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The Patterns of Silence: Performance Structures in Sentence Production

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The pauses produced by speakers while reading familiar material were used to obtain hierarchical sentence structures. Identical structures were obtained from parsing, indicating that the performance structures of sentences are not task specific. The linguistic surface structure of a sentence is a good predictor of the pause durations. However, speakers also revealed a tendency to place pauses between segments of equal length. A simple cyclical model combining, for each pause location, an index of linguistic complexity and a measure of the distance to the midpoint of the segment, accounts for 72% of the pause time variance as opposed to 56% for the linguistic index alone. The generality of the model is shown by its good prediction of the pause durations obtained in unrelated studies in English and American Sign Language.

Two lines of research in language and speech serve as a background to this study on patterns of pausing in speech production. The first concerns the relation between syntax and unfilled pauses (hereafter called "pauses"). A number of studies have shown that the frequency and duration of pauses are related to linguistic structure. For example, pauses are more frequent and longer at the ends of sentences than within sentences. In spontaneous English and French interviews, Grosjean and Deschamps (1975) found that about 70% of all pauses occurred at major constituent breaks (defined primarily as the clause and sentence breaks) and that these pauses were significantly longer than those within constituents. Goldman-Eisler (1972), in an analysis of nine samples of spontaneous speech, noted that 78% of sentences were divided from each other by pauses longer than 0.5 sec and that 66% of transitions between clauses and almost all transitions between words (93%) had a duration inferior to 0.5 sec. Hawkins (1971), analyzing the speech of children, found similar results: 66% of all pauses and 75% of the total pause time occurred at

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boundaries between clauses and between sentences, whereas only 10% of all pauses and 6% of the pause time occurred inside minor constituents. When speakers read rather than speak spontaneously and hence grammatical pauses are not confounded with hesitation pauses, the picture is quite similar. Brown and Miron (1971), for instance, report that up to 64% of the pause time variance in an oral reading task can be predicted from a syntactic analysis of the message.

Our aim in this study is to contribute to this first line of research and to analyze and predict pausing not only between and within major constituents (sentences, clauses, phrases), as previously, but also between every constituent including single words. If a subject is asked to read a sentence at a very slow rate, he will insert a pause between every pair of words of the sentence (Grosjean, Note 2; Lane & Grosjean, 1973). The question now is: how are these pause durations related to the structure of the sentence? Will the pauses within the NP, VP, or prepositional phrase, for example, be of equal length, or will they differ in length depending on the structural complexity of these constituents? How will the clusterings of words imposed by the pause durations correspond to formally motivated clusterings (phrase markers)?

The present study also continues a second line of research, experiments on the performance structure of sentences. Martin (1970), for example, asked subjects to parse sentences by arranging the words of the sentences into "natural groups." The data thus obtained were then hierarchically structured by means of Johnson's (1967) clustering program. The results showed that subjects did not automatically group the verb with the NP object, as linguistic models would predict, but that in many cases (SV)O clusterings were obtained. Likewise, in a probe latency experiment, Hillinger, James, Zell, and Prato (1976) showed that the grammatical relationships of a sentence did not completely determine a subject's grouping strategy.

Suci (1967) assessed directly the validity of pause in speech as an index of unit boundaries in language. Stories learned by subjects were fractured in two different ways: at points where subjects paused (during their recall) and at points where there were no pauses. The parts thus obtained were placed in a random order, forming two new sets of verbal material which the subjects were required to learn. It proved more difficult to learn the material constructed from the nonpause fractures. This outcome applied both to narrative passages and to word lists. Suci concludes: "These experiments suggest that organization of verbal material is not necessarily based on grammatical structure in the traditional linguistic sense . . . This of course does not mean that syntax is not an organizational base in everyday communication. *It indicates only that other structural bases may be operative and that pause may serve to identify the units of these other structures.*" (p. 31; our italics).

From these three studies it appears that sentences may have performance structures quite different from their linguistic surface structure. Therefore the experimental question becomes here: will the structures obtained from pausing at reduced reading rate reflect these performance structures and, if so, what will be the relation between the linguistic surface structure and these performance structures? We want to arrive at a simple model, presumably taking into account the surface structure of the sentence and certain performance variables, that will account for most of the variance in the pause durations when reading sentences.

EXPERIMENT 1

Method

Subjects

Six undergraduate students, with no reported speech or hearing defects, served individually in sessions lasting 30 min.

Materials

Fourteen sentences were taken from a study by Bever, Lackner, and Kirk (1969) and embedded in three paragraphs. Individual lexical items were changed but the surface phrase structure of these sentences, as reported by the authors in Appendix 1 of their article, were respected. The first paragraph was 174 words long and contained four sentences from the Bever, Lackner, and Kirk study and eight dummy sentences; the second and third paragraphs were 210 and 200 words long and contained five sentences each from the study and ten and eight dummy sentences, respectively.

Procedure

The method of magnitude production was used to obtain the readings. The subject read each passage at a normal rate. To the apparent rate of his reading, the experimenter assigned the numerical value 10. A series of values (2.5, 5, 10, 20, 30) were then named in irregular order, twice each, and the subject responded to each value by reading the passage with a proportionate apparent rate. The subjects were seated in an audiometric room and their productions were recorded on a Crown (SS800) tape recorder.

Data Analysis

With six speakers reading the passages at five different rates, twice each, 60 recordings were made of each passage. Oscillographic tracings of readings were obtained (Gould Brush 220; paper speed 25 mm/sec) and were then used to measure the total time spent reading the passages and the silent pauses produced by the subjects. The mimimum duration for a silence to be counted as a pause was set at 25 csec. The mean reading rate produced for the Value 10 was 174.7 words per minute (w/m; SD = 25.35). When asked to reduce their rates, subjects did so by 40% when given the Value 5 (mean w/m = 104.8; SD = 45.5) and by 54% when given the Value 2.5 (mean = 81.1; SD = 37.9). When asked to increase their reading rates, subjects read 48.3% faster than normal for the Value 20 (mean = 259.14; SD = 11.19) and 71% faster for the Value 30 (mean = 297.9; SD = 14.7).

The 60 pauses at each word boundary, in each of the 14 experimental sentences, were then pooled and the mean duration computed and expressed as a percent of the total pause duration in that sentence. Normalizing by total pause time made the results for sentences of unequal length comparable. The number of syllables in a sentence was correlated ($r = 0.63$) with the total pause duration of the sentence. These percent pause durations (%PD) were then used to make hierarchical clusters of the words within the sentences, according to the following iterative procedure (Grosjean & Lane, 1977): First, find the shortest pause in the sentence. Second, cluster the two elements (words or clusters) separated by that pause by linking them to a common node, and delete the pause. (If three or more adjacent words are separated from each other by the same pause duration, make one cluster of these words: trinary, quaternary, etc). Finally, repeat the process until all pauses have been deleted. The tree in Fig. 1 illustrates the process by labelling each node for the iterative cycle in which it was derived.

Results and Discussion

Figure 2 presents two of the 14 hierarchical pause structures obtained as described above. In a few sentences, some words were not separated by pauses but the inclusion of more subjects, more replications, or lower rates of magnitude production would in all likelihood have produced pauses where they are lacking. Thus pauses can be used to obtain complex hierarchical sentence structures which can then be compared to the sentence's surface structure and studied in relation to certain performance variables. Other paradigms have been used by researchers with the same aims: Johnson (1968) used transitional error probabilities (TEP), Martin (1970) employed a parsing technique, Levelt (1969) asked subjects to make relatedness judgments, and Suci, Ammon, and Gamlin (1967) used a probe latency technique (although they did not construct performance structures from latencies).

An examination of the hierarchical structures based on pausing showed that sentences were broken up into groups of words of more or less equal length. For example, in Sentence 1 (Fig. 2) the following groups were separated by pauses ≥ 10% PD: *The expert/ who couldn't see/ what to criticize/ sat back in despair;* and in Sentence 2: *Since she was indecisive/ that day/ her friend/ asked her to wait.* We conducted a second experiment to examine whether breathing might be responsible for this tendency. At very slow rate, the "breath group" might be reduced in size and, instead of comprising the whole sentence (Lieberman, 1967), it might extend over only three or four words.

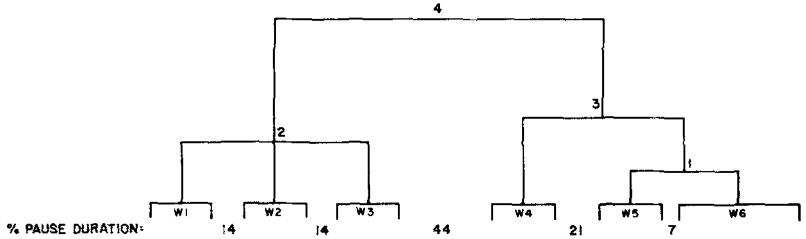

FIG. 1. Hierarchical structure of a hypothetical sentence containing six words (w1–w6) obtained from pause durations. Each node is labelled for the iterative cycle in which it was derived. The height of each node is twice the distance between words which in turn is determined by the length of the pauses.

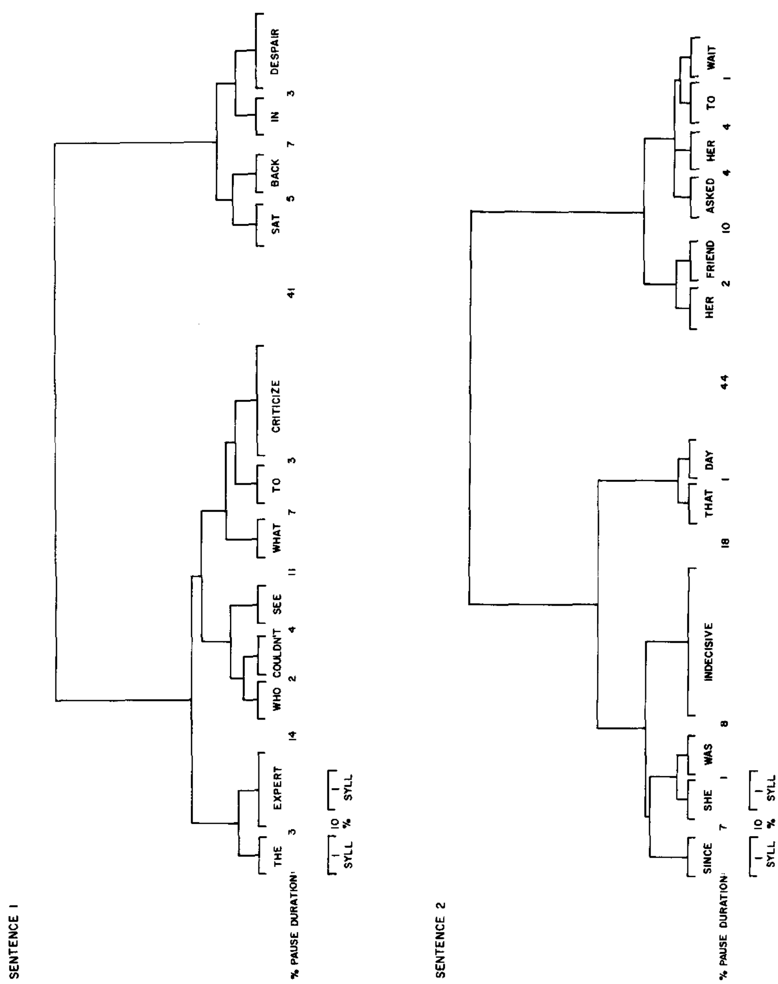

FIG. 2. Hierarchical performance structures of Sentences 1 and 2 obtained from the pause data in Experiment 1.

EXPERIMENT 2

Method

Subjects

Five undergraduate students who had not taken part in Experiment 1 served individually in sessions lasting 15 min. No subject had any reported speech or hearing defects.

Materials

The 14 experimental sentences were removed from their accompanying paragraphs and were presented to the subjects listed one under the other.

Procedure

The method of magnitude production was used again but only low values were presented (2.5, 5, 7.5, and 10). Subjects were asked to read the sentences one at a time at each of these values (presented in irregular order) twice each. In addition, they were told not to inhale during their production of the sentences. They were advised to inhale deeply at the beginning of each sentence and to use up this reserve of air on just that sentence. Their productions were carefully monitored to make sure they did not inhale during their reading (Goldman-Eisler, 1968); if a breath was detected during a sentence, the subject was asked to read that sentence again.

Data analysis

The pauses produced in this second experiment were analyzed as in Experiment 1.

Results and Discussion

Figure 3 presents Sentence 3 as produced in the breathing and no-breathing conditions (Experiments 1 and 2). We observe that the two conditions produce structures that are practically identical. The longest pause is situated after *year* in both structures; the next longest after *winter,* the third after *people*. The only difference is that *the* is now clustered with *after* instead of being grouped with *cold*. The high degree of similarity between the two pause structures is reflected by the coefficient of correlation between the two sets of % pause durations ($r = 0.97$). For all 14 sentences, the mean correlation is 0.87. (Median = 0.90; the lowest correlation is 0.74 and the highest, 0.97).

Thus, identical pause structures will be obtained from readings of sentences whether embracing one or several breath groups. This latter finding (that the presence or absence of inhalation does not determine pause structure) is one of several kinds of evidence that breathing in speech is subservient to pausing (Grosjean & Collins, in press) and not the other way around.

As there were no systematic differences between the breathing and no-breathing conditions, the data from the two experiments were combined in order to increase the reliability of mean pause durations and to assign nonzero values to some of the pause slots.

From the preceding it would appear that pause duration is determined in part by linguistic structure and in part by performance variables but that breathing is not one of these performance variables. The possibility arose, then, that the relevant performance variables are not peculiar to

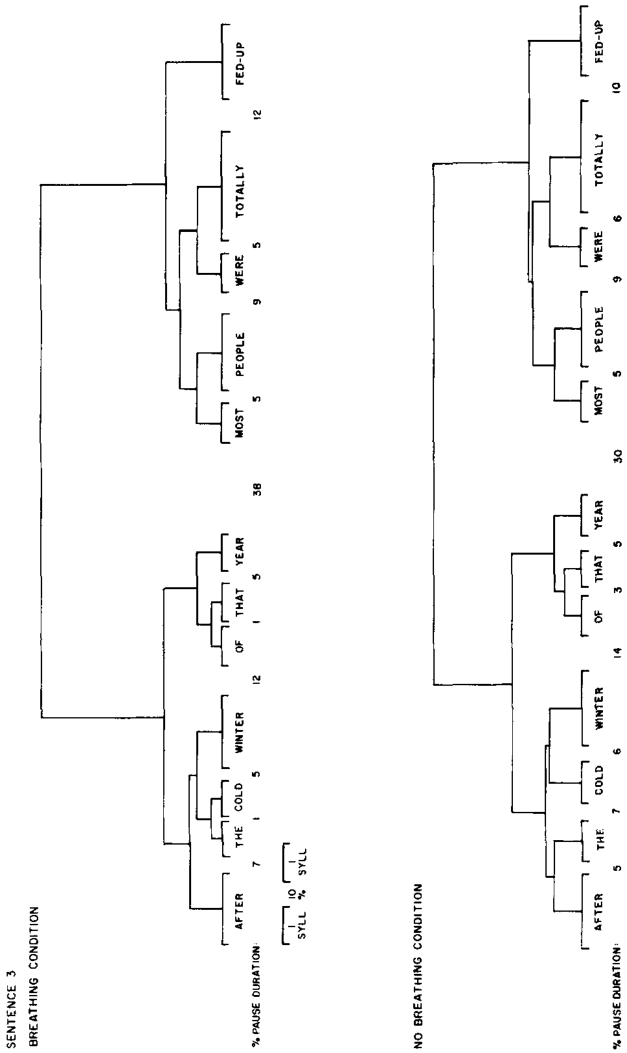

FIG. 3. Hierarchical pause structure of Sentence 3 obtained from the breathing and no-breathing conditions (Experiments 1 and 2).

production but come into play at higher levels of sentence processing. To explore this possibility before proceeding with the analysis of pause duration, we conducted a third experiment with a very different variable: parsing. It now seems likely that several other measures could equally have been used: probe latency (Suci, Ammon, & Gamlin, 1967), transitional error probability (Johnson, 1968; Dommergues & Grosjean, Note 1), or relatedness judgments (Levelt, 1969).

EXPERIMENT 3

Method

Subjects

Fifteen psychology undergraduates just beginning an introductory course in psycholinguistics took part in a group session which lasted 20 min.

Material

The 14 experimental sentences, presented in list form, made up the material to be parsed.

Procedure

These instructions were given to the subjects:

> The following sentences can be divided up into parts or constituents. Please do so according to the model indicated below.
>
> Hypothetical sentence: a a A A b b b B 1 2 2 .
>
> Step 1. Find the main division and put a slash with a number 1 on top.
>
> 1
> a a A A b b b B/1 2 2
>
> here the letters have been separated from the numbers.
>
> Step 2. Consider the two parts independently and divide them up in turn with slash 2.
>
> 2 1 2
> a a A A/b b b B/1/2 2
>
> here the A's and B's have been separated and in the second segment the 1 from the 2's.
>
> Step 3. Continue dividing up each part (4 parts now) using the same procedure: number each slash with a 3.
>
> 3 2 3 1 2 3
> a a/A A/b b b/B/1/2/2
>
> Step 3. Final division (for this sentence):
>
> 4 3 4 2 4 4 3 1 2 3
> a/a/A/A/b/b/b/B/1/2/2
>
> NOTE that some segments may not need dividing up more than once or twice and that others may receive more than 4 or 5 slashes depending on the type of the sentence.
>
> 1 2
> e.g., 1/A A/b b
> ↑
> This segment cannot be divided further.

These instructions were first read by the subjects and then explained again by the experimenter; subjects then undertook to parse the sentences. No actual sentence was ever used as an illustration either in the instructions or in the subsequent explanation.

Data Analysis

The parsing values given by each subject to every sentence were used to obtain a hierarchical structure following the iterative procedure described in Experiment 1. A complexity index (CI) reflecting the hierarchical relations between the words as perceived by the parser was then computed for every word boundary. To do this, we counted the number of nodes dominated by the word boundary node, including in the count the word boundary node itself. Thus, in Fig. 4, the complexity index between *the* and *cold* is 1 (the boundary node dominates no other node but is included in the count) and the complexity index between *winter* and *of* is 6 (the boundary node dominates 5 nodes, (*the cold*), (*the cold winter*), (*after the cold winter*), (*of that*), and (*of that year*), and is included in the count).

The complexity indices associated with the parsing of each sentence were pooled across subjects and means were computed for each word boundary.

Results and Discussion

Figure 5 presents Sentence 4 as structured by pausing and parsing. The two hierarchies are practically identical and the correlation between %PD and parsing CI values is 0.96. For all sentences, the mean coefficient of correlation is 0.92. (Median = 0.94; the lowest correlation coefficient is 0.81 and the highest, 0.97.)

Figure 6 presents a sentence taken from Martin (1970, Frame B sentence) with its parsing values (bottom structure) and the pausing values obtained during Experiment 2 of the present study (top structure). Martin's parsing technique was different from ours; his subjects were not required to give every word boundary a value, but were asked instead to arrange the words of each sentence into natural groups. Also, Martin used Johnson's (1967) hierarchical clustering program to analyze his data. Nevertheless, the results of the two studies are quite similar. Apart from the different grouping of the relative clause *who remember well,* all other

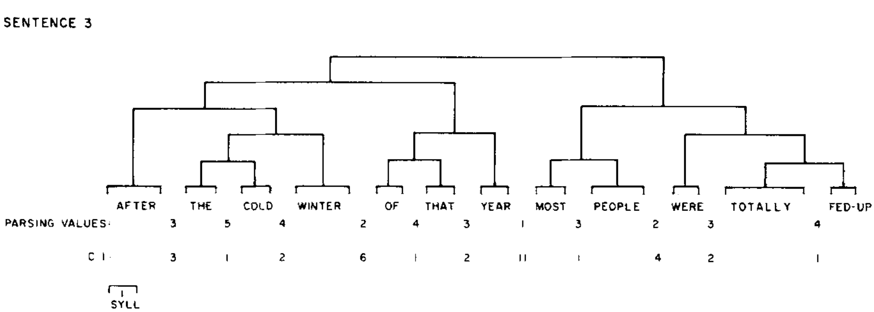

FIG. 4. The hierarchical structure of Sentence 3 as derived from the parsing values of one subject. The complexity indices that were obtained from the structure are indicated below the parsing values.

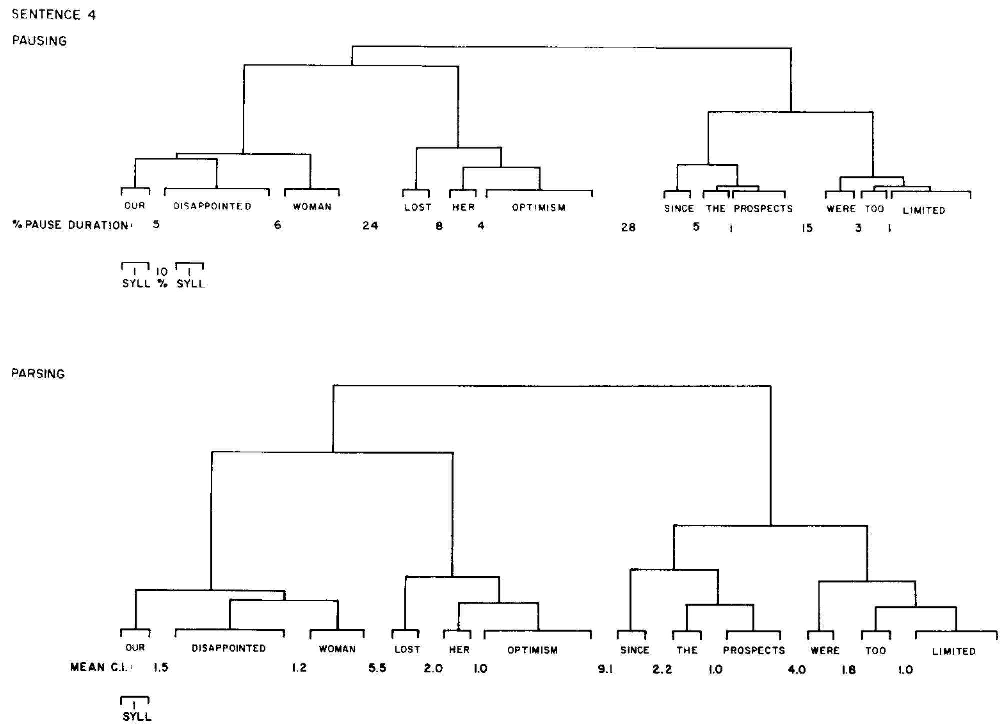

FIG. 5. Hierarchical structures for Sentence 4 obtained from pausing and parsing. Each parsing value at a word boundary is the mean of 15 complexity indices derived from the subjects' hierarchical parsing structures. To give height to the structure, a CI of 1 equals 0.3 cm vertically.

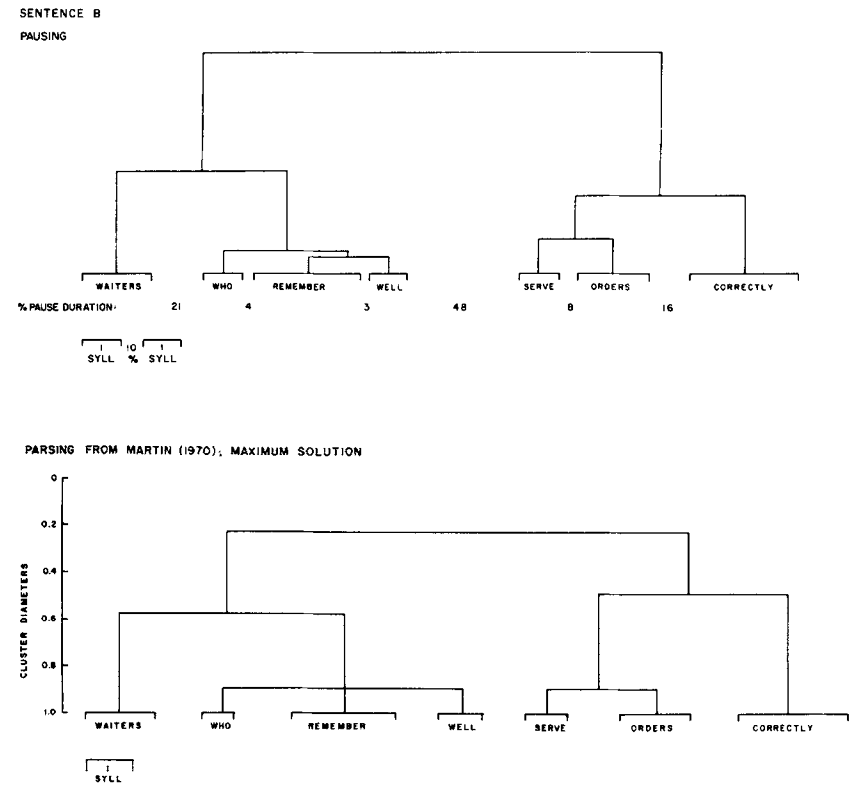

FIG. 6. The pausing and parsing hierarchical structures of a Frame B sentence taken from Martin (1970). The pausing values were obtained during Experiment 2.

groupings are identical and this is reflected by the 0.95 coefficient of correlation between pause duration (our study) and cluster diameter (his study). A sentence from Frame A that we included here (*Chickens were eating the remaining green vegetables*) also received a high correlation (0.85) between pausing and parsing.

Thus pause durations produce reliable performance sentence structures which are not paradigm specific. Similar structures were obtained in the parsing task (and in experiments on short-term memory by Dommergues and Grosjean (Note 1) using transitional error probability as a measure (Johnson, 1968).

The question now is: What variables determine the performance structure of a sentence?

The Prediction of Pause Structures

(1) Syntactic structure. The predictor variable that should account for the greater part of the total variance in %PD, if we base ourselves on preceding studies of pausing, is the surface structure of the sentences. We

therefore drew a surface structure tree of each experimental sentence, using as a guide the brackettings assigned by Bever, Lackner, and Kirk (1969). The next step was to give every word boundary an index of the complexity of the syntactic relations between words in the sentence. Several possibilities were open to us: counting the number of nodes above the boundary; counting the left and/or right brackets at the boundary; computing the node to terminal node ratio of each boundary (Chomsky & Miller's Structural Complexity Index, 1963). This latter approach, which has been employed by a number of other researchers (e.g., Ruder & Jensen, 1972), is not satisfactory when structural nodes are trinary or quaternary (such as, for instance, S → NP Aux VP or NP → Det Adj N). We therefore adopted the same measure as in Experiment 3; the complexity index (CI) at a particular boundary is the number of nodes dominated by the boundary node, including the boundary node itself. In Fig. 7, we present the CI's computed for the surface structure tree of Sentence 5. It should be noted that trinary or quaternary nodes are considered as two (or three) distinct nodes from below (thus *the plan* and *was* are dominated by a node which is distinct from that which dominates *was* and *discussed thoroughly*) but as one node from above; hence the CI is 4 at the break between *lawyer* and *called: (the new lawyer), (called up), (called up Reynolds)*, and *(the new lawyer called up Reynolds)*.

The 14 linguistic trees were indexed in this way and the complexity values were correlated with the %PD. The mean coefficient of correlation was 0.76 (the range goes from 0.60 to 0.90) with a median of 0.80, and the global correlation (pooling across all sentences) was 0.75. Thus the surface structure of a sentence is a good predictor of the %PD, not only at major constituent breaks, as shown by previous studies, but at all breaks in the sentence. Figure 8 illustrates how surface structure and the corresponding pause structure can be quite congruent ($r = 0.92$). Most linguistic breaks are respected in the pause structure (after *book,* after *expert,* etc.) although some slight variation exists at lower levels (for instance, inside *Closing his client's book* and *the young expert).*

It is interesting to note that Brown and Miron (1971) found a 0.74 correlation between the Structural Complexity Index (Miller & Chomsky, 1963) and pause duration in a text read at normal rate. Here, with a different set of materials read at varying rates and with a slightly different index of complexity, the correlation is identical (0.76).

A second point of interest is that the surface structure index of complexity predicts parsing as well as pausing. The mean correlation between CI and parsing for the 14 sentences is 0.82 (the range in coefficients extends from 0.48 to 0.94 and the median = 0.90). However, parsing and pausing are better correlated ($r = 0.92$) than parsing and CI (0.82) or pausing and CI (0.76). Paired t-tests on the three sets of correlation coefficients shows that the parsing-pausing correlation is significantly different

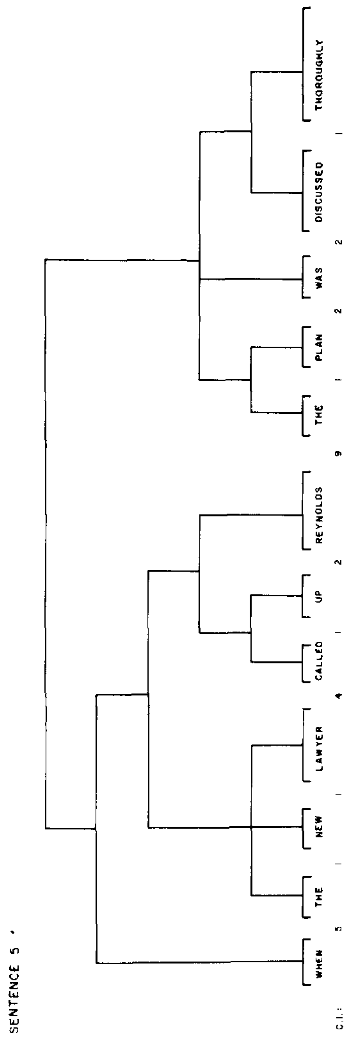

FIG. 7. The surface structure of Sentence 5 with the corresponding complexity indices (CI's) of the syntactic relation between words.

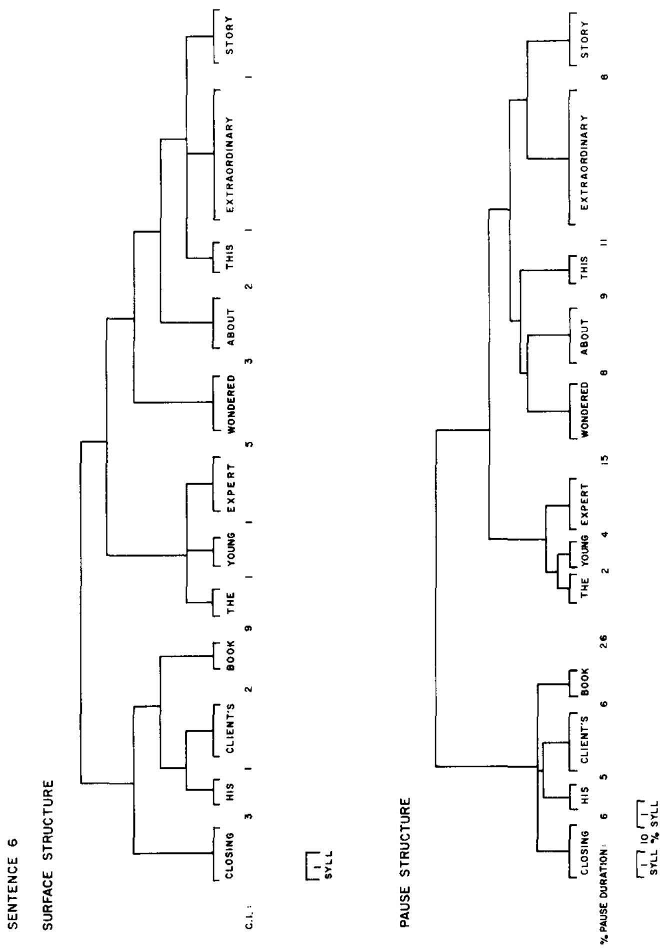

FIG. 8. The surface structure and pause structure of Sentence 6.

from the other two correlations (parsing-CI; pausing-CI): respectively, $t = 2.56, p < 0.05$ and $t = 4.45, p < 0.01$; one tail.

Although the CI is on the whole a good predictor of %PD, it fails at times to account for the pause structure of entire sentences or constituents. Figure 9 presents such a case. The main surface structure break is after the NP (*John*) whereas the longest pause is situated after the NP object (*the strange young man*) (the NP–VP break receives only the fourth longest pause: 10%) and the third linguistic break is after *quick* but it is given the second longest pause (19%). These differences are reflected in the correlation coefficient, which is 0.60.

The main mismatches that were found between the linguistic structure and the pausing data of the 14 sentences are as follows.

(*a*) *The NP–VP Boundary*

In three sentences out of seven for which the NP–VP boundary is the most important break, the longest pause duration is not situated after the NP. What is characteristic of these three sentences is the unequal number of words, in the two constituents: the length of the NP is 1, 2, and 1 words, respectively, and the length of the VP is 11, 10, and 12 words, respectively. Sentence 7 in Fig. 9 is an illustration; the NP is only one word long and the longest pause "migrates" therefore to the break after the NP object. If the NP and VP constituents inside conjoined and subordinate clauses are also of unequal length, then the same phenomenon occurs. For example, in Sentence 2 (*Since she was indecisive that day her friend asked her to wait*), the NP–VP break in the subordinate clause only receives a 2% pause whereas the pause between the verb (*was*) and the adjective (*indecisive*) is 13%.

Therefore, if the number of words in the NP and VP is unequal (for example, if the NP is very short) then subjects will prefer to link the NP subject to the verb and pause mainly before or within the NP object.

(*b*) *Complementizers and Conjunctions*

In a number of cases, sentences start with *that* complementizers and conjunctions; for example, Sentence 12 (*That the matter was dealt with so fast was a shock to him*) or Sentence 2 (*Since she was indecisive that day her friend asked her to wait*). According to current linguistic theory, these elements are directly dominated by the sentence node and therefore the boundary between *that*, for example, and *the matter* (in Sentence 12) will be given a high complexity index. However, subjects rarely pause after these conjunctions and *that* complementizers, and, if they do so, the pause duration is very short. They will prefer to attach these words to the following NP and move the main pause to the end of the NP (which, according to the linguistic tree, should be only the second break). For example, the pause durations for the beginning of sentence 12 are: *That* 7% *the* 2% *matter* 13% *was* . . . Correlations between %PD and CI will be severely reduced by these mismatches.

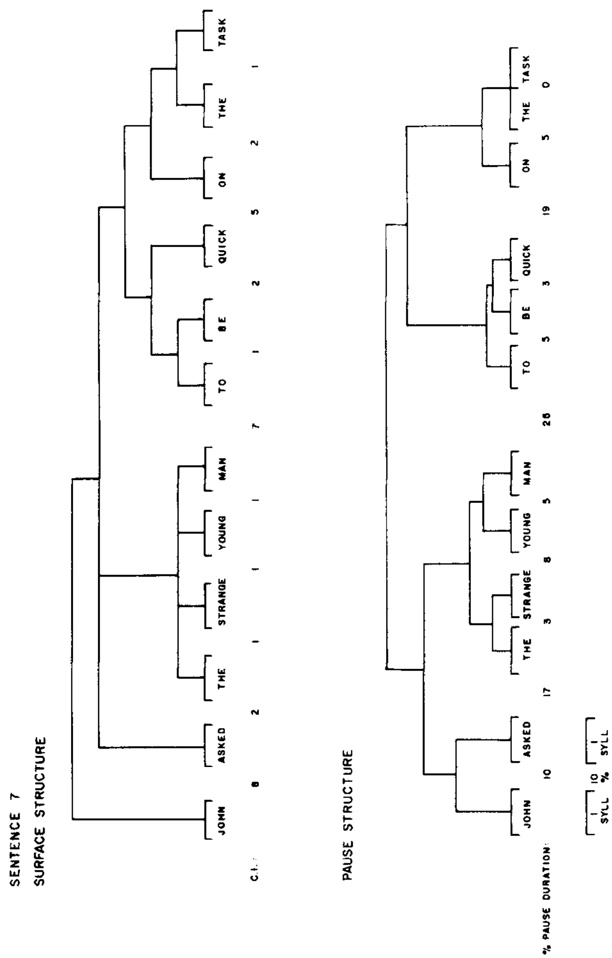

FIG. 9. The surface structure and pause structure of Sentence 7.

(*c*) *The Vb–NP (or PP) Break*

Again, pauses will coincide with this break only if the verb and the following NP (or PP) are of equal length, as in the case of Sentence 5: (*When the new lawyer*)/*called 3% up 5%*/ *Reynolds*/ (*the plan was discussed thoroughly*); but when the two constituents are of unequal length (and this is often the case as verbs are rarely longer than NP objects) then subjects will put a longer pause within the NP (or PP) than between the verb and the NP (or PP). Sentence 6, presented in Fig. 8, contains an example of this: (*Closing his client's book the young expert*) *wondered 8% about 9% this 11% extraordinary 8% story*. Here the longest pause is inside the PP (after *this*), the second longest pause is also inside the PP (after *about*), and only the third longest pause is between the verb and the PP.

(*d*) *The Vb–NP–S Boundaries in the VP*

If the length of the verb, the NP and the infinitival complement are not equal, then the structure of the VP assigned by the pause data will not be trinary. For example, in Sentence 14, the %PD after the verb (*discussed*) is 15% and that after the NP (*the pros and cons*) is 25%.

(*e*) *The Prepositional Phrase*

Prepositional phrases are usually rewritten as follows by current grammars: PP → P NP, consequently the CI predicts a longer pause between P and NP than within the NP. But this only occurs once in six instances in our data (Sentence 7) and in this case the preposition and the NP are almost equal in length (one and two words): (*John asked the strange young man to be quick*) *on 5% the 0% task*. In the other instances, the NP is always much longer than the preposition, and the longest pause is therefore moved to within the NP; for instance, in Sentence 3: *After 5% the 5% cold 5% winter 14% of 3% that 5% year* (*most people were totally fed up*). Thus, once again, when the length of two constituents is unequal (here the preposition and the following NP), the pause between them will not be as long as the linguistic structure would predict, and a pause longer than predicted will be found within one of the two constituents.

We conclude from this study of mismatches that pausing is affected both by the relative importance of constituent breaks, indexed by the CI, and by the relative length of the constituents. When constituents are of unequal length, subjects will attempt to displace the pause to a point midway between the beginning of the first constituent (for example, an NP) and the end of the second constituent (for example, a VP) (if at that point there occurs a syntactic boundary important enough). It would seem that a compromise takes place between this bisection tendency and the linguistic structure of the sentence. Sentence 7 presented in Fig. 9 is an illustration. The main linguistic break (after *John*) is much too near the beginning of the sentence to receive the longest pause. A second important linguistic break (after *asked*) is still too near the beginning, and so subjects will move the longest pause in the sentence to the break between the NP object (*the strange young man*) and the infinitival complement (*to be quick on the task*) which is both a main linguistic break (VP → Vb NP S) and also the middle of the sentence. Another compromise will now take place for each of the newly defined subparts of the sentence: *John asked the strange young man* and *to be quick on the task*. In the first subpart, the break after *asked* is near enough to the middle of the group and important enough linguistically to receive the second longest pause of the sentence. In the second subpart, where the main linguistic break and the middle of the segment coincide after the word *quick*, no compromise needs to take place and the %PD is relatively large (19%). These compromises between the linguistic parser and the bisection parser will continue until all word boundaries have been given a pause duration.

Performance pause structures can therefore be characterized as the product of two (sometimes conflicting) demands on the speaker: the need to respect the linguistic structure of the sentence and the need to balance the length of the constituents in the output. A predictor model of these pause structures will have to take these two demands into consideration.

(2) *A Predictor Model*

(a) Description. To assign to each word boundary a predicted share of the total pause duration in light of its structural complexity and distance from the bisection point, we used an iterative procedure as exemplified in Sentence 8 below.

Step 1. Starting with the largest constituent that has not been analyzed, compute a CI (complexity index) for every word boundary, based on the surface structure tree of the constituent.

By 3 *making* 2 *his* 1 *plan* 2 *known* 9 *he* 5 *brought* 1 *out* 4 *the* 1 *objections* 2 *of* 1 *everyone*.

Step 2. Compute for each word boundary a relative proximity index of that boundary to the bisection point: the number of words from the start (or end) of the constituent to the boundary (whichever is less) divided by half the number of words in the constituent, expressed as a %: %RP.

By 17% *making* 33% *his* 50% *plan* 67% *known* 83% *he* 100% *brought* 83% *out* 67% *the* 50% *objections* 33% *of* 17% *everyone*.

Step 3. Multiply the values assigned to each word boundary: the boundary with the largest product is the constituent break and retains its product.

By 51 *making* 66 *his* 50 *plan* 134 *known* 747 *he* 500 *brought* 87 *out* 268 *the* 50 *objections* 66 *of* 17 *everyone*.

Step 4. Repeat steps 1, 2, and 3 until all word boundaries have a value.

By 100 *making* 160 *his* 100 *plan* 134 *known* 747 *he* 134 *brought* 100 *out* 344 *the* 100 *objections* 200 *of* 100 *everyone*.

Step 5. Compute the predicted percent pause duration at each word boundary by using the following regression equation:

$$\%PD' = .037\,(CI \cdot \%RP) + 1.64.$$

This equation was obtained by regressing the %PD of all 14 sentences on the values obtained in Step 4 for these sentences.

By 5 *making* 8 *his* 5 *plan* 6 *known* 30 *he* 6 *brought* 5 *out* 15 *the* 5 *objections* 9 *of* 5 *everyone.*

(*b*) *Predictive power of the model.* Figure 10 presents the linguistic structure, the pause structure, and the predicted pause structure of Sentence 8. The match between the first two structures (linguistic and pausing) is relatively good but several mismatches do occur: the NP–VP break (between *he* and *brought*) is not respected by the pause data and the

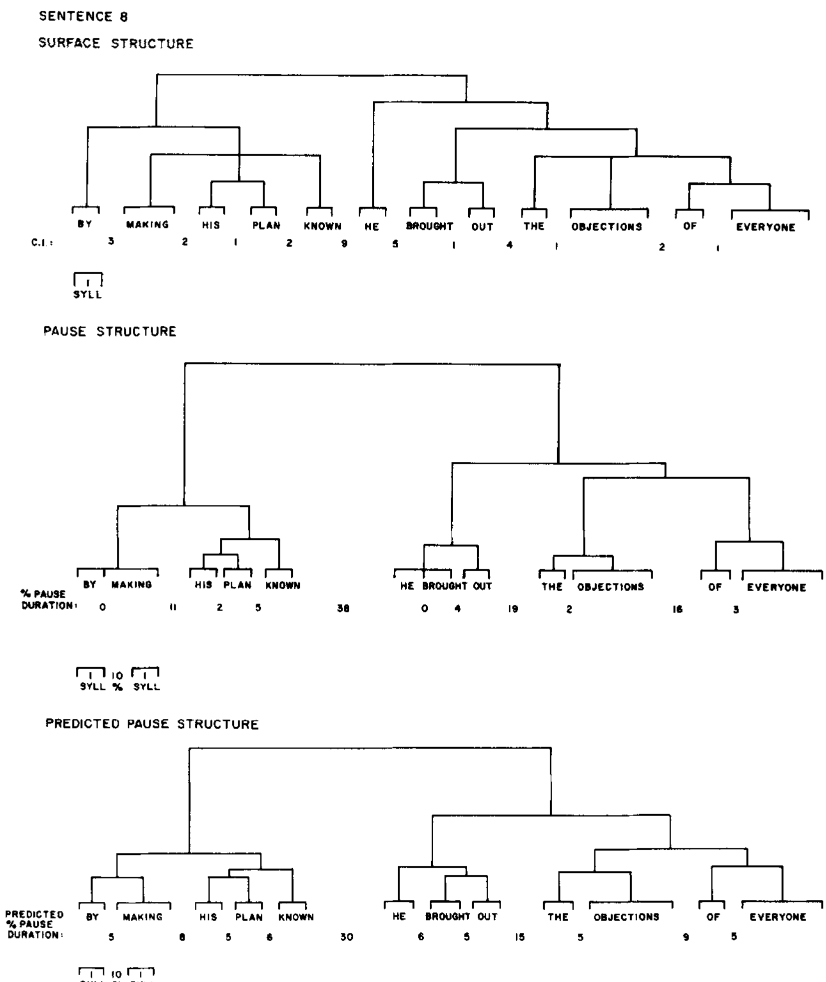

FIG. 10. The surface structure, pause structure and predicted pause structure of Sentence 8.

prepositional phrase (*By making his plans known*) is organized quite differently in the two structures. Consequently, the coefficient of correlation between the CI and %PD is only 0.75. The structure that is produced by the model fits the pause data almost perfectly; by combining %RP and CI, the second main break in the model structure is no longer situated after *he*, as is predicted by the linguistic structure, but after *out* (this is still an important linguistic break that is situated near the middle of the sentence) and the third main break is no longer after *by* but after *By making*. In addition, the NP in the prepositional phrase (*the objections of everyone*) is produced in two distinct clusters by the model (*the objections* and *of everyone*) in complete accord with the pause data. The only difference, a small one, between the pause and model structures is in the organization of *he brought out*. In this case, therefore, the model values predict the pause data almost perfectly (r = 0.96).

Sentence 11, presented in Fig. 11, is another good example of how the model combines the importance of the linguistic break with the bisection

FIG. 11. The surface structure, pause structure, and predicted pause structure of Sentence 11.

parser. The highest CI is after the NP (*The agent*), the second is after *consulted,* and the third after *book,* but as the middle of the sentence (N/2) is also after *book,* the highest product (CI × %RP) occurs after *book* (and not after the first two breaks) in accord with the longest pause in the reading data (25%). Each subpart is not reassigned CI and %RP values by the model and the two highest products again correspond to the next two highest pauses (after *agent* and after *which*). In this way, the 0.72 correlation between linguistic structure and pause structure is increased to 0.92 when pause data are correlated with model values.

The mean correlation between the %PD and the products generated by the model for all 14 sentences is 0.87. (The correlation coefficients range from 0.72 to 0.96 and the median = 0.88). This is significantly different from the mean correlation between CI and %PD (Mean = 0.76) at the 0.01 level (t = 3.20, one tail). (The global correlations when all sentences are pooled are 0.85 and 0.75, respectively). Thus the model accounts for 72% of the total variance in pause time as compared to 56% accounted for by the CI alone. It is interesting to note that the additive model proposed by Brown and Miron (1971) needed three variables (an IC index, a deep structure analogue, and a stochastic measure) to finally account for 64% of the total variance, but never took into account the bisection phenomenon that has been revealed in this study.

In addition to increasing individual correlations, the model decreases the variance of these correlations across diverse sentences; the coefficient of variation is 20% when CI is correlated with %PD but only 8% when the model values are correlated with the pause data. This drop in variance indicates that the low correlations between the predictor variable and %PD have now improved when %PD is correlated with the model values. For example, the three lowest correlations increase from a mean r of 0.55 to r = 0.83.

As for the variance that the performance model leaves unexplained, several probable sources may be indicated. The first concerns the linguistic model itself. For example, in Sentence 12, (*That the matter was dealt with so fast was a shock to him*), the break after *was* is given a high CI (because the auxiliary is put on the same level as the NP and VP in current grammatical theory: S → NP Aux VP) and as it is well positioned in the constituent, the model assigns it a high value (17%). However, the pause duration at that break is very short (2%) and this affects the correlation between model values and the %PD (r = 0.78). Had a different model of linguistic structure been used in which the Aux is a daughter of the verb node (Vb → Aux Vb), then the mean correlations between pause data and CI and pause data and model values would have increased slightly (r = 0.78 and 0.88, respectively, as opposed to r = 0.76 and 0.87 when Aux is considered a daughter of S).

A second cause of variance may concern the impact that the length of the word has on the preceding and following pause. It was found, for example, that the %PD of the break preceding a one-, two-, or three-syllable word (at a constant CI value of 1) remains constant (about 4%) but then rises to 9% before a four-syllable word and to 11% before a five-syllable word.

A third source of variance may concern word and sentence stress and the phonotactic structure of the words in the sentence. For example, in Sentence 2 (*Since she was indecisive that day her friend asked her to wait*), the very short pause between *she* and *was* (2%) is in part explained by the bisection parser but may also be due to the fact that a word ending with an open syllable is less likely to be followed by a pause than a word ending with a closed syllable (W. Cooper, personal communication).

Nevertheless, the present model not only accounts for most of the variance of the 14 experimental sentences but is also a good predictor of the pause data obtained in other experiments. Grosjean and Collins (in press) asked six subjects to read the Goldilocks passage (Grosjean & Lane, 1977) at five different rates. The mean correlation between the CI and %PD for the 11 sentences in the passage is 0.76, but increases to 0.84 when the model is used to predict the pause data. And for a language in another modality (American Sign Language) the model again predicts the pause values better than the linguistic structure by itself. All Sentences 5 signs or longer were taken from the Goldilocks passage (Grosjean & Lane, 1977), and their pause durations in signing were correlated with the CI's of (rather speculative) surface structures and with the model values. The model again was a better predictor than the CI by itself; $r = 0.85$ as opposed to 0.78.

From these latter two studies we conclude tentatively that performance pause structures (the product of linguistic rules and bisection constraints) are not language or modality specific. In addition, the results obtained from signing confirms the earlier finding (Experiment 2) that breathing is not a cause of the bisection tendency, as breathing and signing are independent of one another in sign language production (Grosjean, in press).

Conclusion

In this study we have shown that:

1) pauses can be used to obtain complete hierarchical performance structures for sentences just as other researchers have used TEP, relatedness judgments, parsing, probe latency, etc;
2) the pause structures obtained in the breathing and no-breathing conditions are highly similar. We infer from this and other evidence that breathing does not directly determine the hierarchical pause structure of sentences;
3) the values obtained from the parsing of the experimental sentences are highly correlated with the pausing values. The perfor-

mance structures of sentences appear to be reasonably invariant over a range of tasks;

4) the surface structure of a sentence is a good predictor of the pause distribution when sentences and constituents are balanced;
5) a number of mismatches occur between pause duration and syntactic structure because Ss tend to pause so as to bisect their sentences and constituents;
6) a simple cyclical model which combines multiplicatively a linguistic complexity index and a measure of bisection accounts for 72% of the pause time variance as opposed to 56% when only the linguistic complexity index is used; and
7) the model is also a good predictor of pause data obtained from a second reading experiment and from productions of a language in another modality, American Sign Language.

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