Reprinted from:

Dominic W. Massaro
Program in Experimental Psychology
University of California, Santa Cruz
Santa Cruz, CA 95064

In *The International Encyclopedia of Education*.
T. Husen and T. N. Postlethwaite (Eds.). Oxford:
Pergamon Press, 1985, Vol. 5, pp. 2493-2499.

Information-processing Theory

In information-processing theory, the individual is viewed as a processor of information (Broadbent 1958, 1971, Lachman et al. 1979, Massaro 1975a, Neisser 1967). The researcher attempts to understand what happens to the information as it is perceived and interpreted by the individual. The processing of the information depends on the nature of the sensory system, some memory of past experiences, and goals of the participant. The central assumption of research in the information-processing paradigm is that a sequence of processing stages occurs between stimulus and response. The onsets of these processing stages are successive and each stage operates on the information available to it. (Although the stages are successive they can be overlapping in time. The operation of one stage might begin before the operation of a previous stage is completed.) The operations of a particular stage take time and they transform the information available to that stage and make it available to the next stage of processing. Two theoretical constructs are important in this approach. First, the memory construct describes or defines the nature of the information at a particular stage of processing. Second, the processing construct describes the operations performed by a stage of information processing.

The information-processing approach has major implications for experimentation. The experimenter strives to account for each of the processing stages in the task performed by the individual. This requires that the experimenter make explicit the implicit assumptions inherent in any experimental situation. Failure to do so severely limits what can be learned from the results. The precise analysis given by the information-processing methodology can be thought of as a microscope. It allows the experimenter to see what is not directly observable. The remainder of this article will discuss the information-processing approach to representative areas of research.

1. Psychophysics

The study of the relationship between the stimulus and sensation is the oldest concern of experimental psychologists (Boring 1950). Over a century ago, Fechner inaugurated the study of psychophysics and developed a number of methods for the study of psychophysical phenomena. The central assumption in Fechner's approach is that the observer's response is a direct indication of the sensation. This assumption is rejected in the information-processing framework: it is clear that another process, a decision process, intervenes between the sensation and the response. Accordingly, the observer's response is a function of both sensation and decision and both of these processes must be accounted for in order to understand psychophysical results.

The following sequence of operations is assumed to occur in the psychophysical task: stimulus→sensation stage→decision stage→response. Notice that contact with external events is limited for both stages. The sensory stage's input is the stimulus, which can be objectively observed and measured, but its output is an unobserved sensation. This sensation is made available to the decision stage and is operated on before the subject reports to the experimenter. The output of the decision stage determines the response, but its input is the information given by the outcome of the sensory stage rather than the stimulus itself.

In terms of information-processing theory, Fechner wanted to describe the relationship between the stimulus and sensation. However, it cannot be assumed that this value is known merely by observing the response of the subject. The intervening decision stage may transform the information made available by the sensory stage in any number of ways. If the nature of the decision rule can be determined, however, it may be possible to discount its effect and extrapolate the actual sensation from the response information given by the observer. This model of the psychophysical task has had major implications for both the experimental procedures that are used and the nature of the theories used to interpret the results. Experimentally, the investigator can control for any distortions produced by the decision system by keeping the observer uncertain about the stimulus situation on any trial. In addition, the procedures allow quantitative tests of a wide range of models of sensory performance (Green and Swets 1966). This approach has led to a severe questioning of the concept of a sensory threshold and has generated powerful alternative models of sensory performance. In addition, the application of the decision model to other areas has provided a more direct evaluation of perception and memory phenomena (Massaro 1975a, Wickelgren 1979).

2. Backward Masking

Information-processing theory appears to be particularly well-suited to the dynamic aspects of perception since it is structured along the temporal (dynamic) dimension. The following model has been utilized in research in auditory information processing and speech perception (Massaro 1975a, 1975b): sound→feature detection→preperceptual auditory storage→perceptual recognition. The feature detection process transforms the sound wave pattern into acoustic features that are stored centrally in a preperceptual auditory storage. Preperceptual auditory storage holds the features passed on by the feature detection process for a short time after a sound is presented. The perceptual recognition process resolves the featural information producing a perceptual experience. The phenomenological outcome of primary recognition is perceiving a particular sound of a particular loudness and quality at some location in space.

In speech perception, preperceptual auditory storage accumulates the acoustic features of a speech stimulus until the sound pattern is complete. Recognition occurs during and possibly after this time in order to produce a percept. A second pattern does not usually occur until the first pattern has been perceived. However, if the second pattern is presented soon enough, it should interfere with recognition of the first pattern. By varying the delay of the second pattern, the duration of preperceptual auditory storage can be determined as well as the temporal course of the recognition process. The experimental task is referred to as a backward recognition masking paradigm. Pure tones differing in frequency, intensity, waveform, duration, and spatial location have been employed as test items in the backward masking task.

Speech sounds have also been used in the task. In one study, consonant–vowel syllables /ba/, /da/, and /ga/ were used as test and masking stimuli. Only enough of the syllable was presented to make it sound speechlike. On each trial, one of the three syllables was presented followed by a variable silent interval before presentation of a second syllable chosen from the same set of three syllables. The subject's task was to identify the first syllable as one of the three alternatives. Subjects were told to ignore the second syllable, if possible. The speech sounds were presented at a normal listening intensity.

Correct identification of the first speech sound increased with increases in the silent interval between the two sounds. This result shows that recognition of the consonant phoneme was not complete at the end of the consonant–vowel transition or even at the end of the short vowel segment of the sound. Syllable recognition required perceptual processing after the speech sound was terminated. The second speech sound interfered with perception if it was presented before recognition was complete. These results support the idea that the speech sound is held in preperceptual auditory storage while processing takes place. A second sound interferes with any further resolution of the first sound.

What do these results imply about perceiving continuous speech? The backward-masking experiment with consonant–vowel syllables shows that the consonant is not recognized before the vowel, but rather the syllable is recognized as a unit. In this information-processing model, accurate recognition requires sufficient processing time after the information of the sound pattern is placed in preperceptual auditory storage. There is evidence that vowel and consonant–vowel syllables are processed during the steady-state vowel period. In this view, the extended vowel periods in continuous speech are redundant in terms of providing additional segmental information, but could serve the important function of allowing for sufficient processing time before new information is presented. Silent periods also allow time for processing and it has been shown that silent time after a vowel–consonant syllable is critical for accurate recognition.

The backward recognition masking task has been a very powerful tool in the study of the temporal course of auditory recognition and the properties of preperceptual auditory storage. Similar success has been achieved by employing the same task in the study of visual information processing (Massaro 1975a, 1975b).

3. *Reaction Time*

One of the primary dependent measures of the information-processing approach is that of reaction time—the time between the onset of some stimulus event and some response of the observer (Posner 1978, Theios 1973). Consider the situation in which an observer is required to make choice responses to stimulus events. There are two important stages of processing in the task: recognition and response selection. It is well-known that increasing the number of stimulus and response alternatives in the task increases the overall reaction time. For example, given 2-, 4-, or 8-digit alternatives as stimuli, with 2, 4, or 8 buttons as responses, reaction times increase with increases in the number of alternatives.

One question of interest within information-processing theory is whether the increase in reaction time is due to recognition time, response selection time, or both. One way to answer this question is to manipulate a second independent variable in addition to the variable of the number of alternatives (Sternberg 1969). For example, it would be possible to manipulate the clarity of the stimulus presentation and/or the nature of the response. The clarity of the stimulus presentation would be expected to influence recognition time whereas the nature of the response would be expected to influence response selection time. By assessing whether the increase in reaction time due to each of these variables adds to or interacts with the increase in reaction time with increases in the number of response alternatives, it is possible to determine the stage of processing that is influenced by the number of alternatives in the task. In a related task, Theios (1973) found that response selection time accounts for the increase in reaction time with increases in the number of response alternatives.

4. *Attention*

The information-processing framework is also utilized in the study of attention. The concept of attention in an information-processing model depends on two criteria. First, the human processing capacity is limited; that is, there is a finite limit to the amount of cognitive or perceptual processing that can be carried out at a given time. Second, given this limitation, this processing capacity can be allocated to a particular stage of processing or to particular tasks within a stage of processing. When this is done it can be said that a person is attending. The concept of attention would not be necessary if the system were not limited in capacity, and would not be possible if the system were not able to allocate a limited processing capacity to one task at the expense of another.

To validate the role of attention, it is necessary to ask whether subjects can carry out two tasks as well as one. In the information-processing model presented, it is possible to make this question even more explicit. Having distinguished between stages of processing, it is first necessary to ask whether attention operates within a particular stage of processing. For example, can visual information be recognized, such as a linguistic symbol, as well as when auditory information is being simultaneously recognized, such as the pitch of a tone. The second question asked is whether attention operates across or between processing stages. In this case, it is necessary to ask whether the processing capacity available to one stage is reduced at the expense of processing at another stage. For example, is the detection of a signal impaired by requiring the observer to remember a list of digits at the same time? Massaro (1975a) reviews the literature on limited capacity and attention from the point of view of the information-processing framework.

5. *Speech Perception*

Information-processing theory has also been applied in the study of speech perception. One traditional concern in speech research has been to determine the acoustic features that are utilized in perception. The feature detection process places features in a brief temporary storage called preperceptual auditory storage, which holds information from the feature detection process for about 250 milliseconds. The perceptual recognition process integrates these features into a percept. One critical question is what features are utilized, and a second important question is how are all of the features integrated together. Does the listener only process the least ambiguous feature and ignore all others, or are the features given equal weight, and so on? Despite the overwhelming amount of research on acoustic features, very little is known about how the listener puts together the multitude of acoustic features in the signal.

The integration of acoustic features has not been extensively studied for two apparent reasons. The first is that research in this area was highly influenced by linguistic descriptions of binary all-or-none distinctive features (Jakobson et al. 1961). Given the assumption of a binary representation of distinctive features, the integration of information from two or more dimensions would be a trivial problem. A second reason for the neglect of the integration problem is methodological. The primary method of study involved experiments in which the speech sound was varied along a single relevant dimension. Very few experiments independently varied two or more dimensions within a particular experiment.

Asking listeners for continuous rating judgments rather than discrete judgments provides a more direct method of assessing the nature of the output of feature detectors. In these rating studies (Massaro and Oden 1980), subjects first listened to a stop consonant continuum changing in place of articulation (/bae/ to /dae/) or voicing (/bae/ to /pae/), or a vowel continuum going from /i/ to /I/. The listeners were instructed about the nature of the continuum and were asked to rate the sounds according to where they fell on the continuum. The rating response was made by setting a pointer along a continuous scale. The ends of the scale were labeled with the two alternatives and subjects were told to place the pointer at the location to which they thought the sound belonged.

If a stop consonant is consistently rated as being /bae/ to some degree rather than being either /bae/ or /dae/, there would be evidence for the availability of information about the degree to which a feature is represented in a sound. In agreement with this idea, the results revealed that the rating responses were a systematic function of the stimulus values for each of the three continua. The rating judgments demonstrate that listeners can transmit continuous information about acoustic properties of speech sounds.

Once the idea of continuous features is accepted, the integration of information across two or more features becomes an important issue. In traditional all-or-none classificatory schemes, logical conjunction would be sufficient to combine values across dimensions. Pluses and minuses in the feature matrix are sufficient to classify the speech sound. However, many possible classificatory schemes can be developed to represent the integration of continuous featural information. Tests of models of featural integration require multifactor experiments rather than the more traditional single factor experiment. In a multifactor experiment, two or more acoustic dimensions are independently varied so that all combinations of the values of one dimension are paired with all combinations of the values of another property. The factorial design is optimal because it optimizes the number of data points relative to the number of parameters needed to test the various models of speech perception. This paradigm has proved highly successful in providing tests of quantitative models of the speech perception process (Massaro and Oden 1980).

6. *Reading*

Reading-related research has been carried out within the information-processing framework (Massaro 1975b). The text in reading is a sequence of letters and spaces which conform to orthographic, syntactic, and semantic constraints defining the written language. The average English reader begins at the top left-hand corner of the page and reads each line from left to right. A reader's eye movements are not continuous, but occur in a series of short jumps called saccades. The fixation time between eye movements is roughly 10 times longer than the movement time itself. An average reading eye movement of one to two degrees requires 20 to 30 milliseconds, whereas fixation time averages one-quarter of a second (Woodworth 1938). Initial processing of the visual stimulus must occur during the fixation time between eye movements, since the intensity of the light pattern is too weak and the processing time too short during the eye movement itself.

During the eye fixation the light pattern of the letters is transduced by the visual receptors into a feature detection system which places a set of visual features in preperceptual visual storage: printed text→feature detection→preperceptual visual storage→perceptual recognition. The features are described as visual because it is assumed that there is a direct relationship between the stimulus properties of the letters and the information in preperceptual storage. The passive transduction of feature detection contrasts with the active construction of the following processing stages. There is no end one-to-one relationship between the input and output of the following processing stages since these later stages actively utilize information stored in long-term memory in the sequence of transformations.

Given the set of visual features in preperceptual visual storage, the perceptual recognition process attempts to synthesize these isolated features into a sequence of letters and spaces. To do this, the recognition process can utilize information held in long-term memory, which, for the accomplished reader, includes a list of features of each letter of the alphabet along with information about the spelling of the language. Since there are constraints determining how letters and letter groups can be put together to form English words, the reader's knowledge of this regularity can help resolve the letters in a string that conforms to the language. This knowledge can also help the reader resolve the relative spatial positions of the letters once they are recognized.

The recognition process operates on a number of letters simultaneously (in parallel). The visual features read out at each spatial location define a set of possible letters for that position. The recognition process chooses from this candidate set the letter alternative which has the best correspondence in terms of visual features. However, the selection of a best correspondence can be facilitated by knowledge of spelling. The recognition process, therefore, attempts to utilize both the visual information in preperceptual storage and knowledge about the spelling of legal letter strings. The interaction of these two sources of information is a critical issue in the analysis of word recognition.

The perceptual recognition process transmits a sequence of recognized letters to synthesized visual memory: perceptual recognition→synthesized visual memory←→conceptual recognition→short-term memory. The conceptual recognition process transforms this synthesized visual percept into a meaningful form in short-term memory. It is assumed that synthesized visual memory holds a sequence of letters which are operated on by the recognition process which tries to close off the letter string into a meaningful word. The recognition process makes this transformation by finding the best match between the letter string and a word in the long-term lexicon. Each word in the lexicon contains both perceptual and conceptual codes. The concept recognized is the one whose perceptual code gives the best match and the one most likely to occur in that particular context.

Short-term memory is common to both speech perception and reading. Recoding and rehearsal processes build and maintain semantic and syntactic structures at the level of this memory. The bidirectional arrow between synthesized memory and conceptual recognition means that it is also possible to go from meaning to a visual percept. The recoding operation can transform the meaning of a concept into its perceptual form.

Differences in reading skill have been studied within the information-processing framework. Central to the study of reading difficulty is the determination of the stage or stages of processing responsible for the difficulty. In the present model, for example, deficits could exist at either the temporary processing stages, the long-term knowledge base, or in both. Feature detection, perceptual recognition, conceptual recognition, and rehearsal recoding might each be responsible for various reading difficulties. This general approach has facilitated the design and analysis of research on individual differences and skill in reading (Resnick and Weaver 1979).

7. *Conclusion*

The goal of this article has been to provide an overview of information-processing theory. Although there are other valuable approaches to the study of experimental psychology, the information-processing approach appears to have rather unique implications for methodology and application. It is possible to look forward to additional applications and tests of the theory in a variety of experimental situations. This work should lead to a further refinement of the model and set the stage for applying the theory to more natural contexts.

See also: Memory

Bibliography

Boring E G 1950 *A History of Experimental Psychology*, 2nd edn. Appleton-Century-Crofts, New York

Broadbent D E 1958 *Perception and Communication*. Pergamon, New York

Broadbent D E 1971 *Decision and Stress*. Academic Press, London

Green D M, Swets J A 1966 *Signal Detection Theory and Psychophysics*. Wiley, New York

Jakobson R, Fant C G M, Halle M 1961 *Preliminaries to Speech Analysis: The Distinctive Features and Their Correlates*. MIT Press, Cambridge, Massachusetts

Lachman R, Lachman J L, Butterfield E C 1979 *Cognitive Psychology and Information Processing: An Introduction*. Erlbaum, Hillsdale, New Jersey

Massaro D W 1975a *Experimental Psychology and Information Processing*. Rand McNally, Chicago, Illinois

Massaro D W (ed.) 1975b *Understanding Language: An Information-processing Analysis of Speech Perception, Reading, and Psycholinguistics*. Academic Press, New York

Massaro D W, Oden G C 1980 Speech perception: A framework for research and theory. In: Lass N J (ed.) 1980 *Speech and Language*, Vol. 3. Academic Press, New York

Neisser U 1967 *Cognitive Psychology*. Appleton-Century-Crofts, New York

Posner M I 1978 *Chronometric Explorations of Mind: The Third Paul M. Fitts Lectures, Delivered at the University of Michigan, September 1976*. Erlbaum, Hillsdale, New Jersey

Resnick L B, Weaver P A 1979 *Theory and Practice of Early Reading*. Erlbaum, Hillsdale, New Jersey

Sternberg S 1969 The discovery of processing stages: Extensions of Donders' method. *Acta Psychol*. 30: 276-315

Theios J 1973 Reaction time measurements in the study of memory processes: Theory and data. In: Bower G H (ed.) 1973 *The Psychology of Learning and Motivation*, Vol. 7. Academic Press, New York

Wickelgren W A 1979 *Cognitive Psychology*. Prentice-Hall, Englewood Cliffs, New Jersey

Woodworth R S 1938 *Experimental Psychology*. Holt, New York

D. W. Massaro