SELECTIVE ATTENTION IN MAN

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Fifty years ago psychologists thought of attention as "the focalization of consciousness" or "the increased clearness of a particular idea". But these and other definitions in terms of mental faculties or subjective experience proved sterile for empirical research and ended in a series of inconclusive controversies. Recently interest in this problem has revived, prompted both by the urgent practical need, with the increasing use of machines in industry, to define man's characteristics as an information-handling system, and by two conceptual advances: the rejection of introspective reports as a source of explanation, and the development of scientific models dealing not with the conservation and transmission of energy but with control and communication. There has been a parallel development of interest in the neurophysiological bases of attention and selectivity of response, and the prospect is that the neural structures underlying the functional processes inferred from psychological studies will ultimately be identified; but this paper is confined to behavioural research.

1. Methods, Problems and Approach

Various experimental methods have been used to investigate behaviour in tasks requiring selective attention. Our examples are mainly of human subjects responding to passages of speech. A subject is presented with two or more messages which can differ in physical characteristics such as intensity, frequency or spatial localization, in features of the language such as similarity, meaningfulness, importance to the subject or contextual probability, and finally in the degree to which the messages overlap or are separated in time. He may be asked to respond to one message or to several, or to monitor all messages and respond only to some. The response required may be immediate or delayed; it may coincide with further messages or alternate with them; and it may vary in complexity, for example it may be repeating back the message or replying to questions—the two most common tasks or translating, writing, summarizing or recalling the message.

Examples of problems which arise are the nature of the limits in man's ability to respond to competing messages; the form of selective system used by the brain and the stage at which irrelevant data are discarded; finally, the way in which incoming data are analysed from sound to word and meaning, stored in short-term or long-term memory and used to determine the appropriate response. A useful approach is to start with a general descriptive model, making it more precise as evidence accumulates. The alternatives at this level are usually qualitative and the evidence relates to the type of function rather than to the actual mechanisms which carry it out, and to the order in which the processes occur rather than to their spatial lay-out. Broadbent (1958) made an important contribution with his "filter" and "information flow" theory (see fig. 1), which provides the basis and starting-point for this paper. Some alternative accounts of attention are given by Hebb (1949), Sutherland (1959), Berlyne (1960) and Deutsch & Deutsch (1963).

2. Limits to Performance with Competing Inputs

Many experiments (Broadbent, 1952; Cherry, 1953; Mowbray, 1953; Poulton, 1953; Webster & Thompson, 1954) have shown that if a man must deal with competing messages there is a limit at which his performance will break down. For example, Broadbent asked his subjects to answer questions about a changing visual display and found that their efficiency was lower if two questions (in different voices) were given simultaneously. Cherry showed that subjects who repeated back a passage of prose heard through one ear were unable to report any of the verbal content of another passage presented at the same time to the other ear. They were aware of its general physical characteristics—that it was speech in a man's voice—but they failed to notice when the English changed to German or to speech played in the reverse direction.

What sets the limits to performance in tasks like these? Peripheral masking is unlikely to be the whole answer, since subjects are quite able to handle either of the two messages if no response is required to the other. Moreover, very similar results are obtained when one message is visual and one auditory (Mowbray, 1953). Competition between motor responses may be avoided by requiring successive responses to simultaneous messages, for instance asking subjects to repeat one, then recall the other, as in Cherry's experiment. Thus part at least of the interference must occur at some central stage, either in identification of the words or in memory storage.

An important finding is that this central limit is set not primarily by the number of messages but by their predictability or information content (see Crossman, p. 32 of this number of the Bulletin). Subjects can respond to two simultaneous call-signs chosen from a small set of alternatives, but to only one message chosen from a wider range (Webster & Thompson, 1954). The sound of a buzzer produces more interference with a simultaneous speech task if it requires one of two responses than if a fixed response or no response must be made (Broadbent, 1956a).

3. Broadbent's "Filter" and "Information Flow" Model

To summarize these findings, fig. 1 shows the relevant parts of Broadbent's model. A number of messages may reach the central system, which Broadbent describes as a "filter" and "information flow" theory (see fig. 1), which provides the basis and starting-point for this paper. Some alternative accounts of attention are given by Hebb (1949), Sutherland (1959), Berlyne (1960) and Deutsch & Deutsch (1963).

See also paper by Brown, p. 8 and footnote 2, of this number of the Bulletin.

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Fig. 1. Broadbent’s “Filter” and “Information Flow” Model for Selective Attention (Broadbent, 1958)

The diagram illustrates a model in which man is represented as an information-handling system. The successive parts of the model are discussed in the text.

This leaves the problem of how the brain separates out the single, complex sound-wave reaching both ears into two or more channels, of which it can select one for further analysis. There have been some attempts to specify in more detail how these discriminations are carried out. For example, Cherry & Sayers (1956) have put forward a model for auditory localization in which the signals reaching the two ears are cross-correlated to determine which constitute the same message; the delay interval giving maximum correlation for each message then indicates the apparent position of each source of sound. Another example is the suggestion by Broadbent & Ladefoged (1957) that the cue distinguishing different voices is the larynx tone or pulse modulation rate of the frequency spectrum. When this is the same, different frequencies in the same or opposite ears are heard as one “sound”; when it differs, two “sounds” are heard. This pulse rate may be coded by the nervous system as a rate of firing, so that the channels are not necessarily identifiable with separate neural pathways.

b. Stages of Input Analysis and Level of Filter

It is plausible to suppose that different features of the input messages are discriminated successively, and that the filter selects on the basis of past analyses which inputs will be passed on for further processing and which discarded. Both the order in which the different features are analysed and the stage at which the selection is made could be fixed or variable. There is some evidence that in human selective listening the channel discriminations based on general physical features are always made, and that the filter can operate only at a later stage; Cherry’s subjects could report all these features of the message to which they were not attending (Cherry, 1953). I have shown that the interference with response to a selected message was determined not by the number of irrelevant messages or verbal sequences but by the number of channels in which they were presented, although the minimum physical difference between selected and irrelevant channels was kept constant (Treisman, 1961). This suggests that all the physical features distinguishing the irrelevant channels were being discriminated, whether they were needed for the task or not.

On the other hand, there is little evidence that differences in the purely verbal content of irrelevant messages are noticed or produce differences in interference, provided that they arrive in separate channels from the selected message. For example, Moray’s subjects showed no trace of recognition of a repeated series of words presented in an irrelevant channel, and failed to recall digits that they had specifically been told to listen for (Moray, 1959). To ensure that this was not a limit in memory only, I asked subjects to make an immediate manual response to any digit on either channel while repeating back one message only (Treisman, 1961). The information in the manual response was the same for both channels, but subjects responded only to digits in the selected message. I also failed to produce any change in efficiency of selective response by varying the information content, the meaningfulness or the similarity of irrelevant messages, provided that no consistent differences were produced in non-linguistic features of the sounds (Treisman, 1961). (This last factor was not controlled in experiments by Webster & Thompson (1953) or by Peters (1954), who claimed to find effects on performance of the content of competing messages.)

However, there are a few interesting exceptions to the rule...
that the verbal content is never reported. Moray (1959) showed that subjects sometimes noticed their own names if these occurred in the irrelevant message, and suggested that there might be a specific system, before the filter, for analysing patterns and for identifying highly important signals. I found that subjects occasionally repeated a word from the irrelevant message if it was made highly probable in the context of the message to which they had been attending (Treisman, 1960). This is more difficult to attribute to a specific pattern-analysers, since the range of words which could be made highly probable is very large. Cherry (1953) showed that if identical messages were presented to the two ears a few seconds out of step, subjects became aware that the two were the same. To determine at what level the identity was recognized, I presented the same messages in different voices and also two messages with the same meaning in different languages, using bilingual subjects in the latter case (Treisman, 1961). In both conditions subjects still noticed the identity. Deutsch & Deutsch (1963) argue that these examples of recognition of the verbal content of "rejected" messages imply that selection is made only after full analysis of all inputs. As further support for this idea they quote studies of habituation by Sharpless & Jasper (1956) and by Sokolov (1960).

4. Habituation

If the same stimulus is presented repeatedly, the response originally made tends to decrease or disappear; this change is known as habituation. Like selective attention to competing messages, it implies some form of selectivity or filtering, and Broadbent originally attributed both to the same filter system. He postulated that this had an intrinsic bias for passing novel stimuli ("novel" implying both stimuli which had not been present before and those which had not recently been selected by the filter). As the stimuli to which the subject is being habituated are repeated, they become less novel, and the filter will shift to new channels.

Sokolov (1960) reports some interesting studies of habituation in the arousal response or "orienting reflex". He examined the decrease or disappearance of alpha blocking in the electroencephalogram and the galvanic skin response in human subjects on repeated presentations of the same stimulus. He then altered the stimulus in various ways, and found that the arousal response reappeared not only when the intensity or duration of the habituated stimulus increased but also when it decreased. This makes it unlikely that the habituation is due to perceptual blocking or attenuation of the stimulus, and he concluded that the recurrence of the arousal response was produced not by the stimulus as such, but by a mismatch between the new stimulus and a neural record representing the features of the habituated stimulus. He found, moreover, that this mismatch could imply complex levels of analysis, such for instance as a change in meaning with words. Deutsch points out that selection in these experiments must follow more complex analysis of the signals than discrimination of the simple features which distinguish functional input channels. Broadbent's original account is probably not inconsistent with Deutsch's, since his concepts both of "novelty" and of "filtering" were very general and flexible. However, it does not follow that selection must always be made at this late stage, and a different system may control habituation from that which controls selective attention with competing and highly informative inputs.

5. Word Identification and Selective Response

I have suggested an alternative explanation of the few occasions when the verbal content is identified (Treisman, 1960, 1961). It may be that the channel filter attenuates irrelevant messages rather than blocks them completely. If so, words which were highly important or relevant to the subject could be picked out when the threshold for identifying them was permanently or temporarily lowered within the word-identification system itself, in spite of their reduced signal-to-noise ratio. A possible system for identifying words is a hierarchy of tests carried out in sequence and giving a unique outcome for each word or other linguistic unit. The decision at each test point could be thought of as a signal detection problem (cf. Tanner & Swets, 1954): a certain adjustable cut-off or criterion point is adopted on the dimension being discriminated, above which signals are accepted and below which they are rejected as "noise". The criteria determining the results of the tests would be made more liberal for certain outcomes if favoured by contextual probabilities, by recent use or by importance. Messages attenuated by the filter would pass the tests only if the criteria had been lowered in their favour and, if not, would pass no further through the hierarchy. This would be more economical than Deutsch's full analysis, since most irrelevant words would fail tests early in the hierarchy. Broadbent & Gregory (1963) recently showed that the auditory threshold of one ear is raised if subjects are asked to attend to stimuli in the other ear, and that this change is in the internal signal-to-noise ratio, not in the decision criterion. The complementary test is to show that thresholds are lowered for particular important or probable words and that this change is in the decision criterion, not the signal-to-noise ratio. There is certainly considerable evidence that, with a single message masked by noise, the threshold is lowered both for contextually probable words (Miller, Heise & Lichten, 1951) and for one's own name (Howarth & Ellis, 1961); moreover when two competing messages are presented in the same channel, selection is determined by the transition probabilities between words (Cherry, 1953; Treisman, 1961). But it has not yet been determined whether this is owing, as predicted, to a change in decision criterion.

It seems likely that the channel filter will be used only when two or more competing inputs would together overload the central decision channel. If so, it would not be brought into play in the usual restricted and monotonous environment of an habituation experiment. Habituation could then be attributed not to attenuation of certain input channels but to a change in the criteria for particular test outcomes at any level in the identification hierarchy, depending on the common features of the habituation stimuli used. This change could thus be as specific as the effects found by Sokolov, leaving the criteria for all other features unaffected.

6. Shifting of Attention

The final problems raised relate to the setting and shifting of the filter from one channel to another and to the retrieval of temporarily "rejected" messages. Does the filter take time to shift to a new channel, and can one message be held temporarily in store while another is handled? In an ingenious series
of experiments Broadbent (1954, 1956b, 1957; Broadbent & Gregory, 1961) reached an affirmative answer to both questions. He presented subjects with three pairs of simultaneous digits to be recalled, one of each pair in a different input channel (either the two ears; or ear and eye; or a frequency-filtered and a normal voice). He found that at rates faster than one digit per ear per second, subjects always recalled the digits from one channel first, followed by the other, rather than alternating between the channels to approximate the correct temporal order. The alternating order was possible only when the presentation rate was reduced to half a digit per ear per second where different sense organs were used, and two-thirds of a digit per ear per second with voices differing in frequency spectrum. Two conclusions can be drawn: (i) there is a limit to the rate at which the filter can shift from one input channel to another, which is probably faster the less distinct the channels; (ii) there is a short-term store prior to the filter in which the digits from the second channel are held while those from the first are identified.

Moray (1960) questioned the first conclusion: he showed that if the digits were staggered in time, his subjects could alternate between their ears at rates much higher than those in Broadbent’s experiments. But his own results also show that the subjects did worse when the digits alternated between the ears than when all were given to one ear. This again implies a limit in switching rate, although the shifts appear to be faster for staggered than for simultaneous digit pairs. Perhaps the filter shifts are facilitated by the presence of an external stimulus rather than a stored trace (as with the simultaneous digits). Gray & Wedderburn (1960) also raise a difficulty for Broadbent’s account by their finding that when the words of the initial intake capacity or by a central selection.

Two main questions arise about the nature of the short-term store: (i) whether it is limited primarily by decay of items with time, or by interference between items held in it; (ii) whether it is used only to cope with temporary overloading caused by momentary peaks of information or as a normal stage through which all inputs must pass. Broadbent varied both the time for which the digits in the second channel had to be stored before recall (by increasing the number given in the first channel) and the number of items to be held in store (by increasing the number in the second channel). Both these changes impaired recall, suggesting that the store is limited both by a short decay time (of the order of one or two seconds) and by a small capacity. He also compared recall when subjects were told in advance which series of digits they were to repeat first and when they were told only after presentation of the digits. If all digits were automatically held in store, there should be no difference between these conditions, while if digits in one channel were sent straight through, advance knowledge of the order of recall would allow subjects to choose which to send first and should thus give better results. Broadbent (1957) found that his subjects could perform in either way, but tended to change from an initial strategy of storing all digits to one of sending some through immediately, perhaps because it proves less efficient to hold all digits in the limited peripheral store.

Other recent findings may throw more light on this relatively peripheral “buffer” storage. Rabbitt (1962) has shown that two aspects of a single visual stimulus (its shape and its colour) may be treated in the same way as the digits sent to right and left ears in Broadbent’s experiment on the order of recall. Thus the model for storage and selection can apply to any feature of the input which is as yet uncategorized as well as to inputs coming from one particular channel or source. Sperling (1960) reports an ingenious method of estimating the information available in a temporary store immediately after presentation of a visual display, and of measuring its decay with time. He used a sampling technique to see whether the normal limited peripheral capacity is set by the initial intake capacity or by a central selection. At different intervals after a short exposure he gave a signal to instruct subjects which one of several rows of items they should recall; then used the partial recall to estimate the total number of items available. He found that this was initially two or three times the number in the normal span, but declined rapidly in less than a second to the normal limit. His finding seems closely related to the change from multi-channel to single-channel functioning in Broadbent’s model, although the decay time for vision may be more rapid than for hearing. Finally I compared the storage time for selected and rejected auditory messages: I repeated Cherry’s experiment, presenting identical speech messages to the two ears, separated by a variable time interval, and noted the interval at which subjects recognized the identity, both with the selected message leading in time and with the rejected one leading (Treisman, 1961). In the first case the selected message had to be stored for comparison with the rejected one, and the interval for recognition was 5 sec.; in the second case the rejected message was stored, and the interval fell to 1 or 2 sec. This result is consistent with Broadbent’s estimate of the decay time for as yet uncategorized signals, and shows that identification of the sounds as words may treble their memory survival time.

8. Conclusion

The traditional model of attention has become both more general and more precise: it has been related to the mechanisms of perception as such and has been defined in the language of channels, information, filtering processes and storage. This clarification may open the way to a more exact linking of behavioural concepts with underlying physiological mechanisms which are now being investigated, and some of which are discussed elsewhere in this number of the Bulletin. Developments of great interest are to be expected from the convergence of these two approaches.

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