of time with each underlying sentence, but also in consuming the same absolute range of time, regardless of length. Whereas the average duration of syllables, words, and surface phrases becomes shorter with development as well as with length (adults talking much more rapidly and older children talking somewhat more rapidly than younger children), the amount of time taken to construct underlying elementary sentences, if anything, increases slightly with age. It is within 1.0 to 2.0 seconds regardless of the age of the speaker. Although the increase in sentences duration between 2 and 30 years might be a real developmental change, the variation is relatively small compared to the change in surface duration, and the rate of speech is most nearly a fixed quantity at the abstract level of underlying sentence structure. One infers that the brain processes responsible for the organization of speech into grammatical forms, once available, operate with much the same speed for all speakers at any level of development. In contrast, the duration of words in the speech of two-year olds, for example, is double the word duration in adult speech (0.6 sec for little children compared to 0.3 sec for adults after compression).

Figure 1 shows that speakers at all stages of development consume a roughly equal increment of time with each additional underlying elementary sentence. It is equally clear from Fig. 1 that the youngest speakers also show little compression of surface elements, but that those surface elements which are most abstract (surface phrases) show compression to adult levels at an earlier point in development (two years) than do elements which are less abstract (words and syllables). The order of development thus corresponds to the order in which surface sentence structure develops in children's language (Brown and Bellugi, 1964). This correlation between knowledge of grammatical structure and linguistic performance is understandable if children and adults both attempt to hold constant the amount of time spent constructing underlying elementary sentences. Then, since the time is nearly the same, as the child comes to produce more elaborate (hence longer) surface structures, compression takes place. In effect, the child simply moves farther along the adult compression curve.

Successive holophrastic utterances. Greenfield, et al. (1972) describe evidence showing that children in the holophrastic period encode semantic relations, even though they do not yet combine words grammatically. It may be therefore, that children leave the holophrastic period only when they develop the processes that make possible a serial organization of words in utterances, i.e., sequences of words that express the semantic relations that evolve during the holophrastic period. Such a sequence of development would be consistent with the two-fold way for speech, where the holophrastic period includes development of the left-hand branch and the post-holophrastic period includes the right-hand branch as well. One would not expect from this sequence that holophrastic utte--nces would show any of the temporal characteristics of grammatical patterns. These temporal characteristics ought not to appear even when children produce, as they sometimes do, two or more holophrastic utterances in succession. An example from Smith (1970) is mommy...shoe; the child wished to have his mother put his shoe on. Smith observed of such sequences that unlike true sentence patterns, which are yet to come, there is variable word order in successive holophrastic utterances and there is not a simgle intonation contour. Moreover, the amount of time occupied by the successive words is between 2 and 4 sec compared to a range of 1 to 2 sec for sentences. That is, successive holophrastic utterances lack the serial property of a fixed word order and the temporal property of requiring betwee and 2 sec for completion that are characteristic of grammatical sequences. Thus temporal regulation, which appears to be associated with the process of encoding underlying structure, and serial order are linked in the linguistic development of children. This result is consistent with the hypothesis that the schema for serial order produces underlying sentence structures during actual speech.

Smith's examples come from the speech of one child. Table 2 shows the duration (onset to offset) of 13 successive holophrastic utterances taken from the speech of four other children who have been studied by Maris Rodgon (personal communication). Successive holophrastic utterances are defined by their intonation contours, which are the same over the two words ($\acute{1}\ \acute{2}$, $\grave{1}\ \grave{2}$, or $\bar{1}\ \bar{2}$). Grammatical word combinations have a different contour over each word, the whole making a unified pattern (typically $\acute{1}\ \grave{2}$; but also $\bar{1}\ \hat{2}$). For comparison, 12 grammatical word combinations have also been timed from the speech of the children in Rodgon's study (the subjects were in transition from holophrastic to patterned speech).

Table 2 here

There is clearly a difference in the amount of time

TABLE 2

HOLOPHRASTIC SEQUENCES AND TWO-WORD SENTENCES FROM 18-MONTH-OLD CHILDREN

HOLOPHRASTIC	TIME (SEC)	GRAMMATICAL	TIME (SEC)
Ohpun Matches	3.15	This-is nice	1.35
doggie bye bye	3.90	my shoe	1.05
open purse	3.75	go baby	1.20
doggie woof-woof	2.05	don't doll	1.50
dah awgaw	3.40	book down	0.75
book baby	4.50	open bok	0.90
awgaw bip	1.95	bye da	0.75
duh awgaw	1.65	bye buk	0.90
unguyah buk	4.20	bye bye cow	1.20
bye ligh	3.30	go bye bye	1.20
igh allah	3.00	bai daddy	1.50
bai daddy	1.95	ma mommy	1.05
bai bai daddy	3.30		
AVERAGE DURATION	3.09	AVERAGE DURATION	1.11

allotted to actual word combinations and to successive holophrastic utterances. We find a range of values for the latter that is essentially the same as reported by Smith (they are more variable in word order, also). The grammatical utterances, on the other hand, take somewhat less time than the ones summarized in Table 1, which thus continues the developmental trend noted above, where older speakers take longer to encode elementary sentences.

Evidence from imitation. A different type of evidence which shows that underlying sentence structure plays a central role in regulating the duration of speech can be taken from the temporal organization of imitation. We performed an experiment with 4-and 5-year-old children in which an adult deliberately varied the rate of presentation of model sentences over a wide range, the purpose being to see whether children could copy the rate of the adult's delivery. The model sentences covered a number of different syntactic forms, many of them with more than one underlying elementary sentence, and the adult's speech rate varied from about three times faster to three times slower than normal.

The children were told to say what the adult said, but they were not specifically told to imitate his rate of delivery. Nonetheless, we find that children imitate variations in rate closely. Expressing the adult variation in rate as a deviation, plus or minus, from the adult's own average ("normal") duration for each unit, and the child's variation as a similar deviation from the child's own average duration for each unit, the direction of the child's deviation agreed with the adult's direction on 97% of the trials. On virtually all occasions, then, when the adult sped up or slowed down, the child did the same. The magnitude of the child's adjustment of his speech rate, however, was typically less than that in the adult model, a discrepancy which suggests that the child's change of speech rate was a true change in the speed of sentence processing, and not merely a metronomic following of some external tempo. This discrepancy arose almost exclusively with slow speech. When speech was faster than normal the children came within 9 percentage points of matching the adult, but when it was slower they came within only 45 percentage points of the adult. The reason is that in the case of slow speech the children would not slow down past a point where the total sentence duration was 3 or 4 sec. I will return to this limit in the next section.

This much, however, does not establish that underlying sentences are the controlling units in imitation. To show that sentence duration was the decisive factor, the adult cnanged duration by speeding the output of words within phrases, but introducing long pauses between phrases. In this manner, the duration of <u>superficial</u> linguistic segments is reduced while the duration of <u>underlying sentences</u> is expanded. We find that children imitate the duration of the <u>underlying sentence</u> in such cases. At the same time, they make the duration of surface elements (which had been shorter than average in the model) longer than average. In other words, the children respond exclusively to the time taken to construct the underlying structure, and this duration in turn determines the time allotted to the surface elements in the imitation. This result is as the hypothesis requires, that the first and controlling step in the organization of speech is the production of the underlying sentence structure. Table 3 shows in part the outcome of this phase of the experiment (syllable and sentence data only). Only changes in direction are considered, as it is only the direction of change that children accurately imitate. The finding, clearly, is that the duration of surface

Table 3 here

elements is anchored to the duration of underlying elementary sentences, which in turn, is imitated from the adult model.

The life span of underlying structure. If there are brain processes that construct the structure of underlying elementary sentences, it should be possible to find some maximum duration over which these processes can be made to operate. Beyond this point, if a complete underlying structure has not been constructed, the processes would begin to disintegrate, and the structure would be lost. The 3-4 sec limit on children's imitation noted above might thus arise because the maximum duration of underlying structure is reached after this amount of time. We have checked this estimate by inducing speech in children at rates that we can control.

We first showed the child a picture of some scene - e.g.,

TABLE 3

IMITATION OF SENTENCES WITH AND WITHOUT PAUSES

ADULT MODEL		CHILD IMITATION	
DURATION RELATIVE TO AVERAGE		DURATION RELATIVE TO AVERAGE	
SYLLABLES	SENTENCES	SYLLABLES	SENTENCES
-	-	-	-
-	+	+	+
+	+	+	+

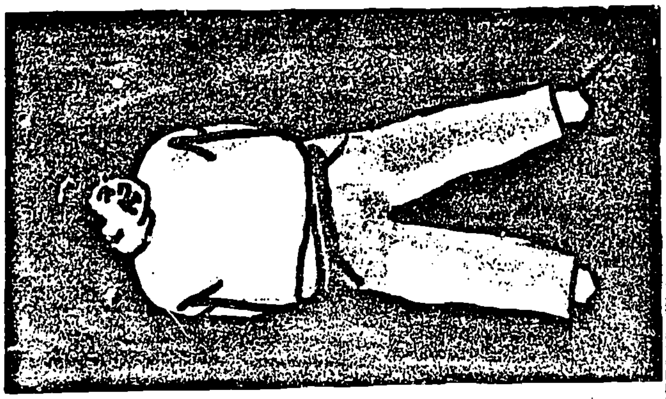
+ = longer than average duration

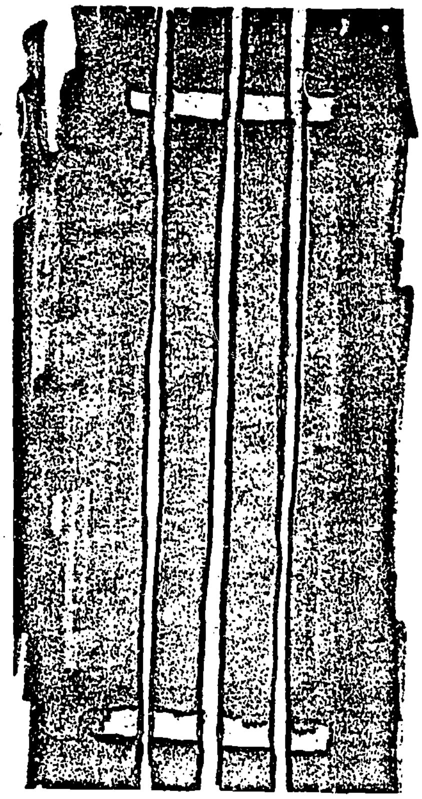
- = shorter than average duration

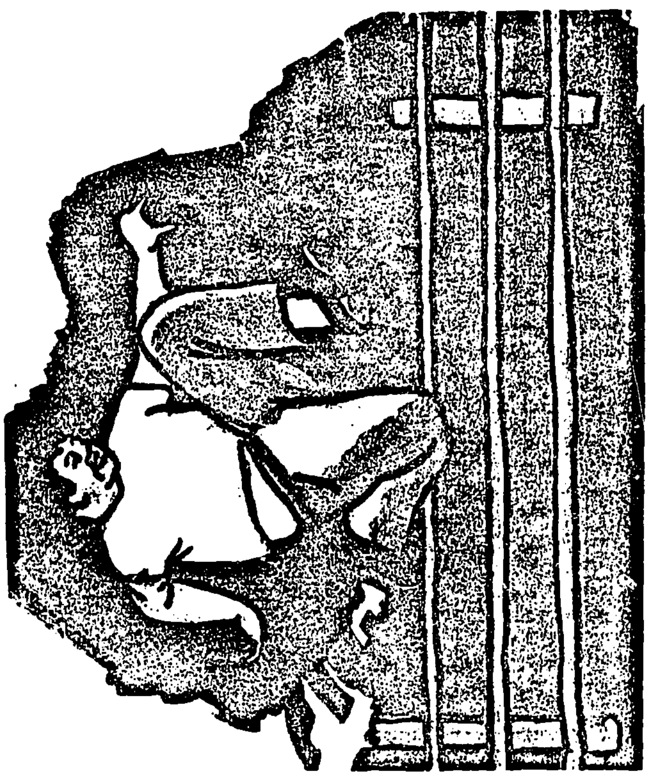
a fat boy jumping over a fence - and asked the child to describe it. We tried to have him use a sentence close to a standard sentence that we had in mind for the picture - e.g., The fat boy is jumping over the fence - but since the exact form of the sentence was unimportant we did not insist on this. With suitable instruction it is possible to convey the idea to 4-year-olds thay they will see a picture in bits, a separate bit for each major part of the original picture, and that they should say the corresponding parts of the sentence as the bits of the picture are revealed. Thus, we first showed the left-most picture of Fig. 2 or 3, and then showed, one by one, the pictures on the right. By controlling the rate of exposure of the right-hand pictures we controlled the child's rate of speech. At a picture every 2 sec, children break the sentence into phrases in a mammer typified by the following, a fat boy...jumps....over the fence (or...jumps over... ...the fence), in which sentence structure is preserved. We conclude that in these cases the child has successfully reconstructed the underlying structure in the amount of time we have given him. Since we exclude from consideration cases where anticipations occur, we eliminate sentences where the reconstruction obviously covered less time.

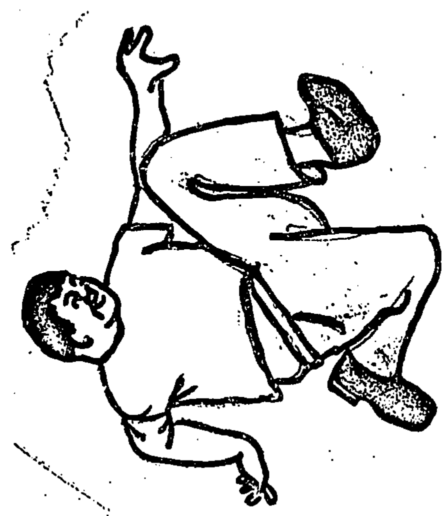
Fig. 2 here

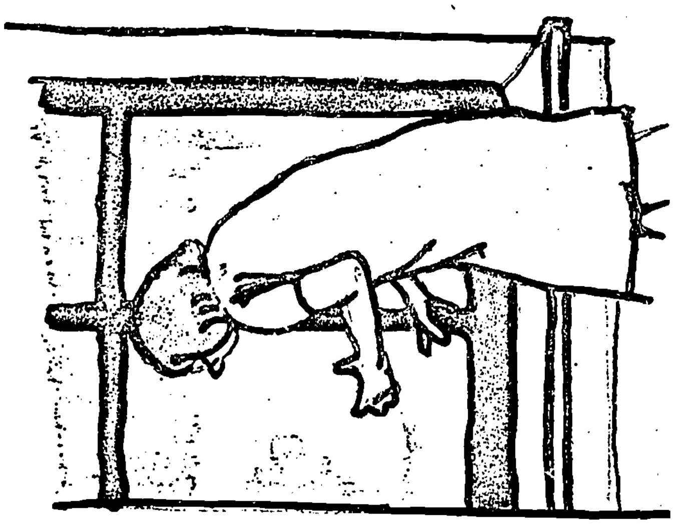
Fig. 3 here

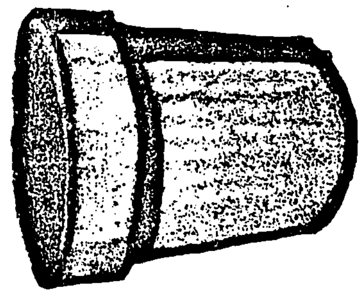


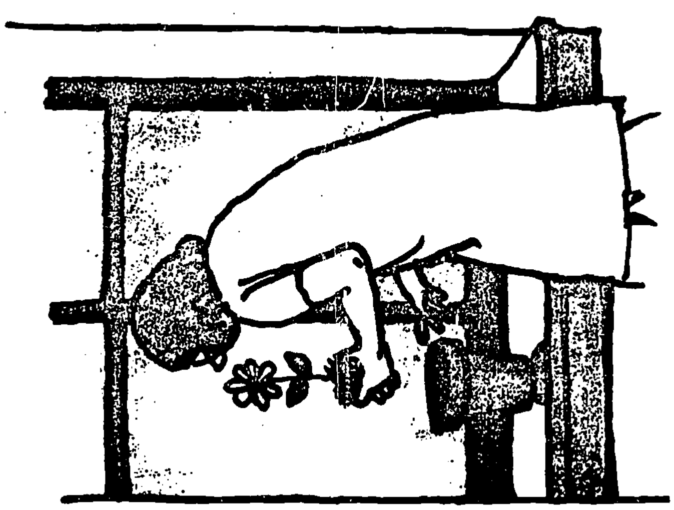












Reducing the exposure rate to one picture every 4 sec had no effect on the ability of children to maintain sentence structure. Children this age are able to rehearse (their lips could sometimes be seen to move) and in these cases the exposure duration did not correspond to the effective sentence duration. However, children sometimes slowed the rate of vocalization when the exposure rate was reduced, usually by extending the vowels. As long as the child is actually vocalizing, his chances for rehearsing must be reduced. We find that if we measure the total amount of time spent in speech, there is a sharp discontinuity in the results. If this total amount of time was more than 3 sec, and the child had not yet completed the sentence he had been uttering, the structure of the sentence collapsed. There was an abort in which the child either began over (The fat boy...is jumping...The fat boy is jumping...), or he repeated the last phrase (The fat boy...is jumping.... is jumping), or he abondoned the structure totally and uttered single words (The fat boy...is jumping...fence) with or without the stock phrase There is, or he inserted words in a non-grammatical way (The fat boy....is jumping....fence over the fence), or he failed with some combinations of these. Thus, we estimate that the outer limit on the amount of time for the construction of underlying sentences is 3 sec for these children, a value that confirms the estimate we obtained from children's imitation.

One could argue that the 3 sec limit on imitation reflects a restriction of memory, but this argument is difficult to apply to the present experiment. A picture was before the child at all times, and the load on memory therefore would have been smaller; but the two methods give almost identical results. Rather than show a limitation on memory, it is reasonable to conclude that preschool children can extend the processes of sentence encoding for no more than 3 sec.

Table 4 here

Table 4 shows the breaking point at 3 sec in the experiment described above. The entries in this table are the average number of seconds that elapsed from the start of the child's speech until the event occurred noted in the left margin - i.e., the disruption of sentence structure (if any) and the end of the trial, when the child finished talking. Values are given separately for the total time speaking excluding pauses and for the total time including pauses; and, in the columns, for sentences whose structure was preserved and for sentences whose structure was lost.

Any temporal hypothesis about Table 4 requires that, when sentence structure is preserved, the time is not greater than when structure is not preserved. In the case of the hypothesis that the total time of actual speech is the critical factor, the prediction is in error only by 0.3 sec. The hypothesis that the critical factor is the total interval, including pauses, over which sentence structure must be maintained is

TABLE 4

RESULTS OF INDUCING SPEECH

TOTAL TIME SPEAKING	SENTENCE STRUCTURE PRESERVED	SENTENCE STRUCTURE DISRUPTED
To Disruption	-	3.0 sec
To End of Trial	3.3 sec	4.9 sec
TOTAL TIME INCLUDING PAUSES		
To Disruption	-	7.3 sec
To End of Trial	8.5 sec	12.0 sec

less accurate, being in error by 1.2 sec. As argued above, the success of the hypothesis that structure collapes when the speaking time exceeds some critical value can be understood as the result of rehearsal, which can go on unimpeded during pauses, but which presumably is blocked during actual speech. The total time spent actually speaking therefore is a more exact estimate of the time over which sentence structure can be maintained. And according to this estimate, the life span of the processes that produce underlying sentences is 3 sec.

The function of temporal regulation. Why is there a limit on the duration of the brain processes that produce underlying sentences? One could argue that what is shown by this temporal regulation is some characteristic rate for cognitive processing in general. Mental activities probably take fairly stable amounts of time, and the flow of speech surely must be influenced by the flow of thought behind it. My argument, however, will assume that the reverse of this is true. The temporal regulation of underlying structure may function to insulate speech from most cognitive processing. While cognitive processing perhaps takes stable amounts of time, the various processes that relate to speech take widely different amounts of time. There is no "general" rate of cognitive processing; the range of variation is at least 500:1. Given that the processing mechanism for speech must connect at varying times with processes that cover such an enormous temporal range, there is a great advantage to be gained in supplying the mechanism with its own, intrinsic time base.

Among the cognitive processes whose durations have been measured are: (1) Scanning visual arrays of letters for the presence of one numeral, which can be done at a rate of about 100 items per second (Sperling, Judiansky, Spivak, and Johnson, 1971). (2) Encoding single visually presented letters, which takes about 500 msec per letter (Posner and Boies, 1971). (3) Negation in sentences which takes between 140 and 700 msec, depending on circumstances (Clark, in press). (4) Storage in long-term memory, which requires about 5,000 msec (Simon, 1969). Other processes have been timed, and no doubt still others could be put to the test of the clock. The point is that there is an enormous temporal range for cognitive operations that in one way or another play a role in the processing of speech. To take the extremes, the 10 msec scanning process discovered by Sperling would presumably be involved whenever one is describing visible events; the 5,000 msec storage process of Simon is involved whenever one uses verbal mediation in memory. There may be other cognitive processes that temporally correspond to the encoding of speech (A. Blumenthal, personal communication), and which may take part in the encoding process. But, clearly, there is a function to be served by having the cerebral schemata for sequences of words operate through a mechanism with a single time base, separate from the majority of cognitive operations.

The question of why the mechanism of speech operates with the particular speed it does (between 1 and 2 sec) can be understood by taking into account the process of attention. Each new underlying elementary sentence encodes further information into some sort of semantic form, and thus requires a shift of attention (assuming that semantically organized information is the focus of attention). Such attentional shifts in fact ordinarily occur every 1 or 2 sec (Broadbent, 1954; Treisman, 1960). Thus, one can speculate, the brain processes for constructing underlying sentences operate in such a manner as to produce new foci of attention at this natural rate. In this sense speech can be said to be the bridge between conscious awareness and largely unconscious cognitive operations, such as indentification, classification, and storage.

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