DOCUMENT RESUME

ED 133 728 CS 003 172

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TITLE Syllables as Visual Units in Letter-String Perception.
INSTITUTION Pittsburgh Univ., Pa. Learning Research and Development Center.
SPONS AGENCY National Inst. of Education (DHEW), Washington, D.C.
REPORT NO LRDC-1976/11
PUB DATE 76
NOTE 21p.

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS *Character Recognition; College Students; *Decoding (Reading); *Reading Processes; *Reading Research; Reading Skills; *Syllables; *Visual Perception

ABSTRACT
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The research reported herein was supported by the Learning Research and Development Center, supported in part as a research and development center by funds from the National Institute of Education (NIE, United States Department of Health, Education, and Welfare. The opinions expressed do not necessarily reflect the position or policy of NIE, and no official endorsement should be inferred. The authors thank M. T. H. Chi, J. Juola, C. Perfetti, R. Rosinski, and G. Taylor for examining earlier drafts and convincing them of some of their errors.

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Abstract

In order to understand the process of reading, it is important to determine how strings of letters are perceived. This study tests the hypothesis that units of visual perception may include pairs of letters and, perhaps even high-frequency, monosyllabic trigrams (three-letter sequences). Participants were asked to report the name(s) of either single letters or trigrams, which were presented tachistoscopically. The trigrams were of varying text frequency and had either one or two syllables. Although letters were perceived more rapidly and more accurately than trigrams when the interval between stimulus and mask onsets (stimulus onset asynchrony, or SOA) was longer (65 or 125 msec), single letters were no more accurate nor faster than high-frequency monosyllables at the briefest SOA (50 msec). These data are taken as evidence that frequent syllables can, under some circumstances, be perceived as holistic units.

SYLLABLES AS VISUAL UNITS IN LETTER-STRING PERCEPTION

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The question of how strings of letters are perceived is important for understanding the reading process. A variety of recent studies (see review in Massaro, 1975) have established that information about orthographic structure exerts great influence on the perception of word-like letter strings. There are two ways in which letter strings could be perceived. First, it is possible that single letters are detected as visual units after which a verbal processor translates the visual units into phonological units, such as syllables or vocalic center groups (Hansen & Rodgers, 1968; Spoehr & Smith, 1973, 1975). Alternatively, there may be visual perception units involving more than one letter (Juola, Taylor, & Choe, in press; Landauer, Didner, & Fowlkes, Note 1). This report presents data supporting the hypothesis that units of visual perception may include pairs of letters and perhaps even high-frequency, monosyllabic trigrams.

Several experiments have addressed the hypothesis and have resulted in claims that visual units of more than one letter are operating. For example, Taylor, Miller, and Juola (Note 2) have shown that response time for same-different judgments of words is longer when the words are printed in alternating upper and lower case type (e.g., "WIsdOm"). In particular, the more case alternations, the slower the response. Juola and his associates (Juola, Taylor, & Choe, in press) have argued that multiletter strings must be the units of perception; multiletter units are broken up by the case alternation, and had single letters been the relevant unit, there would have been no change in response time with these alternations. This argument is not conclusive since it is also possible that case alternations only affect the clustering of detected letters for purposes of verbal parsing at the syllable level.

In a similar study, Landauer et al. (Note 1) superimposed image-degrading visual masks on some of the letters in four-letter words. They found that degrading two nonadjacent letters was more destructive to letter identification than degrading two adjacent letters. From this fact, they concluded that adjacent letters are recognized in parallel, whereas letters further apart are processed in serial order. This suggests either that there are multiletter visual units of perception or that part of a word (perhaps two adjacent letters) is visually processed in parallel at the letter level (perhaps under the control of a verbal perception unit) before the rest of the word is processed. Again, it is not strong evidence for the existence of multiletter visual units.

It is also important to note that demonstrations of differences in perceptual efficiency for orthographically regular letter strings (those obeying English spelling constraints) and irregular letter strings do not prove that there are multiletter visual units. Such experiments (e.g., Baron & Thurston, 1973; Estes, 1975a; Gibson, Pick, Osser, & Hammond, 1962; Herrmann & Laughlin, 1973) show either that letter detection units are biased by visual information surrounding the letters on which they operate, or that verbal multiletter units exist, or (and only perhaps) that there are multiletter visual units.

One type of stronger evidence for the existence of multiletter visual units would be an interaction between the effects of a variable assumed to influence visual letter analysis and the effects of a variable assumed to influence the verbal system. The method of Sternberg (1969) asserts that two variables (e.g., word frequency and image degradation) affect independent stages of processing only if they exert additive effects on processing time. If they interact, then they must be influencing two overlapping processing stages, or possibly one common complex stage. This general paradigm has been employed at least twice with respect to the present question. Landauer et al. (Note 1) failed to find an interaction of word frequency with letter display degradation in a word report task, and Stanners, Jastrzembski, and Westbrook (1975) failed to find an interaction of word frequency and stimulus degradation in a lexicality judgment (Is it a word?) task.

Both experiments stand as counterevidence for the hypothesis that words are always perceived as holistic units, but neither rules out the possibility of subword, multiletter visual units. What we attempted to demonstrate in the present study, using the same Sternberg paradigm as the Landauer and Stanners groups, is that more than a single letter can serve as a unit of visual recognition. The task was to report the name(s) of either one or three letters which were presented with a tachistoscope.

We manipulated one variable that is tied to visual processing and three variables that are tied to verbal processing. The visual variable was the stimulus onset asynchrony (SOA) between the letter display and a very effective masking stimulus. There were three verbal manipulations: (a) either single letters or trigrams were presented, (b) trigrams were of high or low frequency, and (c) trigrams had either one or two vocalic centers (Hansen & Rodgers, 1968).

If the sole visual input to the verbal processing system is the output of a letter-by-letter recognition process, then the effects of the visual variable and the various verbal manipulations should have been additive. The present experiment was a test of this additivity.

Method

Participants

Eighteen college students participated in this study as part of the laboratory requirement for an introductory psychology course. Since this study was initially concerned with individual differences in reading, participants were selected for high or low verbal ability based on the Davis Reading Test. There were no differences between good and poor readers on any of the results reported below. One subject was dropped because he had no correct reaction times for some of the cells of the design.

Materials and Apparatus

All stimuli consisted of one, two, or three characters drawn with a Flair pen on 13 cm x 18 cm index cards (thus they were of low contrast relative to stimuli made with darker press-on letters). The stimuli were presented via a three-channel tachistoscope. All subtended a vertical visual angle of .90 degrees. Horizontally, single letters subtended .57 degrees, two-digit numbers subtended 1.42 degrees, and trigrams subtended 2.25 degrees. To permit complete feature masking, we used letters in the style of Rumelhart and Siple (1974), and digits were composed using the same line segments used for the letters. Luminance of the stimulus, blank, and mask displays was 68 cd/m^2. A small fixation dot was located in the center of the blank field. The mask consisted of all 16 Rumelhart and Siple letter fragments in each of the three letter positions for the trigram stimuli.

Four groups of 14 trigrams each were selected which had either high or low trigram frequency in running text (Underwood & Schulz, 1960), and one or two vocalic centers (Hansen & Rodgers, 1968; Spoehr

& Smith, 1973).[1] High-frequency trigrams had frequencies greater than 250, with a mean of 465 for the one-syllable stimuli and 464 for the two-syllable stimuli. Low-frequency trigrams had frequencies less than 250 with a mean of 54 for both the one- and two-syllable samples. The actual trigrams presented and their frequencies are listed in Table 1. For each of the four sets of trigrams, one-third of the trigram letters were randomly chosen for the single-letter condition.

Design and Procedure

There were three tasks for the participants. First, they had 27 report trials on two-digit numbers, using the general procedures of Spoehr and Smith (1973). This task is irrelevant to the present study except that it provided 32 warm-up trials with the apparatus. The other two tasks were single-letter reports and trigram reports.

In all tasks, the following conditions held: (a) stimulus duration was 25 msec; (b) mask duration was 200 msec; (c) the stimulus onset asynchrony (SOA) between target and mask displays was systematically varied; and (d) a blank field was presented before, between, and after the stimulus and mask displays. An electronic timer was started at the onset of the stimulus display and stopped when a voice key detected the beginning of the participant's oral report of the stimulus. The response time (RT) that was recorded was the time from the beginning of the stimulus to the beginning of the report response. Accuracy refers to whether or not the entire display was correctly reported in correct order. The participants were encouraged to be accurate and, given accuracy, as fast as possible in responding.

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[1]While our actual distinction was between one and two vocalic centers (Hansen & Rodgers, 1968), we have, to facilitate exposition, referred to our stimuli throughout this paper as having either one or two syllables.

Table 1

Trigrams Presented and their Frequency in Running Text

One Vocalic Center		Two Vocalic Centers	
Trigram	Frequency	Trigram	Frequency
High Frequency			
ING	1673	ION	1370
ILL	518	TIO	1025
ALL	498	ATI	799
TIC	481	ITY	358
AST	447	NTL	352
RES	446	ABL	317
TOR	431	ERI	300
EAT	367	TYL	295
ACT	320	ABO	291
NEC	288	ORI	291
OLD	270	LLY	284
NAT	259	ICA	283
ISH	258	RTI	280
LES	255	NDE	253
Low Frequency			
ILD	127	IAL	128
TIM	109	TIA	121
LOC	99	ALI	115
ATT	86	OBL	71
AID	74	GME	60
OIS	63	LCO	53
RUC	50	ABA	52
GLY	48	NCI	44
APH	41	ANO	34
ETS	29	RCU	34
NAR	26	ECA	32
NOL	6	IFU	8
IRK	4	NGO	3
BEX	1	BDO	1

The second task, the letter recognition segment of the study, consisted of three blocks of trials, in each of which all 56 letters were presented (separately randomized for each subject on each trial). Each block was run with a different SOA, and assignment of SOA to blocks was varied over subjects using consecutive rows of a Latin square for each person in turn. Three SOAs were used: 50 msec, 65 msec, and 125 msec. The order of events for the letter recognition segment was as follows: 2 minutes for the subject to examine a sample card with examples of the 26 letters in the Rumelhart and Siple lettering style, 5 warm up trials at 125 msec SOA, and then the 3 blocks of 56 letters each.

The third segment of the study was trigram recognition. The procedure was identical to that of letter recognition, except that 15 warm-up trials were used.

The study took two one hour sessions to run. Most participants completed the numbers and two blocks of letters in one session and the third block of letters plus the trigrams in a second. The warm-up trials were repeated at the start of the second session.

Results

Letter Perception

There were no significant differences in report accuracy or RT between letters sampled from the different trigram types. Consequently, data from the four sets of letters were pooled. For each subject, report accuracy was tabulated for each of three SOAs. The mean proportions correct were .70, .86, and .98 for respective SOAs of 50, 65, and 125 msec. These means were significantly different, $F(2, 32) = 19.6$, $p < .000$. Similar results were found with the RT for correct responses, with mean (harmonic) response times of 618, 538, and 483 msec, respectively, $F(2, 32) = 19.6$, $p < .000$. There were no significant differences between good and poor readers, nor even a slight trend toward difference, $F < 1$.

Trigram Perception

The mean proportions correct and the mean correct response times are shown in Tables 2 and 3. Response times for statistical analyses were obtained by computing, for each subject for each combination of treatment levels, the harmonic mean of the correct response latencies. There were no differences between good and poor readers, $F < 1$. A multivariate analysis of variance of RT and accuracy showed significant effects of SOA, number of syllables, frequency (all $ps < .001$), and frequency × number of syllables, $F(2, 31) = 6.15$, $p < .01$. To further characterize the results, separate univariate analyses were then conducted.

Table 2

Mean Proportion Correct on Trigram Recognition Task

[illegible]	One-Vocalic Center		Two Vocalic Centers	
	High Frequency	Low Frequency	High Frequency	Low Frequency
50	723	563	521	487
65	836	744	706	.681
125	966	920	.853	828
Mean	842	742	693	.665

Table 1

Harmonic Mean of Correct Response Times (msec) on Trigram Recognition Task

	One Vocalic Center		Two Vocalic Centers	
SOA	High Frequency	Low Frequency	High Frequency	Low Frequency
50	612	658	663	682
65	589	632	609	641
125	553	570	569	587
Mean	585	613	614	630

In the univariate analysis of RT, the effects of SOA, number of syllables and frequency were all significant ($p < .001$), but the interaction of number of syllables and frequency was not, $F < 1$. This suggests that the effects of frequency and number of syllables were additive. However, the additive effect breaks down at the shortest (50 msec) presentation times, since the simple interaction effect of number of syllables × frequency at 50 msec SOA is significant, $F(1, 176) = 4.64$, $p = .033$.

In the accuracy analysis, the effects of SOA, number of syllables, and frequency were significant, $p < .001$, and the interaction of number of syllables with frequency was also significant, $F(1, 16) = 6.88$, $p = .018$.

To assure that these effects were not due to differential proportions of words vs. nonwords in the four trigram groups, we computed latency and accuracy measures for words vs. nonwords in each group. There were five words in the one-syllable high-frequency group, one in the one-syllable low-frequency group, and two in the high-frequency two-syllable group. In no case were the latency and accuracy of words significantly better or worse than for nonwords of the same class, nor was there any trend toward a difference. This does not rule out a word

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Comparisons of Single-Letter and Trigram Data

It is important to remember that trigram accuracy is measured in terms of the complete report of all three trigram letters. The accuracy data for letters and trigrams can be compared by examining Figure 1. As can be seen in the figure, accuracy on high-frequency single-syllable trigrams is about the same as for single letters. Under the slowest stimulus condition (SOA = 50 msec), trigram (one-syllable high-frequency) accuracy is slightly above letter accuracy, and in the other two conditions it is slightly below.

Figure 2 shows latencies for correct trigram and letter tasks. Here the letter and one-syllable high-frequency trigram data show a different pattern. Comparing letter RT and trigram RT, we can conclude, since accuracy was equal, that there is an interaction between number of letters being reported, a "verbal" variable, and SOA, a visual variable.

Discussion

The two findings of greatest interest are (a) the comparison between the letter data and that for high-frequency monosyllables, and (b) the interaction between trigram type and SOA. As SOA, and therefore the time for which iconic information is available, decreases, the letter and frequent monosyllable reaction times converge while accuracy stays constant. This is exactly the type of interaction which Sternberg's (1969) method would take as a rejection of the hypothesis that visual quality and number of letters affect independent stages in the perception-and-report process. Also, as SOA decreases, the additive effect of frequency and number of syllables in both the accuracy and speed measures of the trigram task seems to break down. We will consider the

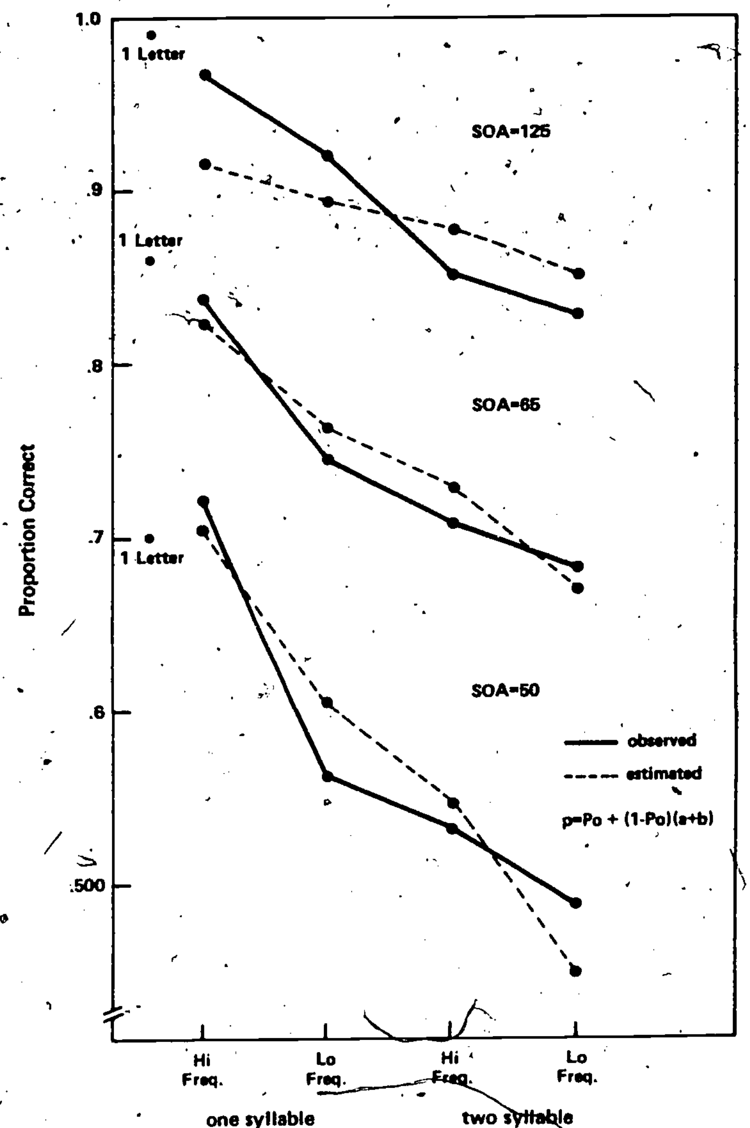

Figure 1. Accuracy in letter and trigram tasks with predicted accuracy superimposed.

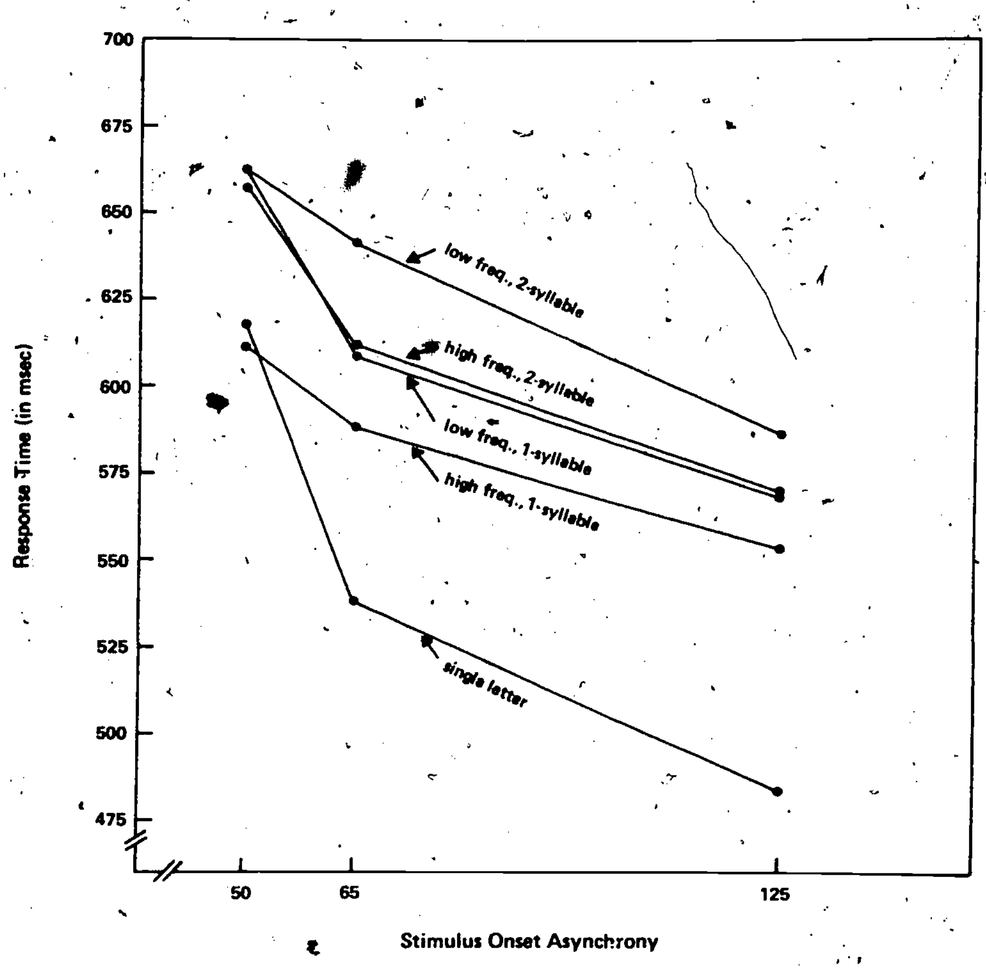

Figure 2. Response times for letter and trigram tasks.

implications of these two findings in terms of the units which can be detected in the processing of letter strings.

Theoretically, unitization can occur at either a perceptual level or at a level closer to the response side of the process. A number of researchers have pointed out this distinction (e.g., Estes, 1975a, 1975b; Healy, 1976; Johnson, 1975), and there are competing unitization models available (e.g., Gibson et al., 1962, vs. Spoehr & Smith, 1975). While many models have been posed as hierarchies of pattern units (Estes, 1975a: Johnson, 1975; LaBerge & Samuels, 1974), it may also be useful to think of visual and name codes, perhaps at several different levels, which can arise independently or with dependence that is a function of the specific circumstances (Posner, 1969, has advanced this type of view).

With respect to the task we used, two basic levels at which unitization might have occurred are the level of visual perception and the level of stimulus naming. At the visual level, one can conceive of a hierarchy of detection in which the (perhaps unnamed) output of letter analyzers is input to syllable (or other higher-level) analyzers. The alternative possibility is that there is direct input of subletter features to a higher-level analyzer. The SOA × number-of-letters interaction suggests that the latter is occurring since high-frequency monosyllables were reported as rapidly as single letters at the shortest SOA. This indicates that when the visual signal is reduced, trigrams can be perceived in the same number of steps as single letters, which, in turn, suggests that visual units of more than a single letter exist. The fact that the letter times converge at short SOA, with only the high-frequency monosyllable times suggests that these visual units are at a level corresponding to syllables. It is important to note that our results may show unitization at the syllable level rather than the word level only because we used short, generally nonword, strings.

We next consider the SOA by trigram-type interaction. Here we find evidence consistent with unitization at a verbal level. With the exception of the shortest SOA, a rather simple model will fit the data. Let us assume, since the task is letter-by-letter full report, that subjects try to perceive, keep track of, and produce each letter separately. Further, let us assume that at a given SOA, the probability that this separatist strategy will succeed is p_o. With probability $1 - p_o$, the independent processing will be inadequate. However, we suggest that if the trigram is frequent (as represented by parameter b) and of one-syllable (represented by a, the probability of the trigram's letters being representable by a single phonological or name code), then a correct response may still occur. Thus P, the probability of correct responding can be expressed as:

$$P = p_o + (1 - p_o)(a + b)$$

With p_o = .45, .67, and .85 for the three SOA conditions, a = .28, and b = .18, this model fits the accuracy data more or less (allowing for ceiling effects), as shown in Figure 1.

However, there is still the differential latency data to account for. Here the syllable and frequency effects are additive at the longer SOAs, but at SOA = 50 msec, there are two levels of RT: High-frequency monosyllables were at one level and the other three conditions were equal and slower. This suggests that the model of initial letter perception followed by possible intervention of higher-order verbal units breaks down at short SOA. One plausible description is that visual unitization effects in a letter-string report task will be seen only when visual input is so limited that the probability of multiletter unit detection is much greater than the joint probability of all letters being detected separately. When visual input is better in a letter report task, perception will be at the letter level with some possibility of unitization effects of a verbal nature.

In this regard, it is interesting to compare the demands of our full report task to those of a forced-choice recognition of only one letter from a string. In the latter case, Johnson (1975) notes that as the visual signal deteriorates, it becomes less reliable to recognize the string as a unit and then decide if it contained a given letter than it is to operate from the outset at the letter level. In our full report task, the opposite is the case. All positions, not just one, must be attended. Therefore, it is better to use the limited time that the icon is available at short SOA for a holistic perceptual detection effort.

We suggest then that all chains of events--letter or group perception followed by letter or group processing--are possible, with the nature of the task and stimuli as well as the quality of the visual signal mediating which chains of events are most probable.

Finally, we note that our use of masking and SOA control to vary visual quality may be crucial to our results. Such manipulations limit how long the visual information is available. The procedures of Landauer et al. (Note 1) and Stanners et al. (1975) failed to find the "visual-verbal" interaction demonstrated in the present study. However, they used words rather than subword strings and used degradation of the display rather than masking. The latter difference may be crucial to understanding why they found no interaction. At any rate, our results provide strong support for the notion that visual units exist at the syllable level.

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