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AN AUTONOMIC REFLECTION OF SYNTACTIC STRUCTURE*

T. G. BEVER
The Rockefeller University

R. KIRK
Massachusetts Institute of Technology

and

J. LACKNER
Massachusetts Institute of Technology

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Abstract—Subjects heard sentences in one ear during which a brief shock was administered before, in or after the division between two clauses. The galvanic skin response (GSR) to shocks objectively at the end of a clause was larger than the response to shocks at the beginning of a clause. This effect of syntax on GSR was larger for subjects who heard the speech in the right ear. An independent effect was that the GSR to shocks at the end of a clause decreased as a function of clause length; responses to shocks at the beginning of a clause were relatively unaffected by the length of the preceding clause in our stimulus materials.

RECENT investigations of speech perception have claimed that listeners actively utilize their knowledge of syntactic structure in the perceptual processing of sentences.† For example, FODOR and BEVER [1] found that listeners tend to report the location of clicks presented in sentences as if the clicks fell between clauses: e.g. a click objectively in the word "tries" or "the" in sentence (a) in Table 1 is most often reported as occurring between those two words. FODOR and BEVER argue that errors in the subjective location of clicks cluster at the points between clauses because the clause is a "perceptual unit" of speech which "resists the interruption by the click." GARRETT *et al.* [2] and ABRAMS *et al.* [3] have demonstrated that these systematic errors in click location are not due to any obvious physical features of the speech signal. Thus, these studies suggest that speech perception involves the "active" development of an appropriate syntactic structure to segment each speech stimulus as it occurs. This view of speech perception contrasts with a view which assumes a "passive" isolation of the syntactic structure from physical features of the speech signal or from perceptual analysis which occurs after the entire sentence has been heard.

Our initial concern was to find a method of studying the normal process of perceptual segmentation as it develops in the normal child, and as it breaks down in the aphasic adult.

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† FODOR and BEVER (1964); GARRETT *et al.* (1965); BEVER *et al.* (1966); ABRAMS *et al.* (forthcoming).

The subjective location of clicks in sentences is not an appropriate technique for study of either of these populations since it requires a verbal or written report of the sentence and of the click location. In the present experiment we show that the syntactic structure of a sentence can influence systematically the change in skin resistance in response to a mild shock presented during the sentence. This indicates that other (less unpleasant) autonomic responses may also reflect the ongoing perceptual segmentation of speech, and be useful in the study of primitive or pathological speech perception. Furthermore, our finding supports the claim that listeners respond to the syntactic structure of speech *as they hear it.*

EXPERIMENTAL MATERIALS

Twenty-five ordinary 12-word sentences were recorded in normal intonation (see Table 1). (The average rate of speech was 6.4 syllables/sec, if the 11 spaces between words in each sentence were counted as $\frac{1}{2}$ syllable. If the spaces between words were not counted, then the average computed rate was 4.6 syllables/sec). Each sentence had two clauses; in five sentences the clause break occurred after the fourth word (as in *a*) and four further sets of five sentences, after the fifth, sixth, seventh, and eighth words (as in *b*, *c*, *d*, and *e*). The two words preceding and following the clause breaks were monosyllables. Five different orders of the twenty-five sentences were copied from a master tape: each experimental order was constructed so that each consecutive fifth contained one sentence with each of the five possible locations of the clause break. A single pulse was then placed on the other track simultaneous with each of the sentences in the five orders.

Table 1. Sample sentences used in the experiment, with clause divisions after 4, 5, 6, 7, and 8 words (The numbers indicate the possible shock positions; see text)

(a) After a few tries the boy beat his father at Chinese checkers.
1 2 3 4 5

(b) To determine the tree's age those boys asked the mean old man.
1 2 3 4 5

(c) The guard took your aunt's purse in which she had ten dollars.
1 2 3 4 5

(d) That the matter was dealt with fast was a surprise to Harry.
1 2 3 4 5

(e) Because coffee spilled on her sky blue dress she left early.
1 2 3 4 5

For each sentence a pulse was placed in one of five positions relative to the clause break: (1) in the middle of the word that came two words before the clause break, (2) in the middle of the word before the clause break, (3) in the clause break (which was located by taking the midpoint between the words on either side of the clause break, since the break often did not coincide with an actual pause in the speech), (4) in the middle of the word after the clause break and (5) in the middle of the second word after the clause break. Sample positions are indicated in Table 1 under each sentence. Pulse placements were distributed such that each consecutive fifth of the five experimental orders of sentences had one example of each of the five possible pulse positions, and each of the twenty-five sentences occurred once with each of the five pulse positions.*

* See Bever *et al.* [4] for a presentation of all the sentences used in this experiment.

PROCEDURE

Twenty undergraduate students at MIT volunteered for paid participation in the experiment. All subjects were free of known speech or hearing defects, had learned English as their native language and were right-handed. Subjects were individually tested. The response electrodes were attached to the palm of the subject's left hand and the shock electrodes to the right wrist. The electrodes were attached ten minutes before the experiment to allow electrical stabilization. A 1.5 V battery and 1000 Ω resistor were connected in series with the GSR electrodes. Input to the amplifier and recorder (Schwartzer E 502) was taken across the resistor. The recorder was adjusted to have a time constant of one second and an upper cut-off of fifteen cycles per second. The voltage of the shock was adjusted for each subject before the experimental session to a level where it would be noticeable but not uncomfortable. The voltage was always kept below 20 volts. The shock was 0.1 sec in duration.

In the experimental session the subject heard one of the experimental sequences of 25 sentences. During each sentence there was a single shock triggered by the timing pulse on the tape. Subjects were instructed to repeat each sentence after hearing it and then to indicate the part of the sentence which was simultaneous with the shock. Subjects were told that the shock could occur anywhere within the sentence—either in words or between words. Ten subjects heard all the sentences in the right ear and ten subjects heard all the sentences in the left ear. Two subjects in each condition heard each of the five experimental orders. A continuous record of skin conductance was taken during the presentation of each stimulus sentence.

RESULTS

Both latency and amplitude measures were taken from the GSR records. The two measures used in our scoring are illustrated on a record of an idealized GSR to a shock in Fig. 1. The "response amplitude" was defined as the GSR magnitude difference between

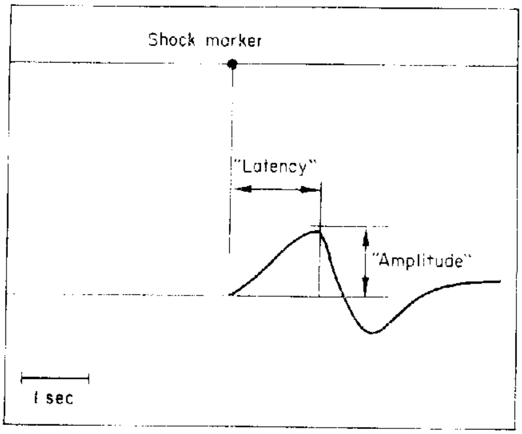

FIG. 1. Typical GSR to shock with an example of the latency and amplitude measures used in this experiment.

the first local extreme following the point demarking the beginning of the particular response and the extrapolated baseline. In addition, the "latency" of a GSR to a shock was defined as the time between the onset of the shock and the first point following it where an abrupt change occurred in the slope of the conductance–time plot. In an attempt to eliminate noise from the scoring procedure only those scores with a latency between 1 to 2.5 sec are considered in the results. All data were scored for latency and amplitude without knowledge of the syntactic structure accompanying the shock position. Overall, 88 per cent of the sentences were recalled correctly after each trial, and none of the sentence recall errors significantly affect the meaning or the syntactic structure of the stimulus sentence.

Of the twenty subjects, three showed GSR changes in fewer than 12 out of 25 possible trials. These subjects were excluded from further analysis. (Two of these had heard the speech in the right ear and one in the left.) The average latency was 1.68 seconds and the response magnitude decreased considerably during the experimental session. For this reason, all responses were ranked according to their relative size in each sequential fifth of the experiment. Note that the materials were balanced so that each fifth contained one instance of each shock position [1–5] and one instance of each clause-break position (a–e). The latency and amplitude data were grouped into three categories: responses to shocks before clause breaks, in clause breaks, and after clause breaks.

Table 2. Amplitude (mean ranks out of a possible 5) in response to shocks occurring before, in, and after breaks between clauses (a low number indicates a relatively large response)

Shocks objectively . . .	Sentences heard in . . . Left ear	Right ear
Before clause break	3.0	2.7
In clause break	3.1	3.0
After clause break	3.0	3.3

There was a definite effect of the syntactic location of the shock on the amplitude of subsequent change in GSR: overall responses to shocks placed before a clause break were larger than to those placed after a clause break. This difference was significant by subject ($p<0.05$ Wilcoxon 2-tail, matched pairs signed ranks) and nearly so by sentence ($p<0.06$ 2-tail).* The syntactic structure also affected the latency of the GSR: latencies are shorter in response to shocks before clause breaks than to shocks after breaks. In our scoring, the point of latency and amplitude interacted such that a higher amplitude would tend to be scored as having a shorter latency. Thus, the latency differences confirm the amplitude differences, but are not independent of them.

The effects of syntactic structure on GSR were stronger for subjects who heard the sentences in the right ear. For those who heard the sentence in the right ear, the effect of the syntactic structure on GSR amplitude was significant by subject ($p<0.01$ two-tailed) although less so by sentence ($p<0.06$ two-tailed). For those who heard the sentence in the left ear, the syntactic effect was not significant although the same trend appeared across sentences ($p<0.10$ two-tailed). Consistent with this difference between the ears was the fact that the effect of the syntactic structure on GSR latency was significant for those subjects who heard the sentence in the right ear ($p<0.01$ two-tailed by subject, $p<0.06$ two-tailed by sentence), but not for those who heard the sentence in the left ear. The difference in the effect of the syntax on GSR amplitude between the subjects who heard the sentences in the right and left ear approached significance ($p<0.06$ two-tailed across the sentences). The difference in the structural effect on latency between those who heard speech in the right and left ears was significant both by subject ($p<0.01$ by χ^2) and approaches significance by sentence ($p<0.08$ Wilcoxon two-tail).

* All statistical tests are by Wilcoxon matched-pair signed-ranks test unless otherwise stated.

Previous experiments on the location of clicks in sentences have found that if speech is heard in the right ear and a click in the left, the subjective location of the click falls prior to the location given by subjects who hear the speech in the left ear and the click in the right [1].

Verbal judgements of shock location were tabulated to the nearest syllable for placements within words or in a particular phrase structure break. All subjects showed a significant tendency to mis-locate the shock as having occurred nearer the clause break than it actually did, as in previous studies on click location ($p<0.01$ by subject and by sentence). No difference appeared in the subjective reports from the subjects on the location of the shock: the average subjective placement of shocks was 0.35 syllables before the objective location when speech was heard in the left ear or in the right ear. The mean amplitude of the GSR for those subjects who heard the sentence in the left ear was higher than the mean amplitude for those subjects who heard the sentence in the right ear ($p<0.01$ by sentence two-tail).

Individuals vary greatly in the amplitude of GSR, so this difference must be examined more carefully by testing the same subject with speech in the left and right ear. All the differences between the right and left ear presentation of speech in this experiment must be studied further, since there were several constant asymmetries in our procedures: namely, shock was always administered to the right hand and the GSR was always recorded on the left hand. It may be that the lateral relations of the speech stimulus, shock stimulus, and the GSR response determine the strength of the syntactic effect, rather than the ear in which the sentence is heard.

In our sentences, before-break shocks tended objectively to precede after-break shocks by one word. Thus, it might be true that the relative size of GSR amplitude to shocks before clause breaks is due to a tendency for the strength of the response to decrease as more of the sentence has passed by, and not as an effect of syntactic structure. To check for this possibility we examined the responses only to those shocks which were in positions which had before-break shocks and after-break shocks (in one set of sentences or another). When only those "overlapping" positions are included, the syntactic effect holds: ($p<0.07$ two-tail for subjects who heard the sentence in the right ear).

Although the syntactic effect obtains for all clause-break positions, a response to the before-break shocks is larger at the ends of short clauses [as in (a), (b), (c)] than at the end of relatively long clauses [as in (d) and (e)]. However, there was no difference in the response to after-break shocks correlated with the length of the preceding clause.* Therefore, the interaction of syntax with GSR in this experiment might be interpreted as the result of two facts: (1) GSR to shocks at the beginning of a clause ("after-break" shocks) is unaffected by the length of the preceding clause; (2) GSR to shocks at the end of a clause ("before-break" shocks) decreases as a function of the length of the clause. Thus the primary effect of syntax on GSR might be either that GSR to shocks is larger to before-break than to after-break shocks, or that GSR to before-break shocks decreases as a function of sentence length more than response to after-break shocks. Since all the sentences in this experiment were twelve words long, further work is necessary to decide which effect is dominant.

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* Significance of the difference between the effect of clause length on before- and after-break shocks ($p<0.02$ two-tail for all subjects, $p<0.10$ for subjects who heard the sentences in the right ear, and $p<0.07$ for subjects who heard the sentences in the left ear).

DISCUSSION

Despite these further questions, the results of this experiment demonstrate that the structure of a sentence can systematically influence the autonomic response system. This strongly indicates that syntactic structure is used actively to modulate attention during speech perception. Recently ABRAMS *et al.* [3] have found analogous effects of syntax on reaction time to clicks in some of the same stimulus sentences. Reaction time to clicks placed just before clause boundaries is slower than to clicks placed just after clause boundaries. Also, reaction time to before-break clicks decreases as a function of clause length, while reaction time to after-break clicks does not. Thus, the aspects of syntactic structure which increase reaction time to clicks decrease the GSR to shocks. ABRAMS *et al.* suggest that at points of slow reaction time the listener is attending primarily to the internal perceptual integration of the immediately preceding stimulus material. If this view is correct, the present experiment indicates that a listener has a lower GSR to a shock when he is actively attending to the external speech stimulus than if he is preoccupied with the internal perceptual analysis of a preceding speech stimulus.

Whatever the exact mechanism, it is clear that autonomic responses to interfering stimuli during speech perception are regularly affected by the perceptual processing of the sentence. In addition to its implications for our understanding of speech perception in normal adults, this fact raises the possibility that autonomic measures will be useful in the study of speech perception in children and aphasics.

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Résumé—Les sujets entendent les phrases par une oreille tandis qu'un choc bref leur est administré avant, pendant ou après la division en deux propositions. La réponse électro-dermale aux chocs à la fin des propositions était plus grande que la réponse aux chocs au commencement d'une proposition. Cet effet de la syntaxe sur la réponse électro-dermale était plus grande chez les sujets qui entendaient les paroles par l'oreille droite. On notait aussi un effet indépendant, à savoir que la réponse électro-dermale aux choc de la fin d'une proposition diminuait en fonction de la longueur de la proposition. Les réponses électro-dermales aux chocs au début d'une propositionne sont relativement pas modifiées par la longueur de la proposition précédente dans le matériel utilisé par nous comme stimulus.

Zusammenfassung—Versuchspersonen, welche Sätze auf einem Ohr hören mussten, erhielten dabei elektrische Schläge, und zwar während oder nach der Pause zwischen zwei Satzteilen. Es zeigte sich, dass der galvanische Hautreflex auf die Schläge am Ende eines Satzteiles objektiv grösser ausfiel als die Reaktion am Beginn eines solchen. Dieser Einfluss der Syntax auf den galvanischen Hautreflex war bei Personen grösser, die die Sprache über das rechte Ohr aufnahmen. Ein davon unabhängiger Effekt bestand darin, dass der galvanische Hautreflex am Ende eines Satzteiles nach einer entsprechenden Schockierung abfiel analog zur Länge des Satzteiles. Der Reflex auf Schläge zu Beginn eines Satzteiles war demgegenüber relativ unabhängig von der Länge des vorausgegangenen Satzteiles.