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VISUAL INFORMATION AND REDUNDANCY IN READING [1]

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Previous studies have demonstrated that a letter is better identified when embedded in a valid spelling pattern than when presented alone. The present results replicated earlier findings in a paradigm that controls for redundancy by presenting the response alternatives after the stimulus presentation. However, this study failed to find an effect of visual similarity. This result suggests that presenting the alternatives right after the stimulus presentation does not control for redundancy since alternatives are eliminated during perception of the stimulus, not after the visual information has been completely analyzed. Identification was, therefore, examined in a task in which *S*s were given the letter and word alternatives prior to the experimental session. This task eliminated the spelling pattern advantage and also provided evidence for visual similarity effects in letter and word identification. The findings are consonant with a visual identification process that analyzes visual features of letters in both letter and word recognition.

Although the study of reading has had a long history (Cattell, 1886; Huey, 1908; Woodworth, 1938), there is no generally acceptable account of the processes involved in letter and word recognition. One possible reason for this may be the confounding of visual and higher order information in many visual recognition experiments. With efforts aimed at studying the visual information available in a visual display, investigators have not adequately controlled for higher order psychological processes. Consequently, inferences drawn from these studies are based on results confounded by an interaction of at least two processes.

Identifying the processes that are involved in discriminating and classifying a visual configuration requires a distinction between two sources of information available to the reader. The first consists of perceptual information that is directly available from the visual configuration of letters and words. The second source is the reader's knowledge of the valid letter sequences that can occur in words. This source of higher order information (sometimes called redundancy) reduces the possible number of valid alternatives for each letter of a word. Knowing the constraints which characterize letter sequences supplements the visual information, thus greatly facilitating the reading process (Bruner & O'Dowd, 1958; Miller, Bruner, & Postman, 1954).

The present research studies how visual information and redundancy contribute to letter and word identification. The first goal was to determine the size of the visual or perceptual unit employed in word identification. A perceptual unit is defined as a visual configuration that is uniquely represented by a property list in long-term memory, where the property list describes the set of visual features in the perceptual unit. The two main theories of the perceptual unit are the single-letter and letter-cluster theories, respectively.

The single-letter theory assumes that word recognition proceeds in terms of an analysis of the visual features of each letter in the word. The identity of the word follows analysis of the visual features in each of the individual letters. The letter-cluster theory is based on the assumption that spelling patterns or words are read without first analyzing the features of their individual letters. As a primary proponent of a letter-cluster viewpoint, Eleanor Gibson (Gibson, Pick, Osser, & Hammond, 1962) hypothesized that the functional unit in word recognition is a

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group of letters forming a spelling pattern. A spelling pattern is a letter cluster that has a specific and relatively invariant spelling-to-sound correlation. Gibson asserts that spelling patterns will be perceived more easily than random letter strings, because in terms of the framework given here, spelling patterns can function as perceptual units, whereas random letter strings cannot. In this case, identification of a spelling pattern would simply involve identification of one perceptual unit, whereas identification of random letter strings involves the identification of two or more units. It should be stressed that according to the letter-cluster theory, the spelling pattern is assumed to have a perceptual advantage in addition to the advantage afforded by the operation of redundancy.

Accordingly, a critical test between these theories requires that the contribution of redundancy in the spelling pattern be eliminated. Reicher (1969) has recently provided such a test by comparing letter and word recognition while attempting to hold the effects of redundancy constant. In his study, *S*s were presented with either one or two letters, one or two four-letter words, or one or two four-letter nonwords. Immediately after the stimulus flash, a visual noise mask was presented that covered the former stimulus position. The masking card also presented two letter alternatives, one of which appeared in the original stimulus and one which was incorrect. To eliminate the operations of redundancy on word trials, both letter alternatives formed a common word with the other letters of the word. The results indicated that *S*s were more likely to choose the correct alternative when the stimulus was a word than when the stimulus was a letter or a nonword.

If redundancy or some other process cannot account for the fact that a letter is better identified in a spelling pattern, the perceptual unit must be larger than an individual letter. According to our definition of a perceptual unit, this means that the visual features of the unit cut across a number of letters. For example, whole-word shape or letter-cluster shape could be a visual feature. These features would differ significantly from the visual features which characterize individual letters. Accordingly, the letter and letter-cluster theories differ with respect to what features are extracted from the visual configuration.

It is therefore necessary to determine whether the same visual features are used in letter and word recognition. The literature contains sufficient data (Clement & Carpenter, 1970; Gibson & Yonas, 1966a, 1966b; Kaplan, Yonas, & Shurcliff, 1966; Neisser, 1964, 1967) which define the visual features employed in single-letter identification. This progress has resulted from Eleanor Gibson's (Gibson, Osser, Schiff, & Smith, 1963) identification of the distinctive features used in recognition of individual letters. Gibson et al. designed a list of distinctive features that describe each grapheme of the set of Roman capital letters. This feature list was then used to predict confusions between the letters and to devise an error matrix of confusions. A series of studies demonstrated that confusion errors correlated with the percentage of features that pairs of letters had in common. Other studies of letter identification (e.g., Clement & Carpenter, 1970) have shown that the letter can function as the perceptual unit, and distinct visual features of the letter are critical for letter recognition.

If the letter is always the perceptual unit of analysis, feature testing in word recognition should operate in the same way as in letter recognition. However, evidence to date contradicts this assumption. The findings of a word advantage effect strongly suggest that feature extraction operates on the spelling pattern of the entire word rather than on the individual letter. In the present study, the visual similarity of letters was varied to test the nature of the perceptual unit in word recognition. Using the probe technique (Reicher, 1969) two levels of visually similar alternatives (similar and distinct) were presented as alternatives following both single letter and word presentations. Presentations consisted of (*a*) single letters followed by two response alternatives of low visual confusability, (*b*) single letters followed by two alternatives of high visual confusability, (*c*) four-letter monosyllabic words followed by two letter alternatives of low visual confusability, and (*d*) four-letter monosyllabic words followed by two visually similar letter alternatives. For single-letter presentations, performance should be less accurate when visually similar letter alternatives are presented than when distinctive letters are presented. Similarity should also operate differently in words than in single letters if a spelling pattern or a word is the perceptual unit. On the other hand, if the letter is the perceptual unit in word recognition, similarity should have equal effects in both letter and word presentations.

TABLE 1

STIMULUS ITEMS USED IN EXPERIMENT I

Letter position tested	Stimulus material: Base word	Alternatives: Similar	Alternatives: Distinct
1	REAL	P	M
	BEND	R	L
	PLOW	B	G
	NAIL	M	P
	CASH	G	R
	EAST	F	C
2	SNUG	M	L
	WAIT	H	R
	AGES	C	P
	SHIN	A	P
	SHIP	K	N
	SKIM	H	W
3	PACE	G	N
	LANE	M	C
	ROBE	P	S
	CURE	B	T
	MOPE	R	L
	TOLL	I	O
4	SLAP	B	M
	STAB	R	Y
	HALE	F	L
	HEAR	P	L
	RICH	K	E
	GRIM	N	P

EXPERIMENT I

Method

Subjects. Nine undergraduate students were each paid $1.50 an hour to participate for five 1-hr. sessions. All *S*s had normal or corrected vision.

Material and apparatus. The word stimuli were 72 monosyllabic four-letter words. The 24 base words are presented in Table 1. The other 48 words are derived by replacing the letter of the base word with the letters corresponding to the similar and distinct response alternatives. The two critical letters that formed the response alternatives in the forced-choice mask were either visually similar alternatives (determined by letter overlap, Connor, 1971) or visually distinct alternatives. Either letter could be substituted to form a new word. For example, given the word LANE, similar alternatives for the third letter consisted of M and N in the mask and visually distinct alternatives consisted of C and N in the mask. The critical letters appeared equally often in the top and bottom positions. This requirement was met for each of the four letter positions. The single-letter stimuli consisted of the same letters and were presented in the same position as in word presentations. The test alternatives were presented in the same way as on word trials, including both similar and distinct pairs.

All stimuli consisted of uppercase letters typed on white index cards. The letters, typed with a Sight-Saver typewriter, subtended a visual angle of 14 min. in height and averaged about 8 min. per letter in width. A three-channel tachistoscope (Scientific Prototype, Model GA) was used to present the stimulus material. The luminance, measured by a Macbeth Illuminometer, was 16.2 ftl. for all three stimulus fields.

Procedure. On each experimental trial a fixation point was first displayed on a blank field. A ready signal from *E* preceded each trial informing *S* to initiate the trial by pressing a hand switch to immediately expose the stimulus. This was followed by the visual noise mask of blocks of typewritten overlapping Ss and Os occupying the position which the stimulus had just occupied. The two response alternatives were displayed directly above the mask and above the position of the probed-for letter. Underscores were used to indicate the position of the critical letter in the stimulus. The *S*'s task was to report aloud which of the two test alternatives occurred in the stimulus presentations.

The *S*s were extensively tested, using a repeated measures design, over 5 days of the experiment. Each *S* contributed 48 observations to each combination of the major variables of the experiment: type of stimulus material (letters and words), similarity of the stimulus alternatives (similar or distinct), and four different positions of the critical letter.

On Day 1 of the experiment, *E* determined the stimulus duration at which each *S* performed at 75% accuracy. The method for determining the duration was a modified method-of-limits procedure. The test items (single letters and four-letter words) consisted of 100 items constructed similarly to those used in the experiment except that all 26 letters were used. Also, stimulus similarity was not manipulated in this set of items. The stimulus durations necessary for 75% correct were within the range of 30–75 msec. The visual noise mask containing the stimulus alternatives followed the stimulus immediately and lasted 150 msec.

The stimulus material was sorted into four blocks of 48 stimulus items with each block containing an equal number of letter and word trials. Within each block, the order of presentation of type of stimulus material, visual and distinct alternatives, and the position of the critical letter was completely random. A short rest period followed each block of trials. This procedure was maintained on the succeeding days of the experiment.

Results

Replicating previous findings (Reicher, 1969), accuracy for words (73%) was superior to that for single letters (64%), F (1, 8) = 18.23, $p < .05$. In contrast to our expectations, however, identification given the distinctive test alternatives did not exceed performance with similar test alternatives. This result was consistent across both letter and word presentations and all serial positions.

Discussion

The failure to find a main effect of similarity was unexpected. In contrast with previous positive effects of similarity, the present results indicate that *S*s do not seem to be able to employ partial information, i.e., visual features in the Reicher (1969) task. For example, consider the presentation of the letter D, in which the *S* sees only the curved feature. When presented with D and K as distinct alternatives he should be able to choose the correct alternative. On the other hand, this partial information would not be sufficient to discriminate the similar alternatives D and O. If *S*s were using partial information in their response selection, one would expect an advantage in discriminating distinctive alternatives. Failure to find a similarity effect suggests that *S* perceives or synthesizes the test letter or word before the alternatives are presented. In this case, if *S* did not synthesize the test item correctly, he would have to guess randomly between the two response alternatives.

If *S*s arrive at a decision about the test stimulus before the alternatives are considered, it is possible that redundancy is still available and operating to facilitate performance when letters are presented in words. During word presentations, redundancy would serve to reduce the number of alternatives, and therefore, *S* would need less visual information for correct letter identification. To illustrate the effect of redundancy, assume that *S* has read out WOR_ in Positions 1, 2, and 3 and a curved feature of the last letter ( )). From the visual information in the curved feature, the alternatives for the last position can only be D, O, or Q. However, if *S* knows the letters must spell a word, D is the only valid alternative. Accordingly, *S* synthesizes the letter configuration as WORD and is correct when presented the alternatives D and K. In the letter-alone case, given the same visual information of a curved feature, *S* also has three alternatives: D, O, or Q. However, without additional information from redundancy, *S* is equally likely to synthesize the letter as D, O, or Q. In the letter-alone case, then, *S* will perceive correctly only 33% of the time. Hence, redundancy serves to reduce the possible number of valid alternatives for word trials relative to letter trials, making an error more likely to occur on letter trials. This analysis indicates that it cannot be assumed that Reicher's (1969) paradigm eliminates the operation of redundancy in word recognition.

Synthesis of the visual stimulus before the test alternatives are considered also explains failure to find a similarity effect. In the example above, if *S* correctly synthesizes a D beforehand he will choose the correct alternative from D and K or D and O. However, if he synthesizes an alternative not presented in the response alternatives, he will have to choose randomly from the two response alternatives. These results, therefore, do not directly test what visual features are employed in letter and word recognition.

EXPERIMENT II

Experiment II was designed as another attempt to investigate the perceptual units and visual features employed in letter and word identification. While Reicher's (1969) intent was to control for redundancy, it appears that presenting the alternatives after each presentation does not eliminate the operation of redundancy. The design of the present experiment offers a better control for redundancy while at the same time manipulating similarity. The *S* was given a fixed number of response alternatives (four) before the experimental session. Since *S* knows the valid alternatives before the test presentation, and therefore before perceptual synthesis, word presentations should not have any advantage due to redundancy. The study, therefore, provides a critical test of whether the word advantage effect is maintained without the contribution of redundancy.

Method

Subjects. Seven undergraduates served as *S*s to complete a requirement for the introductory psychology course at the University of Wisconsin. All *S*s had normal or corrected vision.

Materials and apparatus. Four stimulus alternatives (P, R, C, and G) were chosen from the Gibson (1969) matrix of distinctive features for graphemes. Two pairs of letters have a minimal feature difference that makes them visually similar and highly confusable, i.e., P and R. When paired with the other alternatives these letters have a minimal number of features in common. For example, P and R share four features in common, with only one feature differentiating the two. However, when P and R are paired with C or G they share no features in common and can be defined as distinctive. The letters also complete a common three-letter word when embedded in the center position. Therefore, letter trials consisted of presentation of one of the letters P, R, C, or G; the three-letter word trials consisted of presentation of either APE, ARE, ACE, or AGE. All stimuli consisted of uppercase letters typed on white index cards. The stimuli were typed so that the critical letter always appeared at *S*'s fixation point. All other methodological variables were the same as in Experiment I.

Procedure. On each experimental trial a fixation point was first displayed on a blank field. A ready signal from *E* preceded each trial informing *S* to initiate the trial by pressing a hand switch located to the left, which immediately exposed the stimulus display. Immediately after the stimulus presentation, a visual noise mask was presented for 150 msec. and covered the position of the word or letter. The *S* was to report aloud the letter which appeared during the stimulus presentation; for word trials, this meant responding with the letter in the center position.

On Day 1 of the experiment, *E* determined the duration at which each *S* performed at 75% accuracy in identifying the single letters P, R, C, and G by using the method-of-limits procedure. The range of durations over all *S*s was 20–60 msec. On Day 2, *S*s were informed of the letter and word alternatives and told that for word stimuli the center letter would be either P, R, C, or G. The stimulus material was sorted into four blocks of 56 observations with each block containing an equal number of observations at each stimulus condition. Within each block of trials the order of presentations was random. A short rest period followed each block of trials. The first 32 presentations on each day were treated as practice and were used to adjust the test stimulus duration to maintain *S*s at approximately 75% accuracy. This procedure was maintained on the last day of the experiment. Each *S* contributed 48 observations to each combination of the variables of the experiment: type of stimulus material (letters and words), similarity of stimulus alternatives (similar of distinctive), and the four different test alternatives.

Results

The results were first analyzed using percentage correct responses: the proportion of times *S*s responded with a letter given that particular letter was presented. From this data, percentage accuracy was determined from the total number of correct responses/total number of presentations. These results indicated that *S*s were more accurate during letter presentations (78%) than during word presentations (67%), $F\ (1,\ 6) = 9.62$, $p < .025$. This 11% difference, reflecting greater accuracy for letters alone than letters embedded in a word, eliminates the word superiority effect found in Experiment I.

The effect of visual similarity is best understood by an analysis of errors. If *S*s choose their responses randomly on error trials, they should respond with a similar alternative only 33% of the time. However, on 63% of the error trials, *S*s responded with a similar alternative, indicating they were more likely to respond with a similar alternative than with a distinctive alternative, $F\ (1,\ 6) = 17.92$, $p < .01$. Furthermore, this similarity effect was exactly the same on letter and word trials. Accordingly, the procedure of presenting the alternatives prior to the experimental session facilitated an effect of visual similarity while at the same time eliminating the word advantage effect.

Discussion

Experiment II demonstrated that if *S*s are given the set of stimulus alternatives before the experiment rather than after each trial, letters presented alone are better recognized than letters presented in words. A large effect of visual confusability was also shown for both letters in words and letters presented alone. Both of these results are opposite those found in Experiment I, which presented the stimulus alternatives after each trial. The results indicate that it cannot be assumed that presenting the stimulus alternatives after the stimulus trial eliminated the operation of redundancy in word recognition. Redundancy, therefore, accounts for previous findings that letters are recognized better in words than presented alone or in nonwords (Aderman & Smith, 1971; Gibson et al., 1962; Krueger, 1970; Reicher, 1969; Wheeler, 1970).

One unexpected result of Experiment II was the finding that single-letter recognition was actually better than word recognition. Although the extent of this effect is not clear at this point, *S*s reported that the third letter often interfered with identifying the middle letter. This finding suggests that lateral masking (Townsend, Taylor, & Brown, 1971) may have been operating during word presentations.

More importantly, the effect of similarity can be investigated when higher order information is eliminated. This manipulation served to emphasize visual feature analysis in identification. Under conditions of brief tachistoscopic exposures, *S*s are limited to the number of visual feature tests that can be made. Because this restriction requires an identification before all the alternatives have been eliminated, *S*s should be more likely to respond with a similar alternative than with a distinctive alternative. The present results indicated that visual similarity effects were equal in letter and word recognition, implying that the same visual features are used in letter and word identification. This indicates that the letter is the largest unit of analysis in visual recognition over which feature extraction occurs.

In summary, the experimental question of the present article was to determine the size of the perceptual unit employed in word identification. In answering this question, it was necessary to specify two sources of information which are available to the reader: visual information and nonvisual higher order information or redundancy. Words were better recognized than single letters when both these sources of information were available (Experiment I). However, the word advantage effect was eliminated when redundancy was adequately controlled (Experiment II). These findings and the fact that visual similarity effects operate similarly in letter and word recognition argue against a perceptual unit larger than a single letter.

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