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Phonemes and Alphanumeric Characters: Possible Components of Parallel Human Communication Systems

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Alphanumeric characters and phonemes can be viewed as information codes used by human communication systems. If such communication systems were designed to be effective, then we should expect to find certain characteristics which should be manifested in the nature of the physical representations of the information codes and in the perception of these codes. These characteristics are discussed in terms of their importance to communication systems in general and their manifestations in human audible and visible language. When viewed from the perspective of such communication systems, we should expect to find many parallels in the perception of alphanumeric characters and phonemes. This paper examines some of these parallels, drawing upon our knowledge of human perception.

The purpose of this paper is to examine the perception of components of written and spoken codes of human communication from a broad perspective in an attempt to identify possible similarities. We will focus on the perception of phonemes and alphanumeric stimuli as equivalent levels of components or codes of an effective communication system, and intentionally will side-step the important, often discussed but poorly-answered question whether these components represent the basic units of language.

A. An Overview

Human language normally involves two distinct sets of physical representations of its information code. One of these physical codes involves patterns of sounds varying in time, frequency, intensity, and complexity. The sound patterns are produced by the articulatory system and are perceived by the auditory system. The other code involves spatial patterns of lines, is written, and is perceived in a temporal and spatial manner through the visual system. One level of units for the spoken language is the phoneme, whereas it is the letter for the written language (at least for Western cultures).

There are many well-documented differences between the auditory and visual systems:

differences between the physical nature of auditory and visual stimuli, differences in the nature of the sensory transducers for the stimuli (Geldard, 1972), and differences in the nature of auditory and visual perception. There also are similarities, especially similarities between elements of auditory and visual perception (Julesz & Hirsh, 1972). Thus we must expect to find differences, as well as some similarities between the components of the language codes. However, for the perspective of this paper it is more important that there also exist many parallels between the components of the written and spoken languages as codes for an effective communication system. Independent of stimulus modality, such a communication system is faced with problems associated with pattern recognition. This paper examines some of these parallels in the organization and perception of spoken and written language in the context of such communication systems. We will begin by examining the desirable characteristics of effective communication systems. After summarizing relevant aspects of phoneme perception, we will examine similarities between phoneme perception and the perception of alphanumeric stimuli, as well as the perception of other meaningful stimuli.

B. An Effective Communication System

Let us examine phonemes and alphanumeric stimuli as codes used by a minimum error (therefore effective) human communication system. All communication systems must include a set of transmission processes, a set of reception processes, and a set of physically defined stimuli which represent the code which exists between transmission and reception. The information code must be represented by the overlapping subsets of the potential outputs of the transmitter and all of the stimuli which can be perceived by the receiver.

A minimum error system is most viable when there exists several attributes of the communication code. First, there should be major differences in the manner in which the various components of the language code are produced. In addition, the characteristics of the stimuli which result from these major differences in production also must be perceptually distinct. In this way there will tend to be a high degree of correspondence between the act of producing a given language component and the language component actually perceived. Secondly, although language components may be distinguished from one another by their manner of production, the way in which any specific component is produced must be flexible. By encompassing a broad (rather than a highly restrictive) range of production modes, structural variability of different transmitters may be tolerated. In a human system, where learning and practice are essential for the proper execution of the production sequences by the transmitter (especially by the young and inexperienced), such flexibility is crucial. Thus, we should expect to see some variability within, but basic differences between, language components (e.g., between different phonemes or different letters). It also is highly desirable for differences in the code to be designed around stimulus attributes which are highly discriminable by the receiver. Then members of different code classes will be more discriminable than members of the same code class. The phenomenon called categorical perception defines precisely this relationship (see below). Given these general attributes of a minimum error system, we would expect a high correlation between production and reception of the transmission code.

The conception of an effective communication system is not inconsistent with the notion that a portion of the communication system is composed of (or is under the control of) specialized processes unique to language. Our conception simply is that the communication code involves only a subset of all production and reception processes and the stimuli relevant for each. It implies that the transmission processes could be capable of producing stimuli other than those associated with the communication code and that the reception system could be capable of perceiving stimuli other than those produced by the transmission processes.

Another desirable attribute of the perceptual aspects of an effective communication system is the use of what G. A. Miller calls "chunking" (Miller, 1956). The stimuli which comprise the information code should not be processed and remembered in terms of the individual multitude of stimulus components which, together, are the physical representation of the code. The amount of information which would have to be processed per unit time under such a communication structure would be enormous. This point has been made by many early Gestalt theorists for visual perception (e.g., Wertheimer, 1923) and, more recently, by phonetic theorists (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Rather, the stimulus information should be processed in terms of organized figurally meaningful groupings (e.g., chunked in terms of phonetic or alphanumeric units). This implies that stimuli should be analyzed in terms of molar units, and that the molecular structure of the stimuli should tend to be ignored (unless attention is specifically focused on such aspects).

This description of an effective communication system appears to be consistent with the results of research investigating the production and perception of phonemes. It also is consistent with the production and perception of alphanumeric stimuli, with the phonetic and alphanumeric language systems paralleling each other (and potentially interacting) in terms of the basic attributes defined above for such communication systems.

C. Phoneme Perception

The characteristics of English phonemes important to the definition of the language code are well documented (e.g., Fant, 1968; Stevens, 1971; Denes and Pinson,

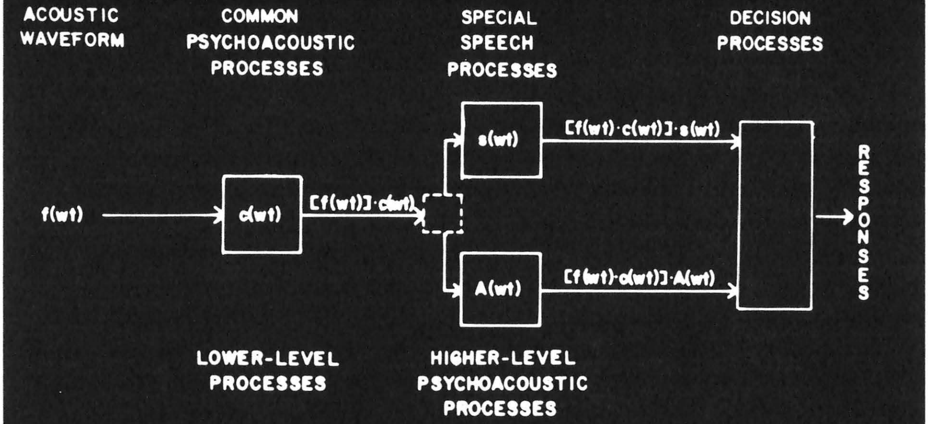
1973) and bear on this discussion only to the extent that they are relevant to the effective communication of information. More important to our comparison of audible and visible languages is the manner in which the perceptual processing of phonetic information occurs.

A simplified version of one general model commonly assumed to describe the relationship between the acoustic and the uniquely phonetic processing of the auditory code is diagrammed in Figure 1. The model, as diagrammed, is essentially the hybrid serial-to-parallel model described by Wood (1975). The initial acoustic waveform is an energy distribution which varies as a function (f) of both frequency (w) and time (t), and thus is described as f(wt). According to the model, f(wt) first undergoes a preliminary psychoacoustic level of processing.

In Figure 1 these preliminary processes have a transfer function described by c(wt), which represents every aspect of auditory stimulus processing common to all acoustic stimuli (whether or not phonetic). The resulting waveform is mathematically described in terms of the convolution of f(wt) and c(wt). This preliminary level of acoustic processing is assumed to involve primarily the simple transduction of the physical waveform of the stimulus into its neural code, and thus often is tacitly assumed to be relatively unimportant in determining the nature of auditory perception. Obviously, this is a simplification of the nature of preliminary acoustic processes which, at a minimum, are known to contain nonlinear components and to smear information in time and frequency. The neural representation which results from the action of these common psychoacoustic processes on the physical waveform is assumed to be fed into a simple decision mechanism (represented in terms of broken lines in Figure 1) which directs the waveform to either (but not both) of the two "higher-level" sets of processes (e.g., Studdert-Kennedy, Liberman, Harris, & Cooper, 1970). If the waveform is recognized as being phonetic in nature, it is fed into a set of special speech processes.

The higher level speech processes are assumed to interpret and classify the stimuli into phonetic categories, ignoring (and somehow permanently losing) information about the acoustic detail of the basic components of such stimuli. If the waveforms are not identified as being phonetic, they are passed through the psychoacoustic processes, then fed to decision processes which determine the appropriate responses for the given situation. There is a large body of literature which seems to generally support this hybrid serial-to-parallel model for acoustic and phonetic processing (e.g., Liberman & Studdert-Kennedy, 1977; Liberman & Pisoni, 1977). For instance, differences in the psychophysical functions describing the perception of phonetic and *selected samples* of nonphonetic, acoustic stimuli provide a major justification for some separation in higher-level acoustic and phonetic processes. An even stronger justification exists in the large body of literature which demonstrates a hemispheric special-

Fig. 1 Simple hybrid serial-parallel midel commonly assumed to describe the processing of phonetic and nonphonetic acoustic signals. Following an elementary analysis, the signals are subjected either to processes specialized for phoneme perception or to general, higher-level psychoacoustic processes (but not both).



Schematic Representation of General Serial-Parallel Model for Acoustic and Phonetic Processing

ization in the cortical locus of control for the speech production and perception (although understanding the significance of these differences is dependent upon the demonstration of actual differences in perception of phonetic and nonphonetic stimuli). These differences would be defined in terms of the differences in the transfer function s(wt), for all uniquely phonetic processes, and a(wt), for all remaining processes *not* involved in phonetic perception.

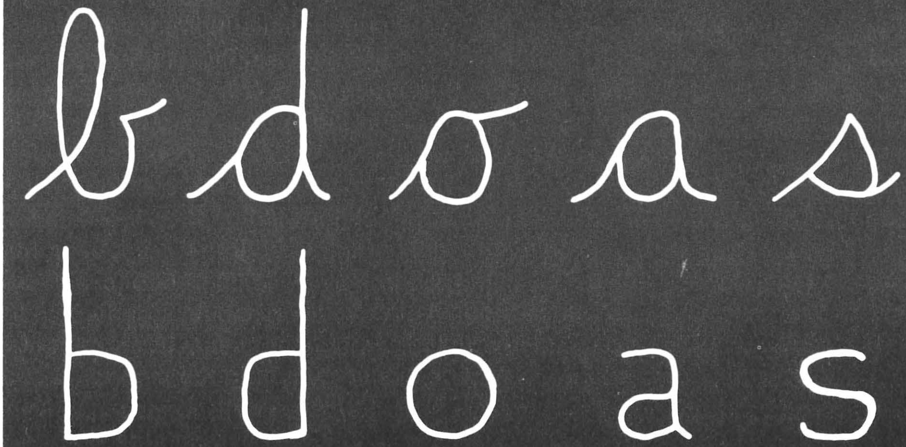
D. Comparisons of spoken and written language

1. *Hybrid Serial-Parallel Model for Written Language*

It can be argued that the general type of hybrid serial-parallel model developed for phoneme perception (see above) is equally applicable for the perception of visually presented letters. Research on stabilized retinal images provides one possible source of justification (e.g., Heckenmueller, 1965). The stabilization of the retinal image removes temporal variation in the proximal stimulus, thus maintaining a specific visual pattern on a given retinal location. Under such conditions, portions of the visual image tend to disappear differentially and selectively over time. For example, Pritchard (1961) found that when the stimulus was a random array of dots or lines, the stimulus components tend to be maintained in unpredictable but confined sections of the retinal field, and tend to lack any meaning or coherence (which was not present to begin with). However, when the stimulus was structured, such as the stimulus "HB " subjects reportedly saw residual stimuli, based on past experience, which were meaningful (e.g., H, B, 3, and 4). Such selective maintenance of stimulus organization must be a consequence of a higher level of organizational analysis probably based upon previous learning. Otherwise we would expect the fading of the visual field to be random. While these findings may imply that visual perception is maintained, or organized, on the basis of the meaningfulness of the stimuli, a more restrictive interpretation (which parallels the phonetic model) remains tenable. Such a hypothesis asserts that after identifying the visual stimuli as being alphanumeric, these stimuli are analyzed and recoded by a set of specialized higher level language processes (e.g., see Figure 1). The original "molecular" attributes (and missing portions) of the stimuli then will be lost (or ignored), with the stimuli being reorganized and completed as meaningful alphanumeric characters. The restructured stimuli then are perceived as complete members of the language code. Whatever the nature of the actual perceptual processes, this research does indicate that the perception of such stimuli (like the perception of phonemes) appear to be at least partially governed by prior knowledge, rather than simply being built up from the physical stimulus properties.

A second and probably stronger justification for an analogous special alphanumeric processor can be found in the principles of perceptual organization found in many modern (and not so modern) alphanumeric displays. With limited sets of unconnected dots or lines, one can display patterns of stimuli which are readily perceived not as individual lines or dots, but as complete letters or numbers. Could such perception of these "incomplete" patterns as "closed" alphanumeric figures be due to the activity of higher level language processes, such as described in Figure 1? In the Gestalt literature we can find further justification for this notion. If one views an apparent random pattern of stimuli, one sees a mosaic of components. However, once a pattern approximating a letter (or number, or face, etc.) is perceived, that pattern will tend to stand out as a "figure," with an identity separate from the background supplied by the remainder of the stimulus array (e.g., see Beardslee & Wertheimer, 1958). That figure now will tolerate a good deal of distortion, yet will maintain its apparent identity and will tend toward being perceived as complete (i.e., closure). Thus, we have the potential justification for hypothesizing the existence of a set of higher level alphanumeric processes analogous to the higher level phonetic processes outlined in Figure 1. Furthermore, the apparently similar perceptual organization of "other meaningful" visual stimuli can be assumed to be processed in a different but related manner which is analogous to the similarities and differences in the perception of phonetic and musical stimuli. Instead of following the logic, often used by phonetic theorists that there exist many different specialized systems, one could assume that we are describing attributes of a general perceptual system.

Fig. 2 Examples of cursive (upper row) and printed letters (lower row) demonstrating that the shapes of the patterns are more similar within types of production (i.e., rows) than within types of letters (columns).



2. Perceptual Invariance

Claims of the uniqueness of the spoken language code has tended to limit generalization of important aspects of the perception of the phonetic code to alphanumeric code and to perception in general. For instance, the physical representation of a single consonant (e.g., /d/) may be a rising change in frequency in the context of one vowel and a falling change in frequency in the context of a different vowel (Liberman, et al., 1967). Thus, we appear to have a perceptual invariance in the context of gross physical differences between stimuli. At a recent symposium on language by ear and eye, it was claimed that, "There is nothing in reading corresponding to the lack of invariance between the speech signal and the underlying phonetic segments . . . " (Kavanagh & Mattingly, 1972, p. 53). However, a close examination of letters used in the English language reveals clear examples of a lack of apparent structural invariance in the definition of certain letters. Furthermore, this lack of invariance in the definition of certain letters is probably related to the production mechanism in an analogous manner that the lack of invariance in phonemes is related to their articulation.

Some examples are summarized in Figure 2. Printed lower case examples of the letters "s" and "a" are similar in structure and are difficult to produce when writing script. In developing an efficiently produced cursive alphabet, the cursive code for the letter "s" becomes more similar to the cursive code for the letter "a" than to the printed code for the letter "s." Likewise, the cursive code for the letter "a" is more similar to the cursive codes for the letters "d" and "s" than it is to the printed code for the letter "a" (see Figure 2). Examining the remainder of the cursive and printed alphabets, one can find a number of other examples in which there is an apparent lack of invariance within the code for specific letters. However, through experience we have learned to recognize and readily perceive different physical codes as being equivalent representations of the same letter. This finding is not surprising, since it is well known that given proximal stimulus patterns often can be produced by an infinite number of different distal stimuli, and a single distal stimulus can produce a large number of proximal stimuli (Hochberg, 1964). One of the basic premises of modern perceptual theory is the existence of transformations of the stimulus input to accomplish perceptual constancy in the context of considerable physical dissimilarity in the proximal stimuli (Gibson, 1966).

These observations lead us to question the uniqueness of an apparent perceptual invariance for phonetic code and to conjecture that the perceptual invariance we have described for physically dissimilar alphanumeric stimuli might involve an equivalent type of perceptual reorganization of physical stimulus information. This possible similarity leads us to look for other possible parallels in the structure of written and spoken codes for language. We believe that there is such a parallel in the phenomenon known as categorical perception.

Categorical Perception

Categorical perception has been claimed to be unique to phoneme perception (e.g., Liberman, Harris, Hoffman, and Griffith, 1957; Liberman, Harris, Kinney, and Lane, 1961) and is believed to occur when stimuli along a continuum are responded to solely on the basis of the absolute labeling or identification grouping of stimuli (Studdert-Kennedy, et al., 1970). Once recognized as being phonetic in nature, such stimuli are believed to be automatically encoded in terms of the specific phonemes (e.g., Figure 1). The encoding process is usually assumed either to involve a reflection back upon the articulatory mechanism (e.g., motor theory of speech perception [Liberman, et al., 1967]) or by the activation of special feature detectors (e.g., Eimas, 1975). This specialized encoding of phonetic stimuli involves a loss of the acoustic characteristics of the stimuli. As a result, phonetic stimuli are discriminable only to the extent to which they are categorized differentially by the phonetic encoding processes.

The following characteristics provide an operational definition of categorical perception: (a) a sharp labeling boundary along a given continuum, (b) approximately chance performance in discriminating stimuli within categories, and (c) a peak in discrimination performance at the category boundary (Studdert-Kennedy, et al., 1970). In practice, this operational definition has been met quite well by phonetic stimuli varying along a limited number of dimensions, although the discrimination peak sometimes is shifted relative to the labeling boundary (e.g., Liberman, et al., 1957), with discrimination performance typically exceeding that predicted from the labeling data (Cutting and Rosner, 1976).

Over the past few years, the notion that categorical perception is the unique property of phoneme perception has lost considerable credibility. Miller, Pastore, Wier, Kelly, and Dooling, (1974) demonstrated this phenomenon with non-phonetic noise-buzz sequences; both Cutting and Rosner (1974) and Pisoni (1977) found it with stimuli varying in relative onset times; and Pastore, Ahroon, Baffuto, Friedman, Puleo, and Fink (1977) found categorical perception when adding a sinusoidal reference to a sequence of clearly detectable tonal stimuli varying only in intensity. Pastore et al. (1977) also found categorical perception with an intermittent visual stimulus. Related effects have been demonstrated for phonetic stimuli with very young infants (Kuhl, 1976), with chinchillas (Kuhl and Miller, 1975), and with monkeys (Morse and Snowden, 1975), and have been demonstrated with adult humans for musical stimuli (e.g., Burns & Ward, 1974; Siegel & Siegel, 1975). These findings are not consistent with the notion of an absolute causality by a set of innate human processes unique to speech perception.

Recently, we have proposed that categorical perception can be associated with the imposition of some reference along a continuum of stimuli (Pastore, et al., 1977). This reference supplies information which is more precise (for the given purpose) than that normally available for use in discriminating stimuli along a given continuum. Thus, in the region of its imposition along the continuum, the reference creates a natural dichotomy for identification or labeling. We have argued that any efficient communication code would tend to develop naturally around such perceptual references. Specifically, it behooves any efficient communication system to have much clearer distinction between identified codes than within identified codes. We therefore ran a set of experiments in an attempt to demonstrate categorical perception with specific alphabetic stimuli.

If one measures the discriminability of a small constant increment in the length of a line as a function of the initial line length, one would expect to find that discrimination performance obeys Weber's Law ($I/I=k$). That is, an increment which is just detectable for a short initial line length will not be detectable when the initial line length is longer. If one now adds a constant reference to the longer line lengths, an increment which was not detectable for a given line length in isolation could now become detectable when viewed in close proximity to that fixed reference. Furthermore, the addition of the fixed reference can serve as a natural boundary between two categories (e.g., longer than, or shorter than, the reference). Examples of this situation are diagrammed in Figure 3, which are representations of the stimuli used in our experiments. When the line is vertical and the reference is in the form of a backwards letter "C," the category "shorter-than-reference" is perceived in terms of the common letter category "D," while the "longer-than-reference category" tends to be perceived as the letter category "P." Likewise, when the line is oblique and the reference is a short, straight line at an intersecting angle, we have the two letter categories "V" and "Y."

Method

Subjects. The four observers in this experiment were all psychophysically trained and had a minimum of one year of experience as observers in signal detection tasks in the psychoacoustics laboratory. The author served as one of the observers. The two subjects who wore corrective lenses for distance vision, wore such lenses during the experiment.

Procedure. We used standard ABX discrimination and single-stimulus labeling tasks in these experiments. The stimuli were projected with three (one for the labeling task) random-access carousel projectors on a large, flat, painted white wall, and were viewed from a distance of approximately twelve feet. In the ABX task, the three stimuli were presented simultaneously for one second with the A (left) and B (right) stimulus positions at the same vertical distance (approximately three feet) from the floor, while the X stimulus was presented in the horizontal center of these two and was displaced slightly upward (approximately four inches) from the A and B stimuli. The three stimuli (A, X, and B) covered a total horizontal distance of approximately nine feet (approximately 41° of visual angle). (The dimensions of the components of each stimulus may be obtained from Figure 3, which is drawn to scale, with the reference (4 inches) being based upon the projected image of the stimuli and corresponding to a visual angle of approximately 1.6°.) The size and spacing of the stimuli were chosen to prevent the observers from making *simple,* direct comparisons across stimuli and to force the observers to scan across stimuli. In most studies on categorical perception, the A, B, and X stimuli are presented sequentially, thus requiring that the observers either use memorial images of the stimuli, or make within stimulus judgments and compare these judgments. Thus, while acknowledging that alphanumeric stimuli are spatially displaced while phonetic stimuli are temporarily displaced, our procedure is analogous to that typically employed in categorical perception studies. In the ABX task, each pair of stimuli was presented eight times in an order which counterbalanced for the assignment of the stimuli to the A and B positions (for line length: A>B or A<B), and the identity of the X stimulus (X=A or X=B). In both the labeling and the ABX discrimination tasks the order of presentation of the stimuli (or pairs of stimuli) was randomized.

All stimuli were generated from carefully prepared ink line-drawings. In all cases two original sets of stimuli were generated. One

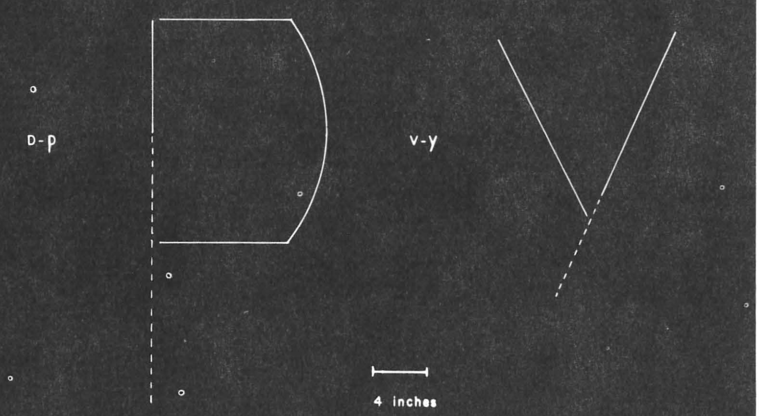


Fig. 3 Diagram, drawn to scale, of the stimuli employed in the D-P and V-Y experiments. The broken lines represent those portions of the stimuli which were varied.

set was photographed as the X stimuli, while the other set was photographed twice and used as the A and B sets of stimuli. Since any small errors or imperfection in the stimuli, would not be common to both the X and the comparison stimuli, this procedure minimized the possibility that the observers could use such imperfections in performing the discrimination. The stimuli are drawn to scale in Figure 3. Both sets of stimuli were varied in terms of the length of the major line component (broken line in Figure 3).

With the D-P set stimuli, the vertical line was varied, while with the V-Y stimuli, the positive diagonal was varied. Finally, the same tasks were run with stimuli compared only to the vertical line which varied in length between 18-3/4 and 23-1/4 inches (range of visual angles of approximately 7.5° to 9.3°). This provided a baseline condition against which the effects of imposing a fixed reference could be evaluated. The projected stimuli were adjusted so that in a progression of increasing line lengths, adjacent stimuli (and thus compared stimuli) would differ by 1/2 inch (or approximately 72′ of visual angle).

Results and Discussion

Figure 4 plots the results of the D-P discrimination task, with the data pooled across the four subjects.[1] For this D-P comparison, we ran the discrimination task for the three sets of stimuli which differed only in terms of the length of the vertical line (8-13 inches, 14-19 inches, 24-28 inches). All four observers independently reported that all of the stimuli with the shortest set of line lengths (8 to 13 inches) always were perceived as "D," while all the stimuli with the longest set of line lengths (24 to 28 inches) always were perceived as "P." Thus, the complete labeling tasks for the two extreme sets of stimuli were not run. In general, discrimination between adjacent stimuli drawn from within a single labeling category is clearly at or near chance (50% correct). The means (and standard deviations) were 65% correct (sd=9) and 53% correct (sd=10) for short and long sets of line lengths, respectively. The stimuli with vertical line length in the range of fourteen to nineteen inches straddle the boundary between the "D" and "P" categories. Here we find a sharp labeling boundary with an associated peak (92% correct) in discrimination performance. Therefore, these data meet the criteria for categorical perception: a sharp boundary between labeling categories, a peak in the discrimination function approximately at the labeling boundary, and close to chance discrimination performance within categories.

The ability of the same subjects to discriminate differences in the length of vertical lines presented alone (with approximately the same range of line lengths as used in the V-Y experiment described next) are diagrammed in the left frame of Figure 5. We could see little value in running these subjects with the longer and shorter sets of line lengths, since our subjects all indicated that for all comparisons they could do little more than guess as to the correct answer. As can be seen, discrimination performance is relatively uniform across the continuum and is close to chance (mean of 64% [sd=8.8]). The boundary between the categories "short" and "long" is not sharp, and there definitely is not a major peak in the discrimination function at or near that boundary. Therefore, it is evident that the imposition of the "backward-c" served as a reference or standard which created a sharp category boundary (between D and P) and a peak in the discrimination function at the category boundary. After the completion of the experiment, all of the observers reported having recognized and used these cues. It can be argued that such a reference makes the information code more efficient by heightening the discriminability of stimuli between categories, thus reducing the uncertainty concerning the specific symbol code in any visual presentation of a component of the language code.

The labeling data for the categories "long" and "short" are also shown in the left panel of the figure. Following Weber's Law [I/I=k], we would expect that the discrimination of the same half-inch increments in line length might be easier for shorter lines and more difficult for longer lines. This did not occur for the single lines, but there was a slight tendency toward this relationship in the overall D-P and V-Y data, although not to the degree reported by Samuel (1977) for phonetic stimuli.

The data from the V-Y continuum are shown in the right panel of Figure 5. As with the data from the D-P continuum, we find a very sharp boundary between the "V" and the "Y" categories, and a peak (100% correct) in the dis-

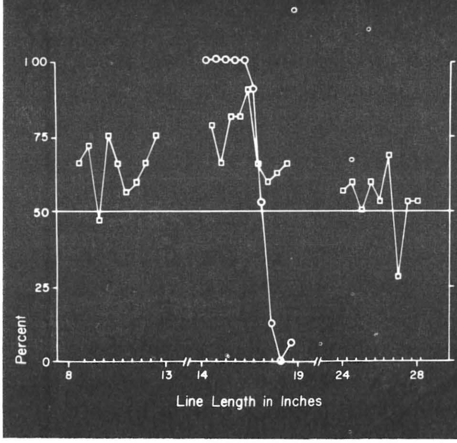


Fig. 4 Results of the labeling (circles) and discrimination (squares) tasks for the D-P experiment.

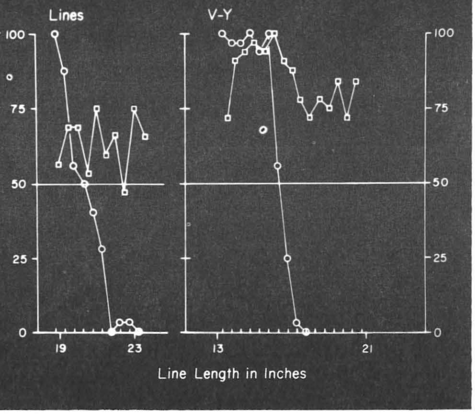


Fig. 5 The results for the labeling tasks (circles) and discrimination tasks (squares) for the line length (left panel) and V-Y experiments (right panel). The labels short and long (for Lines) and V or Y (for V-Y) were employed in the labeling tasks.

crimination function at this boundary. However, the discrimination peak is broader than that for the D-P stimuli and discrimination performance within categories is not reduced to chance, but only reduced from a peak of 100% at the category boundary, to approximately 75% within categories. This absence of the demonstration of chance performance within categories could argue against these results as unequivocally demonstrating categorical perception (Abramson, 1977). Our observers all reported being able to compare the distance between the lower end of each of the two diagonal lines and the theoretical intersection of these diagonal lines. Since the two diagonals were symmetrical around the vertical axis, it would appear that the stationary minor diagonal could serve as the visual reference both at the point of theoretical intersection with the major diagonal (as expected) and for a small range of shorter major diagonal line lengths. This extended reference did not alter the judgment of the categorical boundary between V and Y. It is also possible to argue on logical grounds that, while exhibiting a broad peak, these data represent as much a demonstration of categorical perception as the data from the D-P experiment above and data from most experiments proportedly demonstrating categorical perception. Based upon the data from the D-P experiment, it would seem reasonable to expect that chance performance within categories would have been found had we extended the range of line lengths to be more compatible with the range employed in the D-P experiment (i.e., 8 to 28 inches instead of 13 to 21 inches). Moreover, we again have a clear instance in which a portion of a letter, in this case the fixed diagonal line, served as a standard creating a sharp boundary and a heightened degree of discriminability at that category boundary. Thus, we have the action of the same type of cue for perceptual organization which logically should (and in this case probably is) an important factor in defining these components of the visual language code.

The results of the D-P and V-Y experiments demonstrate that the important phonetic phenomenon of categorical perception also exists for the components of the visible language code. We suspect that we also would find categorical perception for the line length continua between other pairs of visual stimuli, such as Y-X, D-b, and h-n. These findings should not be surprising, since both phonemes and letters are codes for effective communication systems. Such systems should have evolved around perceptual characteristics which would tend to enhance the distinction between different component codes. If we are correct in this conception of categorical perception, and in our conception of the perceptual basis for the equivalence of physically different forms of the language codes (described earlier), then we see little need for hypothesizing a hybrid serial-parallel model (Figure 1) for visible language. Rather, we conceive of many of the salient apsects of the perception of the audible and visible codes for language as expected manifestations of effective communication systems.

[1] The data for the individual subjects were highly similar. These data may be obtained by writing the author.

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