PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Perceptual Experiments and Language Theories [and Discussion]

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Perceptual experiments and language theories

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Constraints upon the structure of possible languages are presumably associated with the machinery available within the person to process utterances. This machinery may reveal its nature through observations that are not themselves meaningful linguistically. That is, two sentences may both be grammatical, and may be logically equivalent, and yet may differ in the speed with which people understand them, or the accuracy with which they are remembered. Such findings then shed light on the biological constraints that limit the possible forms of communication available.

Two particular examples can be taken from studies of working memory and of identification of single isolated words. Both fields reveal important differences in the mechanisms for processing heard and read communication; they also suggest constraints both of a syntactic and of a semantic kind.

Introduction

Psychologists nowadays tend to reject any exact parallel between linguistic formulations on the one hand and psychological mechanisms on the other. This does not mean that linguistic descriptions of the structure of language have no value. To take an analogous case, psychologists working on visual perception do not deny the value of geometric descriptions of the stimuli striking the eye. But the fact that a circle is well described by the equation $y^2 = r^2 - x^2$ does not mean that there is some mechanism in the visual system of humans that corresponds to that equation. In the study of language, the comparable view is that linguistics describes what is perceived, not the process of perception. A sentence produces an impact on listeners or readers by provoking a collection of operations or processes inside their heads, which have the nature of heuristic strategies. These operations then give rise to a representation inside the nervous system. In most cases this representation might well resemble the underlying structure that a linguist would assign to the sentence, or the meaning that a philosopher might hold it to have. But, because the process is not structured in the same way as the utterance itself, it may go wrong if the sentence or the context are unusual and the strategies cease to apply (see, for example, Clark & Clark 1977; Foss & Hakes 1978; Miller & Johnson-Laird 1976). The fact that this view is now fashionable is particularly striking, because 10 or 15 years ago the emphasis was quite the other way. The attractions of sophisticated linguistics were at that time greater. Many people hoped for a straight equivalence between the structure of the language, on the one hand, and of the mechanisms for producing or understanding it, on the other. The reason for the change is the gradual accumulation, over the interval, of a body of observations of the behaviour of natural users of language.

Some of these observations concern judgements about the acceptability of particular sentences; here, the worrying thing is the discrepancy between the judgements of the man in the street and those of people with a knowledge of the academic tradition of grammar. To take an old example, many grammarians hold that the rules allowing embedding of relative clauses

within a sentence may be applied recursively. This would mean that the sentence 'The race that the car that the people that the obviously not very well-dressed man approached sold won was run last summer' is grammatical. The judgements of a sample of the uninstructed are, however, that such a sentence is ungrammatical (Marks 1968). Even more serious, when people are asked to segment a simple sentence containing a first noun phrase, a verb, and a second noun phrase, they feel that the verb belongs with the first noun phrase and not with the second; that is, their intuitions do not agree with one of the most useful segmentations of such a sentence for grammatical purposes (Martin 1970).

Results such as these could be dismissed as due to local differences of dialect or of understanding the purposes of the experimenter; more serious are demonstrations that sentences are systematically understood in ways that sober application of the official structure of the language would stigmatize as incorrect. For instance, with young children the sentence 'The cat was chased by the mouse' tends to be treated equivalent to 'The cat chased the mouse' (Strohner & Nelson 1974). In fact, hasty adult readers may have to reread the original sentence to see exactly what was wrong. A number of similar experimental results suggest that sentences are often understood by a strategy of identifying constituent elements and then assuming that the meaning is the most probable state of the world that links those constituents. A further example of the same strategy can be taken from a minor study of my own in which people tended to judge that the question corresponding to the sentence 'Margaret may be arriving' was 'May be Margaret arriving?' This was done, of course, by arranging that this strange alternative was the only one provided that contained the same constituents as the affirmative statement, just putting them in a different order (Broadbent 1974).

To take an example of another strategy, there seems to be a tendency to link each constituent, if possible, to the one immediately before. Consider the difference in parsing which many of us would give to 'It was the dog I sent after the fox that had rabies' and to 'It was the dog I sent to Newark that had rabies'. The same strategy explains the difficulty of a sentence such as 'I gave the dream I had cherished all my life about living in Ullapool in the herring season up' (Clark & Clark 1977).

Clark & Clark list fourteen strategies of this type for which experimental evidence exists; the list is not exhaustive. It becomes very difficult to believe therefore that the uninstructed user of language comprehends sentences by algorithmic rules of the kind that make for tidy linguistic statements. This had led to the fashionable belief among psychologists that the formulations of linguists or philosophers, however proper within their own discipline, do not say much about the official title of this Discussion Meeting. As a result, psychologists have tended more and more towards experiments on human function that are not explicitly linguistic. For instance, to revert to the earlier example of 'The cat was chased by the mouse', adults do of course understand this correctly if they are listening attentively. But suppose one measures the time they take to do so, a measurement that is not itself meaningful linguistically. Such a measurement shows that the improbable sentence takes a little longer than the probable one of the form 'The mouse was chased by the cat' (Herriot 1969). This indirect evidence shows that the child's strategy has not totally vanished in the adult, but rather is accompanied by others, which check and modify it to give the result that grammarians would wish.

A last example of non-linguistic influences on sentence comprehension makes the same point. Clark & Chase (1974) have looked at the speed with which people verify a simple sentence of the form 'X is above Y'. Suppose that one has been looking at a picture containing a long

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horizontal line and a small star. In that case, true sentences that say 'The star is above the line' are faster to verify than sentences that say 'The line is above the star'. The reason is the bias in visual perception, which makes the line the point of reference. It is easier to match a sentence to a visual percept if the sentence treats the line as given and the star as new than the reverse.

We now have a very large bank of knowledge indeed about the mechanisms that process language in people; most of it is rather detailed and specific, so that it is impracticable to review in a paper as short as this one. Furthermore, most of it spills over into other fields of human function rather than being restricted to language.

The identification of isolated words

Experiments that flash a single word for a tenth of a second, or present it acoustically through a masking noise, are heavily artificial. The use of natural language always supposes a context, if not of other words, then of some non-verbal situation. But words do strike the ear, or to some extent the eye, at successive times. Each of them has to give rise to some representation inside the person which can endure until enough of the sentence is assembled for its structure to be apparent. As we saw earlier, in many cases content words are used to trigger off an interpretation without considering the order in which they arrived; *the mouse chased the cat*. So there must be a mechanism that translates the momentary pattern of light or of sound into a lasting form, and the artificial experiments on isolated words are at least a device for getting at this mechanism. We know furthermore that the same word can result from different input patterns; in the obvious case, the same word may be said by a reader who has seen *2*, *two*, or *II*. More subtly, a spoken word may have a whole phoneme masked by a burst of noise; yet it can be perceived sufficiently completely that the listener cannot tell which phoneme was the missing one (Warren 1970). So, there has to be a mechanism that accepts a variety of evidence as its input and produces as its output some common signal representing the word. (Such a detection system can of course apply to phrases or other constituents rather than to conventional word units, but most experiments are conducted with the latter, so for brevity I shall refer here simply to words.)

Contemporary theorizing in this area takes its point of departure from the 'logogen' theory of Morton (1964, 1969). Morton's view was that each word has a corresponding detection system (the logogen), which would accept inputs from a variety of sources and cumulate the evidence in favour of that word rather than any other. When enough evidence has been accumulated, the logogen fires and perception of that word occurs. This would allow one to handle the phenomena mentioned above; and also such cases as the perception of words when lip-reading, with some auditory and some visual information but each insufficient to give correct perception (McGurk & Marshall 1978). Perhaps the most interesting aspect of the theory, however, lies in the combination of the momentary sensory evidence with other evidence reaching the logogen from a different source. Some words are much more common in the language than are others. Words that are common in the language are much easier to see or hear than are rare words. Rare words are also more frequently produced as misperceptions. If you cannot hear a word correctly through noise, you are likely to think mistakenly that it is a common word, not a rare one. One could represent this in the logogen theory by a pre-existing level of activity in the logogen, which would combine with any sensory evidence to produce a

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single total tendency to perceive that word. In that case, the mechanism could sometimes be fooled, and give an output for a probable word when there was little sensory evidence for that word, and indeed when it was not the correct one. Experimentally, the ratio of the probability of correct responses to that of misperceptions is about the same for common and for rare words, which looks very much as if the logogens for common words start out with an advantage, but the extra evidence from the ear is about the same in both cases (Morton 1969; Broadbent 1967).

Another factor that changes the perceptibility of words is the provision of context. If one is given a few words leading up to the word that one is trying to see or hear, one can perceive it more easily; this experiment can be done with a lot or a little sensory information, and once again the ratio of the probabilities of correct perception with much and with little context is about the same whether there is much or little coming from the eye (Pollack 1964). There is in fact quite a lot of evidence for a single mechanism combining evidence about the presence of a word, whether that evidence is sensory, or comes from general probability of the word, or from contextual probability; and this is the essence of the original logogen theory. Let us take two recent areas of experiment, which put more detail into this view.

Semantic priming

First, consider the way in which the semantic relations between two words alter the difficulty of reading the second word after one has seen the first. Suppose a reader is given the name of a category, such as weapons, or parts of the body. Then words that belong to that category can be identified faster than they would be without priming by the category. The firing of one logogen excites the others in the same logical class and makes them more ready to fire also. One might well have had a theory, however, in which the mechanisms were nested hierarchically, so that all the members of a category received equal degrees of priming when any of them did so. In fact this is not so. When you know that the word is to be a weapon this improves you considerably at reading *gun*, *sword* or *dagger*; but less so at *pike*, *boomerang* or *shillelagh* (Rosch 1975). The degree of priming seems to be much greater for words that are in some sense 'central' to the category, 'good examples' of what is meant by that class of words. We do not find a whole class of words brought to readiness equally; rather, the words appear to be arranged in a multi-dimensional space. Perception of one of them, such as the name of a category, biases the system towards perceiving those words that are closest to the point already excited.

We therefore have to think of the detection systems for the constituents of an utterance as being interconnected; the output from one increases the readiness of certain others to the point that they will fire off on very little evidence. By performing experiments on the words that do and do not facilitate each other, one can trace out the connections of the 'logogens'. As has been said already, these connections do not fit a description of the links between words in single isolated features, but rather in terms of proximity in a multi-dimensional space. The difference is well illustrated by an old example provided by B. F. Skinner: 'The burglar left through the window and clung to the sill by his fingerprints'. It is the convergence of different lines of semantic priming that gives the last word its piquancy. One can see also that this kind of interaction will give rise to probable misperceptions such as transforming 'mouse chases cat' into 'cat chases mouse'.

There is a complication, however, which ought to be emphasized. The earlier evidence suggests that the detection systems, the logogens, operate in a passive way: cumulating evidence

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from any quarter but not searching it out. In a recent study, Broadbent & Broadbent (1980) have confirmed such a view for the case of semantic priming, when people are trying to identify a word that is blurred to the point that few details are visible. In such a situation the chances of correct identification are increased by the provision of a hint word semantically related to the target; showing the word 'robber' makes it easier to read the word 'thief'. But such a hint also increases the chances of saying 'thief' when the blurred word is actually 'thorn'. As in the earlier studies mentioned above, the ratio of correct to incorrect responses of certain word remained constant whether it was primed or not, as long as the stimuli were very blurred. Thus in terms of logogen theory the logogen is simply cumulating evidence from the stimulus and evidence from the priming word.

Broadbent & Broadbent (1980) found rather different results, however, when the stimulus contained more detail, and particularly when the people used in the experiment had seen a number of similar presentations so that they were used to the idea that the word they wanted was an associate of the priming word (Posner & Snyder 1975; Tweedy *et al.* 1977). In that case the number of correct identifications went up more than could be accounted for by the false perceptions (Broadbent & Broadbent 1980, p. 430). In terms of the logogen theory, this would mean that the perception of one word primed the logogen of another, but that this priming then produced an active searching of the visual field for evidence that might confirm or deny the percept suggested by the prime. In everyday terms this is reasonable, but it means that the detection of one constituent of a sentence does not simply increase the probability of some later percepts as opposed to others; it starts the operation of checking the sensory input for the presence or absence of particular elements.

Differences between vision and audition

The second area of recent research that should be mentioned concerns the priming effect of visual inputs upon auditory perception, or vice versa. In the original or simple logogen theory, all evidence cumulates in a single system. Hearing and vision ought therefore to produce a single common effect. Morton (1979) has recently pointed out that this interpretation is somewhat at odds with the results of Winnick & Daniel (1970), who found that people were no better at perceiving a word if they had recently used the same word in naming a picture; Morton and his coworkers have confirmed the result, and also found that people *are* helped in recognizing a different picture with the same name. There is no advantage in reading a word visually from having heard it, but there is an advantage in reading printed material from having seen the word hand-written (Clarke & Morton 1981; Warren & Morton 1981). These results do not fit easily with the concept of a single detection system for each word, receiving all kinds of visual or auditory input. Rather, Morton (1979) now leans towards the view that there are different categorization systems for the eye and for the ear, and that each of these is separate from the mechanism that outputs words. The distinctions fit in with other evidence in later papers in this volume. For present purposes the main point to establish is that one can distinguish different mechanisms operating in reading and listening, so that it may be dangerous to refer interchangeably to 'language use', without being clear which sense organ is involved.

General conclusions on word identification

This sample of results is very selective, but backed by many others. The implications are that the listener or reader identifies each word of the input in the light of a combination of

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evidence from the stimulus itself and from the previous identifications, in a markedly 'left to right' manner. It is not surprising that studies on comprehension of complete sentences should find evidence of, for example, the two strategies mentioned in the introduction. That is, we should find misunderstandings based on the forcing of constituents into a probable relationship, and on linking of each constituent to the one immediately previous. Certain facts about the order of constituents in different languages also become reasonable: Clark & Clark (1977) draw attention to the tendency, across languages, for given information to precede new, and for subjects to precede objects.

Yet it *is* possible to understand sentences correctly, and to do that requires some temporary storage of information from events earlier than the immediately past word or word group. In terms of possible computational models, it is now recognized that considerable success in handling natural language inputs can be achieved by Augmented Transition Networks, moving from left to right through the input. (The specific form of such a system is of course debatable (Fodor & Frazier 1980).) Yet it is necessary for such systems to keep registers of some of the earlier events in the stream. We may need to know, at a late stage in a sentence, whether the subject is singular or plural, and which past nouns can be the reference of a female pronoun. The detection system, the logogen, must therefore produce an output that is held temporarily until needed. The structure of possible languages may be affected, not only by the word identification mechanism but also by the limits of this temporary storage.

Temporary or working memory

Vision and audition

There is of course an obvious difference between normal reading and listening to speech, in that the person who is reading can take information into the nervous system in an order different from that of the words on the page. When we mention a lady in this sentence, there can be a long sequence of intervening words, enduring for several lines, and then when we mention her again the reader can go back to locate the referent. With hearing, the same mechanism is not available. However, a good deal of evidence has accumulated to show that the listener has a specialized memory for heard items, which endures longer and is more efficient that that for material that is seen. If one hears a series of items and attempts to recall them, the last item is better recalled if it is heard than if it is seen, but this is not true if an irrelevant word is heard after the last item of the series (Conrad & Hull 1968; Crowder & Morton 1969; Crowder 1978). The irrelevant word has much less effect, however, if it is acoustically different from the ones before it, as by being spoken in a different voice of in some cases coming from a different spatial location. So the information is held in a relatively sensory, non-linguistic form, which can suffer interference from similar later events.

At one time it was thought that this special acoustic form of temporary storage lasted only a few seconds, but later evidence has made it clear that this is not so; it still seems to be present even after longer periods, as long as no similar sounds have occurred in the interval (Broadbent *et al.* 1978, 1980; Martin & Jones 1979; Penney 1979; Watkins & Watkins 1977, 1980). The special form of acoustic store does not show itself in most experiments, except for the last item presented, because words are usually spoken in the laboratory at an even speed and on a steady intonation. Thus all except the last have been followed by other similar sounds. If, however, one introduces differences of timing or of pitch, a specialized acoustic store will show itself for earlier events than the last of the series. In natural speech, I can mention a *lady*, with a difference

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of intonation and a pause after the word, and when the listener comes later to some reference of her, the referent will still be present in acoustic form. (Notice how I have dealt with the corresponding visual problem in this written presentation.)

For visual information, this kind of internal store is not available, at least as long as the visual input occurs in the same location in space (Broadbent & Broadbent 1981*a*). So the reader is more dependent upon the order in which words strike the eye than the listener is upon the order in which they strike the ear. This is bound to have an effect upon the types of construction that are acceptable in the two forms of language, though the effect may go either way. It is desirable for written English to allow the reader to traverse steadily through the sentences and not to force back-tracking to take advantage of the external storage provided by the printed page. Although eye movements do sometimes reveal such regressions, with the eyes leaping back from late in a sentence to the beginning, regressions are not the normal thing in reading. They are associated with poor readers rather than good ones, and with difficult writing rather than clear style. The good reader does not look back often, and yet there is no temporary sensory memory available of the kind that assists the listener.

This means of course that the same sentences may be acceptable to the ear and not to the eye, or vice versa. Some statements widely quoted in the literature are based originally on observations with one kind of stimulus and appear not to hold for the other. For example, Bransford & Franks (1971) showed that people presented with sets of separate sentences such as 'The ants in the kitchen ate the jelly', 'The sweet jelly was on the table', and so on, will often confidently assert that they have received the sentence 'The ants in the kitchen ate the sweet jelly which was on the table'; even though that sentence has never actually been presented, only the separate propositions that make it up. This finding appears in many text-books; it is less often pointed out that it was obtained with sentences heard rather than seen. Indeed, one authoritative text actually describes the experiment wrongly. In fact the result is less likely to hold when the original sentences are seen rather than heard (Flagg & Reynolds 1977). In other words the recombination of sentences, into new integrated representations, plays a larger part in listening than it does in reading. The earlier sentences can still be held in temporary memory when listening, and combined with later ones. Rather different types of structure therefore become appropriate in written language; hence perhaps the greater prevalence in writing of utterances that conform to grammatical conventions.

There is another way in which written language may be processed, and that is by deliberately exaggerating the availability of the entire sentence, so that the reader goes through it slowly and in an order different from that of the words on the page. By such a strategy one can disentangle sentences such as 'The race that the car that the people', etc. This is not a manner in which the bulk of users of the language are prepared to operate, but it seems in some cases to develop in the particular academic subculture that makes great use of written language. The intuitions, about permissible structures, of people from this subculture are therefore somewhat different from those of the majority of language users. These intuitions are therefore suspect as sources of information about language in general. Indeed, they are often themselves influenced by earlier formal theories about language; for example, this seems the obvious explanation for the notion that left-embedded sentences are grammatical. To take another example, this is certainly the reason for my own horror at the use of the word 'disambiguate'; my intuitions on this point are of course based on formal training in classical languages, and are not shared by most contemporary academics.

To sum up, a temporary storage system is available for heard materials. This means that

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speech, as compared with written language, can use structures that refer back to elements arriving previously. At least this is true if the written language is of high standards of style and can be read as a continuous stream without puzzling over the text as if it were a railway timetable. Any suggestion that structures that require this latter form of processing shed light on linguistic universals does not seem very appealing.

Non-sensory working memory

Even written language, however, does require the reader to hold temporary representations for a short time, until later inputs arrive and allow a single unified structure to be created in a more permanent memory. To go back to the study by Bransford & Franks mentioned in the last section, the reader who recalls a single event involving ants, jelly, kitchen, and table must have held each of the parts of this event briefly until information arrived about other parts. Only then was the unified memory formed, and the isolated parts discarded. To take a simpler example, the sentence 'mouse chases cat' means something different from 'cat chases mouse'. For the reader to get to different positions at the end of the two sentences, the early words must have been held temporarily in each case. Yet people can understand written English even if each word is presented separately for a brief flash in the same location, for example by putting each word on a frame or two of a cine film (Forster 1970; Potter *et al.* 1980). Given the relative inefficiency of sensory memory in vision, this means that there must be some other kind of temporary memory at work.

One candidate is the reader's own articulatory system. Poor and novice readers can often be seen articulating. We all know how helpful it is, when trying to remember a telephone or car number, to say it oneself. If one does so aloud, one is of course creating the acoustic memory already considered. Even if one does so silently, however, it seems to be possible to hold a few items by rehearsing them internally. Correspondingly, a good deal of disturbance is produced in memory if one asks somebody to say something irrelevant, such as 'bla, bla, bla', all the time they are watching material that is to be recalled. This effect has been very beautifully analysed by Baddeley & Hitch (Baddeley & Hitch 1974; Baddeley 1979), and their broad conclusion is that some temporary storage does take place in the articulatory system but that there is a residue of temporary or working memory that is not articulatory. One holds some elements neither in a sensory memory nor in an articulatory loop, but rather in some abstract form of storage used only while processing is in progress. In addition to the evidence of Baddeley & Hitch, Broadbent & Broadbent (1981*b*) have provided further evidence for such a memory. We presented items one after another visually, always in the same place, to cut down the sensory storage; and asked people to recall each list of nine letters. In some lists, every group of three letters made up some meaningful sequence, such as UNO, or IBM. These lists were much easier, which means that people had held the letters individually for a while but then had been able to go back over the separate letters and recode them into their larger units. The interesting point emerges when people try the same task with articulation suppressed. They show just as great an advantage of the meaningful groups over the meaningless strings of letters. So, one may use articulation to store the triplets once their significance has been detected; but the very temporary storage needed to hold them while they are still individual letters does not seem likely to be articulatory.

There does seem therefore to be some form of temporary storage that is abstract, neither sensory nor articulatory, and which is available for holding intermediate stages of processing of language. This can be used even by the person who is a skilled reader without back-tracking,

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or who is listening to a steady and monotonous speaker. How large is this abstract working memory? Most discussion of memory limitations in human beings tends to consider the memory span, the number of items that can be repeated back after one presentation, as specifying a limit. That span is of course about seven items. But it represents a combination of all the various forms of temporary memory that we have considered, rather than the non-articulatory working memory alone. A variety of different lines of evidence (Broadbent 1975, 1981) suggest that the latter can hold much less, only about three or four independent units. (Each unit may of course stand for a complex word group or another non-independent chunk, on the basis established by Miller (1956).)

It is an interesting exercise to see how one could process an incoming sentence by using only three temporary memory locations; that is, if one is able to place nothing in one of those locations except at the cost of losing what was there already. It would be reasonable to allow also a facility whereby one could transfer to permanent memory the triplets of items ABC present in temporary memory at one time; and store them as a single relationship B (A, C) at a location X, which itself must be held in temporary memory. With such a restricted system it would just be possible to handle a simple declarative sentence with subject, verb, and object, such as 'mouse chases cat', and to put into permanent memory a structure different from 'cat chases mouse'. It is even possible to manage 'mouse that psychiatrist treated chases cat'. In the latter case the mouse and psychitrist could be linked by 'treatment', and that relation passed to permanent memory while leaving the mouse in the temporary location. The main clause could then proceed as before. The problem comes with a further embedding; 'mouse that psychiatrist whom Felix recommended treated chases cat'. Now one cannot dispose of the mouse to permanent memory before dealing with Felix's recommendation of the psychiatrist, because the connection of mouse and psychiatrist is unspecified at the time that we are trying to process the central clause.

It has of course long been recognized that there is a sudden fall in acceptability when a second level of embedding is used, and this has been linked to limitations of memory (see, for example, Blumenthal 1966; Chomsky 1965; Yngve 1961; Reich 1969). But as long as one thought of human short-term memory as coping quite well with seven items, the sharp break seemed arbitrary. Now that we have evidence for a much smaller number of items in the true central working memory, it seems reasonable to suggest that the size of that memory determines some of the structural features which have been claimed as linguistic universals. The very wide distribution of S–O–V and S–V–O structures in languages, to which Clark & Clark (1977, p. 546) call attention on the basis of the work of Greenberg, seems highly intelligible for such a memory. So also is the adjacency of adjectives and nouns. One may well follow the Clarks in suggesting that universals rest on the basis of the processing machinery available to handle language, when people use it in ordinary life.

Conclusions

This cursory survey has deliberately emphasized two points about the perception of sentences. First, there are marked differences between reading and listening. In priming of word perception, it makes a difference whether one primes in the same sensory mode or not, and in the analysis of memory mechanisms it is clear that there are facilities available in one mode that do not appear in the other. Although there are therefore common mechanisms in the handling of speech and written language, there are also separate ones.

Secondly, there is a distinction between semantic and syntactic contexts. The perception of

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a word is affected by earlier words, according to their positions in some semantic space. As a result sentences may be interpreted according to the most probable relationship of the constituents, rather than according to the intended meaning. Syntactic context, however, requires a more specific use of stored information. When we consider the amount of storage likely to be available, we can see plausible reasons why structures take the form they do.

These particular points have been emphasized, because the next papers will shed further light upon them. The findings themselves are characteristics of processing at the psychological level; they are linked with findings at the physiological.

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Discussion

B. D. Josephson, F.R.S. (*Department of Physics, University of Cambridge, U.K.*). The question has been raised of the roles of the different types of memory involved in language processing. It may be worth noting a useful analogy with the pocket calculator, where in some instances at least four types of memory may be identified: (i) the memory for the display, (ii) the operational stack or its equivalent, (iii) the main memory with addressable locations, and finally (iv) the magnetic card or memory module used for long-term storage. These types seem to be well adapted to particular tasks, and it is tempting to assume that nature employs similar methods. In the context of Dr Broadbent's talk, his 'working memory' seems to be related to type (ii) above, but the third kind of memory, which is directly addressable by a program, would seem to be required for the storage of miscellaneous information such as the potential referents of pronouns.

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