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Visual factors in word perception*

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An experiment is reported confirming the existence of the "word-letter phenomenon" (WLP): At tachistoscopic exposure durations, each letter of a four-letter word is perceived more accurately than a single letter. Data obtained rule out several artifactual interpretations, including the possibility that perception of letters in a word is facilitated merely by the presence of adjacent contours. The WLP is shown to depend critically on what type of display is used as a pre- and postexposure field. While a masking field of high-contrast random contours produced a large and reliable WLP, a plain white field eliminated the phenomenon entirely. This pattern of results suggests several ways in which perception at the word level may differ from perception at the letter level.

Reicher (1969) and Wheeler (1970) have reported that four-letter words can be perceived more accurately than a single letter at tachistoscopic exposure durations. The experimental design used by Reicher and Wheeler allowed them to conclude that Ss were actually picking up more information from *each* letter in a four-letter word than from a *single* letter presented alone. For example, Ss were more accurate in deciding whether they had seen an "H" or an "R" when the stimulus was "HEAD" than when it was just "H." We shall call this finding the "word-letter phenomenon" (WLP) to distinguish it from the "word-apprehension effect" (WAE), in which words are perceived more accurately than are strings of an equal number of unrelated letters (e.g., Neisser, 1967; Smith & Haviland, 1972).

The existence of the WLP suggests that when people perceive words the whole is, in some way, more than the sum of its parts. If we could understand *why* this is the case, we might have an important clue to the nature of the reading process, still a mystery after nearly a century of research. So far, however, the WLP has resisted interpretation. No current theory of the processing of briefly presented letter arrays (e.g., Rummelhart, 1971; Estes, 1972) would have predicted it. Wheeler (1970) proposed five explanations of the WLP, but experimental tests led him to reject all of them. Three other explanations that he proposed have not yet received any experimental support.

The experiment reported below had two purposes: first, to replicate the WLP under conditions that would rule out possible artifactual interpretations; and second, to examine the effects of altering visual display conditions.

Since both Wheeler (personal communication, 1972) and E. E. Smith (personal communication, 1972) have had difficulty in replicating the WLP reliably, it was important first to confirm its existence. Considerable care was taken to rule out artifactual interpretations, including the possibility that perception of letters in a word is facilitated merely by the presence of adjacent contours.

The method used was designed to provide for the fairest possible comparison of the amount of information picked up from a single letter with the amount of information picked up from each letter in a four-letter word. On some blocks of trials, S was presented with tachistoscopic exposures of four-letter words. Shortly after each word was presented, S's perception of one of its four component letters was tested with a forced choice between two words that differed only in the letter being tested. For example, if the stimulus word was "COIN," S might be tested on his perception of the first letter with a forced choice between "COIN" and "JOIN." On other blocks of trials, corresponding single-letter stimuli and choice alternatives were presented. If the stimulus was the letter "C" alone, the two choices were "C" and "J" (see Table 1).

This procedure eliminated several aspects of Wheeler's (1970) design that might have biased performance toward either letters or words: (a) Wheeler presented S with a mixed list of both words and single letters. Since S could not know before a trial which kind of material would be presented, it is possible that he found it advantageous to maintain a "word set" throughout the experiment and was simply unprepared to perceive single letters optimally. We grouped trials by type of stimulus, allowing S to prepare before each trial for the kind of item that would actually be presented. (b) Wheeler found that presentation of the choice alternatives immediately after the stimulus interfered with

Table 1
Illustrative Stimuli and Alternatives

Type of Stimulus	Stimulus	Choice Alternatives	
Word (W)	COIN	COIN	JOIN
Letter (L)	C	C———	J———
Letters with "#" signs (L#)	C###	C###	J###

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performance on single letters. He did find a significant, though considerably smaller, WLP on trials with a 1- and 2-sec delay between stimuli and choices. Since, however, S could not know before each trial whether the choices would be delayed or not, spurious effects due to *anticipation* of a zero-delay trial may have been present on all trials. We relied on a simple procedure in which S viewed alternative choices outside of the tachistoscope, well after offset of the stimulus. Processing of the stimulus should thus have been insulated from any interference due to onset of the alternatives. (c) Wheeler used two letters as choice alternatives for both word and letter stimuli, and did not indicate to S which letter position was being tested. Position uncertainty probably made little difference to S on single-letter trials. On word trials, however, S may frequently not have known which of several partially processed letters was the one being tested. Thus, the testing procedure may have been biased against words. By following word stimuli with pairs of choice *words* differing by only the critical letter, we remedied this problem. Our choice alternatives also allowed S to make his decision at the whole-word level if he wished to do so. Because the two choice words differed by only one letter, our procedure still did not permit S to do anything more than guess randomly on the basis of information from the three noncritical letters.

Some of Reicher's Ss and some of our pilot Ss suggested that a single letter "is hard to find" or "gets lost" in the stimulus field. If this were the case, performance on single letters might be improved by placing contours in the unoccupied letter positions. We therefore compared performance on words and single letters with performance on a third type of stimulus, identical to a single-letter stimulus except that number signs ("#") were used to fill the three empty positions (see Table 1). This symbol was used as a dummy place-filling item because it contains approximately the same density of contours as a letter, but yet is not easily confused with any particular letter.

As an additional control, half of our Ss were given advance knowledge about the position in which the critical letter was to appear for letter stimuli but not for word stimuli. If the WLP depends on a single letter being "hard to find," eliminating position uncertainty for letters might drastically reduce or eliminate the phenomenon. Since Ss in this condition remained uncertain about the critical letter position with word stimuli, a bias was clearly introduced in favor of letter stimuli. We hoped that the WLP would be robust enough to override this bias.

Pilot data indicated that the WLP might be obtained under some masking conditions but not under others. The results obtained below by manipulating this variable not only suggest why the WLP has proven troublesome to replicate, but also provide a clue to its nature.

METHOD

Subjects

Forty-eight University of Pennsylvania students with normal or corrected-to-normal vision served as paid Ss.

Apparatus and Stimuli

Stimuli were presented to Ss in a two-field Polymetric tachistoscope with modified timer accurate to ±.5 msec. Stimuli were typed on white cards using an IBM Model 12 electric typewriter with carbon ribbon. At the viewing distance of 39 cm, stimulus letters were approximately .42 deg high and up to .33 deg wide. A stimulus word subtended approximately 1.40 deg.

Stimuli were of three kinds (see Table 1): four-letter words (W), single letters occupying one of the four positions of letters in a word (L), and single letters with the other three positions occupied by "#" signs (L#). Stimulus items were derived from a list of 112 pairs of words that differed by only one letter (28 pairs differing in each letter position). Approximately half of the words were taken from Wheeler's (1970) stimulus list, and the remainder were selected from a crossword puzzle dictionary. Infrequently used or potentially offensive words were excluded. Each pair of words was used for the construction of six stimuli. Two W stimuli were prepared, using each member of the pair as a stimulus word. Two yoked L# stimuli were prepared by replacing the three noncritical letters of W stimuli with "#" signs. Two yoked L stimuli were prepared by simply deleting the noncritical letters of W stimuli, leaving the critical letter in the same position. The two choice alternatives presented after a given stimulus item consisted of the item itself and the paired item of the same stimulus type. Choice alternatives were displayed so that S could quickly determine the critical letter position for all types of stimuli.

Procedure

S sat looking into the tachistoscope, which was adjusted to a comfortable height. After hearing a "ready" buzzer, S looked toward the middle of the masking field. When he felt that he was attending properly, S pressed a foot switch; .3 sec later, the stimulus was briefly exposed. Immediately after stimulus offset, the masking field reappeared and remained on until presentation of the next stimulus. Shortly after viewing a stimulus, S raised his head and looked over the top of the tachistoscope to view the choice alternatives at the top of the stimulus card. (The typical S waited about a second before looking out of the tachistoscope.) S indicated his choice verbally by naming the critical letter appearing in one of the two alternatives. S then looked back into the tachistoscope, and, after a delay of about 4 sec, E activated the "ready" buzzer for another trial. Since S controlled the timing of stimulus presentation, both of viewing choice alternatives and of verbally responding, the rate of presentation of trials varied somewhat. Almost all Ss received between six and eight trials per minute.

Design

Each S served for one session of 336 trials, divided equally among the three types of stimuli. He saw one W, one L, and one L# stimulus derived from each of the 112 word pairs. Trials were grouped into blocks according to stimulus type. A session consisted of 18 blocks of trials, grouped into six cycles of successive blocks of W, L, and L# stimuli.

The first two cycles (20 trials/block) were used for practice and determination of approximate threshold durations by a modified staircase method. At attempt was made to keep Ss at a performance level of 75% correct choices, averaged across all three types of stimuli.

Each of the remaining four cycles also consisted of successive blocks of W, L, and L# stimuli, but with 18 trials/block. Threshold durations were adjusted after each three-block cycle if average performance deviated much above or below the 75% level. Since the first 2 trials of each 18-trial block were discarded, the data retained for analysis from each S consisted of 64 trials each for W, L, and L# stimuli.

The 48 Ss were divided into four equal groups on the basis of two factors: whether or not position cueing was employed and which type of masking field was used.

Cueing

In the NO CUE condition, S had no way of knowing before a trial which of the four letter positions would contain the critical letter, since the cards were sorted randomly with respect to critical letter position. In the POSITION CUE condition, cards were arranged so that each L and L# block in Cycles 3-6 consisted of stimuli with the critical letter in only one position. E indicated this position to S before each L and L# block began. W cards were left unsorted so that S would have no way of knowing before any trial which letter position would be critical. For half of the POSITION CUE Ss, position of the critical letter changed in a left-to-right sequence through Cycles 3-6; for the other half, the sequence was reversed. L and L# cards in practice cycles (1 and 2) were sorted into 10-trial runs on each critical letter position.

Masking

For the 24 Ss in the PATTERNED MASK condition, the pre- and postexposure field consisted of a white card with black, pen-drawn contours in a rectangular array approximately 3.4 deg wide and 1.8 deg high (see Fig. 1). Both curved and jagged contours were present in an irregular pattern with approximately the same grain size as a capital letter. Pilot studies showed that this mask produced stronger masking (higher thresholds) than other patterned masks explored. The luminance of the stimulus field was approximately 1.6 log fL and that of the masking field 1.5 log fL, measured with an SEI photometer.

The WHITE MASK condition was based on pilot observations suggesting that the size of the WLP was influenced by the type of mask used. Since we had been careful to use the most severe masking we could in the other condition, we decided to go to the opposite extreme and use a plain white field of approximately the same luminance as the stimulus field. We found, however, that under these conditions, threshold exposure durations were under 5 msec, too short for us to make minor adjustments accurately with the controls on our timer. We therefore used neutral density Kodak Wratten filters to reduce the luminance of the stimulus field to .9 log fL. The pre- and postexposure field remained considerably brighter (1.5 log fL) and was white except for four fixation dots at the corners of an imaginary rectangle the size of the patterned mask used in the other condition.[1]

Threshold exposure durations were slightly lower for WHITE MASK Ss than for PATTERNED MASK Ss (a mean of 26.6 msec vs 31.7 msec, with some overlap in the distributions).

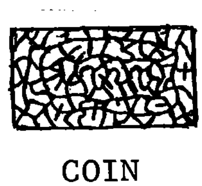

Fig. 1. Facsimile of the contoured masking field used in PATTERNED MASK conditions. Sample word stimulus is shown to same scale.

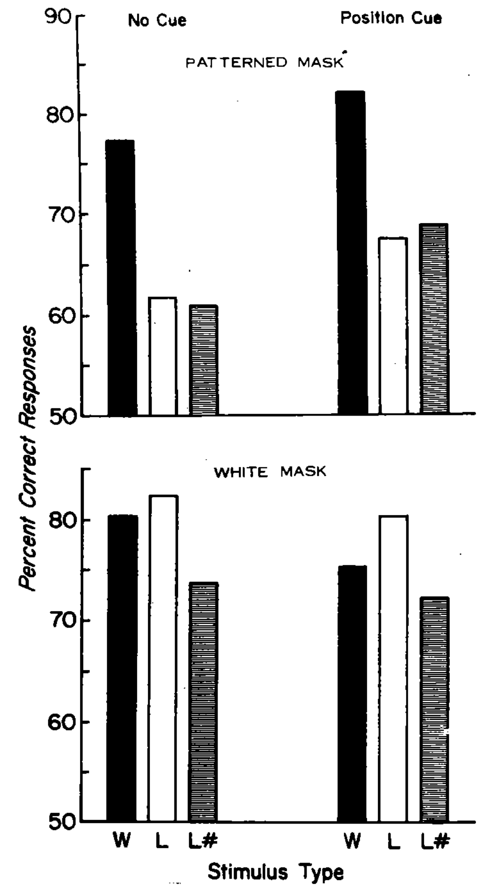

Fig. 2. Percentage of errors as a function of stimulus type (W words, L single letters, L# single letters with "#"-sign placeholders), presence or absence of position cueing of L and L# stimuli, and type of masking field; 768 trials/data bar.

Nuisance Factors

The following factors were counterbalanced between Ss: BLOCK ORDER (in a cycle, the sequence was L-W-L#, W-L#-L, or L#-L-W), SEX of S, and STIMULUS ITEM (for each pair of choice alternatives, one member was actually a stimulus for half of the Ss; the remaining Ss received the converse set of stimuli to control for item biases). Since none of these factors produced a significant effect, the data reported below are pooled across them.

RESULTS

Patterned Mask

The top half of Fig. 2 shows the percentage of errors on each type of material for NO CUE and POSITION CUE Ss run with a patterned mask. Since Ss were run at individually determined threshold durations, no significance can be attached to the fact that NO CUE Ss made somewhat more errors than did POSITION CUE Ss on all three types of stimuli.

The most important result is that W performance was better than L and L# performance for both NO CUE and POSITION CUE Ss. The differences, which range from 13.3% to 16.4%, were all significant at the .001 level using Kincaid's (1962) method of pooling contingency tables. The difference between performance on L and L# stimuli did not approach significance for either cueing condition.

Nonparametric tests confirmed these results (significance levels reported are based on a two-tailed sign test).[2] All 12 NO CUE Ss made fewer errors on W stimuli than on either L or L# stimuli ($p < .002$). Of the 12 POSITION CUE Ss, 11 made fewer errors on W than on L stimuli ($p < .01$) and 10 made fewer errors on W than on L# stimuli ($p < .05$). In both groups, approximately equal numbers of Ss made fewer errors on L than on L# stimuli, and vice versa.

White Mask

In striking contrast to PATTERNED MASK Ss, WHITE MASK Ss showed no WLP at all (see bottom half of Fig. 2). NO CUE Ss, whose data permit the fairest comparison of W and L performance, actually made 2.0% more errors on W than on L stimuli, although this difference was not significant. In another deviation from PATTERNED MASK results, WHITE MASK Ss made considerably more errors on L# stimuli than on L stimuli. The difference of 8.6% was highly significant ($p < .001$ using Kincaid's method) and reliable across Ss (11 out of 12 did better on L stimuli; $p < .01$). Performance on L# stimuli was also worse than on W stimuli by 6.6% ($p < .002$ using Kincaid's method). This difference was also reliable across Ss (10 out of 12 made fewer errors on W than on L# stimuli, with one tie; $p < .02$).

POSITION CUE data are virtually identical except for a slight improvement on cued L and L# stimuli relative to uncued W stimuli. Performance on L stimuli was now 4.9% higher than on L stimuli, significant according to Kincaid's method ($p < .01$) but not reliable across Ss (7 out of 12 made fewer errors on L stimuli, with two ties; $p > .1$). The L-L# difference remained virtually identical (8.2% vs 8.6%), as might be expected if both types of stimuli were helped about the same amount of cueing. The L-L# difference was again significant using Kincaid's method ($p < .001$) and reliable across Ss (9 out of 12 had fewer errors on L stimuli, with two ties; $p < .05$).

Statistical Comparison

The results with the WHITE MASK clearly did not conform to the pattern of results with the PATTERNED MASK. The statistical significance of this different pattern was tested with 2 by 2 factorial chi-square tests (Li, 1964, p. 475, with Yates correction), using the sign-test data reported above. The main effect of the masking variable was significant for the critical W-L difference ($p < .001$) and for the L-L# difference ($p < .01$), but not for the W-L# difference ($p > .1$). Neither the cueing factor nor the interaction of both factors approached significance for any of the stimulus pair differences.

DISCUSSION

The experimental design provided for a comparison of single-letter and word perception free from several potential biases that may have distorted previously reported results. Our data indicates that with strong patterned masking, all four letters in a four-letter word *are* perceived significantly better than a single letter presented alone. The difference found is larger than the WLP obtained by Reicher (1969) and Wheeler (1970), and larger than the WAE obtained by Reicher (1969) and Smith and Haviland (1972). The fact that the W-L difference was virtually unchanged when Ss knew in what position a single letter would occur demonstrates the robustness of the WLP when pitted against a position-uncertainty bias which almost surely favored L stimuli. The fact that performance was no better on L# stimuli than on L stimuli suggests that single letters are not harder to see because the stimulus field contains fewer contours as a whole or because a single letter lacks adjacent contours.

Several procedural differences may account for our finding a larger WLP than was reported by Reicher (1969) or Wheeler (1970): (a) We adjusted exposure durations more frequently to keep individual Ss away from ceiling and floor effects; (b) we presented Ss with whole-word choice alternatives after word stimuli; (c) we used high-contrast black-on-white background stimuli rather than stimuli generated on a CRT face; (d) we segregated different kinds of stimuli into separate blocks rather than using a mixed list; and (e) we used a high-contrast patterned masking field before and after the stimulus.

Our data shows that the large and robust WLP obtained with a patterned mask can be entirely eliminated by the use of a plain white pre- and postexposure field. The change in the size of the W-L difference from PATTERNED MASK to WHITE MASK conditions is highly significant.

This finding suggests that failures to replicate the WLP may be due, at least in part, to use of less effective masking.

The fact that patterned masking seems to be necessary to obtain the WLP may also be an important clue to the cause of this phenomenon. The following kinds of interpretations have occurred to us:

(1) *Different systems for letter and word processing.* Patterned masking might be producing the WLP directly, by interfering with the processing of isolated letters more than with the processing of words. Since, with a patterned mask, performance was no better on L# stimuli than on L stimuli, it seems unlikely that letters in a word are protected from masking effects merely by the

presence of adjacent contours.[3]

There is another possibility, however. Let us assume that single letters (with or without nonsense adjacent contours) are processed by the same system that processes geometric shapes in general. Since the masking field consists of a haphazard array of geometric patterns, we should expect it to produce a great deal of noise in the same system that is processing single letters. Extraction of information about a letter should be much more difficult, and any information that is extracted might subsequently be degraded or erased (cf. Kahneman, 1968). It is quite possible, however, that words are processed by a system that is, at some level, distinct from the system that processes single letters and ordinary geometric shapes (cf. Liberman et al, 1967; Mattingly et al, 1971, for an analogous argument, backed by considerable data, that speech is not processed by the same system which processes simple sounds, including those that are components of speech, e.g., second formants). Whether the hypothetical system used to perceive words is specialized to pick up words themselves, or spelling patterns, or indeed complex meaningful stimuli in general cannot be specified at this time. All that is essential for the hypothesis is that information about word stimuli be processed by a system subject to less interference by a patterned mask than the system processing single letters.

(2) *Faster processing of words.* Both of the two prevailing explanations of backward masking (see Kahneman, 1968, for a review) are consistent with the claim that a mask serves to limit the amount of time in which stimulus information is available for processing. According to "interruption" theory, the limitation on processing time occurs because the arrival of the masking stimulus interrupts processing of the preceding stimulus, subjectively "erasing" it (Averbach & Coriell, 1961). "Integration" theory, which has been most forcefully advocated by C. W. Eriksen and his collaborators, is consistent with the interpretation that processing time is limited because integration with the mask *degrades* stimulus information, thus shortening the duration that it remains in useful form (cf. Neisser, 1967). If either line of reasoning is correct, patterned mask data might be explained by the simple assumption that words are processed faster than single letters. If so, a word might be more likely to have been identified than a single letter before the stimulus is interrupted or degraded by the mask. Actually, it is not necessary for processing of a word to be *completed* faster than processing of a letter; what must happen faster is transfer of relevant stimulus information to some state not subject to interference by patterned masking. Under WHITE MASK conditions, this is no patterned mask to limit the time during which stimulus information is available for processing, so, according to this hypothesis, speed of processing should be a much less important factor in limiting performance.[4]

(3) *Removal of lateral interference bias against words.* In the absence of a patterned mask, it is likely that lateral inhibitory effects from adjacent letters hurt performance on words relative to single letters. Eriksen and Rohrbaugh (1970) have found that, under similar conditions, the presence of any nearby contours interferes with the perception of a single letter. The spacing of letters in our word stimuli is well within the range of visual angle found critical by Eriksen and Rohrbaugh. Thus, without a patterned mask, whatever factor causes the WLP might still be operative, but its only effect would be to keep W stimuli from being *harder* to see than L stimuli. The fact that WHITE MASK Ss made significantly more errors on L# than on L stimuli provides internal evidence for lateral interference under these conditions. According to the hypothesis being advanced, the proper control group for W stimuli should perhaps be L# stimuli, not L stimuli. If so, the significant superiority of W performance to L# performance provides direct support for the claim that the WLP is present even under WHITE MASK conditions, although reduced in size to 6.6%.

Why should a lateral interference bias obscure the WLP only under WHITE MASK conditions? The reason, according to this hypothesis, is that it makes a great deal of difference whether simultaneous adjacent contours are the *only* source of contour interference (WHITE MASK) or are merely a minor *additional* source (PATTERNED MASK). Weisstein (1968) has hypothesized that the same neural mechanism is responsible for the disruptive perceptual effects of both simultaneous contours and successive contours. It is quite plausible that the amount of perceptual disruption produced by such contour interference follows a law of diminishing returns. If so, the addition of simultaneous adjacent contours in the absence of other contour interference (WHITE MASK) might produce a significant decrement in perception, while the addition of simultaneous contour interference to strong forward- and backward-masking contour interference would produce very little *further* decrement in perception. The assumption that the contours in the patterned mask have a much more powerful effect than do simultaneous adjacent contours is clearly justified. Use of a patterned mask instead of a plain white field of equal luminance raises thresholds by a factor of 5 or more; the presence of simultaneous contours raised thresholds by 1-2 msec at the most. The conclusion that simultaneous adjacent contours provide negligible additional interference under PATTERNED MASK conditions is supported by the lack of any difference in performance on L and L# stimuli.

Hypothesis 3 is compatible with the view that the cause of the WLP has nothing to do with the (presumably sensory) processes being manipulated by changes in viewing conditions. The WLP should be obtainable under a wide variety of visual conditions, *provided* they do not introduce sensory processing biases against words. Indeed, the WLP might even be obtainable under WHITE MASK conditions if some other means of removing the purported bias could be found (e.g., spreading out the letters in a word).

In summary, we have suggested three hypotheses to explain why the WLP was obtained strongly with patterned masking and not at all without it. The first two suggest that this finding provides an important clue to the nature of the WLP. The third suggests that patterned masking merely *unveils* the WLP and that one must look elsewhere for clues to its nature.

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NOTES

1. In our WHITE MASK condition, the elimination of patterned masking is, of course, confounded with a reduction in brightness of the stimulus. To keep performance near threshold, the elimination of patterned masking must be confounded with *some* other change, if only a reduction in exposure duration. Due to intensity-time reciprocity, it is unlikely that maintaining the brightness of the stimulus but reducing its duration would have produced any important change in the results.

2. The assumptions underlying use of Kincaid's method do not permit generalization of significant results beyond the sample of Ss used. Significant results on a sign test are not subject to this limitation.

3. It is conceivable that Ss have trouble with L# stimuli because they often cannot tell which features that they have detected belong to the letter and which belong to the "#" signs. If so, facilitation at the sensory level by the "#" signs might not show up in our data. The fact that L# performance was negligibly better than L performance, even with cueing, makes this possibility unlikely.

4. What constraints might assume greater importance under WHITE MASK conditions? Since the stimulus field is much lower in luminance than before, only a fuzzy or incomplete representation of the stimulus may register at peripheral levels of processing (e.g., many contours might fail to excite appropriate line or edge detectors). If so, the ability to retain partial information about letter identity might become more important as a determinant of relative performance. It is likely that Ss find it easier to retain partial letter cues for a single letter than for several letters at the same time. While S may be able to encode the fact that a letter "is rounded at the top and has a little line segment," he can scarcely perform several such feats simultaneously on multiletter stimuli. Thus, any advantage for W stimuli under WHITE MASK conditions due to *residual* speed-of-processing constraints may be offset by better use of partial cues for L stimuli.

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